

HAND DIFFERENCES IN BRAILLE LETTER LEARNING IN
SIGHTED CHILDREN AND ADULTS

Thesis for the Degree of M. A.

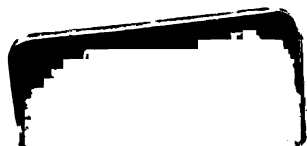
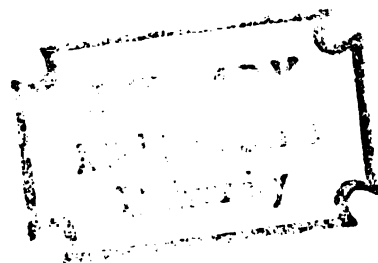
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ABSTRACT

HAND DIFFERENCES IN BRAILLE LETTER LEARNING IN SIGHTED CHILDREN AND ADULTS

By

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The purpose of this study is to investigate age and sex differences in hemisphere specialization as measured by hand asymmetry on a braille letter learning task. In right-handed persons, the left cerebral hemisphere is typically specialized for language functions, the right hemisphere for spatial perception. Since braille reading is a language skill, superior right hand performance would be expected because the right hand's major, more direct cortical representation is to the left hemisphere.

Hermelin and O'Connor (1971), however, reported better left hand reading of braille letters and passages by blind children and adults. They proposed that braille configurations are treated as spatial stimuli to be analyzed more efficiently by the right hemisphere before or during verbal identification and naming by the left hemisphere. Thus the left hand should have an advantage.

Further support for the hemisphere specialization hypothesis was provided by Rudel et al.'s (1974) study of braille learning by naive, sighted seven- to 14-year-old children, which eliminated possible experiential factors accompanying the study of blind

subjects. Rudel et al. found left hand superiority, but only in the oldest children, and more reliably in boys than girls. They therefore suggest that right hemisphere specialization for spatial processing develops later in girls than boys and/or that girls rely more than boys on left hemisphere strategies to code difficult discriminations.

The current study further assessed hand, sex, and age differences in braille learning in sighted, right-handed college students and third, fifth, and eighth graders - 16 males and 16 females at each grade level.

The stimuli were sets of six braille letters (four letters per set for third graders) typed, with a braille typewriter, on ordinary playing cards. Hand testing order and braille set assigned to hand were counterbalanced within each grade x sex group. Each subject received five blocks of 12 letter presentations (trials) to each hand (eight trials for third graders), for a total of 60 trials per hand (40 trials for third graders). The letters assigned to each hand were each presented twice within a block of trials.

Subjects were told the names of the first six (four) letters while feeling them, and had to guess the names on subsequent trials. The subjects had four seconds (three seconds for college students) to feel each pattern, after which the experimenter called for the letter name. Whether the subject was right or wrong, the experimenter then said the correct name. The subject could see neither his hands nor the braille cards.

Performance was significantly better with the left hand than with the right, primarily reflecting a difference at the last two trial blocks. Scores were generally higher for the second hand tested, but the difference between hand scores was greater when the left hand was tested second than when the right hand was second. Also, hand asymmetry was more marked for the third grade and college groups than for the intermediate grade groups. These effects are reflected by significant testing order x hand and grade x hand interactions. There were no sex differences nor interactions with other variables, except that, among the third graders, left hand superiority was significant only for the boys - consistent with Rudel et al.'s findings.

The results support Hermelin and O'Connor's hypothesized two-stage coding process for braille reading. As Bryden and Allard (1976) suggest in regard to the visual discrimination of Roman alphabet letters written in script-like typefaces, braille letters may require a large degree of "initial preprocessing" by the right hemisphere before identification and naming by the left hemisphere.

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INTRODUCTION

The purpose of the present study is to investigate age and sex differences in cerebral specialization as measured by hand asymmetry on a braille letter learning task. After a summary of the general nature of hemisphere asymmetry, previous findings related to the independent variables of sex and age will be discussed. Issues to be considered regarding sex differences are: a possible adult sex difference in degree of lateralization and its implications for sex differences in cognitive abilities; and the nature of asymmetries shown by adults in the somatosensory modality, especially with a braille letter learning task. Issues to be considered regarding age differences include: a possible interaction of age and sex differences in the development of hemisphere specialization; and previous developmental findings for somatosensory tasks specifically.

Nature of Hemisphere Asymmetry

It is well-established that the two cerebral hemispheres are specialized for certain types of functions. While the exact nature of these functions is not clear, various general characterizations have been suggested. Among these characterizations of the left-right asymmetry are serial or temporal v. parallel processing (Cohen, 1973; Halperin, Nachshon, & Carmon, 1973), analytic v.

wholistic processing (Levy, 1969; Levy-Agresti, & Sperry, 1968; Bogen, DeZure, Tenhouten, & Marsh, 1972; Nebes, 1971), and verbal v. spatial or nonverbal item processing (Kimura, 1973; White, 1972).

These characterizations have been derived from two major sources: clinical studies, which have yielded a general picture of psychological functions most severely disturbed by damage to one or the other hemisphere or, in the case of split-brain patients, by preventing the participation of one hemisphere; and dichotic listening and visual half-field presentation studies with normal subjects. Because contralateral connections are stronger than the ipsilateral ones in the visual and auditory systems, when material presented to the left visual half-field or ear is recognized and recalled faster or more accurately, the superiority of the right hemisphere for the processing of that type of material may be inferred, and the analogous holds for the left hemisphere. In general, a left visual hemifield superiority has been found for the recognition of complex geometric designs, including faces, and for dot localization and enumeration of dots in a random pattern. The left ear has shown superiority for the recognition of animal and environmental sounds and musical timbre. A right ear and right visual field superiority has been found for the recognition of digits, words, temporally patterned stimuli, such as sounds varying in the number and duration of frequency transitions, and easily labeled materials.

Sex Differences

Sex Differences in Performance on Various Cognitive Tasks

Sex differences in performance on a variety of perceptual and cognitive tasks are well-established. On the one hand, women are superior to men in various measures of verbal ability, including fluency, articulation, and sentence complexity, and in the ability to perceive direct elemental relations more readily than broad, integral relationships among content areas (Garai, & Scheinfeld, 1968). Broverman, Klaiber, Kobayashi, and Vogel (1968) characterize the tasks for which women are superior as those requiring simple perceptual-motor associations and rapid perception of detail. This type of task includes clerical aptitude tests, and tests involving fine manual dexterity and the rapid naming of words and pictures. The measures of verbal performance in which women excel are included in this categorization, since complex verbal behavior initially involves the learning of motor control of the vocal apparatus and simple associations of letters with sounds.

Men, on the other hand, surpass women on various spatial tasks requiring the mental visualization and rotation of objects and shapes, the ability to inhibit the influence of the surrounding field, and a sense of direction (see review in Harris, 1977). Males excel, for example, on the spatial subtest of the Differential Aptitude Test (Hartlage, 1970), which requires the mental visualization of three-dimensional patterns from two-dimensional ones and subsequent matching to perspective drawings of alternative objects. Males also excel on tasks requiring the inhibition

of the surrounding field, such as the Rod and Frame Test and the Embedded Figures Test (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962), and on visual and tactual maze learning (Porteus, 1918; Langhorne, 1948), and road map tests, when the ability to perceive directions from the opposite perspective is required (Money, Alexander, & Walker, 1965). These spatial abilities are thought to involve an underlying capacity to inhibit responses to immediately obvious stimulus attributes in favor of responses to less obvious ones (Broverman et al., 1968). A spatial sense, then, seems to require the ability to visualize the whole object or picture at once in order then to manipulate it.

The different abilities in which males and females are superior may be said to involve the cognitive modes associated with the right and left cerebral hemispheres, respectively. The right hemisphere is specialized for processing spatial material, while the left hemisphere is specialized for processing verbal, sequentially presented material. These parallels suggest the possibility that sex differences in cognitive abilities reflect sex differences in hemisphere functioning.

Explanations for Sex Differences in Terms of Cerebral Asymmetry

Two major explanations of these sex differences in terms of hemisphere asymmetries can be distinguished (Harris, 1977).

Difference in extent of lateralization. One explanation presupposes that the two sexes differ in the extent to which the verbal and spatial functions are lateralized to the two hemispheres.

One view, suggested largely by comparisons between left- and right-handers (Levy, 1969), is that language functions are more bilaterally represented in the female. A reason why bilateral language representation might result in the female's relatively poor spatial ability stems from Semmes' (1968) proposal that it is the different structural organization of the hemispheres that leads to functional specialization. Semmes, Weinstein, Ghent, and Teuber (1960) tested brain-injured war veterans on simple cutaneous tasks. For the left hand, deficits on the tasks were not clearly related to lesions in the right sensori-motor region. For the right hand, though, deficits were strongest for subjects with lesions in the left sensori-motor region. These results suggested to Semmes that the left hemisphere is characterized by focal representation, or the integration of sets of similar functional units. In contrast, the right hemisphere was thought to be characterized by diffuse organization, or the convergence of unlike elements. From Semmes' (1968) proposal it may be inferred that intrusion of language representation into the right hemisphere competes with and prevents the formation of the kind of diffuse organization favorable to spatial processing.

This competition model proposes that if bilateral language representation is the cause of the poorer spatial ability of females, then left-handers, who as a group show weaker lateralization than right-handers (Goodglass, & Quadfasel, 1954), should be poorer in spatial ability than right-handers. In general, this has been found to be the case. Levy (1969) reported a significantly

greater discrepancy between verbal and performance scales of the WAIS in left-handed male graduate science students than in a comparable group of right-handers. The verbal scores of the two handedness groups were similar, but the left-handers scored significantly lower on the performance scale.

Nebes (1971b) tested college students and post-doctoral fellows on a spatial task requiring the subject to decide which of the three sizes of complete circles presented in free view matched an arc which was blindly explored with the index finger. The left-handers were significantly worse with both hands in performing this matching.

Clinical data also support the competition model. Lansdell (1961) found that among patients who had an operation in the left temporal lobe, women's scores on a test requiring the explanation of common proverbs were not affected, while men's scores declined. Lansdell (1962) also measured scores on the Graves Design Test of men and women with right or left temporal lobe surgery. Among patients with left hemisphere surgery, men's scores rose and women's declined. When the operation was performed on the right hemisphere, the men's scores declined while the women's rose. Lansdell concludes that the types of processing underlying verbal ability and artistic preference (the presumptive index of non-verbal, spatial ability) are lateralized to opposite hemispheres to a greater degree in males than females.

McGlone and Davidson (1973) have reported evidence at least partly supporting this model. In part of their study, they

administered Thurstone's PMA spatial relations test to high school and university males and females, along with a dichotic word listening task and a tachistoscopically presented dot enumeration task. Those subjects with a same-side superiority for both the dichotic words and dot enumeration tasks also obtained lower scores on the spatial relations test. However, subjects with the reverse of normal organization obtained the lowest scores on the spatial relations test. In addition, only women with higher left ear scores on the dichotic words task performed poorly on the spatial relations test, whereas the competition model would predict that this would be true for men also.

Finally, dichotic listening studies show that, where a sex difference appears, it is towards greater right ear superiority for verbal stimuli for right-handed men than women (Harshman & Remington, 1975; Lake & Bryden, 1976).

Difference in preferred mode of processing. A second explanation for sex differences in spatial ability holds that the difference is not in extent of lateralization but in the extent to which the two sexes tend to invoke a left or right hemisphere mode of processing. If women favor a left hemisphere, verbal approach to problem solving, the degree to which this mode is inefficient for solving spatial problems would determine the poorer performance of women on spatial tasks. Kimura's findings (1969) on a dot localization task support this explanation. She posits that "males and females may approach even simple perceptual tasks differently, often related to their differential use of

verbal and non-verbal systems" (p. 445). She presented a single dot to the left or right visual half-field and asked the subject to find the location of the dot on a visual matrix with 25 possible choices for the location. In the first task, when the dots were presented within a square frame, she found a left visual field superiority for the men and no field differences for the women. On the second task, when the dots were presented without a frame and with a better super-position of pre-exposure and exposure fields, the left visual field was superior for both sexes. No sex difference in overall scores was found. Kimura concludes that if the neural system for representing external space is more right hemisphere dependent in men, this might give them an advantage in some tasks. But, "when the task can be performed with either the left or the right hemisphere mechanisms, males will employ the right system, while females will not" (p. 456).

Findings by Mellone (1944) also partly support this explanation. Mellone gave seven-year-old boys and girls a battery of spatial and verbal tasks. Factor analysis of the scores showed that a third factor, loading heavily on tasks requiring the manipulation of material through visualization, was necessary to explain the boys' scores, but not the girls'. Furthermore, while the boys were better at some tasks, such as mazes and block counting, the girls performed equally well in the reverse similarities (mirror) test and other tasks loading heavily on the boys' spatial factor. Mellone concludes, "maybe girls just perform the same task in different ways" (p. 15).

More evidence is needed to determine whether and how functional asymmetry of the brain contributes to sex differences in verbal and spatial ability. The second main theory is the simplest explanation and can account for much of the data used to support the first approach. For instance, Lansdell's findings (1962) could be interpreted to mean that women simply tend to use a left hemisphere mode of processing for the analysis of art pictures, and even tend to do better at analyzing this type of spatial material when forced to use a left hemisphere mode. Men, on the other hand, tend to analyze the pictures as spatial material, with a right hemisphere mode of processing. McGlone and Davidson's finding (1973) that more females than males show a right visual field superiority for dot enumeration may also be accounted for by the second explanation. Their finding that the reverse of the normal visual field and ear superiorities results in the worst performance could mean that each side of the brain is inefficient at performing the type of task for which the other hemisphere is usually specialized.

No previous study has directly compared these two major explanations, perhaps because the degree to which a certain mode of processing is used depends, in turn, on the degree to which the type of cerebral organization best subserving that mode has been developed (Harshman, & Remington, 1975).

The evidence for sex differences in functional asymmetry, gathered mainly from dichotic listening and visual half-field presentation studies, suggests that females show less of a right

ear superiority for dichotically presented verbal stimuli and less of a left visual field superiority for ambiguous or largely spatial material. The present study was designed to determine whether the sex differences in asymmetry that have been found for the visual and auditory modalities also appear in the somesthetic modality. While this study did not attempt a direct test of the two explanations for sex differences, it was hoped that the results would suggest the degree to which the two modes of processing lead to good performance for the two sexes.

Asymmetry in the Somesthetic Modality for Adults

Indications of asymmetry in peripheral sensitivity. Most studies of asymmetry in the somesthetic modality in normal adults have concentrated more on measures of acuity than on complex task performance, and no major sex differences in asymmetry have been reported.

Differences in tactual sensitivity have been found in favor of the left side of the body, but the differences have not been consistent. In the previously cited study by Semmes et al. (1960), normative data on pressure sensitivity, two-point threshold, and point localization were gathered. Asymmetry was found only for the pressure stimuli, and the greater sensitivity of the left side reached significance only for the thumb area. Corkin, Rasmussen, and Milner (1970) also found that the left thumb was more sensitive to pressure.

Weinstein and Sersen (1961) found a greater left side sensitivity for the palm, forearm, and sole, but not for the thumb, in normal dextrals, and to a lesser degree in sinistrals. Weinstein (1968), using the same three measures employed by Semmes et al. (1960), found no overall difference between the sides for any measure, but for the pressure sensitivity and two-point threshold, laterality interacted with body part tested. For the two-point threshold, the right index finger was slightly more sensitive than the left, while five other body parts showed a left side superiority. Sex was a significant factor only for the pressure sensitivity measure, which showed greater sensitivity for women than for men.

Finally, using a measure of pressure sensitivity in which surface area of the stimulators was held constant, Carmon, Belstrom and Benton (1969) found no significant difference in thresholds between the hands.

The many inconsistencies in these data suggest that their use for characterization of the lateralization of somatosensory functions is limited. It is true that other factors besides peripheral sensitivity contribute to the left-right asymmetry, since the hand that would be expected to be more callused for left-handers (the left hand) is also more sensitive (Weinstein, & Sersen, 1961), and other body parts besides the hands have shown left-right differences. The extent to which differences in cortical organization are responsible for the asymmetries is unclear. Even though the hand should be the most susceptible part of the body to show asymmetry because of its extensive cortical representation (Carmon

et al., 1969; Sinclair, 1967), this more sensitive part might also be more closely integrated with subcortical, possibly thalamic structures (Weinstein, 1968). It is also paradoxical that it is acuity measures that are different for the two sides and not the localization measure, which seems to have a spatial component. Since the spatial measure should depend on hemisphere differences, the interaction with subcortical structures may be responsible for differences between sides of the body in sensitivity.

Because of these inconsistencies in the adult sensitivity data and the relatively small magnitude of the asymmetry, hand differences found in complex cognitive tasks may be attributed to differences in central processing over and above differences in sensitivity. In addition, asymmetry has been shown for different parts of the hand for complex tasks, so the asymmetry could not result from differences in the sensitivity of the left and right palms or fingers alone.

Indications of asymmetry in more complex tasks and confounding factors. Most studies of hand asymmetry in tasks requiring higher level processing have looked at brain damaged (Semmes, 1965; Boll, 1974; Fontenot, & Benton, 1971) and commissurotomed patients (Milner, & Taylor, 1972; Nebes, 1971a, 1972). The right hemisphere seems to possess a greater capacity for processing spatial information presented in the somesthetic modality. For instance, the tactile perception of direction (Fontenot, & Benton, 1971), the identification of digits traced on the finger, and visual identification of shapes after tactile exploration (Boll, 1974) have

been shown to be more impaired with the ipsilateral hand in right hemisphere damaged patients than with the ipsilateral hand in left hemisphere damaged patients. Fontenot and Benton (1971) found no difference between the contralateral hand scores for the two brain damaged groups, while Boll (1974) found that subjects with right hemisphere lesions made significantly more errors. These findings indicate that the right hemisphere plays a more important role in processing information for tasks requiring an appreciation of spatial relations, at least when the tasks do not involve a large amount of motor sequencing (Kimura, & Archibald, 1974).

The few studies of hand asymmetry in complex tasks with normal adults have yielded conflicting results. Gardner (1942) found no clear lateral preference for tasks requiring the sorting of corks of different size and shape with the hands and feet. When the corks were sorted into groups of cylinders and cubes, the right hand was slightly, but consistently, better. When the corks were sorted according to size, a slight left hand advantage was consistently shown. In an additional task, Gardner asked the subjects to read with their fingers Latin Alphabet letters made of cord stretched upon cardboard. The left hand was quicker in both the left to right and right to left reading directions, suggesting that the letters were being processed as spatial forms.

Nebes (1971b) tested normal left- and right-handed college students on a task requiring the subjects to estimate, by feeling an arc, the size of the complete circle to which it belonged. While a left hand superiority had previously been found for

commissurotomized patients on the same task (Nebes, 1971a), there was no significant hand difference for the students.

In addition, using trained and untrained typists, Provins and Glencross (1968) measured hand asymmetry on three typing exercises for each hand that involved letters on one half of the keyboard only. The letters were first arranged in words, then in a random order (providing the same sequence of movements for both hands), and then just the home keys (those in the middle row where the fingers rest) were used. For the untrained typist, no hand difference was found for the first exercise, and a right hand superiority was found for the other two exercises. One reason for the failure to find a better left hand performance on these exercises requiring a knowledge of the spatial placement of fingers could be the reliance of the untrained typists on vision. Rudel et al. (1976) note that much of the lateralization evidence for the right hemisphere comes from experiments where vision is excluded.

The trained typists did show a left hand superiority for the first and third tasks, but no hand difference for the randomly arranged letters. In this case, though, different amounts of practice with the two hands, the left hand having more key letters, could explain the hand difference as well as a central processing explanation. When studying somatosensory functions in normal subjects, then, practice effects should be carefully controlled.

It seems that asymmetries in somatosensory functions, like visual and auditory functions, are sensitive to task difficulty and

memory demands, as well as to differential practice. Benton, Levin, and Varney (1973) found a left hand superiority for the tactile perception of direction using lines fairly close in orientation. They noted, though, that some studies of the perception of direction in brain damaged subjects had failed to find this left hand superiority in their normal control subjects. Umiltà et al. (1974) explained this discrepancy by presenting orientation discrimination tasks of varying difficulty. In the easiest task, the lines differed greatly in their orientations, and in the most difficult task, the slopes of the lines differed only slightly. A right hemisphere superiority was found only for the most difficult task. In addition, Benton et al. (1973) presented the lines for a duration of only one second, in contrast to the long durations used in the other studies that resulted in an overall average of only two errors for the control subjects.

A similar effect of task difficulty was found by Dee and Fontenot (1973) in a tachistoscopic visual perception study with undergraduate men. They presented outline drawings of complex shapes for 15-25 msec. in either the left or right visual field. After an interval varying from zero to 20 sec., the subject was asked to indicate whether or not a figure presented in central vision was the one he had just viewed. A significant left visual field superiority was found only at the two longest intervals. Increased memory demands when a tactile presentation method is used have been found to be especially impairing, particularly for subjects untrained at efficient methods of haptic exploration

(Davidson, Barnes, & Mullen, 1971). Perhaps since most normal subjects are untrained in the recall of complex shapes, especially those examined haptically, even very short memory intervals would be sufficient to bring out left-right asymmetry.

In summary, there is a suggestion of left hand superiority for spatial tasks, but the effect appears to depend on factors such as practice, task difficulty, and memory load. As for sex differences, little is known.

Use of a braille learning task. The tactile task chosen for the current research was braille discrimination. There are several advantages to the choice of braille. The three factors noted as possible contributors to the appearance of a left hand superiority for spatial tasks are accounted for. First, the task is fairly difficult for an unpracticed sighted person, since the dots are spaced just above the normal two-point threshold. Second, since braille is an identification task, it requires remembering a label that fits the total bundle of features (Gibson, 1969), so that the more difficult processing of the total pattern or higher order structure is the preferred strategy. This image of the total bundle of features must be stored in memory. Thirdly, while braille is an established system for the blind, it is unlikely that sighted persons have practiced on a similar task.

Another advantage of the braille task is that it requires only the movement of fingertips, so that the kinesthetic feedback from hand and wrist movements can be minimized. This precaution is necessary because at least one study has suggested that there

is bilateral kinesthetic feedback from hand movements (Levy, Nebes, & Sperry, 1971). Levy et al. (1971) found that split-brain patients could arrange plastic letters with the left hand to make a word, but could not say what the word was. But then, allowed to write the word with their left hand, they were generally able to name it. Apparently even this simple handwriting was sufficient to cue information ipsilaterally.¹

In a study with split-brain monkeys, Brinkman and Kuypers (1972) also found some ipsilateral control for arm movements, but no ipsilateral control for fine movements of the extremities. When one eye of the monkeys was covered, the ipsilateral arm could move in the general direction of a food morsel, but the fingers could not locate it exactly until accidental contact was made. Concentration of movements in the fingertips, then, should reduce any possible feedback via ipsilateral motor pathways.

Other research on split-brain human subjects has shown that it is possible for the ipsilateral hemisphere to process tactual information regarding simple tasks, such as the perception of the presence or absence of stimulation (Sperry, Gazzaniga, & Bogen, 1969). But the ipsilateral hemisphere does not process more complex information, such as a two-point discrimination on the fingers, the interpretation of skin writing, or the perception of shapes (Geschwind, 1970; Sperry et al., 1969).

Finally, a braille learning task resembles Kimura's (1969) visual dot localization task because it has both verbal and spatial components. Braille consists of dot patterns that may either be

analyzed and recalled as spatial configurations, distinguished from one another by the number and location of their dots, or as symbols for verbal material, the way sighted individuals recall their alphabet. As Kimura (1969) suggests, a task that can be performed with either hemisphere is likely to reveal differences in the way males and females approach the problem.

Past studies of braille discrimination by adults. In general, anecdotal and formal evidence regarding hand differences in braille reading speed and accuracy suggests a left hand superiority (Smith, 1929, 1934; Merry, 1931; Grasemann, L., as cited in Villey, 1931; Burklen, K., as cited in Villey, 1931; Critchley, 1953; Hermelin, & O'Connor, 1971). These findings are inconclusive, since the procedures often failed to control for factors such as direction of reading. Furthermore, analyses of sex differences were not carried out. Finally, the general trend was absent in other reports. Foulke (1964) found no hand asymmetry on a braille reading task, while Villey (1931) found a left hand superiority for German subjects, but a greater right hand preference for the fastest readers among American subjects.

A major problem with making inferences about central processing from these studies is that all of the subjects were blind, except for the three subjects tested by Smith (1929) and Merry (1931), and therefore, experienced different amounts of training and practice with the two hands. As Hermelin and O'Connor (1971) point out, the left hand would tend to gain practice during the early stages of learning to write. As the child wrote with his

right hand, he would have to feel the letters to be copied with his left.

Clear support for left hand superiority in braille reading was found by Hermelin and O'Connor (1971). They tested 15 blind adults on a task involving the reading of braille letters randomly arranged in vertical columns. There was no difference between the hands in speed of reading for either the index or middle finger. But for the middle finger, there were fewer errors with the left hand. These findings suggest that only when a generally unpracticed finger, such as the middle finger, is used, can individual differences in reading experience be reduced enough for the between-subject hand difference, reflecting differences in central processing, to appear. It may be inferred from this study that braille reading tends to be approached as a right hemisphere function.

The results of a study by Feinberg and Harris (1975) of braille letter learning by sighted adults support the conclusion that the task is approached as a right hemisphere function. They provided one of the only analyses of adult sex differences on the task and found no significant difference between the magnitude of the left hand superiority for the two sexes. A suggestion of sex differences in learning style was found in the correlation of degree of left hand superiority with overall learning scores. Those men who showed a large left hand superiority tended to perform better on the task as a whole, while the opposite was true for the women. Kimura's finding (1969) of sex differences

in approach to tasks that can be performed with either left or right hemisphere mechanisms was thereby supported. One purpose of the present study is to seek further support for this conclusion.

Age Differences

Interaction of Age and Sex Differences in the Development of Cognitive Skills and Hemisphere Specialization

The sex differences in verbal and spatial skills well-established in adults have also been found in children for some measures. These differences become stronger with age. For girls, as compared to boys, the first word is produced earlier, a higher rate of spontaneous babbling is found, and performance on early linguistic measures better predicts later measures of general intelligence (Cameron, Livson, & Bayley, 1967). Male superiority on spatial tasks, such as maze learning (Porteus, 1918; Mellone, 1944) and road-map reading (Money et al., 1965) has been found as early as age seven. It remains to be asked what the process of development of hemisphere specialization is, whether this process differs in males and females, and whether this process could influence the sex differences in pattern of cognitive abilities.

Generally, hemisphere specialization is evident at an early age. In fact, most recent research with infants indicates at least a partial predisposition of the hemispheres for certain basic functions (Molfese, 1973; Turkewitz, Moreau, Davis, & Birch, 1969; Rudel, Teuber, & Twitchell, 1974). A good portion of the studies of hemisphere specialization in young children have

employed a dichotic listening technique with verbal stimuli. Most of these studies have found a substantial right ear (left hemisphere) superiority at the youngest age tested - three years (Nagafuchi, 1970; Ingram, 1975a), four years (Kimura, 1963; Geffner, & Dorman, 1976), and five years (Kimura, 1967; Knox, & Kimura, 1970; Pizzamiglio, & Cecchini, 1971). In addition, a left ear superiority for the recognition of dichotically presented nonverbal environmental sounds was found at the age of five years, the youngest age tested (Knox, & Kimura, 1970).

These dichotic listening studies have generally found either a constant or decreasing magnitude of ear asymmetry with increasing age. As Satz, Bakker, Teunissen, Goebel, and Van der Vlugt (1975) point out, clinical evidence of recovery from childhood aphasia (Lenneberg, 1967) and hypotheses about the likely developmental process suggest an increasing lateralization with age, at least until about age ten. Satz et al. (1975) attributed the lack of a developmental increase in lateralization in past studies to a possible ceiling effect imposed through the use of tasks too simple for older children. To avoid this possible ceiling effect, Satz et al. (1975) tested five- to 11-year-olds on a more difficult dichotic task consisting of four digit-pairs per trial. They found a significant overall right ear advantage (REA), a significant improvement in performance with age, and a significant increase in lateralization with age. While the right ear was slightly better than the left for the five-year-old group, the ear asymmetry was not significant until age nine.

There are two possible problems with the Satz et al. (1975) study, though. First, all the older children were right-handed, while 26% of the five-year-olds and 12% of the six-year-olds were classified as mixed or left-handers. The presence of mixed and left-handers could be one of the reasons why the ear asymmetry for the youngest groups did not reach significance. Second, the more difficult task, chosen to avoid a ceiling effect, may in fact have been too difficult for the youngest children, creating a floor effect and minimizing ear asymmetry. Geffner and Dorman (1976) found a significant REA for lower-class four-year-olds on a simplified dichotic listening task of one monosyllable pair per trial, when no asymmetry was found previously on a more difficult task (Geffner, & Hochberg, 1971).

In summary, no clear picture of the development of hemisphere specialization emerges from the dichotic listening data. The assumption with the best chance of reconciling all the data may be early onset of hemisphere asymmetry, and increase in strength of lateralization with age.

Infant sex differences in lateralization have generally not been noted, and sex differences on the dichotic listening tasks were weak if found at all. Weak sex differences in REA were found at the youngest ages tested and were generally contradictory. Geffner and Hochberg (1971) found that the sex difference in mean REA was greatest for the four-year-olds, with this difference favoring girls. Similarly, a greater mean REA for five-year-old girls was found by Kimura (1967) and Pizzamiglio and Cecchini (1971).

On the other hand, Geffner and Dorman (1976) found a significant REA for four-year-old boys, but not four-year-old girls, and Nagafuchi (1970) found more significant differences between ears for groups of boys than for girls.

Most verbal dichotic listening studies have not disclosed a sex difference in overall performance, although Kimura (1963) reported that girls were superior to boys at ages four, five, and six. Thus, while there is a suggestion that the adult female superiority on many linguistic tasks may be evidenced to some degree by the girls on these tasks, the way the development of hemisphere specialization influences these cognitive abilities has not been established.

In the previously cited study with dichotic presentation of nonverbal environmental sounds (Knox, & Kimura, 1970), all sex by age groups showed a significant left ear advantage (LEA) in a first experiment, while all groups except the youngest (five-year-old) girls did so in a second experiment replicating the first. Boys showed better recall than girls in the first experiment, but not in the second. In additional experiments using animal sounds, no LEA was found, but boys performed better than girls in both a dichotic and monaural presentation. These experiments suggest that a male superiority for right hemisphere functions may begin to appear at an early age, and there is a hint that the process of lateralization of these functions is slower for females.

It seems important to consider developmental studies of hemisphere specialization in other modalities, both to yield a more complete picture of the developmental process and to provide more nearly "pure" spatial tasks.

Age Differences in Asymmetry in the Somesthetic Modality

Several developmental studies of asymmetries in the somesthetic modality have centered on measures of sensitivity and motor functions. In a study of tactual thresholds in a predominantly right-handed population, Ghent (1961) found that girls showed the adult pattern of greater sensitivity for the non-dominant thumb at around six years of age, which then diminished around 11 years of age. Boys, however, showed a slightly greater sensitivity of the dominant thumb at five and six years of age, no difference between the hands from seven to nine years of age, and a greater non-dominant thumb sensitivity at age 11. Kimura (1963) supported this finding that the left thumb becomes more sensitive than the right earlier in right handed girls than boys.

Denckla (1973) examined simple repetitive tapping and successive finger movements (sequentially tapping each finger against the thumb) in children five to eight years of age. Here, just as in the studies of somesthetic sensitivity, the increasing ability of the non-preferred hand, rather than the expected increase with age in strength of right-handedness, represented the expected adult pattern of specialization. No hand asymmetry was found for the successive finger movements, but a right hand superiority

which decreased with age was found for the tapping task. Using a similar finger tapping task, which required the subjects to tap a key as quickly as possible, Ingram (1975b) found an asymmetry in favor of the right hand for children as young as three years. In addition, right hand performance was less variable on a task in which the subjects were instructed to tap at the steady rhythm of a metronome (Wolff, & Hurwitz, 1976). These findings suggest a left hemisphere specialization for the precise temporal regulation and serial ordering of motor movements.

A left hand superiority in relation to motor movements has been found in children as young as three years for tasks requiring the subjects to copy various hand postures and finger spacings (Ingram, 1975b). Spatial elements in these tasks may have led to a right hemisphere superiority.

Sex differences on these motor tasks are difficult to relate to the sex differences revealed in the dichotic listening data. First, of all the motor tasks mentioned, boys surpassed girls in only one. They were faster on one repetitive tapping task, and then, only at age five (Denckla, 1973). Contrary to this finding, boys were generally not superior to girls on the dichotic listening tasks for which a left hemisphere superiority was found.

Second, girls at most of the ages tested were better than boys on the successive movements task (Denckla, 1973), on the hand postures and finger spacing tasks (Ingram, 1975b), and at keeping a steady beat and keeping the rate of an entraining metronome

(Wolff, & Hurwitz, 1976). Asymmetry was significantly greater for girls only on the "left hemisphere task" of keeping a steady tapping rate (Wolff, & Hurwitz, 1976). This superiority of the girls on both left and right hemisphere tasks could reflect the generally faster growth rate of girls, as Wolff and Hurwitz (1976) and other authors have suggested. Another reason could be that these motor tasks, such as the successive finger movements, require cooperation between hemispheres, which may be an important feature of girls' early maturation (Denckla, 1973). Finally, the greater asymmetry of girls on at least one "left hemisphere" motor task may support those dichotic listening studies which found a greater REA for girls at the youngest ages. Girls' greater ability on some verbal tasks, then, could stem from an earlier differentiation of left hemisphere functions.

Further study of hand differences in more complex functions is important for full comparison of the development of asymmetry in the somesthetic modality to the development in other modalities, to gain a more complete picture of possible sex differences in hemisphere specialization, and to assess the effect of looking only at preferred hand developmental trends in perception. Four studies of cerebral asymmetry with normal young children involving the higher ability to discriminate shapes and objects through the haptic sense will be considered (Witelson, 1974, 1976; Rudel, Denckla, & Spalten, 1974; Rudel, Denckla, & Hirsch, 1976).

Past research has shown that the ability and the inclination to use the haptic sense to gain information about the environment

develops later than does dependence on the visual or auditory sense (Abravanel, 1973; Rudel, & Teuber, 1971; Fellows, 1968). While Piaget and Inhelder (1956) emphasize the early importance of the haptic sense and the similarity between the processes of constructing a percept in the visual and tactile senses, they conclude that shape construction in the tactile sense lags a year or two behind that in the visual sense. Piaget and Inhelder attribute the slower development of the tactile sense to their theory that "exploration by eye is much easier than exploration by touch, for the simple reason that a visual centration may embrace many more elements simultaneously than a tactile centration, and hence visual shapes are more rapidly constructed than tactile ones" (pp. 24-25).

As Connolly and Elliott (1972) state, "If it is true that man, having freed himself from the requirements of locomotor activity by developing a bipedal gait, developed thereby unrivalled manual dexterity - then the hand should be a late developer, showing adult skill as the result of a long period of juvenile experimentation and sensory-motor integration" (p. 371). This evolutionary explanation for the slow development of hand abilities possibly could hold true for sensory ability of the hand as well.

Contrarily, it could be argued that children have greater sensitivity than adults because skin growth is not accompanied by an increase in nerve fibers, in which case discriminatory ability should be greater in the early years. However, no significant difference between the sensitivity on the palms and forearms of children age six to eight and adults has been found, and

adults are more sensitive than the children on the tip of the middle finger (Peiper, 1963).

The evidence, then, suggests that studies of asymmetry in the haptic modality will reveal a slower schedule of hemisphere specialization than has been established by the dichotic listening studies. This hypothesis would have to assume that certain types of processing specific to the haptic modality exist or that the use of a preexisting hemisphere style of problem solving does not take place until greater skill in a modality is established. Perhaps since most studies of the development of haptic perception have required the child to use his preferred hand, the slow development of this modality has been exaggerated. In addition, emphasis on use of the preferred hand could distort the patterns of development of the two sexes.

Against these speculations of a later cerebral specialization for the haptic modality, the first of the studies noted above (Witelson, 1974) revealed a left hand superiority for the discrimination of nonsense shapes at all age levels tested, the youngest being six years. Witelson presented three dimensional nonsense shapes and embossed letters in a counter-balanced, repeated measures design using a dichhaptic presentation technique. Her aim was to determine whether there was a left-right asymmetry in the perception of linguistic and non-linguistic tactual stimuli in neurologically intact individuals. Just as studies in the other modalities have revealed, a left hand superiority for the discrimination of the spatial stimuli was found. No asymmetry

was found for the linguistic stimuli, though, and Witelson suggests that within the tactual system, linguistic stimuli may have to be analyzed first by a spatial code and then changed into a language code. At least initially, then, the right hemisphere is thought to have a more important role in the processing of somesthetic linguistic stimuli, so a right hand superiority is precluded. Hermelin and O'Connor (1971) reasoned in a parallel fashion that "the brain treats tactile input such as braille as spatial items, to be analyzed by the right hemisphere before or while verbal coding of the material takes place in the left" (p. 434).

Two confounding factors are evident when considering Witelson's results. First, only boys were tested, and their initial superiority on tasks requiring the discrimination of spatial stimuli might tend to bias them in favor of a right hemisphere mode of solution. Secondly, response method was confounded with hemisphere superiority for processing. For the spatial stimuli, subjects were told to point with their left hand to the correct shape in a visual array. The activation of the right hemisphere for a response could be largely responsible for the left hand superiority. In fact, some of the subjects were also given a control condition in which they were asked to point with their right hand, and no significant difference between the hands was found.

In a second study, Witelson (1976) tested girls, as well as boys, on the same task, using nonsense shape stimuli. The children were six to 13 years of age, and all were strongly right-handed. Again, a left hand superiority was found for the boys at all ages tested. No hand difference was found for the girls,

and a trend toward left hand superiority was found at age 12 only. Witelson concluded that, for boys, the right hemisphere is specialized for processing spatial material at least by age six, while the processing of spatial material is bilaterally represented in girls at the ages tested. Since this conclusion of a sexual dimorphism in the neural organization of right hemisphere functions has not been indicated in the auditory, motor, or hand sensitivity tasks described, further support is needed.

Use of a Braille Learning Task With Children

Use of a braille learning task with blind children has yielded conflicting results. On the one hand, Fertsch (1947) had blind children from grades three to 11 read two paragraphs, one with each hand, and measured reading time as well as comprehension. Those children who read equally fast with both hands had the fastest reading times, those with a right hand superiority had the second fastest times, and those with left hand superiority had the slowest times. Age and sex differences were not analyzed, though, so it is possible that the younger children were responsible for the right hand superiority, which then diminished and eventually reversed with age. This speculation is based on the finding to be described of Rudel et al. (1974) that younger, sighted girls show a large right hand superiority for braille letter discrimination.

Contrary to Fertsch's (1947) suggestion that the right hand was superior for reading braille, Hermelin and O'Connor (1971) found support for a left hand superiority in a controlled setting. They measured speed of reading and number of errors made in

reading simple sentences for 16 blind children, 14 of whom were right-handed, two bidextrous. Differences in reading speed and number of errors for both the index and middle fingers were found in favor of the left hand. Age and sex differences were again not reported.

Finally, Rudel et al. (1974) used a braille letter learning task to study the development of cerebral specialization in normal, sighted children. Boys and girls, ranging in age from seven to 14 years, had to learn the names of 12 braille letters, six to each hand. For girls, the expected adult pattern of a significant left hand superiority did not emerge until about 13 years of age, and the right hand was better at ages seven to 11. There was no hand difference for the younger boys, but a significant left hand superiority emerged by age 11. These results for the girls parallel closely the findings of Witelson (1976). Rudel et al. (1974) concluded that the girls' right hand superiority could reflect either a greater reliance on left hemisphere verbal coding strategies or a slower, less complete lateralization of right hemisphere specialization for spatial functions. Either of the possible explanations for sex differences previously outlined can explain the difference found here.

Another study by Rudel et al. (1976) sought, in part, to determine whether in the first study the requirement of naming the braille letters affected the pattern of asymmetry revealed. In the second study, therefore, the subjects judged only whether two braille letters examined sequentially by the same hand were the same or different. The results were essentially the same.

In addition to the previously noted advantages to the braille learning task, then, a braille task also is likely to reveal age differences in preferred approach to problem solving. The verbal response mode used in Rudel et al.'s paired associate learning task is appropriate for braille learning, and the confounding factor of Witelson's hand pointing response is thereby partly avoided.

Contributions of the Current Study

The present study was carried out with several aims in mind: First, it was hoped that clearer evidence would appear bearing on the question of sex differences in hemisphere specialization. While it is generally concluded that men show a stronger REA for verbal stimuli than women, suggestions of adult sex differences in degree of right hemisphere specialization for spatial processing warrant further study.

Second, the nature of cerebral specialization for complex tasks in the somesthetic modality has not been investigated so much as that for tasks in the visual and auditory modalities. To gain a complete picture of lateralization patterns, many modalities should be considered. In addition, rather than employing a passive stimulation technique, it was decided to allow subjects to actively examine the braille letters with their index fingers in almost any way. As described by Gibson (1962), active, or "haptic" (Revesz, 1950), perception is not the mere sum of the kinesthetic sense, consisting of feedback from the joint positions, and of the sense of new and changing patterns on the skin.

The purposive movements of the subject determine what he is perceiving. The use of an active exploration technique takes advantage of this supposition that asymmetries in scanning patterns contribute to asymmetries of perception, and it also resembles actual braille reading more closely.

Finally, it was hoped that the development of right hemisphere specialization for spatial processing would be further clarified. The sex difference in this process of development reported by Witelson (1974, 1976) and Rudel et al. (1974, 1976) might also be given support.

METHOD

Subjects

The subjects were college students and third, fifth, and eighth graders, with 16 male and 16 female right-handers in each age group.

The children were students in the elementary and junior high schools in a predominantly middle class, suburban community. Matched pairs of males and females were formed according to age, and the children thereby assigned to subgroups. The average age for both the male and female third grade groups was nine years, five months. For the male and female groups, respectively, the average ages for the fifth grade groups were 11:0 and 11:1, and for the eighth grade groups were 14:2 and 14:0.

Handedness for the third and fifth graders was determined by noting the hand used when the children were asked to perform five actions (Annett, 1970a): (1) to point to a picture, (2) to draw a circle, (3) to cut a strip of paper with scissors, (4) to throw a ping-pong ball in a basket a few feet away, and (5) to unscrew the lid of a jar. If at least four of the five actions were performed with the right hand, and if the teacher designated the child as a right-hander, the child's scores were included.

For the third and fifth graders, a letter explaining the study was sent to the parents of all participating children. (A copy of the letter is provided in Appendix A.)

The eighth graders were selected haphazardly by the experimenter from volunteers in several mathematics classes varying in ability level. Students not participating in physical education classes because of minor injuries also made up part of the sample.

The college students were Introductory Psychology students at Michigan State University who participated for course credit. Handedness for the college students and eighth graders was determined by scores on a 12-item handedness questionnaire (Annett, 1970b; see Appendix B) designed to assess a continuum of strengths of right- and left-handedness and validated on the basis of task performance (Raczkowski & Kalat, 1974). A student's scores were included if he scored in the first four of the total of eight categories, where category one indicates the strongest degree of right-handedness.

The tactile sensitivity of all subjects was judged to be unimpaired. The sensitivity thresholds determined by a two-point discrimination procedure were within a range of 1.6 mm. to 3.1 mm.

Stimulus Set and Subject Design

The stimuli were braille configurations used in the standard braille alphabet. The letters were printed by a braille typewriter in the center of standard plastic playing cards. The backs of the cards were covered with nail hardener to preserve the raised dots.

For the third graders, two supersets (A and B) of eight letters were used, and each superset was divided into two subsets (1 and 2). The letters are shown in Figure 1. The subsets were

Figure 1.--Assignment of subjects to letter sets for each school grade-by-sex group.

DOT PATTERNS USED AND SUBJECT DESIGN

THIRD GRADERS (N=32)

	HAND ASSIGNED	SUBSET 1				HAND ASSIGNED	SUBSET 2			
		B	J	S	K		C	W	O	I
SUPERSET A		●○ ●○ ○○	○● ●● ○○	○● ●○ ○●	●● ○● ●○		●○ ○○ ●○	●● ○● ○○	○● ○● ○○	●○ ●● ●○
N = 4 boys	L					R				
4 boys	R					L				
4 girls	L					R				
4 girls	R					L				

	HAND ASSIGNED	SUBSET 1				HAND ASSIGNED	SUBSET 2			
		A	X	R	H		D	F	Y	U
SUPERSET B		●● ○○ ○○	●○ ○○ ●●	●● ●○ ○○	○● ●● ○●		○● ●○ ○○	●● ○○ ●○	○● ○● ○○	●○ ●● ●●
N = 4 boys	L					L				
4 boys	R					R				
4 girls	L					L				
4 girls	R					R				

FIFTH GRADERS (N=32), EIGHTH GRADERS (N=32)
and COLLEGE STUDENTS (N=32)

	HAND ASSIGNED	SET A						HAND ASSIGNED	SET B					
		B	C	J	O	I	K		A	D	F	Y	H	U
5th grade		●○ ●○ ○○	●○ ○○ ●○	○● ●● ○○	○● ○● ●○	●○ ●○ ○●	●● ○● ○○		●○ ○○ ○○	●○ ○○ ○○	●○ ○○ ○○	●○ ○○ ○○	●○ ●○ ○○	●○ ●○ ○○
8 males	L							R						
8 males	R							L						
8 females	L							R						
8 females	R							L						
8th grade														
8 males	L							R						
8 males	R							L						
8 females	L							R						
8 females	R							L						
College														
8 males	L							R						
8 males	R							L						
8 females	L							R						
8 females	R							L						

Note: In this figure, only letters B and J correspond to the braille patterns.

chosen to contain one two-dot, two three-dot, and one four-dot letter and no left-right mirror image patterns. They are similar to the set used by Feinberg and Harris (1975), with an adjustment made for a particularly easy subset and two mirror image patterns within their subset A. For blind subjects, mean recognition time for the majority of letters was determined to be between .02 and .07 seconds. Two letters, one in each superset, had longer times (Nolan & Kederis, 1969).

The letter names chosen for the dot patterns were those judged least likely to be acoustically confused with another letter of the alphabet according to the experimenter's own judgment and limited pilot data. In addition, names of letters that resembled any of the dot patterns in shape, such as the L, were excluded. Letter names were assigned to subsets to obtain a fairly even balance of the first, possibly overlearned, letters of the alphabet across subsets and to avoid acoustically similar names in the same subset. To meet these criteria, all the letter names assigned to the braille configurations do not match their names in the braille alphabet, except for letters "B" and "J."

Half of the third grade subjects of each sex received one superset, and half received the other. Each subset was used equally often with the left hand as with the right, and equally often first or second. The design of the study is also shown in Figure 1.

For the other three grades, two sets (A & B) of six letters were used. The sets were chosen to contain two two-dot, two

three-dot, and two four-dot letters and to meet the same criteria used for the third grade letter sets. Half of the subjects of each sex at each of the three grade levels were tested with the right hand first, and half were tested with the left hand first. Within each sex by grade by hand testing order group, half of the subjects were given Set A to the left hand and Set B to the right hand, and half were given the sets to the opposite hands.

The fewer stimuli for the third graders, as well as a shorter presentation time for the college students, were designed to make the task more subjectively equal for the four grade levels. Subjective equality was emphasized as opposed to objective equality because the difficulty of the task and memory load required have been found to be important variables influencing the degree of hand asymmetry (Benton et al., 1973; Dee & Fontenot, 1973; Umilta et al., 1974).

Apparatus

A large board about 30 in. (76.20 cm) in height served to block the experimenter from the subject's view. There was a space of about 3 in. (7.62 cm) between the board and the table for the subject to place his hands through, and a shelf extending about 12 in. (30.48 cm) on the subject's side of the board to prevent him from viewing his hands. The board was placed on a desk or table measuring as close to 35 in. x 35 in. (88.90 cm) as possible, since that was the width of the legs supporting the board.

Two metal card holders about 2 in. (5.08 cm) apart were screwed into a small board which was placed at a comfortable reaching

distance directly in front of the subject. The card holders were placed close together to reduce the possibility that attention directed to the left or right of body midline would influence the pattern of asymmetry found.

The subjects were tested in small experimental or storage rooms with either one or two experimenters present.

Research Design

Each third grader received 44 letter presentations to one hand at a time, half of the subjects beginning with the left hand and half with the right. Four letters of one subset were presented to one hand, the four letters of the other subset within the same superset to the other hand. Between trials to each hand, a rest period of about one to three minutes was given.

Each subject in the other three grade groups received 66 letter presentations to one hand at a time. The six letters of one set were presented to either the right or left hand first, and then the six letters of the other set were presented to the other hand. Again, a short rest period between trials to each hand was given.

Each of the six (four, for the third graders) letters in a set (subset) was presented once during the first six (four) trials. The subjects were told the name of each of these first letters while they were feeling it. Within subsequent groups of 12 (eight) trials to one hand, the six (four) letters were presented twice in random order, with the constraint that no letter be presented on two consecutive trials. The subjects, then, were given

five groups, or "blocks," of 12 (eight) letter presentations to each hand, for which the results were compiled separately.

Procedure

Upon entering the room, each subject was seated opposite the experimenter at the table and assisted in finding the two card holders. The subject was told that he would be learning to read braille and would be given cards that contained spatial configurations representing letters. He was asked to keep his hand in a ready position near the card holder so that he would be able to begin feeling the letter with his right or left index finger as soon as a card was placed in position. He was told that he would have four seconds (three, for the college subjects) to feel each letter, and that he should give his best guess for the letter name when the experimenter said "answer." The "answer" was said as the experimenter removed the card after the four- (three-) second presentation period was over. Whether the guess was right or wrong, the subject was told the correct answer after every trial.

The instructions were modified slightly for the third and fifth graders (see Appendix C). The word "bumps" was used instead of "spatial configurations," and the index finger and right and left hands were pointed out to the child rather than verbally stated. For all grade levels, it was emphasized that the bumps (spatial configurations) would not in any way feel the way the letters look.

Each subject also received two practice cards for each hand before the test trials for that hand. The two practice letters were three-dot letters different from those presented during the learning trials. Letters with the same number of dots were selected to avoid encouraging the subjects to concentrate on the general number of dots as a main discriminating feature.

Subjects were told the names of the practice letters on the first two trials and asked to guess the names on the following trials. A subject who could not guess the two letters correctly in a row after six presentations of each letter in an ABBA order was excluded from the experiment.

After the main learning task, handedness information and two-point limen scores were gathered from each subject. The two-point thresholds were determined by averaging the values from one ascending and one descending series, measured with an ordinary compass used for drawing circles. In addition, the college subjects were given the Spatial Relations Subtest of the Differential Aptitude Test. The entire experiment lasted about 30-40 minutes for the children and about an hour for the college students.

RESULTS

Practice Trials

Two subjects did not reach the criterion for inclusion in the study. This criterion was to identify the two practice letters in two consecutive trials within six presentations of each letter. Both subjects were girls, one in the third grade and one in the fifth grade, and both failed with the left hand. They were replaced with other children from the same classes.

In Figure 2, the mean number of trials needed to reach the practice criterion is plotted as a function of grade, sex, hand testing order, and hand used. In general, the number of trials to criterion decreased with increasing grade for the males, ranging from an average of 4.1 trials for the third grade boys to 2.6 trials for the college men. For the females, the average number of trials to criterion decreased from 4.1 trials for the fifth grade girls to 2.6 trials for the eighth grade girls, but an intermediate average number of trials was needed for the other two grades.

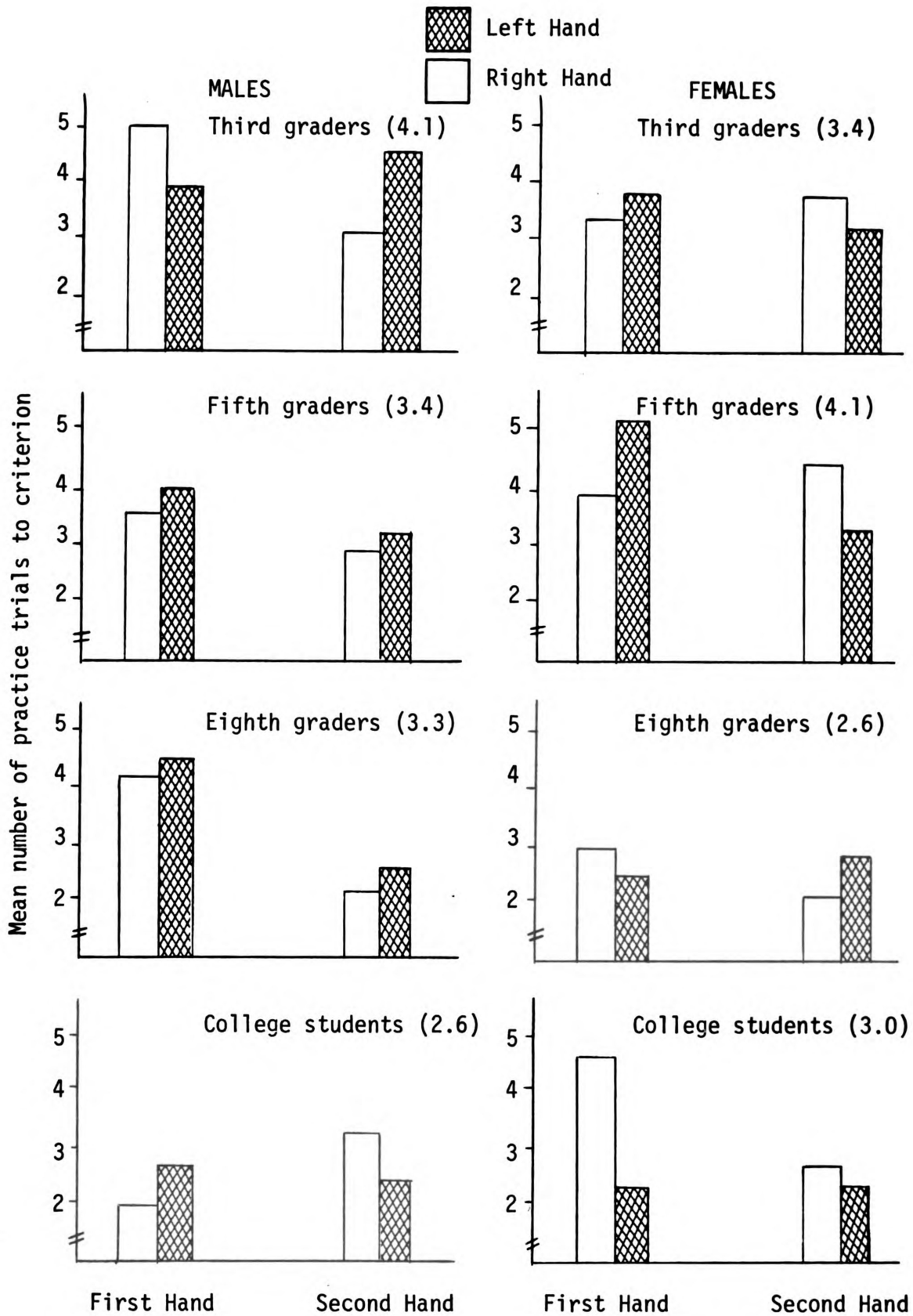
For all subgroups of the three lowest grades, Figure 2 indicates that the second hand tested generally required fewer trials to reach criterion than did the first hand tested. This trend was reversed for three of the four sex by order subgroups of college students. For each of these three subgroups, the average number of trials to criterion for the first hand tested

was less than 2.6, fewer than any other grade by order by sex subgroup except one. The fact that the initial scores for these three college subgroups were very low could have resulted in a floor effect. In that case, the greater number of trials required by the second hand could be due to such factors as fatigue or careless mistakes.

It is also apparent from Figure 2 that for the three lowest grades, improvement with the second hand tested was about the same when the left hand followed the right as it was when the right hand followed the left. For the third grade males and eighth grade females, improvement was equal in these two conditions. For the other four grade by sex subgroups, slightly more improvement occurred when the left hand was tested first, so that the right hand was better overall. The initial scores for these four subgroups, though, were greater for the left-hand-first condition.

In contrast to the three lowest grades, the left hand was slightly better overall for the college students. For females, the second hand tested required fewer trials than the first when the right hand was tested first. In the left-hand-first condition, the second hand required a greater number of trials. Again, this unequal facilitation of the second hand in the two hand-testing-order conditions could be related to the level of initial scores. In the left-hand-first condition, the average number of trials to criterion for the left hand was so small that a decrease for the second hand was unlikely. For both order subgroups of college

Figure 2.--Practice scores as a function of grade, sex, hand order, and hand used. (Average number of practice trials to criterion are in parentheses for each grade x sex group.)



males, the initial scores were low, and the second hand tested required a greater average number of trials for subjects to reach criterion.

Test Trials

Scores Summed Across Hands

To compare across grade groups receiving a different total number of learning trials, the data are presented in terms of the proportion of letters correct per trial block. These proportion scores were obtained by dividing the number of letters correct in each block by the number of letters presented in a block (eight for the third graders, 12 for all other grades). Since t-tests revealed no significant differences between scores on the various letter sets for any grade (Appendix D), the letter set groups were combined for all analyses.

The proportion of letters correct per trial block for the hands combined is presented in Table 1 for sex and hand order groups at each grade level. Over all groups, the proportion scores tended to increase across grade level, with the main increase occurring between the fifth and eighth grades. The third and fifth grade scores were almost identical, as were the eighth grade and college scores. The uneven improvement across grades is explained by the different methods used. The task was objectively easier for the third graders, who had fewer letters to learn, and was more difficult for the college group, who were given three seconds instead of four to inspect each letter.

The same general age trend was evident for the males considered separately, although the fifth graders scored very much lower, and the eighth graders very much higher, than the other groups. The females' scores also increased across grade level, but with the smallest increase occurring between the fifth and eighth graders. The male and female scores were almost identical when averaged across grade levels.

When the hand testing order groups were considered separately, a gradual increase across grades in proportion of letters correct was evident in the right-hand-first group only. No consistent trend across grades was found in the left-hand-first group. The scores for the two hand-testing-order groups averaged across grade levels differed by only one percent.

A multivariate approach to repeated measures ANOVA with multiple dependent measures at each measure point was performed on the proportion scores for both hands combined. The effects of sex, grade, and hand testing order (left or right hand first) were tested with multivariate F ratios. Within each multivariate F, five univariate F ratios were computed to test the effects for each trial block separately. The analysis revealed no significant effects of sex, grade, or hand testing order, and no significant interaction of these variables. (The multivariate F ratios are provided in column 1 of Table 2.)

The standard deviations for all groups with hands combined are provided in parentheses in Table 1. The deviations were homogeneous across groups, ranging from .157 to .193. The

TABLE 1.--Average Percent Correct at Each of Four Grades for Sex and Hand Order Groups and for All Groups Combined.

	Males	Females	Right Hand first- Left Second	Left Hand first- Right Second	Overall Average Percent Correct
3rd grade	.503 (.167)	.522 (.160)	.503 (.169)	.523 (.158)	.512 (.162)
5th grade	.490 (.178)	.534 (.175)	.513 (.166)	.512 (.188)	.513 (.176)
8th grade	.620 (.193)	.538 (.159)	.568 (.177)	.591 (.185)	.579 (.180)
College	.575 (.187)	.572 (.172)	.617 (.190)	.530 (.157)	.572 (.180)
Average over 4 grades	.547	.542	.548	.539	.544

largest and smallest variances were compared in an F-ratio, which was not significant ($F = 1.48$, d.f. = 15,15, $p > .05$).

Difference Between Hand Scores

Difference scores were obtained by subtracting each subject's proportion score for the right hand from his proportion score for the left hand. A multivariate approach to repeated measures ANOVA with multiple dependent measures at each measure point was performed on these difference scores (see column 2, Table 2) to test the effects of hand and its interactions. Averaged over all conditions, the left hand scores were significantly better than the right hand scores ($F = 5.66$, d.f. = 5,108, $p < .0002$). However, the univariate F ratios computed for each

TABLE 2.--The Multivariate F Values for the Main Analysis of Percent Correct Scores.

Using Sum Across Hands at Each of Five Observation Points (trials)				Using Difference Between Hands at Each of Five Observation Points (trials)			
Source	d.f.	F	p	Source	d.f.	F	p
Grand Mean	5, 108	333.64*	p < .0001	Hand	5, 108	5.66*	p < .0002
Grade	15, 298.5	1.64	p < .06	Grade x Hand	15, 298.5	1.67*	p < .055
Sex	5, 108	.204	p < .96	Sex x Hand	5, 108	.648	p < .66
Order	5, 108	1.32	p < .26	Order x Hand	5, 108	7.14*	p < .0001
Grade x Sex	15, 298.5	.872	p < .60	Grade x Sex x Hand	15, 298.5	1.14	p < .32
Grade x Order	15, 298.5	1.08	p < .38	Grade x Order x Hand	15, 298.5	1.59	p < .07
Sex x Order	5, 108	.666	p < .65	Sex x Order x Hand	5, 108	3.77*	p < .0035
Grade x Sex x Order	15, 298.5	1.22	p < .26	Grade x Sex x Order x Hand	15, 298.5	.790	p < .69

(*p < .05 will be considered the cut-off level for significance.)

trial block separately reached significance at the last two trial blocks only, indicating that the hand effect was strongest at these points. (The univariate F ratios are provided in Appendix E.) Since the step down F value for the fifth trial block was significant, none of the other step down F ratios can be interpreted. (See Appendix F for the step down F ratios.)

Grade interactions with hand. Table 3 shows the average percent correct responses for each hand at the four grade levels and the overall percent superiority of the left hand. Although the left hand was superior at each grade level, the effect was much stronger for the third grade and college groups. This difference among grades was reflected in a significant hand by grade interaction ($F = 1.67$, d.f. = 15,298.5, $p < .055$).

None of the corresponding univariate F ratios was significant, indicating that the effect was a general one for all trial blocks considered together. The step down F ratio for the fifth trial block reached significance, so none of the trial blocks could be eliminated from consideration.

Hand testing order interactions with hand. The average percent correct responses per trial block for each hand for each grade and each hand testing order are plotted in Figure 3. The pattern of hand superiority was different for each of the hand testing order groups, and these differences appear to be consistent across grade level. For both order groups, the hand tested second was better overall, but the difference between the first and second hand scores was not equal in the two order groups. When the right

hand was tested second, it was better than the left by a small margin. When the left hand was tested second, its superiority over the right hand was relatively large, thus yielding an overall superiority of the left hand. The implied hand by order interaction was significant ($F = 7.14$, $d.f. = 5,108$, $p < .0001$).

The univariate F ratios for this interaction reached significance at all trial blocks except the last. The step down F ratio did not reach significance for the last trial block, was marginally significant for the fourth trial block ($p < .0697$), and was significant for the third trial block. These step down and univariate F ratios indicate that, controlling for the first four trial blocks, the hand $\times$ order interaction had no effect on the scores for the last trial block. Controlling for the first three trial blocks, the interaction had only a marginal effect on the scores for the fourth trial block. Thus, as shown in Figure 3, there was a trend toward left hand superiority in the fourth trial block, and especially the fifth trial block, regardless of order condition. While the right hand was generally superior in the early blocks of the left-hand-first condition, by the fifth trial block, the left hand was better than the right for the third and eighth graders, and was nearly equal to the right for the other two grades.

Sex interactions with hand. The mean percent correct responses per trial block for each hand according to sex and hand testing order are plotted in Figure 4. The difference between hand scores was about the same for both sexes. While the basic

Figure 3.--Mean percent correct responses per trial block for each hand according to school grade and hand testing order.

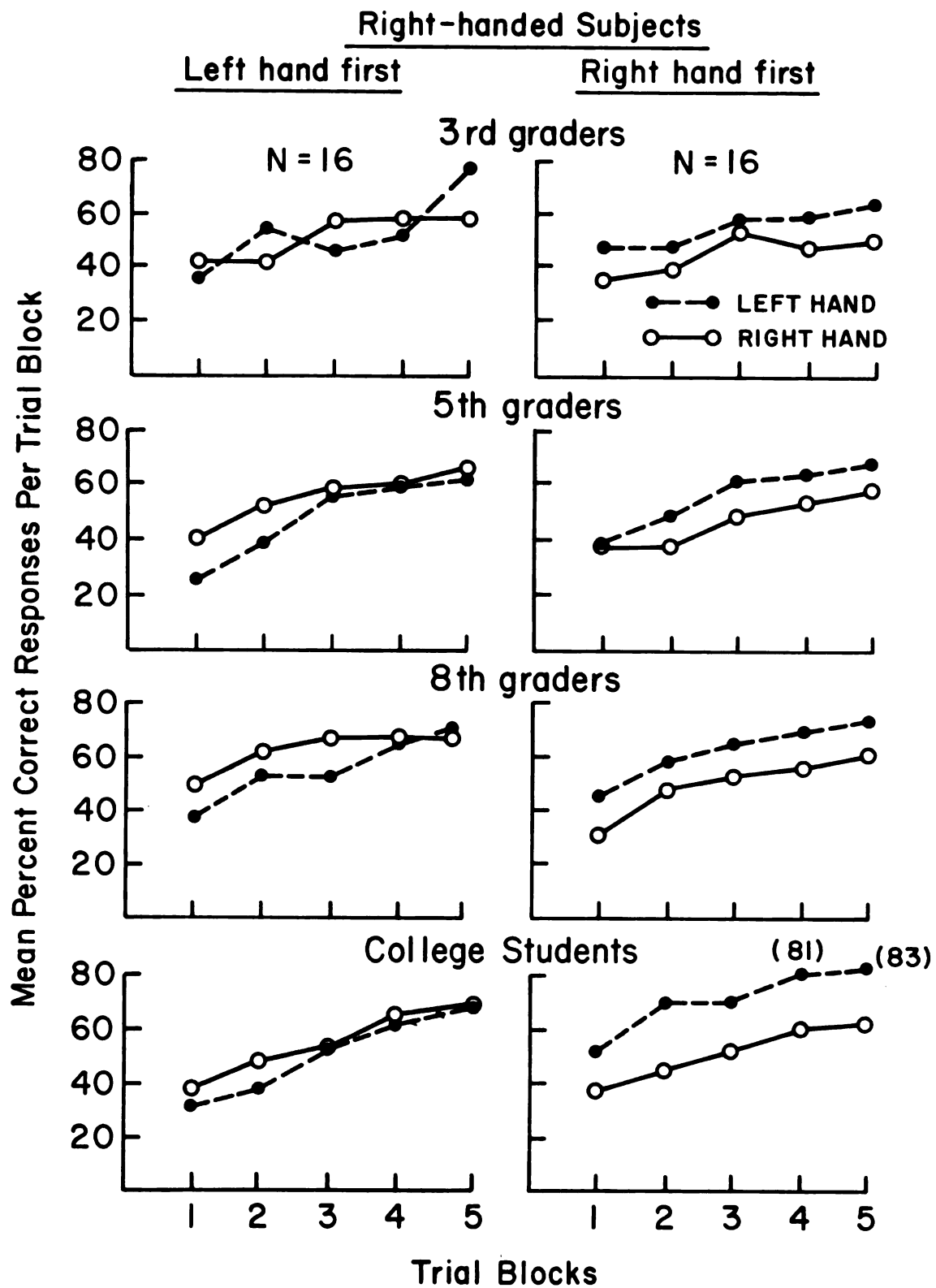


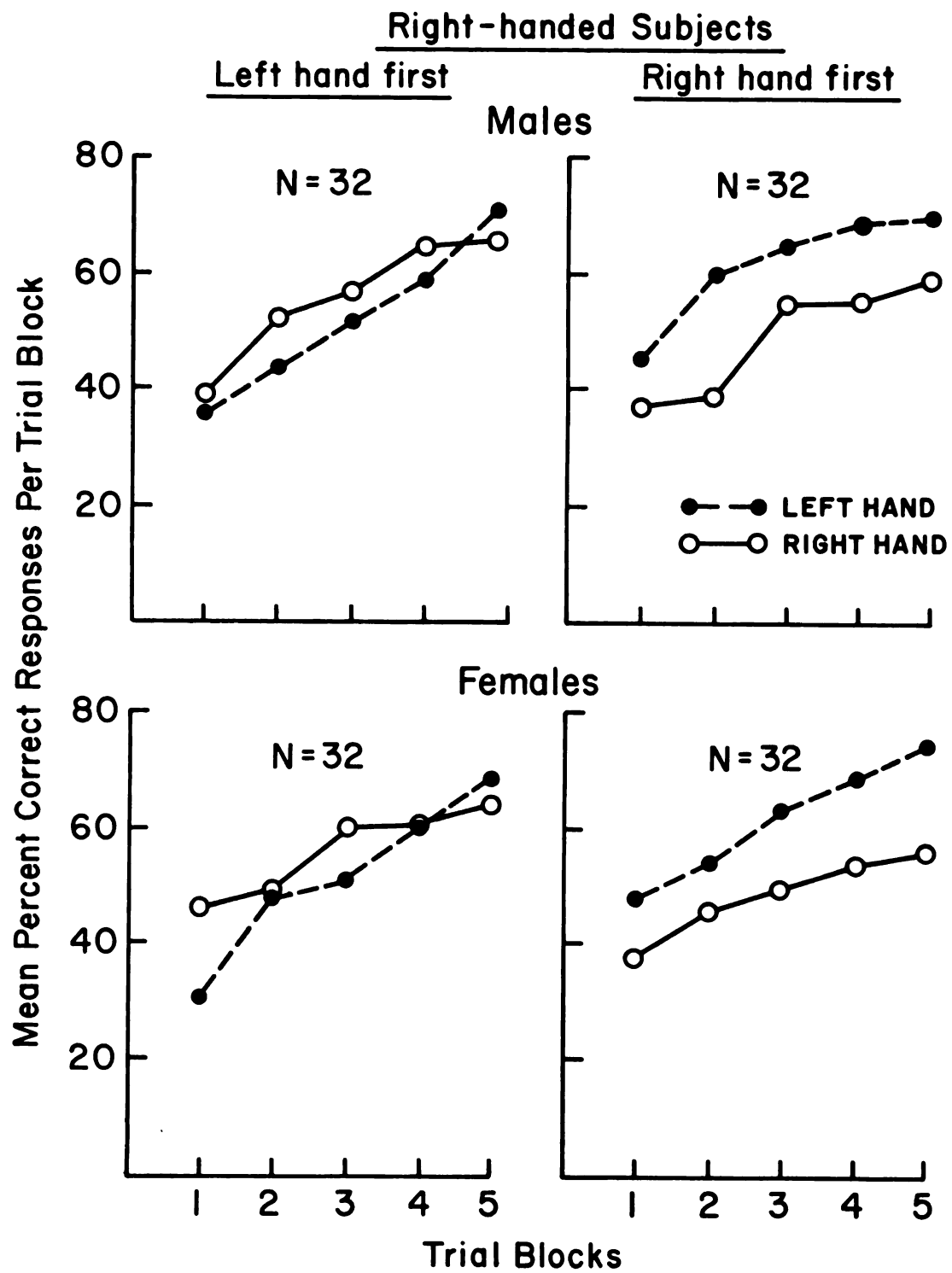
TABLE 3.--Mean Percent Correct Responses Per Trial Block According to School Grade and Hand. (The standard deviations for each hand x grade group are in parentheses).

	Left Hand	Right Hand	Percent Superiority of Left Hand % Increase
3rd Grade (N=32)	.54 (.16)	.48 (.16)	13.1%
5th Grade (N=32)	.52 (.17)	.51 (.18)	2.6%
8th Grade (N=32)	.59 (.19)	.57 (.17)	4.2%
College (N=32)	.61 (.20)	.54 (.15)	14.4%

effect of hand testing order was also similar for both sexes, the specific pattern of hand differences in the early trial blocks appears to have differed for the two sexes. For the males, the difference between the scores for the second hand tested and the scores for the first hand tested was much greater at the second trial block than at either the first or third trial block. This pattern was reversed for the females in that the difference between hands was relatively small at the second trial block. This sex difference in pattern of learning scores for the first and second hand tested is reflected in a significant multivariate F ratio for the sex by order by hand interaction ($F = 3.77$, d.f. = 5,108, $p < .0035$).

The observation that the major contribution to this interaction was made by scores in the second trial block is supported

Figure 4.--Mean percent correct responses per trial block for each hand according to sex-of-subject and hand testing order.



by the fact that only the univariate F ratio for the second trial block reached significance. In addition, the step down F values for the last three trial blocks were not significant, while the step down F ratio for the second trial block did reach significance. These step down F values lead to the conclusion that, controlling for all earlier trial blocks, scores on the last three trial blocks did not contribute to the significant multivariate F ratio. Essentially, then, the difference between order conditions was the same for both sexes, except for a difference in the pattern of scores in the early trial blocks.

The mean difference between the percent correct scores for the two hands is provided in Table 4 for each sex at the four grade levels. (A graph of the percent correct scores for both hands at each trial block for each sex by school grade group is also provided in Appendix G.) A positive mean difference indicates that the proportion of letters guessed correctly was greater with the left hand than with the right. The table reveals that the change in hand asymmetry across grade levels was different for males and females. While, for both sexes, the trend across grades was characterized by an early positive asymmetry, followed by a large decrease in asymmetry, and finally with a recovery of asymmetry at the college level, the peaks occurred at different points for the two sexes. The males showed the highest degree of positive asymmetry at the third grade level, and a slight negative asymmetry at the following fifth grade level. Positive asymmetry then returned gradually to a fairly high level for the college males.

The females did not show a fairly high degree of positive asymmetry until the fifth grade, which was then immediately followed by an extremely small asymmetry for the eighth grade girls. The college women showed a high degree of positive asymmetry, almost equal to the asymmetry for the third grade boys.

TABLE 4.--Mean Difference Between the Percent Correct Scores for the Two Hands (Left Hand % Correct Score Minus Right Hand % Correct Score) for Each Sex at Each Grade Level.

Grade	Males	Females
3rd	.106	.021
5th	-.027	.054
8th	.043	.007
College	.060	.094

This general trend of sex differences did not reach significance, as is shown by the non-significant F ratios for the sex by hand and the sex by grade by hand interactions.

Possible effects of a sex by grade interaction on hand differences were also examined by using a different measure of laterality. This second measure was used because it has been shown (Harshman & Krashen, 1972, as cited by Marshall, Caplan, & Holmes, 1975) that a laterality measure computed by simply subtracting the left ear score from that of the right ear is negatively correlated with overall accuracy. Table 4 shows, for each grade by sex group, a mean of laterality coefficients, which were computed according to a formula devised by Marshall et al. (1975) and designed so that

the coefficients would be independent of overall accuracy. The possible range of the laterality coefficients is from 1.0 to -1.0, and, again, a positive measure indicates a left hand superiority.

The trend for males was similar to the original trend reported. A strong left hand superiority was evident for the third graders, followed by a reverse to a slight right hand superiority for the fifth graders, and then a gradual increase in left hand superiority up to the college level.

The laterality coefficients for the females, though, led to a slightly different interpretation of the development of hand asymmetry. Since none of the mean laterality coefficients for the third, fifth, and eighth grade girls exceeded .047, there was no tendency toward even a moderate left hand superiority for any of the grades. Only at the college level did the mean laterality coefficient indicate a definite left hand superiority for the females. The asymmetry for the college women appeared to be stronger than that for the college men, as was also indicated by the simple mean hand difference scores.

TABLE 5.--Mean Laterality Coefficients for Each Sex at Each Grade. (Laterality coefficients were computed according to the following formula [Marshall et al., 1975]: If total correct $[L_c + R_c] < 50\%$, $[L_c - R_c] \div [L_c + R_c]$; if total correct $> 50\%$, $[L_c - R_c] \div \text{total errors } [L_e + R_e]$.)

Grade	Males	Females
3rd	.139	.046
5th	-.048	.047
8th	.094	.005
College	.136	.177

Individual Differences

To conclude that the braille learning task was indeed atypically approached as a right hemisphere task by a given sex or grade, the direction and approximate magnitude of the asymmetry for each subject must be considered along with the mean laterality scores. Table 6 shows the distribution of subjects in each grade and sex group according to the degree of hand asymmetry. Hand asymmetry was measured by subtracting the proportion of letters correct with the right hand from the proportion correct with the left hand.

The two hand testing order groups were combined in this table, with the figures for the right-hand-first condition provided in parentheses. If no tendency toward right or left hemisphere processing existed, it would be expected that the distribution of subjects in each grade by sex group would be symmetrical around the "no difference" point. The scores for subjects in the right-hand-first condition would be above the zero point, and those for subjects in the left-hand-first condition would be below the zero point. However, if a right hemisphere strategy was indeed favored by a given group, subjects with a left hand superiority should show a large hand difference, and subjects with a right hand superiority should show a small hand difference. In addition, more subjects should perform better with the first hand in the left-hand-first condition than in the right-hand-first condition, so that a majority of subjects show a left hand superiority.

At least 50% of the male subjects at each grade level identified a higher percentage of letters with the left hand

(top half of table). The distribution of males most indicative of a right hemisphere strategy being favored in that group was found at the third grade level. For ten of the 16 third grade

TABLE 6.--Distribution of Subjects in Each Grade x Sex Group According to the Extent of Hand Asymmetry (Left Hand % Correct Score Minus Right Hand % Correct Score). (Number of subjects in order 1 (right-hand-first) included in parentheses.)

	% Correct Left Hand Minus % Correct Right Hand	3rd Grade	5th Grade	8th Grade	College
Males	+.25↑	3 (1)	0	1 (1)	2 (1)
	+.10 → +.24	7 (4)	3 (3)	7 (3)	6 (6)
	+.01 → +.09	2 (1)	5 (3)	2 (2)	3 (1)
	No diff.	2 (2)	0	1	0
	-.01 → -.09	0	2 (1)	2 (2)	2
	-.10 → -.24	1	5 (1)	0	2
	-.25↓	1	1	3	1
Females	+.25↑	1 (1)	3 (3)	2 (2)	5 (4)
	+.10 → +.24	4 (2)	4 (1)	3 (3)	4 (3)
	+.01 → +.09	1 (1)	2 (1)	2 (1)	2
	No diff.	1 (1)	0	0	1 (1)
	-.01 → -.09	5 (3)	4 (3)	2	0
	-.10 → -.24	4	2	6 (2)	3
	-.25↓	0	1	1	1

boys, the left hand score was higher by a margin of at least ten percent. Twelve of the 16 third grade boys scored higher with the left hand than with the right hand, and this proportion was significantly greater than the fifty percent expected by chance ($\chi^2 = 4.0$, d.f. = 1, $p < .05$). At no other grade level was the

number of subjects with higher left hand scores greater than what would be expected by chance.

For the females (bottom half of Table 6), only at the fifth and college grade levels was the left hand score higher for at least 50 percent of the subjects. The distribution of fifth graders was suggestive of at least a moderate trend toward right hemisphere processing in that group because for four of the seven girls with higher right hand scores, the difference between the percent scores for each hand was less than ten percent. The distribution of college females also indicated a trend toward right hemisphere processing in that group, and was very similar to the distribution for college males. At no grade level was the distribution of female subjects according to degree of hand asymmetry significantly different from chance.

In general, then, the distribution of individuals according to direction and magnitude of hand asymmetry was more supportive of a right hemisphere strategy for males than for females at the third and eighth grades, equally supportive for college men and women, and more supportive for fifth grade girls than boys.

Correlates of Hand Asymmetry

Total learning scores. If the greater left hand learning scores reflect the superiority of a right hemisphere strategy for braille discrimination, then those subjects with the greatest degree of left hand superiority would be expected to have the highest

total learning scores. The correlations between these two variables are shown in Table 7 for each grade and sex group. None of the correlations reached significance.

The failures of the correlations to reach significance may be related to the finding (noted by Marshall et al., 1975) that simple difference scores tend to be negatively correlated with overall performance. This negative tendency of the correlations could have acted against a positive tendency due to the hypothesized superiority of right hemisphere processing for the braille task, thereby resulting in non-significant correlations. To avoid this negative bias of the correlation of hand asymmetry and total score, the two variables were dichotomized, and a Fisher Exact Test for independence was computed for each grade by sex group. The null hypothesis in each instance was that there was no association between whether a subject's left hand score was greater than his right hand score and whether or not his total braille learning score was above or below the median for that group. The cell frequencies were compared to tabled values (Roscoe, 1969), and in no case was the null hypothesis rejected. In general, then, use of a right hemisphere strategy on the braille task does not appear to yield any particular advantage.

Limen scores. Each subject's overall limen scores were computed by averaging the two-point thresholds measured by one test in an ascending order and one in a descending order for each hand. For each subject, the right hand limen score was then subtracted from the left hand limen score to yield a measure of

TABLE 7.--Correlation Between Total Number of Correct Responses (Both Hands) and Degree of Hand Asymmetry (Left Hand Minus Right Hand Scores), Where + r Means Better Overall Performance Associated with Left hand Superiority, and - r Means Worse Overall Performance Associated with Left Hand Superiority.

	3rd Grade	5th Grade	8th Grade	College
Male	N = 16 .315	N = 16 -.159	N = 16 -.024	N = 16 .158
Female	N = 16 -.317	N = 16 -.019	N = 16 .263	N = 16 .419

(No correlations significant [all $ps > .10$])

Note: The correlations are for hand testing order groups combined. In general, they represent the average of the correlations computed for the two order groups separately, none of which reached significance.

greater right hand sensitivity. Table 8 provides the correlations of degree of greater right hand sensitivity with left hand superiority on the braille learning task for each grade by sex group. Negative correlations indicate that those subjects who performed best on the learning task with their left hands also had more sensitive left index fingers. While six of the eight correlations were negative, none reached significance (all $ps > .10$).

Spatial test scores. The Spatial Relations subtest of the DAT was administered to the college students to examine the relationship between performance on a conventional spatial test and performance on the braille learning task. The correlations of Spatial Relations test scores with total number of letters correct on the braille task are provided in the first two rows of Table 9 for each sex by hand testing order group. For each subgroup, the correlation of spatial scores with total braille

learning scores ranged from .24 to .81. Across testing orders, the correlation was higher for males (.54, $p < .05$) than for females (.36, $p > .05$).

Correlations were also calculated between spatial scores and hand asymmetry on the braille task. None of the correlations (shown in second row of Table 9) was significant.

Table 9 also shows the average spatial scores for males and females with testing order groups combined. Males scored significantly higher than females, suggesting that overall performance on the braille learning task might be better for men than for women, if braille is approached, at least initially, as a spatial stimulus. No sex difference in overall performance on the braille learning task was found, but this lack of a difference probably was not the result of having chosen a sample of women with atypically good spatial ability.

TABLE 8.--Correlation Between Degree of Left Hand Superiority on the Learning Task (Left Hand Total Score Minus Right Hand Total Score) and Degree of Greater Right Hand Sensitivity (Left Hand Limen Score Minus Right Hand Limen Score).

Sex	<u>Grade</u>			
	3rd Grade	5th Grade	8th Grade	College
Male	(N=16)	(N=16)	(N=10)	(N=16)
	-.164	-.057	-.528	-.214
Female	(N=16)	(N=16)	(N=13)	(N=16)
	.407	.300	-.061	-.161

(No correlations significant [all p 's $> .10$])

Note: Again the correlations are for hand testing order groups combined. They generally represent the average of the correlations for the two order groups separately, two of which reached significance.

TABLE 9.--Average Spatial Relations Test Scores for the Male and Female College Groups and Correlations of Spatial Relations Test Score with Two Measures of Performance on the Braille Learning Task.

		College Males			College Females		
		Order 1	Order 2	Total	Order 1	Order 2	Total
Correla- tions of Spatial Relations Test score with:	Total # of letters correct on the braille learning task	(N=8)	(N=8)	(N=16)	(N=8)	(N=8)	(N=16)
		r= .235	r= .813*	r= .538*	r= .665	r= .361	r= .357
	Hand asymmetry on the braille learning task (left hand score minus right hand score)	r= -.122	r= -.233	r= -.051	r= .109	r= .487	r= -.055
Average Spatial Relations Test Scores (t=4.35**, d.f.=30)		$\bar{X} = 49.10$ (s.d. = 8.39)			$\bar{X} = 33.44$ (s.d. = 11.48)		

(*p < .05; ** p < .01)

Types of errors. Analysis of hand differences in type of errors on the braille learning task may suggest differences in processing strategy of the two hemispheres. Errors on the learning task were characterized according to two dimensions appropriate for the stimuli used - number of dots of the letter missed (two, three, or four) and extent of error (number of dots of response letter = number of dots in stimulus letter; number of dots of response letter $\neq$ number of dots in stimulus letter; no response or response letter not in letter set). The third graders' errors were excluded from this analysis because the third graders received a different number of letters in each set than the other grades, making a division of errors along comparable dimensions difficult.

The mean number of errors for each hand in each error category are shown in Table 10 for both dimensions of error. About twice as many errors were made on both the three- and four-dot letters as on the two-dot letters. Also, most errors were committed by guessing a response letter with a different number of dots than the stimulus letter. This general pattern of errors was the same for both hands, with the left hand having committed slightly fewer errors in five of the six error categories.

Two four-way ANOVAs (sex by grade by hand by error type) with repeated measures on two factors were performed on the error scores. Each ANOVA considered one dimension of error characteristics. For both analyses, there was a significant main effect of error type, but no other main effects or interactions were found. (The ANOVA table is provided in Appendix H). Failure to find a

hand by error type interaction suggests that at least for these two dimensions of error type, the hand difference on the braille learning task was more quantitative than qualitative.

TABLE 10.--Mean Number of Errors for Each Hand in Each Error Category Averaged Over Sex and All Grades Except the Third Grade.

Number of dots of missed letter	<u>Hand Used</u>	
	Left	Right
2 dots	4.16	4.81
3 dots	8.79	9.45
4 dots	9.07	9.05
<u>Extent of error</u>		
Same number of dots	8.04	8.35
Different number of dots	14.09	14.96
No response or not in letter set	2.78	3.66

DISCUSSION

Scores Summed Across Hands

When the two hands were considered together, the effects of grade, sex, hand testing order, and their interactions did not reach significance. There was a general trend across grades toward an increase in learning scores and a decrease in number of practice trials needed to reach criterion. As previously suggested, the failure of the grade effect to reach significance is most easily explained by the slightly different testing methods used at various grade levels. The largest increase in average learning scores occurred between the fifth and eighth grades, possibly because the testing method was held constant for those two grades. Since the third graders received four letters to each hand instead of six, their scores could have been increased relative to the next grade levels. And since the college subjects received a shorter presentation time for each letter, their scores could have been decreased relative to the younger subjects.

Since, contrary to what would ordinarily be expected, the grade effect was not significant, the tasks can be considered at least fairly equal in difficulty across grade groups. The similar standard deviations across grades also may reflect in part similar difficulty levels. If the task had been overly easy or overly difficult for one age group, for instance, the scores might have tended to cluster at one end of the scale. This differential

emphasis on subjective equality might contribute to the differences between the developmental pattern of hand asymmetry found in this study and the developmental pattern found by Rudel et al. (1974), who apparently used the same method for all grades.

No general sex differences in overall performance on the learning task were found. In fact, averaged over all grades, the difference between the average learning scores for each sex was .005. This lack of a sex difference on a task which is considered to require at least some "spatial" analysis, such as the discrimination of orientation and spacing differences between the letters, is not consistent with general findings of sex differences in cognitive abilities (e.g., Harris, 1977).

The moderate correlations between overall learning scores and scores on the DAT Spatial Relations Test for the college subjects could also support the consideration of the braille task as having spatial elements. While all of these correlations could be explained by a general intelligence factor instead of the similarity in spatial skill requirements of the two tests, the sex difference in magnitude of the correlations suggests a sex difference in factors contributing to the correlations. General intelligence might have been the underlying variable responsible for the moderate, yet non-significant correlation for females. Two studies with children, not college students as in the current study, have found a similar correlation of general intelligence with spatial test performance for girls, but not for boys (Porteus, 1918; Mellone, 1944). For males in the current study, the correlation between performance on the braille task and spatial test

scores was significant, suggesting that a spatial skill factor might have been the cause of the strong relationship. This suggestion is related to Mellone's (1944) finding that a spatial skill factor was necessary to explain boys', but not girls', performance on a variety of cognitive tasks.

In many other studies that have employed supposedly right hemisphere tasks (e.g., line orientation judgments, arc-circle matching, maze tests) no analysis of sex differences was provided. Several studies, though, have reported no sex difference in total performance on this type of task - braille letter learning and discrimination (Rudel et al., 1974, 1976), dichhaptically presented shape recognition (Witelson, 1976), visual dot localization (Kimura, 1969), and visual dot enumeration (McGlone & Davidson, 1973).

The results of these last mentioned studies along with the absence of sex differences in overall performance in the current study could be taken to indicate either: 1) women are processing the information differently, yet just as effectively as men, or 2) the type of processing for which the right hemisphere is specialized overlaps but is not identical with the type of tasks generally performed better by men. The first possibility will be brought into question as a result of data from the current study. If the second possibility is accepted, then any explanation of sex differences in cognitive abilities in terms of cerebral specialization must take into account that women perform just as well as men on many right hemisphere tasks.

While the grade by sex interaction was also non-significant, the point at which the greatest increase across grades occurred differed for the two sexes. The dominant contributors to the overall pattern of the greatest increase in learning scores between the fifth and eighth grades were the males. The females started out by performing slightly better than the third and fifth grade males and showed the smallest increase in performance between the fifth and eighth grades. This difference in the general trend of increase across grades might be due to the earlier maturation of the girls or to the possibility that girls are less affected by specific characteristics of the method used. Girls, for instance, might give closer attention to the task, especially when it is fairly difficult, so that increasing the number of letters from four to six would not be so detrimental for them.

These characteristics of the change in male and female learning scores across grades were reversed in the practice results. Even though the learning scores for the males increased the most between the fifth and eighth grades, the number of practice trials needed to reach criterion decreased the least for the males between those two grades. For the females, the largest decrease in the number of practice trials needed occurred over that period. This difference between the practice and learning trials suggests that the results for the first two letters presented to each hand are not good predictors of later performance.

There also were no significant effects of hand testing order or any of its interactions with other variables. Despite this,

different patterns of change across grade levels were evident for the two testing order groups, and these patterns are similar to trends in Rudel et al.'s data (1974). Little or no increase in learning scores across grade levels was evident for the left-hand-first testing order, while a steady increase in learning scores was evident for the right-hand-first order. This difference might exemplify Rudel et al.'s (1974) and Witelson's (1974) suggestion that performance of one hemisphere is influenced by the prior activation of the other. Their suggestion depends on the assumption that when one hand is tested, the opposite hemisphere is activated and at least partly responsible for the style in which the stimuli are processed. When the next hand is tested, then, the ability of the opposite hemisphere to process stimulus information may be affected by that subject's first approach to the task.

If prior activation of one hemisphere does influence performance by the other, then the current results suggest that the benefits of prior left hemisphere activation increase as the child matures, while the benefits of prior right hemisphere activation remain constant. This explanation is consistent with the results of a study which compared the importance of verbal and tactual features for the encoding of braille letters in memory by blind children (Millar, 1975a). The stimuli were three lists of braille letters that were: 1) similar in feel, but different in name sound, 2) similar in name sound, but different in feel, and 3) different in both feel and name sound. Each child was tested with a letter set size for which he scored below the ceiling level

and above chance. Results indicated that children testable with small letter sets had higher scores for the list of letters similar in name sounds than for the other two lists. Children testable with larger sets scored higher on the list of letters similar in feel than on the other lists. Thus, since the list similar in verbal features was more confusing for the more able children, they must have tended to encode the letters verbally.

This increase in the importance of verbal features as discrimination and memory ability increase may partly explain the increase in performance across grades for the right-hand-first group in the current study. It would seem that as the grade and ability of children in this group increased, the benefits of prior activation of the verbal left hemisphere increased, and therefore performance scores increased across grades. Millar (1975b) also found the same relative importance of tactual and verbal features for sighted children in a serial object recall task. These studies by Millar thus suggest that the left hand advantage in the current study might be thought of as partly an advantage for prior activation of the left hemisphere in the right-hand-first condition.

Difference Between Hand Scores

Left Hand Superiority

The finding of an overall hand asymmetry on the braille learning task in favor of the left hand was predicted and is consistent with most other research (Smith, 1929, 1934; Hermelin & O'Connor, 1971; Rudel et al., 1974, 1976; Feinberg & Harris, 1975).

Reasons for left rather than right hand superiority. One major issue regarding left hand superiority on the braille learning task is why that specific task would be of a right hemisphere nature. As others have noted (Hermelin & O'Connor, 1971; Rudel et al., 1974), consideration of braille learning as a right hemisphere task implies that its character as a linguistic system must be overshadowed by the spatial analysis of dot patterns required. It is not clear why the spatial requirements should be dominant over the linguistic nature of the stimuli in the case of braille, and not in the case of our Latin alphabet presented both visually (Kimura, 1966) and haptically in one case (Witelson, 1976, as cited in Rudel et al., 1976). The main reason may be that braille letters are more difficult to discriminate, requiring differentiation of minute differences in orientation and spacing of dots separated by a distance just outside the minimum two-point threshold. Thus, even for blind children familiar with the braille system, the analysis of braille letters is faster and more accurate when the message is first analyzed directly by the right hemisphere (Hermelin & O'Connor, 1971; Wilkinson, 1976).

This notion that the superiority of right hemisphere processing for braille learning may stem from the greater difficulty of discriminating braille compared to Latin letters is related to the findings of Bryden and Allard (1976). They presented college men and women with individual letters in one of ten widely-varying typefaces, using a tachistoscopic presentation method to project the letters to the left and right visual fields. Subjects were asked to indicate orally the letter shown, which was thought to

be a task of a primarily verbal nature, likely to yield a left hemisphere superiority if the verbal-nonverbal distinction of hemisphere processing was critical. The analysis revealed a typeface by visual field interaction, indicating that the majority of typefaces showed a left hemisphere advantage, while two typefaces, which were more difficult and more "scriptlike" than the others, showed a right hemisphere advantage. Bryden and Allard (1976) explain these results in terms of hemisphere processing differences. They speculate that the right hemisphere is more efficient at certain global preprocessing operations carried out prior to letter naming, while the left hemisphere is better at the more analytical identification and naming stages. Since the letters in the scriptlike typefaces probably require more initial preprocessing "to normalize the stimulus and to focus attention on the relevant characteristics of the target" (p. 198), then the fact that the right hemisphere is a more efficient preprocessor becomes important, and a right hemisphere advantage is found. Braille letters and possibly Latin letters examined tactually are also likely to require a good deal of right hemisphere preprocessing because of their complexity and the inexperience of sighted subjects at recognizing letters examined haptically, as suggested also by Hermelin and O'Connor (1971) and Witelson (1974).

It has also been suggested that right hemisphere specialization for a task such as braille discrimination is partly dependent on the exclusion of vision from the task (Rudel et al., 1976). Right hemisphere specialization for the braille learning task, then,

would be related to the inability of naive, sighted subjects and blind subjects to connect the tactile patterns to visually familiar forms. Since it would be possible for blindfolded sighted subjects to visualize familiar Latin letter cut-outs while palpating them, the lack of a left hand superiority on that task would be explained.

Two questions follow from this suggestion. First, it is not clear whether it is the presence of visual together with tactile requirements that is not conducive to right hemisphere specialization or whether it is the presence of vision itself. The reason for distinguishing between the two alternatives is not clear. In any case, several studies have found a right hemisphere specialization for tasks involving vision alone, such as dot localization (McGlone & Davidson, 1973; Kimura, 1969). Also, as cited earlier, Gardner (1942) reported a left hand (right hemisphere) superiority for sighted subjects in speed of reading nonsense syllables formed by cord stitched upon cardboard. Since these sighted subjects should have been able to visualize the Latin letters, the study does not support the suggestion that right hemisphere specialization is related to the exclusion of vision.

Second, it is unclear whether "visualization" or "visual involvement" is the key variable. If it is the latter, then the difference between haptic perception of the braille and Latin alphabets would not be explained. If the former, very subtle differences in the character of visualization must determine whether the task will be of a right hemisphere nature. The majority of naive, sighted subjects in the current experiment

could readily say how they were visualizing the braille letters, and, in some cases, the braille letters were being related to letter forms they knew.

Meaning of the asymmetry in terms of cerebral mechanisms.

Another major issue regarding left hand superiority for the braille learning task is the meaning of the asymmetry. One theory (e.g., Kimura, 1967) attributes asymmetries to the "structural prepotency" of the hemispheres for given tasks and the stronger contralateral connections of the auditory, visual, and tactile systems. In the case of braille discrimination, stimuli palpated by the right hand would reach the "prepotent" right hemisphere as a degraded signal, partly because of the effects of transfer across the corpus callosum and partly because the left hemisphere is less capable of processing the signal in the first place. Stimuli received by the left hand would reach the right hemisphere directly, thereby resulting in a clearer signal to analyze, although the information still must cross over to the left hemisphere to be described in language.

A different view has been argued by Kinsbourne (1973). He reasons that lateral asymmetries are due to "attentional sets" induced by the nature of the task or response method. When the task or response method favors the processing in one hemisphere, that hemisphere is then activated, turning attention toward the opposite side, and, at the same time, inhibiting activation of the other hemisphere. Thus, on the braille learning task, the "natural" activation of the right hemisphere for this type of spatial task would direct attention toward the left hand, thereby facilitating its performance.

While the current results do not permit clear choice between these two views, the finding that the hand difference was significant only for the last two trial blocks can be more easily explained by the attentional theory. Thus, the attentional set became stronger with an increasing number of trials to one hand, with the set to attend to the left hand being more conducive to the natural right hemisphere activation for braille discrimination. This finding is more difficult to explain in terms of the first view, unless we assume that in the first blocks of learning trials, analysis of braille letters with either hand must be both spatial and verbal.

Rudel et al.'s (1974) and Witelson's (1974) findings of the effects of prior activation of one hemisphere on the performance of the following hand may be taken to support the attentional theory. The current findings, however, suggest that there is only a "practice" effect for the second hand tested. In the case of the right-hand-first testing order, the better performance of the second hand is influenced as well by right hemisphere superiority. Therefore, neither theory of lateral asymmetries would be supported by the analysis of order effects.

Findings on braille learning tasks using an alternating hand method (Feinberg & Harris, 1975; Harris & Wagner, 1974) also may be taken to support Kinsbourne's view. The alternating hand method in both studies involved the presentation of letters to the left and right hands in simple alternation, using the paired associate learning technique of the current study. The subjects, male and female college students, were given four braille letters to each hand, and each letter was presented to only one hand.

An overall left hand superiority was found, with a greater asymmetry for the final trial blocks. Kinsbourne's attentional view would be more appropriate than Kimura's view for explaining this increase in asymmetry across trials. The conclusion would be that the spatial nature of the braille learning task eventually induced the natural attention of the right hemisphere, which facilitated performance with the left hand.

But, the attentional theory would suggest that the left hand superiority found with the sequential hand method of the current study would be greater than the asymmetry found with the alternating hand method. The formation of a strong attentional set should be aided by having a block of stimuli for which the attention is completely directed toward the left hand. Against this prediction of the attentional view, the same degree of asymmetry was found for the two methods. In summary, then, it seems that hand asymmetry on the braille learning task may be explained by elements of both views.

Hand differences in type of errors. A final issue regarding left hand superiority on the braille task concerns the character of the errors made by both hands. It could be that the method of exploration of each hand was influenced in some way by the contralateral hemisphere to which most of its information was initially sent. The type of errors made by each hand, then, would be related to the type of processing or problem solving approach for which the contralateral hemisphere was specialized.

No relation between hand and type of errors was found in the current study, though, with errors categorized mainly according

to the number of dots in the stimulus and response letters. The equal number of two-, three-, and four-dot letters in a set made these categories convenient to use.

One reason for the independence of hand and error type might be that exploration method tends to depend on the cognitive style of the subject, which is constant for both hands. Another reason might be that the error categories chosen were not capable of differentiating the processing of the two hemispheres. Rudel et al. (1976) categorized errors in a braille discrimination task according to whether they involved discrimination of a difference in number, displacement, or orientation. No hand difference in type of errors was found. Thus, it seems that over a variety of error categories, hand exploration patterns are not related to processing mode of the contralateral hemisphere.

Grade and Sex Interactions With Hand

While all grade groups showed some degree of left hand superiority, the greatest asymmetry was found for the third grade and college groups. This grade interaction was also modified by sex, although the grade by sex by hand interaction did not reach significance. The pattern of hand asymmetry across grade levels for the males is similar to the developmental pattern found by Rudel et al. (1976) in a study involving same-different judgments of braille letters, although asymmetry was established later in Rudel et al.'s (1976) study. For the males in the current study, hand asymmetry was very strong at the third grade level (as shown by the difference in proportion scores and individual difference

data). This peak of asymmetry was followed by a weak asymmetry in favor of the right hand for the fifth grade boys, a moderate left hand superiority for the eighth grade boys, and a return to a fairly strong asymmetry for the college men. Rudel et al. (1976) found a strong asymmetry for males at ages 11 to 12, but, as in the current study, the asymmetry declined for the older males and even reversed to favor the right hand at one point. Significant left hand superiority did not return for the adult males tested by Rudel et al. (1976), though.

The decline of left hand superiority for the older boys is difficult to explain. While it could be that Rudel et al.'s task was not difficult enough to elicit a left hand superiority for the 13-year-old and adult males, task difficulty does not explain the decline in asymmetry in the current study. The task was made objectively more difficult for the fifth graders than for the third graders, yet only a weak asymmetry was found for the fifth grade males.

The pattern of hand asymmetry across grade levels for the females was similar to the studies by Rudel et al. (1974, 1976) and Witelson (1976) only in that the onset of left hand superiority was later for the females than for the males. In the three other studies, a tendency toward right hand superiority was shown by the younger girls. In the current study, though, there was a tendency toward left hand superiority for the third grade and, especially, the fifth grade girls. A left hand superiority was found for the females in the other three studies at age 13, but

there was no hand difference for the eighth grade girls (14-year-olds) in the current study. As in Rudel et al.'s (1976) study, the college females showed a strong left hand superiority. Reasons for these differences in the development of right hemisphere superiority for the females are not clear.

A few general issues in regard to sex and grade interactions with hand asymmetry are apparent. First, left hand superiority appeared at an earlier age for the boys in the current study compared to the studies of Rudel et al. (1974, 1976). One reason for this earlier appearance of asymmetry might be the difficulty of the task involved. Rudel et al. (1974) employed a letter learning task in which, after every six naming trials, they repeated the names of the letters to the subjects while the subjects felt the configurations. Their later study (1976) involved the judgment of two braille letters as simply same or different. In contrast, subjects in the current study were only told the letter names while they were feeling the configurations during the initial presentation. The subjects needed to store in memory information regarding the total bundle of features of the braille letters so that letter names could later be associated with individual letters. This increased difficulty of the task could be the reason why an earlier left hand superiority was found.

In agreement with this reasoning, a right hemisphere superiority for male subjects at age six was found for Witelson's (1974, 1976) difficult task--discrimination of complex nonsense shapes. The lack of verbal elements in the task, as well as the

difficulty, might explain the early appearance of asymmetry for the boys. Given the apparent importance of the difficulty of the task, determination of a subjectively equally difficult task for each subject might be a way to control for task difficulty, and thereby possibly yield a clearer picture of the development of lateralization.

Second, just as in Rudel et al.'s studies (1974, 1976), left hand superiority emerged later for girls than for boys. As stated in the introduction, this later emergence may reflect a possible greater tendency by girls than boys to invoke a language mode of processing and/or a delayed onset of right hemisphere mediation of spatial tasks (Harris, 1977).

Since the left hand was superior on the learning task for both male and female college students, the lack of a sex difference in overall performance probably does not stem from use of different problem solving approaches by the two sexes. In fact, the left hand superiority was greater for the women than for the men, as was also found by Rudel et al. (1976). Also, for both male and female college students, the correlation of left hand superiority with total learning score was positive, indicating a weak tendency for a right hemisphere strategy to lead to better performance for both sexes.

It might be, then, that the spatial tasks on which men excel only represent the most complex abilities for which the right hemisphere is specialized. If so, only when the task was very complex would the supposed greater bilateral language representation of the

female become impairing or the supposed tendency of females to invoke a verbal mode of processing emerge. A more extensive study of sex differences in hemisphere specialization in relation to differences in cognitive abilities should include a complex, right-hemisphere task on which men excel.

Finally, the significant interaction of sex by order by hand may mean that the observed sex differences in asymmetry were biased by the number of trials included in the task. It appears that during the second trial block, the difference between hands was much greater for males than for females. The reverse was true for the third trial block. This interaction indicates a sex difference in learning patterns that could have biased the overall sex differences in asymmetry that have emerged in other studies, especially those with a small number of trials.

APPENDICES

APPENDIX A

Letter Sent to Parents of Third and Fifth Graders

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Letter Sent to Parents of Third and Fifth Graders

Michigan State University

Department of Psychology
20 February 1975

To parents of children at the Sycamore School:

We are trying to understand how blind persons can use their sense of touch to recognize objects and patterns. We are planning research with blind students here at Michigan State University and at the Lansing School for the blind, but we think we can improve our understanding of how the blind use their sense of touch by also studying normal sighted children and adults. The simple task we have used with adults requires the identification of dot patterns by touch. This spring we are planning studies at the Sycamore School to examine the way children of various ages perform on a similar task. Our primary aim is to compare the different learning styles of children at different ages. We hope that analyses of these differences in learning style can tell us something about the best general type of teaching methods for blind as well as for sighted children of different ages.

We plan to begin our work next week, and we would like your child to participate. The individual research sessions will not last more than about 25 minutes, and we will schedule these sessions so that the children will not miss special events planned by the class. Each child who participates will probably participate only once. Our experience over the past eight years of research in the Molt schools has been that children very much enjoy the various games and tasks which we have devised for research in perceptual development.

We would like to stress that we take all necessary means to insure the privacy of each child who participates. This means that the records of all individual observations are kept strictly confidential, not only from the children but also from all others not directly associated with the project. In addition we use a name-code system so that no child's name ever appears with his results. And as we said above, our interests are in changes associated with age rather than in the performance of individual children.

We are conducting this work with the cooperation of Mr. Watkins, principal of the Sycamore Elementary School, and your child's teacher, with the expressed understanding that any parents who, for any reason, do not wish to have their child participate, would so inform us either by telephone or through a note to their child's teacher. If you have any questions about the work, please don't hesitate to call us at either of the numbers listed below.

Several M.S.U. students will be working with us on this project - all under our direct supervision. They are Sharon Guilds, Robert O'Neill, and Richard Saenz.

Thank you for your consideration of this letter.

Yours sincerely,
Nancy M. Wagner
Nancy M. Wagner
M.A. candidate, M.S.U.
Phone: 353-6767

Lauren Jay Harris
Lauren Jay Harris
Professor of Psychology, M.S.U.
Phone: 353-0792

Barry D. Watkins
Barry D. Watkins
Principal
Sycamore School

APPENDIX B

Handedness Questionnaire

APPENDIX B

Handedness Questionnaire

NAME _____ AGE _____ SEX _____

Were you one of twins, triplets at birth or were you single born?

*Please indicate which hand you habitually use for each of the following activities by writing R (for right), L (for left), E (for either).

Which hand do you use:

1. To write a letter legibly?
2. To throw a ball to hit a target?
3. To hold a racket in tennis, squash or badminton? . . .
4. To hold a match whilst striking it?
5. To cut with scissors?
6. To guide a thread through the eye of a needle (or guide needle on to thread)?
7. At the top of a broom while sweeping?
8. At the top of a shovel when moving sand?
9. To deal playing cards?
10. To hammer a nail into wood?
11. To hold a toothbrush while cleaning your teeth?
12. To unscrew the lid of a jar?

If you use the RIGHT HAND FOR ALL OF THESE ACTIONS, are there any one-handed actions for which you use the LEFT HAND? Please record them here

If you use the LEFT HAND FOR ALL OF THESE ACTIONS, are there any one-handed actions for which you use the RIGHT HAND? Please record them here

APPENDIX C

Instructions (for the third & fifth graders)

APPENDIX C

Instructions (for the third & fifth graders)

Have you ever known any blind children? Well, they can't read the way you read because they can't see the letters. The way blind children can read is by feeling groups of bumps. Each group of bumps means a different letter to them. (Alternately: Each of their letters is a different group of bumps.) The bumps that they feel do not in any way feel the way letters look to you.

You are going to learn to read the way blind children do. (Talk about making bumps with the typewriter.) I will let you feel the bumps on each card and tell you what letter it is for a blind child. Then I'll let you feel the bumps again, but this time you'll have to guess what letters they are. Put your hands under the board and find those card holders. When I put a card in this holder (indicate), feel the bumps on it with this finger of this hand (indicate); and, when I put a card in the other holder, feel the bumps with the same finger of your other hand (indicate).

O.K., let's practice for a minute. Here is the first card in this holder. O.K., you can start to feel the bumps. This is an A. Here is another card (present this letter to the same hand). This is a B.

Now, feel the cards again. I'll let you feel the bumps on each card for a short time. Then I will say "answer" and you try

to guess what the letter is. I will always say what the letter is whether your guess is right or wrong.

Here is one of the cards (present A to same hand presented to above). You can start to feel the bumps right away when you hear the card go in the holder.

Answer A

(When child guesses the two letters correctly, go on to the next stage.) These cards were just for practice, so let's put them away because now I'm going to give you some more cards to feel. These cards will be different cards - you will not feel the A and B again. (Follow same procedure as below, but present all 6 (4) letters before asking child to guess.)

(Before asking child to guess, say) - Now, you can feel these cards again and you should try to guess the name of each one just the way you did before.

The same procedure was then followed for the other hand.

APPENDIX D

Tests for Differences in Difficulty of Letter Sets

APPENDIX D

Tests for Differences in Difficulty of Letter Sets

TABLE D1.--Average Scores for 5th Grade, 8th Grade, and College Students With Letter Sets A and B, and for 3rd Graders With Each Letter Subset.

Grade	Letter Set		t value
	Average Number of letters correct for Set A	Average Number of letters correct for Set B	
College	(N=32) $\bar{X} = 32.22$	(N=32) $\bar{X} = 36.59$	$t = 2.01$ (d.f.=30, N.S.)
8th Grade	(N=32) $\bar{X} = 33.22$	(N=32) $\bar{X} = 36.28$	$t = 1.60$ (d.f.=30, N.S.)
5th Grade	(N=32) $\bar{X} = 31.59$	(N=32) $\bar{X} = 29.90$	$t = .96$ (d.f.=30, N.S.)
3rd Grade	(N=16) Subset 1	(N=16) Subset 1	$t=1.46$ (d.f.=14, N.S.)
	Subset 2	Subset 2	
	21.25	18.44	
		22.19	
		20.19	
			$t=1.35$ (d.f.=14, N.S.)

TABLE D2.--ANOVA Testing the Difference Between 3rd Grade Letter Supersets.

	Source	d.f.	MS	F	p
3rd Grade	Letter set (A-B)	1	28.9	.474	$p > .05$
	Hand	1	102.5	4.44	$p < .05$
	Hand x set	1	9.9	.429	$p > .05$
	Error _b	30	61		
	Error _w	30	23.1		

APPENDIX E

Interpretable Univariate F Ratios

APPENDIX E

Interpretable Univariate F Ratios

TABLE E1.--Univariate F Ratios for Hypotheses Yielding Significant Multivariate F Ratios in the Analysis of Percent Correct Scores.

Significant Multivariate Effect	Univariate F Ratios for Separate Trial Blocks (in order)	d.f.	p
Hand	.0006	1,112	p < .9798
	5.7134	1,112	p < .0186
	1.3104	1,112	p < .2548
	6.7782	1,112	p < .0105*
	20.5472	1,112	p < .0001*
Grade x hand	1.1824	3,112	p < .3198
	1.8493	3,112	p < .1424
	1.4733	3,112	p < .2257
	.3193	3,112	p < .8115
	1.6529	3,112	p < .1813
Order x hand	14.8603	1,112	p < .0002*
	21.6165	1,112	p < .0001*
	18.5745	1,112	p < .0001*
	18.0487	1,112	p < .0001*
	5.6280	1,112	p < .0194
Sex x order x hand	2.7323	1,112	p < .1012
	6.6604	1,112	p < .0112*
	1.0470	1,112	p < .3085
	.1307	1,112	p < .7184
	.7987	1,112	p < .3735

(*p < .01 will be considered the cut-off level for significance.)

APPENDIX F

Interpretable Step Down F Ratios

APPENDIX F

Interpretable Step Down F Ratios

TABLE F1.--Step Down F Ratios for Hypotheses Yielding Significant Multivariate F Ratios in the Analysis of Percent Correct Scores.

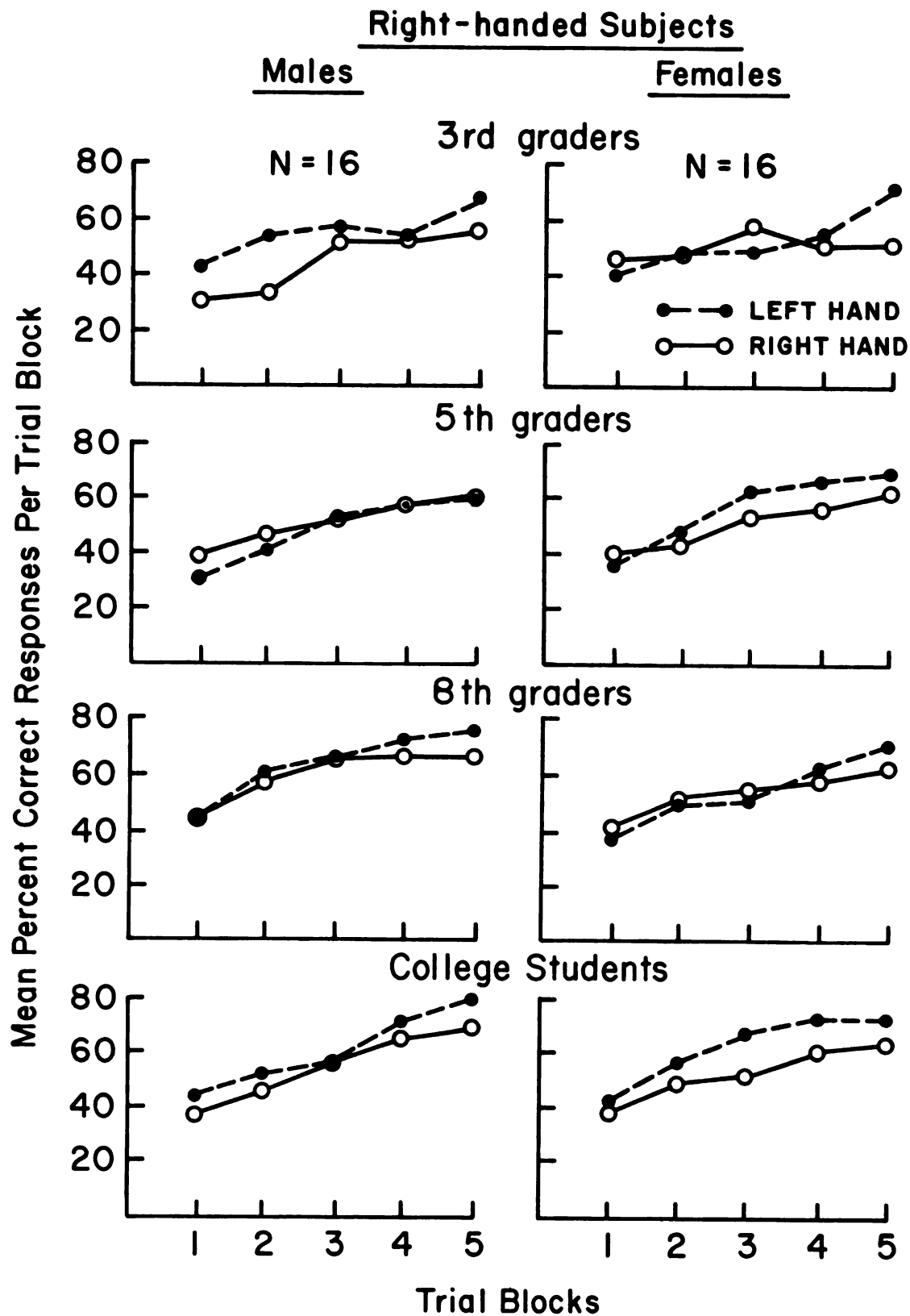
Significant Multivariate Effect	Step Down F Ratios for Separate Trial Blocks (in order)	d.f.	p
Hand	.0006	1,112	p < .9798
	6.8614	1,112	p < .0101
	.2259	1,112	p < .6356
	4.5408	1,112	p < .0354
	14.9614	1,112	p < .0002*
Grade x hand	1.1824	3,112	p < .3198
	1.2042	3,112	p < .3117
	2.1847	3,112	p < .0939
	.2118	3,112	p < .8881
	3.6253	3,112	p < .0154*
Order x hand	14.8603	1,112	p < .0002
	9.6538	1,112	p < .0024
	5.4516	1,112	p < .0214*
	3.3573	1,112	p < .0697
	.0096	1,112	p < .9222
Sex x order x hand	2.7323	1,112	p < .1012
	12.7774	1,112	p < .0006*
	2.3072	1,112	p < .1317
	.4939	1,112	p < .4837
	.2785	1,112	p < .5988

(*p < .05 will be considered the cut-off level for significance)

APPENDIX G

Mean Percent Correct Responses Per
Trial Block for Sex x Grade Groups

Figure G1.--Mean percent correct responses per trial block for each hand according to sex and school grade.



APPENDIX H

Error Type ANOVAs

APPENDIX H

Error Type ANOVAs

TABLE H1.--The F Values for Two Four-way ANOVAs Performed on Two Dimensions of Error Characteristics.

Source of Variance	Analysis Using Number of Dots of Letter Missed as Measure of Error Type			Analysis Using Severity of Error as Measure of Error Type		
	d.f.	F	p	d.f.	F	p
Sex	1,90	.419	p<.519	1,90	.128	p<.721
Age	2,90	.826	p<.441	2,90	2.19	p<.117
Sex x Age	2,90	1.05	p<.355	2,90	1.00	p<.370
Hand	1,90	1.29	p<.259	1,90	3.30	p<.072
Sex x Hand	1,90	1.55	p<.216	1,90	1.50	p<.223
Age x Hand	2,90	.180	p<.836	2,90	.674	p<.512
Sex x Age x Hand	2,90	.452	p<.638	2,90	.964	p<.385
Error Type	2,180	158.30	p<.0005*	2,180	177.09	p<.0005*
Sex x Error Type	2,180	1.95	p<.145	2,180	.713	p<.492
Age x Error Type	4,180	2.19	p<.072	4,180	.579	p<.678
Sex x Age x Error Type	4,180	.307	p<.873	4,180	.858	p<.491
Hand x Error Type	2,180	1.06	p<.349	2,180	.249	p<.780
Sex x Hand x Error Type	2,180	.047	p<.954	2,180	1.51	p<.223
Age x Hand x Error Type	4,180	1.51	p<.200	4,180	.543	p<.705
Sex x Age x Hand x Error Type	4,180	1.09	p<.362	4,180	.586	p<.673

(*p < .05 will be considered the cut-off level for significance.)

NOTES

1. Gazzaniga (1970) emphasizes other possible reasons for a verbal description or naming of sensory information projected to the right hemisphere in addition to an explanation in terms of ipsilateral connections. It might be due to rudimentary speech from the right hemisphere or to the transfer of information to the left speech center through the midbrain (p. 118).

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