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FUNCTIONAL HAND ASYMMETRY AND BRAILLE READING IN BLIND READERS

By

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ABSTRACT

FUNCTIONAL HAND ASYMMETRY AND BRAILLE READING
IN BLIND READERS

By

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Some research suggests that braille, because of its configurational-spatial design, will be more efficiently processed by the right (non-language) than left (language) cerebral hemisphere in right-handed individuals. Therefore, left (non-dominant) hand performances would be expected to be better. Alternatively, any reading task should be better processed by the left cerebral hemisphere suggesting better right-hand performance.

Twenty-three right-handed blind students (10-20 years old) were given letter identification and paragraph reading tasks. Only fast-reading females showed a left-hand advantage for reading paragraphs, but no hand or sex differences were found for single letter identification. For both males and females who initially preferred their left hand for reading, left hand superiority was found for both tasks, though the reverse was not found for subjects who initially preferred their right hand.

The results support the idea that braille reading has an important configurational-spatial component, but hand differences also are related to an initial reading skill, sex of subject, and initial hand preference for the task.

The very time I thought I was lost,
my dungeon shook and my chains fell off.

James Baldwin

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I. INTRODUCTION

Braille reading, like visual reading, involves the reception and interpretation of graphic symbols. By contrast, the most obvious differences between the two forms of reading are the type of symbolizations and the organic system used. Braille is perceived through the fingers and print is perceived through the eyes. These differences mean braille must be read at a much slower rate than print. Despite this, the reading of braille involves many of the same factors necessary for successful visual reading such as perceiving, understanding, conceptualizing, and experiencing the graphic forms (Rex, 1970).

The study of the process of learning to read braille is of particular interest because reading braille requires the accurate perception of spatial patterns having linguistic labels. Since tactual spatial skills involving the mental rotation and transformation of objects perceived in space are found to be highly correlated with right hemisphere functioning and the development of linguistic skills is related to left hemisphere functioning, the question is, how is braille learned? For instance, one technique for reading braille is for the left and right forefingers to start moving across the axis of a punctographic line of cells to the middle of the page. Then the right finger sweeps across the rest of the line while the left forefinger helps to identify unusual collections of symbols or goes to the next line to establish a continuity in the reading material. Since this is only one style or technique used

to identify the symbols, it is essential to note that readers must explore, touch, and move their fingers up and down and around the cell or adjacent cells to discriminate the arrangement of dots until they become clear.

For these reasons, braille has been used as one vehicle for understanding the complexity of multi-dimensional tactual stimuli, that is, understanding the influence of pattern, number and direction of a stimulus as it relates to the functioning of the two cerebral hemispheres. Consequently, it was the intent of this study (1) to identify the hemispheric specializations which may facilitate the cognitive understanding of a complex informational system, such as the Braille Code, and (2) to determine whether any of the observed hand differences in braille reading can be attributed to functional cerebral asymmetry.

II. REVIEW OF RELEVANT LITERATURE

Asymmetrical Processing Differences in the Human Brain

This chapter begins with a brief outline of recent research on hemispheric asymmetries so as to provide a framework from which to view the braille literature on hand asymmetries. The braille literature is then looked at in terms of the various stages or strategies in which braille is learned and the cognitive processes involved in these strategies.

It is widely accepted that the two cerebral hemispheres have different functions. The left hemisphere, which controls the right side of the body, appears for the most part to control speech and language mechanisms. The right hemisphere controls the left side and primarily subserves spatial functions. These characteristics have been inferred from clinical studies of deficits produced from damage to the right and left hemispheres (e.g., McFie, Percy, and Zangwill, 1950; Semmes, Weinstein, Ghent, and Teuber, 1955; DeRenzi and Spinnler, 1966); and split brain patients, whose hemispheres are prevented from transferring information across the corpus callosum (this literature is reviewed by Nebes, 1974).

Additional support for hemisphere asymmetries has come from studies with normal subjects on dichotic listening tasks (Kimura, 1961) and tachistoscopic recognition tasks (Kimura, 1966; Kimura, 1969; White, 1972). In terms of the auditory and visual modalities, the superiority

of the right or left hemispheres for processing is inferred when, for instance, a stimulus presentation to the right visual half-field or ear is recalled or recognized faster or more accurately than the left. As a consequence, it has been suggested that the contralateral connections are better at relaying information between the two hemispheres and they also inhibit the ipsilateral connections (Kinsbourne, 1973).

In this connection, Cohen (1973) has shown that the time necessary to mediate verbal material requires a more serial processing procedure and because of this, it is better processed by the left hemisphere. Conversely, by implication the right hemisphere is better able to process nonverbal or spatial material in a more parallel manner (Kimura, 1973; White, 1969; Smith and Nielson, 1970). This dichotomy has also been characterized as requiring "propositional" as opposed to "appositional" thinking (Bogan, 1972). The former term refers to logical-analytic processing of the left hemisphere and the latter to the gestalt-synthetic approach of the right hemisphere. In summary, these findings have led to characterizing the cognitive processing of the left and right hemisphere as serial or temporal v. parallel processing; propositional v. appositional processing; and verbal v. nonverbal processing.

Left-Right Hand Differences in Braille Reading

Functional hand differences in blind braille readers. Several studies have attempted to demonstrate hand superiorities in braille reading by examining hand differences when using letters, sentences, and varied directions of reading (Villey, 1931; Smith, 1929; Fertsch, 1947; Foulke, 1964; Hermelin and O'Connor, 1971a, 1971b). Observations have

suggested that the left hand is the preferred hand for braille reading implying that, it is also superior for speed and accuracy (Critchley, 1953; Grasemann, cited in Villey, 1931; Bürklen, 1917, cited in Lowenfeld, Abel, and Halten, 1969). Most of this evidence is inconclusive, since the procedures rarely controlled for reading style, sex or grade differences, but they also suggest that while there may be hand superiority for reading, there also may be a demonstrated hand preference for the same or opposite hand suggestive of functional hand differences (Villey, 1931; Smith, 1929).

For example, Critchley (1953) observed that the practiced braillist is able to read with both index fingers effectively, even though many readers eventually chose a master finger. This distinction suggestive of a learned manual preference is not altogether obvious, since each hand may be accurate in its decoding of the braille symbols and the two hands appear to discriminate the dot configurations simultaneously. Critchley suggested, however, that for a majority of braille readers the left index finger is the finger of choice even though the bi-manual reading may involve two distinct identification processes. Therefore, the finger chosen to be the "master finger" must give the reader additional information or insight into the nuances of the code that are not perceived by the other finger or fingers involved in the reading process.

Specifically, Critchely speculated that a bi-manual technique of reading involving swift small-range searching movements facilitated a relationship such that one finger (right) is devoted to the "service of recognition" and the other (left) the "service of control" (p. 22). This process would enable the braillist to develop a sense for the constituent dots and to identify the collection of symbols as a whole-tactual gestalt.

The recognition process is facilitated by the fluctuation in the stimuli which intensifies each configuration and adds to the degree of sensory perception (Critchley, 1953, p. 24).

In other studies, the finger relationship leading to left hand preference of superiority in reading is not so clear. For instance, Foulke (1964) had experienced adult braille readers use their eight fingers (excluding the thumbs), alternating preferred and nonpreferred fingers, to determine the reading rate for randomized letters in a horizontal direction. The lines consisted of five, equally spaced, five letter groups. Although some readers were better with one hand than the other, this as a whole showed no consistent relationship between reading speed and hand used. These data suggest that (a) additional practice received by the preferred hand and (b) that there is a substantial loss in reading ability from the index finger to the little finger. The latter finding may be related to the differences in the supply on sensory nerve endings of the fingertips or the cortical representations for each fingertip.

Using blind subjects, Fertsch (1947) compared good and poor readers to determine which hand was more efficient. The subjects were students (30 girls and 33 boys) in grades 3 - 11 attending a school for the blind. Fertsch did report the number of boys and girls in each grade. The subjects were divided into those who scored in the upper and those who scored in the lower third in comprehension on a standardized silent reading test.

Each subject read a paragraph from the grade one and a half level of the Shank Test of Reading Comprehension. The paragraph was transcribed into braille and then divided into two parts. Each part was equal in length, number of lines (6), number of cell units (175), and number of

signs (32). First, the subjects silently read part one of the paragraph with their right hands alone. Then they read part two with their left hands alone. Comprehension was tested at the end of each half by asking three questions about the text of each part. The questions were prepared for the Shank Test. Handedness was assessed by grip strength and ball throwing. Sixty of the subjects were designated as right handed and three as left handed.

The blind readers were classified then into three groups (1) right dominant, right hand more effective than the left hand; (2) left dominant, left hand more effective than the right hand; and (3) hands equal, both hands equally effective. The best readers were those who read equally well with either hand and used both together. Fertsch also found that the speed scores for the right hand dominant readers were higher than those for the left hand dominant group. The poor readers characteristically kept right and left hands close together. Consequently, they read less material with each hand independently. It should be noted that Fertsch did not consider errors per cell unit, sex or grade differences, or interaction effects. Thus, the evidence supporting right hand superiority is somewhat weak. However, the results imply that hand preference and superiority in reading are related to accuracy and speed in reading ability.

Two experiments by Hermelin and O'Connor (1971a, 1971b) with blind children and adults specifically addressed the issues of handedness, differences in braille materials, and the functional asymmetry of the brain with respect to braille reading.

In the first experiment, Hermelin and O'Connor (1971a) tested 16 children, all blind from birth, between the ages of 8 and 10. Handedness

was determined by a seven-item test. Fourteen children were right handed and two were ambidextrous. Twelve children read spontaneously with their index fingers close together. Four read with the index finger of their left hand. Each child's index and middle fingers were tested separately to determine "finger" reading speed. Individual symbols were scored, instead of words or letters, because many abbreviations and contractions were used. The left index finger reading times proved to be significantly faster than the right index finger reading times. Similarly, the left middle finger reading times were significantly faster than the reading times for right middle finger. Hermelin and O'Connor (1971a) attributed the differences between the left and right hand in reading speeds partly to the left to right direction during braille reading; partly to the left to right direction during braille reading; partly to the greater convenience of motoric scanning, and partly to the fact that many of the children read primarily with their left hands.

To control for the possibility of a motoric scan bias, Hermelin and O'Connor (1971b) arranged a random set of alphabetical letters into vertical columns. The subjects were 15 totally blind adults, age 25 to 65. Although speed and accuracy were both stressed, speed did not prove to be a significant factor and did not, therefore, differentiate between the hands. However, 11 of the 15 subjects made significantly fewer errors with their left hand even though the right hand had read more letters (based on the combination of correct and incorrect letters scored). The authors suggest that two factors contributed to finding different reading speeds for the group of adults and the group of children. First, many of the adults were self-taught, no longer valued speed of reading at the expense of accuracy, and switched to the left hand because

it seemed more efficient. Second, the difference in the material, letter v. sentences, made it difficult to compare the two groups with regard to reading speed, which suggested that the type of material being read might affect reading speed.

Hermelin and O'Connor interpret their data as indicative of the cortical asymmetry for verbal and spatial-tactile stimuli and argued that the brain operates to interpret braille as spatial-tactual items first, to be subsequently analyzed more accurately by the right hemisphere. If this hypothesis is correct, it might be expected that hemispheric processing would be affected by (1) the varying amounts of practice and experience reflecting different stages in the acquisition of braille reading skills (e.g., Fertsch, 1947); (2) the methods of teaching braille; and (3) the means of coding the different braille characters (e.g., tactual and/or phonological).

The present study was designed to consider the above mentioned factors for a braille reading task and to determine at what stages, if any, left hand superiority in braille reading would occur.

Stages in acquiring braille skills. As was alluded to earlier, there are many techniques for reading as well as for acquiring efficient, braille reading skills. From the data presented thus far, several factors could affect braille reading: (1) the amount of training and experience often interpreted as practice (Foulke, 1964; Hammill and Crandell, 1969); (2) the serial perception and complexity of the task (Flanagen, 1964; Weiner, 1963); and (3) the tactual and phonological similarity of braille characters (Ashcroft, 1960; Nolan and Kederis, 1969; Harley and Rawls, 1970; Millar, 1975a). And although the intelligence of the blind person is cited as a prerequisite for minimal tactual perceptive ability above the minimum needed for learning to read print. These are important concerns which will be considered shortly. However, what seems to be essential for determining how the complex braille configurations are read is further understanding of the development or stages involved in the attainment of competent braille reading skills.

Kusajima (1974), for instance, kymographically recorded individual finger movements of blind children reading braille. The progressive variations in the relationship between the two index fingers were noted when the braille reader moved from beginner to intermediate and intermediate to advanced reading stages of competence. The study revealed that the beginning readers who were unfamiliar with the dot configurations tended to read letter by letter, predominately with the right hand. They characteristically made numerous up and down, zig-zag movements, with many fixations on the "spatial" forms of the words. At this stage the letters must have appeared to be arranged randomly until the distinct spatial arrangements could be identified.

The readers in the intermediate stage read with their fingers lightly pressed together. Their reading fingers moved together from the beginning to the end of the line. Eventually, however, some of the intermediate readers separated their fingers so that sharing or exchanging of roles occurred. In other words, even though these readers may have started reading the lines with their fingers pressed together, they eventially separated them towards the end of the line so that the reading material appeared to be divided into two parts. This stage suggests that the introduction of the left hand improved the processing of the spatial forms which lead to greater hand independence and an implied improvement of reading skills.

The advanced readers were competent with both left and right fingers and usually read half of each line with the left and right index fingers, respectively. Their finger movements were smooth, symmetric, and easy.

The results from Kusajima's study clearly show that changes in the hand(s) used seem to reflect patterns or strategies for decoding the configurations based on practice or experience. That is, increasing the level of practice should predict independent fluid finger movements and increases in good reading skills, whereas less practice and experience on a complex sequential tactual task should predict more dependent fixated finger movements and poor reading skills. Furthermore, the shifts in reading modes mark the initiation of changes in the reader's ability to perceptually discriminate or cognitively process increasing amounts of information simultaneously and successively. Consequently, it is suggested that these developmental changes in hand preference for reading (e.g., the beginners with an apparent right hand preference for looking for spatial cues change to intermediate readers using both hands) are indicative of the congitive strategies used to identify the braille dots (parallel-nonverbal v. serial-verbal). And it is also suggested that the level of practice or experience of the reader (beginner v. advanced skills) will determine the hemispheric specialization and thus the hand that is superior for reading.

Several studies of hand asymmetries on complex tactual tasks (Gardner, 1942; Provins and Glencross, 1968) and simple successive finger movements (Denckla, 1973; Ingram, 1975; Wolff and Hurwitz, 1976) substantiates these inferences, in part, and provides a dichotomy from which to compare the tactual discrimination strategies and skills found in braille reading.

Reading stages compared with similar adjustments in normal sighted adults and children. In the following studies it should be noted that the hand asymmetries are divided along dimensions of practice (training) and type of finger movement (non-serial or serial v. parallel). To be clear, serial means successive ordering of movements and non-serial or parallel means that the order of movements are necessarily successive. In this sense, Provins and Glencross (1968), studying trained and untrained typists found that the discrimination of letters that formed words, random letters, and the letters of the home keys (those in the middle row where the fingers rest) yielded left-right asymmetries similar to what was demonstrated by Kusajima's braille readers. That is, the untrained or less practiced and least skilled typists showed a right hand superiority for random letters and home keys (assumed to be less familiar to the typist) and no hand difference for the words. The trained or more practiced and skilled typists demonstrated a left hand superiority for the words and home keys (assumed to be more familiar to the typists).

Similarly, studies by Gardner (1942) on hand sorting (right hand superiority) and tracing (left hand superiority) tasks with adults; and Ingram (1975) with successive finger tapping (right hand superiority) and with copying various hand postures and fingers spacings, (left hand superiority) with children, have found right and left hand superiorities for tasks requiring the same type of processing.

One explanation for these lateral hand differences in somatosensory functions may be that the untrained or less practiced individuals process unfamiliar and successive tapping tasks in a serial-temporal manner. The evidence above shows that the right hand or left hemisphere might be better for this. Likewise, because the trained or practiced individual

is familiar with the task, finger movements may not have to be successive because the focus of attention is on a different aspect of the information which is better processed in parallel, by the left hand or right hemisphere.

Another explanation of the left hand superiority found on tasks such as tracing and copying is that they generat mental images of the figure or object whereby the processing is parallel in a spatial sense (Paivio, 1971), and image-symbols are more likely to be processed by the right hemisphere or left hand (as suggested by Hughlings Jackson, 1874, cited in Penfield and Roberts, 1959). Together these explanations suggest that the stage of reading depends on the relationship between practice or level of reading skill and the type of motor activity needed to process the tactual stimuli.

Consequently, this relationship must also determine hand asymmetry and hemisphere specialization for reading. Moreover, less skilled braille readers, who attempt to decode configurations with their right hands in a serial or verbal processing manner should be limited in their reading ability until their left hand is introduced enabling the non-verbal spatial forms to be processed in parallel. Therefore, increased reading skill would mark a change in what the reader was doing. The skilled reader must attend, integrate, and process the braille information coded by the two hands, perhaps in the way Critchley (1953) suggested through the adaptation of recognition and control roles for both hands. However, since braille configurations appear to always be a successive series of letters, when both hands are capable of reading braille, what processing strategy would then dominate (serial-left hemisphere or parallel-right hemisphere)? Accordingly, it seems that the braillist would

still have to decide which features (verbal or nonverbal) to encode. Therefore, it is still a question as to which finger will be the one of choice or superior for reading.

The Effect of Phonological Cues on Tactual Perception and Teaching Methods

Millar's (1975) study of how blind children three to ten years old encode nonverbal and verbal features used three lists of successive braille letters to determine at what skill level phonological and tactual cues were coded. The three item sets used were: (1) letters similar in feel, but dissimilar in name sound, (2) letters similar in name sound, but dissimilar in feel, and (3) letters dissimilar in both name sound and feel. The results, contrary to Kusajima's (1974) findings, suggested that less skilled blind readers tended to encode tactual features, while readers tended to encode verbal or similar sounding features. Overall, however, letters similar in feel and different in name sound were more easily recalled by both skilled and unskilled readers.

Although hand and sex differences were not assessed for this study, the results also imply that the memory recall process for tactual and verbal features varies with ability and learning levels as well as with the hand used to haptically identify the dot features.

These findings are of some importance for identifying characteristics of potentially "good" and "poor" readers within each developmental stage, as well as for teaching braille readers how to improve their reading strategies. As an example, two early studies, one by Bürklen (1917) on the legibility of the braille characters, the other by Maxfield (1928)

on observing teaching methods of braille, were concerned with these problems. In comparison with poor readers, readers who were characterized as having "good" reading styles were found to make fewer repeated movements, to apply slight and uniform pressure on the dots, to proceed in a straight horizontal line, and to read ahead with the left hand before finishing the preceeding line with the right hand. And "poor" readers repeated horizontal finger movements, used heavy unsteady pressure on the dots with excessive up and down movements on individual letters, and frequently used lip movements and inner speech, both of these being properties believed to retard reading. These characterizations are very close to how Kusajima (1974) described beginning and advanced readers.

Though Bürklen (1917) did not indicate the skill levels of his subjects, three fourths of his subjects read better with their left hands. Consequently he argued that the reading difficulties encountered were problems in the identification of word forms: the size, shape, and spacing of the letters. By implication Bürklen suggests the reader should be taught to use the left hand. However, Maxfield (1928) delineated of three methods of teaching children braille which significantly influence the comprehension of "word forms" in the braille code: the letter method, the letter-word method, and the word method. From her observations, Maxfield implied that the right hand was better for overcoming reading difficulties and should be used for braille reading.

Maxfield (1928) assumed the letter method and the letter-word method only enabled the child's finger to encounter dots or letters one at a time in only a passive mode of perception. The word method, on the other hand, used contractions (of dot symbols) which represented several letters and phonological combinations, i.e., 'tion', 'ment', 'bl', 'ch', 'sh';

therefore, these symbols could be encountered and understood in a "sweeping movement across the line," in an active mode of perception as opposed to the passive letter, letter-word mode of perception. Maxfield advocated use of the word method because the others essentially represented the passive modes of perception and reflected the major difference between "good" and "poor" readers as a consequence of their respective styles. Moreover, since the right hand was far more capable of sweeping movements, it was therefore best for reading.

Whatever teaching method is taught (the letter method or the word method which are assumed to use the left and right hand respectively, both seem to overlook the possibility that verbal and tactual features are subject to different, yet necessary coding processes that may change according to the individuals ability to integrate the information coming from both hands. Consequently, to evaluate the learning of braille, one must consider: the level of practice, the task difficulty, the memory load, and the strategy best suited to the individual for coding tactual and phonological (verbal) features of the code.

In summary, the studies of blind braille readers generally demonstrated that braille reading skills are acquired in stages that vary with ability and can change with practice, experience, or training; yet there may be constraints on the ability to progress through learning levels and to recall verbal and nonverbal features, constraints that are related to the task, the type of hand movements, and the cognitive processes used.

In this regard, it seems that these factors would predict hand asymmetries based on the type of features by which the readers would find hardest to discriminate (Millar, 1975). This is an important predeterminant for hand asymmetries, since even very skilled readers have difficulty recalling the tactual features of braille letters (Millar, 1975). Consequently the left hand must be essential for reading braille competently. One purpose of this study was to further substantiate this contention.

There were two important developmental problems with the preceding research, though. First, the data on hand asymmetries very rarely considered the age where the change-over took place, and second, the differences between the sexes for processing braille configurations. Perhaps both children and adults who were unfamiliar with braille configurations would show even stronger left hand superiorities for the learning of braille dot configurations, and could provide additional insight into age and sex differences for processing braille. The research on somatosensory functioning and motor asymmetries with sighted subjects is relevant to the discussion of these issues.

Age and Sex Differences in the Development of Hemispheric Specialization and Cognitive Skills

Somatosensory differences in normal subjects on complex motor tasks. Several studies emphasizing the ability to discriminate stimuli tactually and the serial ordering of motor movements have revealed conflicting results for hand asymmetries. Figures such as simple geometric forms have been used to determine the degree of sensitivity and the left-right hand asymmetry for normal individuals. For example, Becker (1931) applied geometric figures to the palms of adult subjects and discovered that the left palm required fewer presentations for recognition (3.94) than the right palm.

In one of two studies, Gardner (1942) used nonsense syllables made up of alphabet letters to test 30 sighted college students on a tracing task. The material consisted of heavy cord stitched to cardboard to form raised Latin-type letters. Fifty groups of these letters were traced from left to right and right to left. The unpracticed subjects identified the letters from left to right and right to left, and made fewer errors with their left than their right hands suggesting they were processing the spatial forms rather than the verbal features of the letters.

In a cork sorting experiment, Gardner (1942) found that the right hand was better when the corks were sorted into groups of cylinders and cubes, and the left hand was better when the corks were sorted according to size. There were no hand differences when the corks were sorted according to different sizes and shapes. One explanation for these differences that was suggested earlier may be that the determination of the size of an object like tracing of an object or area facilitates the generation of mental images or pictures that do not have to be processed in serial order. Consequently, haptic perception in the case of some sorting demands can focus more on the location of spatial features which are most adequately performed by the right hemisphere. These speculated hand differences also appear to be present in very young children.

On a finger tapping task, which required three to five year old right-handed children to tap a key as quickly as possible, Ingram (1975) found the right hand to be better as early as three years. In children five to eight years of age, Denckla (1973) measured simple repetitive tapping movements (index finger against thumb) and successive tapping movements (each finger in turn against thumb) for each hand. Though right hand superiority was found on the tapping task for Denckla's subjects, it decreased with age and no hand asymmetry was found for the successive finger movements. The girls, however, performed more rapidly than the boys on the successive movement task with both hands demonstrating that the coordination necessary for this type of sensorimotor skill depends on inter- and intra-hemispheric cooperation.

Evidence of sex-related differences in haptic perception. Witelson (1974) used a dichhaptic presentation technique to determine whether left-right asymmetries would be demonstrated for three dimensional nonsense shapes and embossed letters. This study, although done only with boys six to 13, found left hand superiority for the discrimination of nonsense shapes as early as six. No asymmetry was found for the discrimination of letters. On a similar task just using nonsense shapes, right handed boys and girls ages six to 13, were tested (Witelson, 1976). Left hand superiority was again reported for the boys but no hand differences were found for the girls.

One explanation Witelson gives the for hand and sex differences is that girls may have bilateral representation for processing spatial stimuli and this would increase the probability of finding no hand asymmetries. In contrast, boys appear to have right hemispheric specialization for spatial stimuli by about the age of six. Witelson (1976) also suggests that the bilateral representation in females may be a function of hemispheric processing differences in females. Semmes (1968) proposed that the neural structures may be organized to function differently and this may change as the individual matures.

Semmes (1968) proposed explanation in terms of a maturational effect for the change in processing differences is noteworthy. Earlier it was stated that the left hemisphere was dominant for verbalizing and analyzing information serially and that the right hemisphere was dominant for establishing a spatial gestalt. In the context of language acquisition, Semmes has suggested that fine sensorimotor control exhibited by the left hemisphere for articulation would require an increase in the localization of similar sets of functional grammetical units, such as the ordering of phonemic elements. This would represent a focal or precise coding of input and output elements in temporal and sequential ordering. By contrast, Semmes suggested that since the integration of encoding elements in the right hemisphere does not appear to be specialized for language directly, it must be more diffuse or less forcused, thereby more conducive for visuo-spatial perception. This would allow the right hemisphere to grasp and integrate fragmentary or dissimilar units of information as a whole or as a total gestalt. Semmes speculates that these two processes would become more differentiated as the individual matures.

An important implication can be drawn from Semmes' (1968) suggestions. First, specialization in females and males delineates two distinct coding processes that would undoubtably tend to dominate the person's perception of the world. In other words, since females may develop an earlier focally-organized hemisphere which codes in an analytical and serial fashion, this mode of hemispheric dominance may supersede right hemispheric functioning, i.e., spatial coding, even when the task is more global or gestalt oriented. In this respect, males who do not show this type of "language" specialization might be at an advantage in terms of perceiving stimulus configurations, gestalts or wholes (Harris, 1975b). Thus, the specialization of the hands demonstrated by the previous studies reflects sensorimotor control consistent with right and left hemisphere development in males and females and the possibility of interhemispheric competition for control of the motor pathways. The research on hemispheric commissurotomy patients and motor functioning seems appropriate for discussion at this point.

Hemispheric Specialization and Interhemispheric Competition for Control of the Motor Pathways

Motor adaptations. The hemispheric specialization of commissurotomy patients has provided insights into the basis dissimilarities between the two hemispheres (Sperry and Gazzaniza, 1967; Levy, Nebes, and Sperry, 1970). The method of processing sensory information based on the commissurotomy data has produced two general types of hemispheric processing. First, the right hemisphere is instrumental in spatial recognition and in completing fragmentary or partial information. If this capacity is impaired the individual will have trouble structuring and organizing his spatial environment. Second, the sensory input is monitored according to a competing-interacting response hierarchy, with the hemisphere whose specialty the tasks requires, will gain control over the motor pathways that are needed to perform the task.

Levy, Trevarthen, and Sperry (1972) tachistoscopically presented conflicting stimuli simultaneously to both hemispheres. The commissurized patients had to report one of two ways: (a) pointing with the right or left hand to the correct item among an array of complete stimuli or (b) naming or verbally describing the stimulus. The stimuli were left and right half chimeras of faces, antlers, and common objects. The results were that the subjects pointed to the stimulus seen in the left visual field and named the stimulus seen in the right visual field.

Levy interprets the results not as an interference or transitory effect as was previously assumed but as the product of a competition effect. Here, two hemispheres have responded to a hierarchy programmed for the specialty necessary for the completion of the task.

Trevarthen and Kinsbourne (cited in Levy, 1972) also noted that in all three categories of stimuli tested, each hemisphere tended to complete its own half-field percept. Evidence for this was demonstrated when without warning a manual response was blocked and the subject was requested to verbally describe the image seen. Since the object described was that projected to the left hemisphere, each subject described that image correctly. Consequently, the right hemisphere in the right handed subjects seemed to use a strategy that (1) perceptually apprehended the shape, (2) stored the visual material as a visual code without recourse to verbal labelling, and (3) dominated the response when no verbal labelling was required, even with the ipsilateral right hand. The specialty necessary for the completion of these tasks lay in the perceptuo-cognitive realm of cerebral functioning, requiring oculomotor search and retrieval as opposed to mechanisms governing the motor expression in pointing.

Bryden and Allard (1976) suggest that the perceptual processing prior to naming represents a global preprocessing operation, whereby the stimulus is normalized or stored and attention is focused on "relevant characteristics of the target" (p. 198). Because this type of hemispheric processing is more closely associated with the right hemisphere it may be that this ability is a structural by-product as Semmes (1968) suggested. It is also indicative of task complexity.

The research by Bryden and Allard illustrates this latter point. Ten different typefaces of Roman letters were tachistoscopically presented to college students. The more difficult script-like letters exhibited a left visual field or right hemisphere advantage, while the others were best recognized in the right visual field. The authors argue that the greater global preprocessing capabilities of the right hemisphere were necessary to evaluate the more complex features of the script like typeface.

Essentially, the studies cited above illustrate that the two hemispheres can accomplish the same task but by characteristically different strategies. On the one hand, in reference to visual stimuli, there appears to be a two part process wherein (1) when visual material needs to be preprocessed and visually coded without a verbal label, the right hemisphere will dominate the motor system whether on the left or right side; and (2) when the visual material requires a verbal and/or conceptual symbolic transformation, the left hemisphere will dominate the motor system.

Braille stimuli on the other hand still pose a question of whether braille will require a similar two-part decoding process, since the braille reader is likely to use multiple strategies in the course of completing the spatial-verbal material. Consequently, which hemisphere controls the motor system leading to different braille identification strategies will most likely be governed by cortical influences and their past response pathways.

Braille letter learning in sighted subjects. There have been several studies with blind children that have suggested that the right hand is better for reading braille, at least initially (Fertsch, 1947; Kusajima, 1974; Maxfield, 1928), while other studies have implied that the left hand is superior for reading braille, a complex tactual motor

task (Hermelin and O'Connor, 1971a, 1971b; Gardner, 1942). Subsequently, several studies were designed to determine whether left-right hand differences related to braille reading were a function of age, sex, practice, and/or hemispheric specialization strategies (Rudel, Denckla, and Spalten, 1974; Rudel, Denckla, and Hirsch, 1977; Feinberg and Harris, 1974; Wagner, 1976). These latter studies used sighted subjects and resulted in findings that are still somewhat conflicting with respect to the degree to which each variable is likely to contribute to hand asymmetries, but they do provide greater insight into the problem of determining hand superiorities for reading braille.

Inexperienced sighted children, ages seven to 14 years old, were used by Rudel et al. (1974) to study single-letter -raille recognition in a paired associate task. The children's index fingers were guided over the braille letters by the experimenter to begin with, in order to orient the children to how the letters felt. Then the children were encouraged to feel the letters on their own. In general, the left hand was superior to the right, but the effect varied by age and sex. In this respect, Rudel et al. (1974) suggested that the order in which the hands were tested may have had a greater affect on the girls than the boys. The boys were superior with their left hand regardless of the order of testing (right hand or left hand first), and significantly so by age 11. But, the girls achieved left hand superiority only after using their right hands first and then, only after the age of 12.

The left hand superiority found on this letter recognition task by the girls may be the result of a shift from early verbal coding strategies to the development of lateral representation specific for processing spatial cues, or, perhaps that when the left hemisphere is activated by right hand reading, the right hemisphere may be activated in such a way as to ameliorate the sensitivity of the left hand. In this regard, both Rudel et al. (1974) and Witelson (1974) have argued that the performance of one hemisphere may be the result of prior activation or stimulation of the other.

In another study by Rudel et al. (1977), subjects were asked only to make a same-different judgement about braille letters presented, presumably to minimize left hemispheric functioning. The results strongly paralleled the findings of the earlier Rudel et al. (1974) study, but the hand order effects were not as strong.

Feinberg and Harris (1974) tested undergraduates and had them learn braille letters by feeling them actively, to simulate the searching movements often observed in braille readers. Two sets of eight letters were used: four to each hand. There were a total of 40 trials per hand instead of six trials as used by Rudel et al. (1974). When the hands were tested in straight alternation over the 80 trial periods, the left hand was found superior for right handers. These findings were confirmed by Harris and Wagner (cited in Harris, 1975a).

Wagner (1976) was also able to demonstrate an overall left hand superiority for sighted children and adults similar to that found by Rudel et al. (1974). However, in contrast to Rudel's et al. (1974, 1977) findings, the pattern of hand asymmetry revealed lateralization for the boys (age nine) and no consistent demonstration of right hemispheric processing in girls until they reached college age. Wagner and Harris (1977) attribute the age and sex differences found, to invariant lateralization in boys, that is, age did not necessarily determine specialization for spatial perception by the right hemisphere, and, possibly to an increase in memory demands for girls. Consequently, Wagner and Harris (1977) concur with Millar's (1975) speculation that braille is a complex task that is capable of being decoded by a variety of strategies which depend on practice, sex and age of the individual, but conclude that braille is predominately a right hemispheric task which is suggestive of left hand superiority.

Contributions of the Current Study

This study proposes to determine whether the left or right hand is superior in braille reading by blind readers under two conditions: (1) controlled motoric scanning, and (2) verbalization. There were several remaining questions about the previous studies which suggested the necessity for a new study, for example: (1) will the speed and accuracy of braille reading be affected when a subject reads letters as opposed to sentences; (2) will speed and accuracy of braille reading be affected when vocalizing, i.e., reading aloud; (3) do good (fast) and poor (slow) readers use different strategies when reading; (4) does the time of onset of blindness affect hand asymmetry?

The assumption underlying the two experimental conditions, controlled motoric scanning and verbalization, is that each facilitated a different cognitive process. Two factors that directly affect cognitive processing in braille reading are: (1) level of reading skill and (2) the task of decoding the braille symbols (Hampshire, 1974). The type of stimuli selected for this study, i.e., letters and paragraphs, may appear to be similar, but it is likely that each requires different hemispheric strategies for decoding tactual-spatial input. Consequently, in a single letter identification task in which the right or left direction of motoric scan is controlled, the left hand or right hemisphere should be better at processing the letters, regardless of whether speech is involved. Paragraph reading which involves complex sentences, i.e., understanding the basic contractions as well as syntax and meaning, should require a different type of processing not only because of its complexities but also because of the way the individual choses to encode the information (Millar, 1975). Therefore, the cognitive processing of braille symbols might vary according to the level of braille reading skills, sex, and decoding strategies.

Also, since the development of hand asymmetries appeared to be related to age, to what extent does length of blindness affect the developmental level of skill in reading and the acquisition of different modes or strategies of processing.

Experimental Hypotheses and Tests

The first hypothesis is that the left hand or right hemispheric will be superior in identifying single braille letters despite having to say them aloud. This is primarily expected because each letter must be processed as an individual tactual configuration without phonological structuring or scanning aids.

The first hypothesis is in direct contrast to the commissurotomy studies of chimeras by Levy et al. (1972), in which verbal labelling of a nonverbal stimulus was found to be a left hemispheric skill for right handers. In experiment I, the letter identification experiment, it is proposed that the identification of a specific spatial configuration appears to warrant the initiation and continuation of the tactual-spatial strategy of the right hemisphere which at that time might dominate the motor pathway. However, if right hemispheric cognitive processing persists during word or sentence reading, slower and poorer readers will develop. In other words, these readers will have continued using a letter by letter or "static" reading style. Usually they read with their two fingers close together. The major consequence encountered when using a "static" reading style is a decreased level of comprehension.

The second hypothesis is that poor or slow readers will show left hand superiority for paragraph reading while good or fast readers will read equally well with both middle fingers. Evidence, thus far, does not appear to show any clear developmental level for simultaneous improvement of left developmental level for simultaneous improvement or impairment of left or right hand reading performances. But, two factors apparently influence the development of the better reader. One factor is inherent in the reading style which it is more "dynamic." The two fingers appear to separate and begin to show a "division of labor," much the way Critchley (1953) described earlier. The right finger sweeps across the line more freely, indicating that the left hemisphere has developed an adequate level of nonverbal-verbal transfer. The second factor is that there appears to be a sex difference in the acquisition of right or left hand superiority. It could be argued that females achieve an earlier right-visual and right-tactual superiority because their left hemispheres mediate both verbal and nonverbal stimuli. This particular kind of cerebral representation during childhood could very well afford females a slight advantage in expressive language skills (McGlone and Davidson, 1973) and early right hand superiority (Rudel, 1974; Feinberg and Harris, 1974), which would allow for an easier transition from "static" to "dynamic" reading styles. This kind of arrangement would clearly benefit females unless competition effects within the same hemisphere were to make it impossible to process nonverbal stimuli in the left hemisphere.

The third hypothesis is that there will be interhemispheric effects when left hand superior subjects read sentences aloud. Verbalizing will obscure the left hand effect, i.e., right hemispheric cognitive processing. This finding would be consistent with the findings for commissurized patients which demonstrated the competing response hierarchy (Levy et al., 1972). The process of verbalizing will probably lengthen reading times and increase the number of errors, but left hand superior subjects on the letter identification task should show less of a left hand effect.

Finally, the fourth hypothesis is that congenitally blind readers will read better than partially signted or adventitiously blind individuals. In the case of the congenitally blind child, birth stress may be reflected in the grequency of the left handedness implying right hemisphere superiority. Wortchell ((1951) suggests that congenital and adventitiously blind individuals might differ in their methods of translating somatosensory cues because of the latters' propensity to form visual images. The adventitiously blind individual might rely more on propositional thinking or visual translations instead of tactual-spatial means of interpreting the symbols. Thus, handedness and the time of onset or length of blindness may have some relevance for determining good or poor braille reading skills. Clearly accurate and efficient braille reading depends on the strategy used to comprehend the material.

Rationale for using the Middle Finger

There are a variety of methods of teaching braille reading. However, the technique most frequently used involves variations of the two index fingers moving across a line of braille type together. The remaining

fingertips although available are generally not used.

In an experiment to determine the amount of transfer of braille reading to the normally unused fingers (excluding the thumbs), Foulke (1964) found that the middle finger took significantly less time and made fewer errors than the ring and little fingers. He attributed the differences to the musculature associated with the ring and little fingers and the greater degree of control and manipulation in the middle and index fingers. In addition, Hermelin and O'Connor (1971a, 1971b) found that braille readers were able to use their middle fingers and adequately comprehend the material. More importantly, the asymmetry effects were stronger for the middle fingers than the index fingers.

It could be concluded that the middle fingers will serve as an adequate substitute for the index fingers and the relatively unpracticed middle fingers will make slightly more errors and be slower in performance than the index fingers. But, using the unpracticed middle fingers will more clearly indicate the functional asymmetry of the two hemispheres by minimizing the effect of finger sensitivity due to years of experience across the age groups while synthesizing the information.

In summary, the four hypotheses are: (1) In the task of letter identification there will be left hand superiority for both sexes, despite having to say the letters aloud; (2) Slow or poor readers will demonstrate left hand superiority on the paragraph reading task while fast or good readers will read qually well with either hand; (3) Vocalizing while reading paragraphs will obscure or mask the left hand superiority effect for those who demonstrate it; and (4) Congenitally blind subjects will read better than adventitiously blind or partially sighted readers.

III. METHOD

This study has two experiments with two preceding questionnaires. The questionnaires helped to determine the handedness and the history of blindness for each subject. In experiment I, the letter identification experiment, the Controlled Motoric Scan Measure was used to evaluate hand asymmetries for simple, elementary reading material. For experiment II, the paragraph reading experiment, the Gates-MacGinitie Reading Test, Form D-2 was used to determine hand asymmetries for complex reading materials.

Subjects

The sample consisted of 33 subjects, 16 females and 17 males, who were braille readers attending Michigan School for the Blind. The students were in grades 5-12. All used braille as their primary means of reading, although their degree of blindness varied. Their ages ranged from 10 to 20 years.

Materials

The Handedness Questionnaire. The handedness questionnaire shown in Appendix A, consisted of 20 items. Twelve items were from the Edinburgh Inventory for Handedness (Oldfield, 1971), and eight new items were made to account for characteristics specific to the blind.

History of Blindness. This questionnaire contained in Appendix B, consisted of nine items designed to assess the history of blindness and the acquisition of braille reading skills.

Controlled Motoric Scan Measure. This measure was devised to test speed and accuracy under conditions controlling for a left to right reading and scanning bias. (A copy of the measure is provided in Appendix D.) There were eight lists of 26 randomized letters typed in braille on a standard sheet of braille paper (30 x 25 cm). The braille dots were of standard height and size, since they were transcribed using a Perkins Braille Typewriter. The practice list was horizontally arranged and the control and six experimental lists were vertically arranged to be read from the top of the page to the bottom. The control and experimental lists included a total of 182 letters. There were no abbreviations or contractions on this measure. If an error was committed while identifying a letter, the letter was crossed out. The number of mis-identified letters for each column was indicated at the bottom of each column.

The Gates-MacGinitie Reading Test, Form D-2. Part I of the Gates-MacGinitie Reading Test for grades 4-6 was used to measure the dependent variables, reading speed and accuracy (See Appendix E). This test consisted of 30 short paragraphs, each 2-3 sentences long and containing between 28 and 30 words. Four words followed each paragraph. One of these was the correct response for the paragraph, i.e., completed a sentence or answered a question appropriately. If the subject answered with the wrong word the error was marked on the paragraph sequence number above the space where the paragraph time was recorded.

The 30 paragraphs in experiment II were divided in three parts. Part I of this experiment consisted of six paragraphs with approximately

174 words each. Parts II and III contained 12 paragraphs with approximately 348 words each. The paragraphs were distributed among the three parts in such a way that each part had a equivalent level of difficulty. Part I constituted the control condition of the second experiment, and Parts II and III the repeated measures of that experiment.

Each paragraph was transcribed by a skilled braille typist using the appropriate braille abbreviations and contractions. Three paragraphs were typed on one page, a standard sheet of braille paper (30 x 25 cm). The line lengths approximated those in braille reading classes. The braille dots were of standard height and size because they were transscribed using a Perkins Braille Typewriter. The experimenter's manuals were set up to parallel the subject's test booklets, i.e., three paragraphs to a page.

Data Record Sheets. Data recording sheets were designed to facilitate the recording of the data. The data recording sheet for the first experiment contained each of the alphabetical lists used (see Appendix D). It was used by the experimenter during the testing sessions and at the time the lists were coded from the taped recordings of the first experiment. This provided a check against experimenter error and protection against mechanical failure of the recording equipment.

A second data recording sheet provided spaces for recording paragraph reading times, sequential errors, total times and total errors. It also provided spaces for summarizing the data from the second experiment (see Appendix F).

Additional testing apparatus included a stop watch, a cassette tape recorder, and cassette tapes.

Research Design

Each subject in experiment I read a horizonal list of 26 randomly arranged alphabet letters in his normal reading style for practice. A vertical column of 26 randomly arranged alphabet letters was then presented as a control list, to be read by each subject with his index fingers or in his normal reading style. The six experimental lists or trials that followed were read with the middle finger of each hand in an alternating finger procedure. Half of the subjects began with the middle finger of the right hand and the other half began with the middle finger of the left hand.

Following the six trials for experiment I, three sample paragraphs were read by each subject in his normal reading style. The subjects were asked to select an answer for each paragraph that best completed the paragraph or answered the question. The subjects, then, read and answered three paragraphs silently and three paragraphs aloud in their normal reading style.

The subjects were told they would be reading the remaining 24 paragraphs with the middle fingers of each hand in an alternating finger procedure (three paragraphs were read with the right or left middle finger followed by three read with the left or right middle finger, etc.). Again, three sample paragraphs were presented to be read either silently or aloud but this time with the middle finger of the subject's choice.

The first 12 paragraphs were read silently and the second 12 paragraphs were read aloud depending on the condition. The results for each silent and alound condition were compiled separately and compared to the three silent and three aloud control paragraphs.

Procedure

Subjects were tested during two sessions. The first session consisted of an interview with each subject by the major experimenter. The Handedness Questionnaire and the History of Blindness Questionnaire was administered. The objective of the first session was to determine handedness prior to the experimental testing session so that subjects could be randomly assigned to the experimental conditions. This interview was also arranged and conducted in order to maintain confidentiality regarding each subject's history of blindness.

During the second session, trained aides (three undergraduate women) administered the Controlled Motoric Scan Measure and the Gates-MacGinitie Reading Test. The major experimenter introduced the subject to the aide. The subject was seated opposite the aide, who gave the subject a test booklet containing the braille copies of the measures. The experimenter had a similar booklet containing the non-braille copies of the instruments and the appropriate instructions for their administration.

Experiment I. The experimenter began by giving the instructions for the Controlled Motoric Scan Measure, experiment I (for instructions see Appendix C). The experiment began with the subject reading the practice list. Then each subject was asked to read the control list in his normal reading style. The experimenter timed the subject and coded which hand the subject used.

After asking for questions, the experimenter stressed speed and accuracy, started the tape recorder and stop watch, and checked the errors committed as the subject read aloud.

After the subject completed the control list, the experimenter stopped the tap recorder, recorded the times elapsed, and gave the instructions

for the six experimental trials. After checking for questions, the experimenter indicated the appropriate starting finger and reminded the subject to say the letters out loud and to read as fast as possible with accuracy. Then the experimenter started the tape recorder again and the timing for the first trial began. After each trial, the experimenter stopped the subject and reminded him to say the letter aloud and switch to the middle finger of his opposite hand. Then the experimenter turned the page, instructed the subject to begin and started the timing. This procedure was the same for five additional trials, a total of seven - one control and six experimental lists.

Experiment II. Following the completion of the alphabetical lists, the experimenter gave the instructions for the sample paragraphs of the reading test (see Appendix E). After the subject completed the samples, the experimenter gave the instructions for Part I, the control condition, in which the subject used his normal reading style. After checking for questions, the experimenter turned the page, instructed the subject to read the first paragraph and say his answer aloud. The subject gave his response and stopped. The experimenter recorded the time expired and whether or not an error was committed. If an error was committed the experimenter noted the error by marking the paragraph sequence number above the space where the paragraph time was recorded. Then the experimenter indicated when the subject was to start each successive paragraph. After the first three paragraphs were completed, the subject was instructed to read the last three aloud.

When the subject completed Part I, the experimenter gave instructions for Part II, which explained the alternating finger procedure. The experimenter then turned back one page and instructed the subject to use

the middle finger of one of his hands to read the first, second, and third successive paragraphs using the same finger. Then the subject was instructed to read silently or aloud according to condition. Each subject read 30 paragraphs, 15 silently and 15 aloud. There were 30 recorded times for each subject. The subject changed fingers at the end of each page, or every three paragraphs. The experimenter reminded the subject when to change fingers and when to read aloud.

After completing section two, the experimenter gave the instructions for Part III, which used the alternating finger procedure but in a different sequence. After checking for questions, the experimenter indicated the appropriate finger to begin with, reminded the subject to say the words aloud, stressed speed and accuracy, turned the page and started a procedure similar to the second part. The elapsed time was again recorded for each response along with errors. At the end of each page, or every three paragraphs, the experimented reminded the subject to change to the middle finger of the opposite hand and to read silently or aloud.

Upon the completion of the 30 paragraphs, the subject was thanked for his cooperation and told he did a good job.

IV. RESULTS

Six subjects (three boys and three girls) who were determined to be left handed by the Handedness Questionnaire were excluded from the analyses because there were not enough subjects per cell to make a statistical comparison. Consequently, the total number of subjects in these analyses was 27. A brief description of the six subjects' performance of both experiments will be presented after the data on the 27 right-handers are presented.

First, the results are presented according to the analyses done by sex of subject. Both single letter and paragraph reading results are described. In the analyses based on sex, the speed of reading paragraphs is the focus since the subjects had very little difficulty in accurately answering the paragraph questions or paragraph statements. Subsequent analyses for hand preference are then presented, with a comparison of differences between individuals. The results from the preference analyses were also contrasted to determine the extent of preference group differences. Finally, comparisons between sex and type of blindness are presented.

Test Trials for Letter Identification and Paragraph Reading

Single braille letters. In order to test for Hypothesis I, left hand and right hand performances in the reading of braille letters, were compared by subtracting the control reading time from the mean for the three trial reading times for each finger. An error rate was obtained by subtracting the mean number of trial errors for each hand from the control error rate. After grouping by sex of participant, t-tests were performed contrasting left and right hand reading speed scores and errors for each sex. There were no significant differences found (see Table G1, Appendix G).

Paragraph reading. To determine the difference between sex and right and left hand performances (hand differences) on the paragraph reading task difference scores were computed by subtracting the mean of the three control trials read silently from the mean of the experimental silent trials for the right finger and the left finger, respectively. Similarly, the mean for the three control trials read aloud was subtracted from the mean of the experimental aloud trials for the right and the left finger, respectively. The differences between right and left fingers were tested using t-tests for dependent samples. (The results are presented in Table G2, Appendix G.) These analyses failed to disclose any significant effects for either the male or female groups. When all the subjects were combined, the difference between the right and left fingers was also nonsignificant.

To evaluate the effect of verbalization on the differences between right and left hand performances, additional t-tests were performed (see Table H1, Appendix H). Table 1 presents a summary of the results for the effect of varbalization as a function of handedness. A significant result was obtained in the comparison between the silent-right and aloud-right conditions for the male group and the combined group with the better performance occurring in the silent reading condition. There was

a trend in the same direction for the left hand. The combined groups comparison between the left versus right hand aloud condition also showed a trend toward better left hand performance.

Table 1. Results of the t-tests between the silent and aloud conditions for the right and left hand in the paragraph reading task.

		Difference Means (in seconds)			
Hand	Group	Silent	Aloud	t	df
Right	Boys	152.50 (σ-154.31)	195.14 (σ-102.02)	-2.25*	13
	Girls	106.61 (σ= 67.38)	113.61 (σ= 78.94)	- .68	12
	Combined	135.59 (σ=121.70)	155.88 (σ=127.65)	-2.20*	26
Left	Boys	94.35 (σ=102.59)	110.14 (σ-102.02)	-1.83	13
	Girls	79.23 (σ= 67.69)	80.38 (σ= 91.62)	- .05	12
	Combined	87.07 (σ= 86.23)	95.81 (σ= 96.48)	- .76	26

(*p < .05)

Speed of reading. Next, to test for Hypotheses II and III and to assess the different effects of reading speed, subjects were grouped according to verbalization condition, sex, and reading speed (fast or slow). Fast and slow readers were determined by selecting the subjects with the fastest total (left and right hand) reading times (7 boys and 7 girls) to be in the fast reading group and those with the slowest total reading times (7 boys and 6 girls) were placed in the slow reading group. Comparisons were made for right and left hand reading performances, and Table 2 presents the results of the eight comparisons. Table 2 shows

Table 2. Results of the t-tests between right and left hand performance in the silent and aloud conditions for the paragraph reading task as a function of sex and rate of reading.

Condition	Group	Rate of Reading	Difference Mean (in seconds) Right	Left	t	df
Silent	Boys	Fast	74.14 (σ= 37.99)	52.14 (σ= 16.55)	1.50	6
		Slow	250.85 (σ=178.70)	136.57 (σ=135.54)	1.09	6
	Girls	Fast	67.71 (σ= 27.23)	46.28 (σ= 26.83)	4.84**	6
		Slow	152.00 (σ= 73.00)	117.66 (σ= 82.71)	.58	5
Aloud	Boys	Fast	100.28 (σ= 50.55)	77.00 (σ= 35.09)	1.27	6
		Slow	290.00 (σ= 50.55)	143.28 (σ= 35.09)	1.37	6
	Girls	Fast	71.71 (σ= 42.34)	41.42 (σ= 28.18)	3.76**	6
		Slow	162.50 (σ= 86.48)	125.83 (σ=120.78)	.58	5

(**$p < .01$)

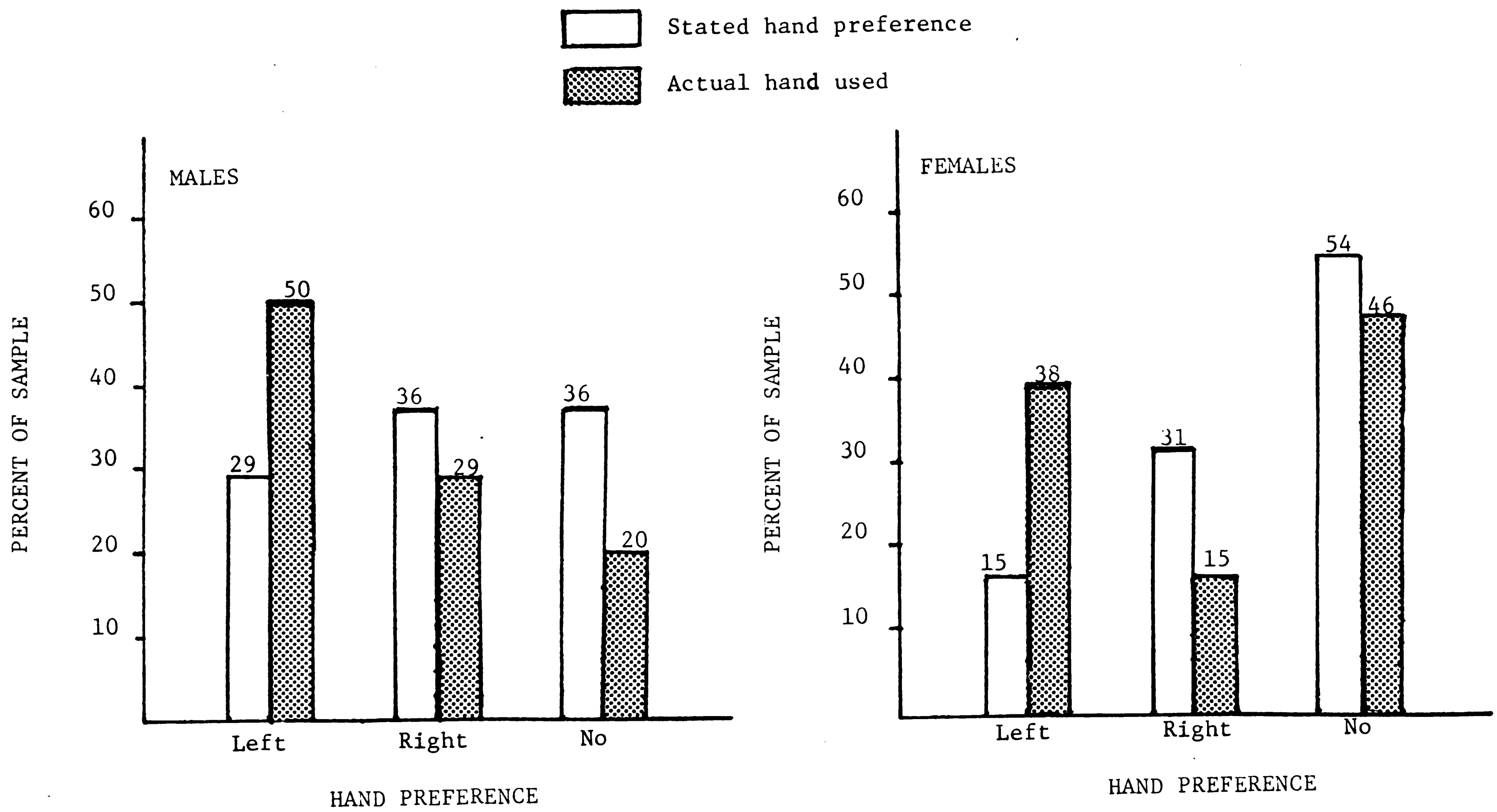
that for females, left hand performances were better for the faster reading group in both the silent and aloud conditions, respectively. In the comparison between left and right and silent reading for males, there was a trend toward faster left hand reading. The males also demonstrated a significant result for silent right hand reading (74.14 seconds) when compared with aloud right hand reading (100.28 seconds) (see Table I1, Appendix I).

Verbally-stated Hand Preference Versus the Actual Hand Use

To determine which finger was the "finger of choice" for braille readers, the 27 right-handed subjects were grouped according to stated hand preference and the actual hand used. Initially, the participants were divided into three groups according to the hand that they perceived as best for reading. This was their stated hand preference as determined by the History of Blindness Questionnaire, i.e., (1) those who felt they read better with their right hand; (2) those who felt they read better with their left hand; and (3) those who felt they read well with both hands - had no hand preference. Next, subjects were grouped according to their actual hand (behavioral) used, i.e., their preference as indicated by choice of index finger used during an initial reading performance.

Figure 1 presents a comparison of the actual (behavioral) hand used and the verbally-stated hand preference. The graph shows an increase in the number of subjects preferring their left hand a decrease in the number of subjects with preferences for their right hand or for neither hand. The males who stated a right hand preference or no hand preference chose to use their left hand more often. For the females, the percent of those

Figure 1. Comparison of stated hand preference and the actual hand used for braille reading by males and females.


Stated hand preference
Actual hand used
MALES
PERCENT OF SAMPLE
60
50
40
30
20
10
29
50
36
29
36
20
Left
Right
No
HAND PREFERENCE
FEMALES
PERCENT OF SAMPLE
60
50
40
30
20
10
15
38
31
15
54
46
Left
Right
No
HAND PREFERENCE

subjects who used their left hand increased and the percent for those using their right hands decreased. Those who indicated no hand preference decreased in number slightly.

Hand Preference

Single braille letters. To determine whether actual hand preference affected reading performance the left and right hand reading speeds and the error rates were contrasted by t-tests after grouping by actual hand used. These analyses were again testing for Hypothesis I and compared subjects as a function of the hand they actually preferred to use. Table 3 shows that the group preferring to use their left hand demonstrated a significant left hand advantage for letter identification and least errors. The t-tests revealed no significant difference for the other two groups. The male and female scores for the left hand preference group were very similar.

Table 3. Results of t-tests for mean times and mean errors during the letter identification task by behavioral hand preference.

Hand Preference	Mean Time (in seconds)				Mean Errors			
	Left	Right	t	df	Left	Right	t	df
Left	31.75	66.91	3.89**	11	4.41	8.25	2.49*	11
Right	101.90	53.20	- .93	9	10.00	5.60	-1.12	9
No	54.40	34.00	-1.87	4	4.60	4.80	.09	4

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

Paragraph reading. To determine how hand preference affected paragraph reading performance, t-tests for dependent samples were performed on the right and left difference for the three preference groups (left preference-12 subjects; right preference-10 subjects; no preference-5 subjects). Since these t-tests were a re-evaluation of Hypotheses II and III, fast and slow readers were again determined by selecting the subjects with the fastest total (left and right hand) reading times to be in the fast reading group and those with the slowest total reading times were placed in the slow reading group (left preference-6 fast readers, 6 slow readers; right preference-5 fast readers, 5 slow readers). The no preference category was not divided according to total reading times because the number of subjects in the group N = 5, was too small to do a comparable statistical analysis for their data. Table 4 presents the results and reveals a significant effect for performances by the group which preferred the left hand.

When speed of reading was controlled in addition to controlling for hand preference and verbalization condition, left hand superiority occurred for both left hand preference groups and for the fast readers in the right hand preference group (see Table 5 for the comparison).

The occurrence of this effect with the faster readers in both the left hand and right hand preference groups is an indication that the left hand effect was strongest for these subjects. The pattern of hand asymmetry was consistent for the faster readers of both left and right hand groups with masking of the effect occurring in the aloud condition for the right hand preference group. The masking effect may be what Levy el al. (1972) were referring to as an inhibitory reaction that results from competition between the two hemispheres when some readers read aloud.

Table 4. Results of the t-tests between the mean difference scores in seconds for the left and right hand paragraph reading conditions as a function of hand preference.

Preferred Hand	Difference Means Right	Left	t	df
Right	155.00 (σ= 76.76)	250.00 (σ=265.15)	1.21	9
Left	456.50 (σ=282.10)	156.25 (σ= 72.04)	3.40*	11
Both, equally	168.40 (σ= 93.99)	112.60 (σ= 50.67)	1.41	4

(*$p < .05$)

However, the slower left hand preference group also demonstrated left hand superiority in the aloud condition and with a notable trend in that direction occurring during the silent reading condition. Although the slower left hand readers demonstrated a marginal hand effect, suggesting left hand superiority in the silent condition, the aloud condition clearly demonstrates hand asymmetry under potentially inhibiting conditions.

The subjects recognized as having no preference showed a significant right hand effect for silent reading when silent versus aloud conditions were compared. This is consistent with an earlier mentioned paragraph effect found for the combined groups in that silent reading with the right hand proved to be faster. No other significant interactions occurred within this group (see Table J1, Appendix J; Table K1 and K2, Appendix K).

Table 5. Results of the t-tests between right and left hand performance in the paragraph reading task as a function of verbalization, hand preference and rate of reading.

Condition	Hand Preference	Rate of Reading	Difference Means (in seconds) Right	Left	t	df
Silent	Right	Fast	73.20 (σ= 28.46)	39.60 (σ= 22.15)	4.58**	4
		Slow	74.60 (σ= 39.38)	194.00 (σ=154.70)	-1.67	4
	Left	Fast	138.50 (σ= 63.92)	61.83 (σ= 27.50)	2.79*	5
		Slow	290.33 (σ=170.76)	93.16 (σ= 48.11)	2.40	5
Aloud	Right	Fast	80.00 (σ= 52.61)	53.40 (σ= 47.21)	2.64	4
		Slow	82.20 (σ= 57.40)	213.00 (σ=177.78)	-1.90	4
	Left	Fast	168.16 (σ= 97.41)	71.16 (σ= 35.51)	2.64**	5
		Slow	316.00 (σ=149.57)	86.33 (σ= 38.38)	3.07*	5

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

Individual Differences

To determine the degree of hand asymmetry as indicated by differences in right versus left hand performances, reading rates were assessed for each subject in order to find the percent of difference for speed of reading on both braille reading tasks as a function of hand used. The percent difference was obtained by calculating the mean time taken to read the three columns of 26 letters by the left and right hands, respectively. The actual finger (hand) preferred and the percent difference between each finger for each subject on the individual braille letters tasks are presented in Table L1 (see Appendix L).

All of the subjects in the group preferring their left hand read faster with the left hand during the letter reading task. Here, each subject's perception of actual hand preference was accurate in terms of the hand asymmetry. For the subjects who indicated both, or no hand preference, forty percent read faster with the left hand the remaining sixty percent were better with the right hand. Half of the subjects preferring the right hand found their left hand to be faster. Therefore, only half of the right preference group were accurate in their perception of (1) which hand they would use and (2) which hand was more effective for reading.

While reading paragraphs, Table 6 shows that all of the left preferrers favored a left hand approach. The magnitude of the asymmetry increased for each subject in this group when compared with their performance when reading single letters. The subjects without hand preference shifted in various ways in their strategies of approach during the paragraph reading task. Four of these subjects during the paragraph reading task used their left hands, whereas five used their right hands, when reading letters. The remaining subject favored his right hand, but the difference decreased slightly.

The right preferrers also used various approaches during paragraph reading as compared with the letter reading task. First, the number of

Table 6. Mean reading times and percent differences for 12 paragraphs combining 'aloud' and 'silent' reading conditions as a function of behavioral hand preference in the single letter identification task.

Preferred finger for Braille-reading	S#	Age	Mean reading time in sec./paragraph Middle finger: Left	Right	Percent difference	
MALES (N=14)					Faster Hand	
Left Index (N=7)	1131	10	153	288	L	88.2%
	1241	18	42	600	L	1328.6%
	3031	16	234	490	L	109.4%
	4051	15	274	360	L	31.3%
	4111	17	136	352	L	158.8%
	2191	11	172	204	L	18.6%
	2201	15	217	236	L	8.8%
Left and Right Index (N=3)	2071	17	86	175	L	103.4%
	3011	18	161	189	L	17.4%
	1161	15	138	105	R	31.4%
Right Index (N=4)	3151	10	97	154	L	58.8%
	4181	13	159	183	L	15.1%
	1171	18	215	191	R	12.6%
	2091	20	512	152	R	236.8%
FEMALE (N=13)						
Left Index (N=5)	1142	16	76	280	L	268.4%
	3042	18	72	102	L	41.7%
	3122	17	123	150	L	21.9%
	3222	15	174	314	L	80.5%
	4262	16	137	240	L	75.2%
Left and Right Index (N=2)	1082	11	115	155	L	34.8%
	2022	20	92	106	L	15.2%
Right Index (N=6)	2252	12	217	258	L	18.9%
	4212	13	108	126	L	16.7%
	4272	18	70	101	L	44.3%
	2062	14	55	60	L	9.1%
	1232	15	317	223	R	42.2%
	1102	14	600	474	R	26.6%

subjects favoring the left hand increased. Most of these subjects during single letter reading processed the letters better with the right hand or the left hemisphere. The remaining subjects whose right hand was faster during paragraph reading were accurate in their perception of hand use. However, several had favored the left hand for single letter reading.

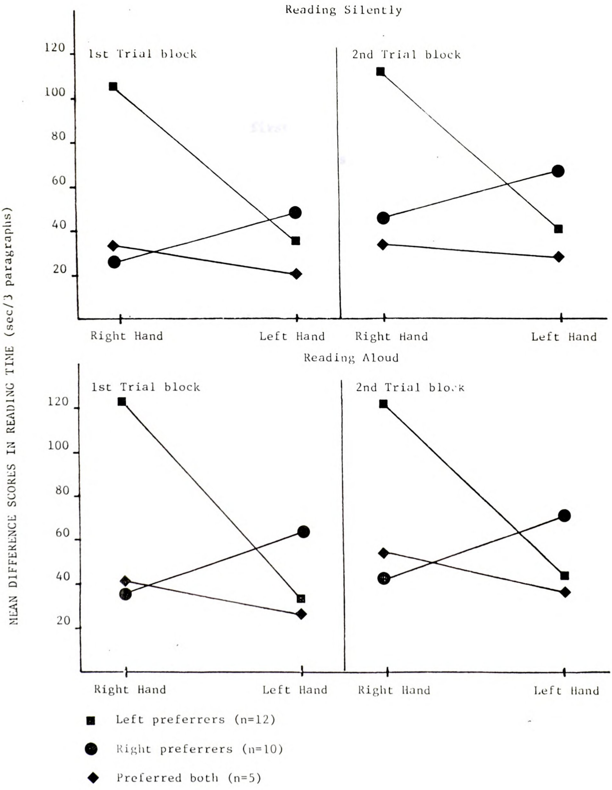
Comparatively, more subjects favored their left hands when reading and the magnitude of the left versus right hand percent difference increased during the more complex paragraph reading task. In the case of those favoring the right hand, the right hand or left hemisphere may be required depending upon the task, but at least fifty percent of these subjects were using their left hands to read the braille information.

Preference Contrasts

To determine whether there was a hand preference effect within verbalization conditions, i.e., comparing right hand and left hand performances during the silent conditions and the aloud conditions in the paragraph reading task, the mean was computed for the three paragraphs read with each hand, respectively. These means are plotted in Figure 2. During the first and second trial blocks of the silent reading section, the left hand reading time of the left preferrers was almost three times faster than the right hand reading time. In contrast, the right preferrers' time with their right hands was faster over both trial blocks with a slight increase in left hand reading times. For the group preferring both hands, left hand times appeared to be slightly faster than right hand times over the two trials blocks. Reading speed during the second trial increased for all groups.

Comparing the three groups for the mean difference scores in the

Figure 2. Mean difference scores in seconds for the paragraph reading task for the verbalization conditions as a function of hand preference.


Reading Silently
1st Trial block
2nd Trial block
120
100
80
60
40
20
Right Hand
Left Hand
Right Hand
Left Hand
Reading Aloud
1st Trial block
2nd Trial block
120
100
80
60
40
20
Right Hand
Left Hand
Right Hand
Left Hand
MEAN DIFFERENCE SCORES IN READING TIME (sec/3 paragraphs)
Left preferrers (n=12)
Right preferrers (n=10)
Preferred both (n=5)

performance of the same hand, reading performance with the right hand was faster for the right preferrers than for the other two groups. The left hand for the 'both' (no preference) group and the left preference group was relatively faster than the left hand for the right preference group.

Reading aloud during the first and second trial produced similar patterns of right-left hand functioning as was demonstrated for each of the three groups while reading silently. Left hand reading preference during the first trial block for the left preferrers did appear to slightly improve or be stable despite the apparent verbalization effect which influenced the other scores. Two differences in the right versus left hand reading comparisons occurred during the silent reading. First, the 'both' group increased its right hand reading speed to a point where it was greater than that shown by the right preference group. Second, the right preference group demonstrated better right hand reading during the aloud reading conditions than the second trial of the silent reading phase.

Type of Blindness

Hypothesis IV was tested by computing two 2 x 2 ANOVAs to examine the effects of sex and type of blindness for the dependent measures of total time to read three columns of 26 letters and total errors made during these trials by each hand on the letter identification task. Table 7 shows no sex difference for time for either group. Type of blindness, however, did affect the total number of errors made by the right hand. Table 8 demonstrates that the adventitiously blind group made significantly more errors ($X = 8.3$) with their right hands than the congenital group made ($X = 5.7$) with their right hands.

The difference between right and left hand performances on the

Table 7. Results of the analyses of variance for total reading times by congenital and adventitiously blind males and females in the single letter condition.

	Right Hand			Left Hand		
Source	MS	df	F	MS	df	F
Sex (A)	131.70	1,26	<1	12045.73	1,26	<1
Type (B)	254.77	1,26	<1	5309.60	1,26	<1
A x B	1513.80	1,26	<1	3190.49	1,26	<1

Table 8. Results of the analyses of variance for number of errors by congenital and adventitiously blind males and females in the single letter condition.

	Right Hand			Left Hand		
Source	MS	df	F	MS	df	F
Sex (A)	.46	1,26	<1	288.17	1,26	<1
Type (B)	3566.74	1,26	5.06*	162.20	1,26	<1
A x B	29.45	1,26	<1	45.91	1,26	<1

(*p < .05)

paragraph reading task was computed in a 2 x 2 ANOVA as a function of sex and type of blindness. There were no significant differences (see Table M1, Appendix M).

The Left Handed Subjects

There were six subjects who were found to be predominately left handed from the Handedness Questionnaire. In terms of stated preference, the History of Blindness Questionnaire revealed that three of the six (2 males, 1 female) preferred to use their left hand to read, one (1 female) preferred to read with the right hand, and two (1 male, 1 female) felt they read well with both hands - had no hand preference. Subsequent reading on the single letter identification task, experiment I, demonstrated that the three left preferrers and the two no preference readers read faster with their left hands. They also read faster with their left hands during paragraph reading. The one left hander, who stated that the right hand felt better for reading, read faster with the right hand on both the single letter identification task and the paragraph reading task.

V. DISCUSSION

Interpretations and Implications

Summary of Major Findings

The initial questions addressing hand usage for certain types of braille reading were found to have a bearing on many braille readers, since more than half of the readers stating a preference for the right hand or no preference for either hand switched to their left hand when asked to identify letters. These shifts in hand use by the readers indicates that they are unaware of the functions of each when reading and that different types of materials may elicit a different hand response based on the difficulty of the material. For these reasons, the results from the study will be discussed in terms of verbal and behavioral preference observations. Later, a presentation of analogous visual reading operations will be made because they appear to parallel the braille reading process and the phenomena observed in the study.

On the test of perception of single letters, the sex by verbal preference by hand interactions were not significant. In addition, there were no hand differences found when the sexes were combined. Since this task was designed to facilitate a "spatial" analysis, that is, discrimination of the orientation and configuration of the letters, finding no sex difference is not consistent with reports of male superiority for spatial ability (Harris, 1978). It also should be noted that on this task, the alternate presentation of letters proved to have no significant benefit

for either hand. In this instance, the lack of order effects argues against the possibility of hand superiority being the result of prior activation or stimulation of the left or right hemispheres as was evident in the Rudel et al. (1974) study on letter discrimination.

However, finding no hand differences suggests that the stimuli were perhaps too simple to actually differentiate differences. According to this speculation, a reasonable explanation supporting this suggestion may be found in the level of experience of these subjects, since all the readers were old enough to be receiving grade 2 braille instructions. Harley and Rawls (1970) noted that grade 1 braille, a braille equivalent for the 26-letter alphabet, is primarily used with very young blind children and newly blinded adolescents and adults. After adequate mastery of grade 1, braille readers move to grade 2 braille. Since most of the braille readers in this study have made the transition to grade 2 braille which includes abbreviations and contractions, the reading ability of these subjects could be considered to be at least on an intermediate level. Therefore, an additional factor of rote memory for single letters must be a concomitant effect when subjects become more experienced, so that hand differences may not be as distinguishable.

Despite the verbal preference findings which showed no hand differences, the behavioral preference data for the latter task indicated significance for the left preferrers. This finding does support the general prediction for left hand superiority for elementary letter identification but implies no apparent sex differences. Thus, to the extent that the right hemisphere has been shown to significantly discriminate spatially organized letters the results are consistent with other reports of left hand superiority (Hermelin and O'Connor, 1971a; Rudel et al., 1974, 1977;

Feinberg and Harris, 1974; and Wagner, 1976).

While a left hand advantage was found for left preferrers, subjects who preferred their right hand or no hand preference for reading failed to demonstrate a significant left or right hand advantage even though some of the individuals in both groups read better with their left hands. The individual differences found might be taken to indicate that for this reformulated group of subjects, the task again was too simple to reveal an overall hand difference. Furthermore, since appropriate controls were taken at the outset of this task suggesting no observable differences between individuals, the lack of any significant hand differences for these subjects might be attributable to characteristics within the two groups such as hand ambidexterity or levels of experience. The behavioral findings on a group and perhaps on an individual level supports the possibility that a tactual-spatial strategy involving a left-hand right-hemisphere as opposed to an alternate right-hand left-hemisphere strategy could be better for this type of reading. The next question may be: at what level or in which group of braille readers might left hand superior reading occur consistently?

At a more complex level, verbal preference paragraph reading revealed no differences for overall sex by hand interactions, while there were significant sex differences for fast and slow readers. Though the areas where significance was obtained differed for each sex, the predicted greater left hand superiority for males was not found. The faster reading males demonstrated that the right hand will read better during silent reading as opposed to reading aloud. This result by itself is not unusual, since silent reading in general is done much faster than oral reading. It suggests, though, that with braille, the actual vocalization connected with this task may decrease reading efficiency with the left hand while significantly decreasing right hand silent reading. It may be that among these males a hemispheric inhibitory function exists when vocalizing; but the quantitative differences within each hemisphere when processing more complex linguistic tactual stimuli such as contractions and words during the vocalizing phase does not show that the right hand is better than the left hand. Therefore, the prediction that left hand superior male subjects will lose their advantage when reading aloud cannot be considered from this data. However, the reading method used by the faster reading males may add some clarity to the processing differences.

The finger placement pattern for these subjects was predominantly fingers together with some separation suggestive of a letter by word synthesis. Accordingly, a letter by word synthesis assumes the reader is at an intermediate stage of reading where both hands can contribute on an equal basis depending on what end of the intermediate continuum they are at. When the reader is forced to read with only the right hand, the greater mobility found in the right hand could account for a significant decrease in right hand reading during silent reading because more emphasis might be placed on completing the gestalt aspects of the configurations; whereas right hand aloud reading would conceivably focus more emphasis on the linguistic-phonetic aspects of the reading. In the latter situation, reading times would definitely increase. This brief explanation implies that these are differential advantages under special conditions for faster reading males only. It says nothing about the superiority for reading one hand may have over the other for braille readers in general.

As for the slower male readers, who did not show any of the effects above, perhaps, they are at the letter by letter stage of reading efficiency as suggested earlier by Maxfield (1928). Reading words in a letter by letter manner would decrease reading speed as well as comprehension and may not be affected by vocalization under any conditions. The consequences of this strategy suggest their reading level has not reached a point where sequential letters produce meaningful phonemes and words as incentives to increase reading efficiency. These readers as a group showed no consistent pattern of finger placement.

Since neither fast (good) nor slow (poor) male readers demonstrated significant left hand superiority, these subjects do not appear to have reached the developmental level where one hand demonstrated superior reading effectiveness or where the two fingers could function together yet independently, i.e., in a division of labor style of reading. However, a closer look at the individual subject data revealed that fast and slow male readers read slightly faster with the left hand irrespective of vocalization. This means that male braille readers at certain skill levels clearly develop a hand preference for learning to read or may read better with a particular hand. In this case, the terms "good reader-poor reader" as suggested by Maxfield to distinguish proficiency of style or method during braille reading may be somewhat misleading, primarily because for the males tested using complex reading materials the level of reading ability which is often indicative of hand superiority is confounded with hand preference.

Presumably, since no significant hand asymmetry was found for either group of males, one might expect females to have demonstrated similar results. Unexpectedly, however, the faster reading females read significantly faster with the left hand in both silent and aloud conditions.

Finding left hand superiority during silent reading is contrary to what would have been predicted from earlier studies (Mellone, 1944; Maccoby, 1966) where males would be expected to demonstrate the spatial skill for a task of this type or in studies where there were no sex differences (Kimura, 1969; McGlone and Davidson, 1973). The more specific vocalization finding may mean: (1) these females are processing the information differently from the faster reading males, and/or (2) their ability to discriminate tactual stimuli appears at an earlier maturation level which facilitates acquisition of the task.

The first possibility was indicated when close inspection of each reader's finger placement style was noted. The majority of these females read with index fingers apart during normal reading as predicted; this is indicative of a clear "division of labor" where both fingers are equally skillful at comprehending the dot configurations. In this sense, Maxfield's theory does apply and indicates reading with fingers apart facilitates a more comprehensive word by word approach whose feasibility is based on a higher level of perception capable of withstanding the effects of reading aloud which earlier suggested a possible shift to the left hemisphere or right hand. In contrast, the majority of the males were using a "fingers together" or one finger approach to accomplish normal reading. Apparently, reading style reflects as aspect of cognitive processing indicative initial right hemisphere control which may ameliorate the acquisition of braille reading skills for some individuals, especially females.

Secondly, this effect might be the result of finding these females at a higher maturation level than the males. Wagner (1976) suggested that at various grade or age groups females may be inclined to pay closer

attention to braille characteristics despite increased in the difficulty of discriminating specific letters. Her fifth grade and college level females, who are comparable in age to those in this study, showed clearer left hand asymmetry on the learning task than the males at the same age. The relevance of the maturation factor rests with the fact that, if these females are able to apply the word by word approach as a result of greater or earlier maturity, they also may be taking advantage of the highly overlearned spatial associations. Broadbent (1974) argues that such familiarity might prompt a more direct focusing of the "linguistic" aspects of the code toward the right hemisphere because of its dominance for continuing total gestalt. Nevertheless, these females are approaching the braille configurations in a different manner than the males and their approach affects cognitive processing whereby the right hemisphere seemingly has more control over the reading process than the left hemisphere.

This study demonstrates with blind female braille readers that the right hemisphere plays a strong role in processing tactual linguistic-spatial information under both vocalizing and non-vocalizing conditions. It also implies left hand reading superiority prevails regardless of sex and suggests again that a particular hand preference for reading may manifest itself at some developmental level in the braille reading process. Consequently, a third explanation which considers the possibility that these females have developed a specific hand preference different from males should be questioned.

The behavioral preference results for paragraph reading revealed additional information about the development of hand preference leading to asymmetries in braille reading for females. First, of those fast reading females who demonstrated significant left hand superiority, only

half were in the left preference group. The left preference group showed consistent left hand asymmetry despite the phonètic-linguistic requirements of the task and across both fast and slow reading levels. However, it appeared that a preference for left hand reading led to significant practical asymmetry even if the person was at the beginning levels of braille reading. Consider for example, four subjects within the left preference group, who said they characteristically did not use their right hands to read. That is, their reading finger(s) had been established through practice and experience to be the left. Consequently, reading with the right hand in some cases became awkward, confusing and in one case was completely unintelligible. This evidence substantiates what Hermelin and O'Connor (1971a) reported of a young student's inability to read when his left, "reading hand" was incapacitated. Other reports attest to the validity of this phenomenon with adults (Hermelin and O'Connor, 1971b; Ward, 1977). In these cases, preference for the left hand was related to decoding spatial symbols more efficiently.

Secondly, the other half of the fast reading female group was in the fast right hand preference group. Surprisingly, when one observes the right and left hand differences for this group the differences are not large but the data does show that the left hands of this group performed better than the left hands of the left preferrers. It would seem that these individuals are approaching an advanced level of skill where efficiency is combined with speed. Also, it is possible that the performance of one hemisphere is influenced by the prior activation of the other. That is, as the benefits of prior left hemisphere activation increase, especially as the child matures, the benefits of prior right hemisphere activation may also increase or remain constant as exemplified by the

Rudel et al. (1974) and Witelson (1974) experiments. At a descriptive level, these subjects were using a reverse linguistic-spatial operation, that is, spatial components are considered perhaps secondarily while enhancement of the left hand performance occurs concurrently.

Several speculations arise from these findings about the ability or potentiality of females within these two groups (fast left preference and fast right preference) to decode spatial configurations with linguistic components and their hand preferences relative to reading hand methods for complex stimuli. First, the left hand asymmetry found in left preference subjects must involve the right hemisphere despite its limited linguistic ability (Levy et al., 1971) and the neural mechanisms which anticipate this particular cognitive process must analyze the stimuli in a spatial-linguistic operation by using these limited linguistic resources. Then the neural mechanism apparently facilitate transfer of the spatial symbol to the left hemisphere. This process for these people is much more efficient than a right-hand left-hemisphere approach used by others at the beginning and more skilled levels of braille reading. In addition, the function of the left hand must be so essential to the reading process that predominantly left hand readers resist changing to the right hand for faster reading even though the right hand clearly possesses greater mobility in the left to right reading process. The existence of this asymmetry suggests a distinct adaptation in neural mechanisms involving a left hand to right hemisphere operation because of its greater efficiency, and because it represents an enhancement in the decoding process.

Second, evidence from the fast right hand preference group suggests a quantitative specialization in both hemispheres for identifying verbal components, thus raising the possibility of there also being greater

hemispheric equipotentiality in some females at the lexical level of object identification. Since, from previous reports, it is known that males appear to demonstrate more cerebral asymmetry for visuo-spatial gestalt processing tasks, it may be that females have more bilateral representation (Ades, 1974; Coltheart, Hull and Slater, 1975). This bilateral representation may account for the left hand superiority along with the very adequate right hand ability found in females as an outgrowth of maximally processing the braille configurations. Their approach may be based on matching the alpha-numerical characteristics of the words which would use the potentials of both hemispheres: the right hemisphere would detect the basic gestalt of the configurations, the left hemisphere would detect the verbal numerical components of the configurations. However, it is unclear whether these individuals tend to process the dot configurations as physically-identical or as similarly formed letters suggestive of parallel right hemisphere processing; or as nominally-identical or as dissimilarly formed letters which would be suggestive of serial left hemisphere processing (Cohen, 1972; White and White, 1975). Nevertheless, females who tended to exhibit left hand superiority on a task of this complexity have allocated the left hand to do at least half, it not most of the reading, because of its efficiency at decoding the dot symbol and its ability to enhance understanding under several conditions.

The group of slow female readers represents another important facet of the continuum. While no consistent finger placement pattern could be drawn from their verbal preference data, it was apparent from the results that neither hand demonstrated an advantage for reading. The behavioral preference group of slow right hand readers of which many were females from the slow readers group, read faster with their right hands even though the left-right hand differences were non-significant. It would appear that these readers have an insensitivity to the gestalt of the spatial configurations and rely quite heavily on the linquistic information conveyed by the configurations. This approach implies that the right hand is doing the majority of the reading in a word by word manner as was suggested by Maxfield for teaching beginning readers to read.

Using the word by word method at this stage of braille reading must also restrict the cognitive processing to a linguistic-phonetic operation which limits the exchange of information by the left and right hemispheres. The limitations of this method are noteworthy. First, because of the complexity of the configurations, the reader may eventually have to identify the spatial relationships of the dots in order to achieve adequate understanding of the syntax of the sentences, and this added endeavor will increase reading time. Second, in the right hand to left hemisphere operation, the neural pathways in the decoding process may lead to a confused or degraded transfer of the configurations. This confusion is most often reflected in the number of errors made by the reader. For example, in this study it was predicted that congenitally blinded subjects would read faster and more accurately than adventitiously blinded subjects. This proposed advantage was postulated for several reasons: (1) from evidence cited earlier, braille seemed to be primarily a left-hand right-hemispheric task; (2) from observations of recently blinded right handed children, braille reading was often attempted with the right hand presumably because of its greater dexterity; and (3) from observations it was suspected that an adventitiously blinded child was using a verbal-linguistic mode of analyzing the dot patterns because of the previous capacity to see which detracted from his focusing on the tactile aspects

of the configurations. Though the prediction of faster reading did not reach significance, it was found that the adventiously blind readers made more errors with their right hand on both single letter and paragraph reading tasks. This result further substantiated the importance of the spatial decoding process for facilitating the accuracy and content of braille reading materials and further underscores the limitations reading primarily with the right hand may have.

To summarize this section, the male and female comparisons revealed hand asymmetries for several groups that were largely contingent on behavioral hand preference as opposed to stated hand preferences for simple and complex sets of braille configurations. Left hand superiority or left hand dominance indicative of right hemisphere dominance of the motor pathways and cognitive processing in reading was most clearly demonstrated for the faster reading female groups but was generally attributed to reading hand methods represented partially by finger placement patterns.

The type of processing was represented by the relationship between the hands as well as reflected progress through three stages of reading: beginning, intermediate, and advanced. The attainment of increasing skill in braille reading was considered to be strongly connected to the role of the left hand which was inhibited, enhanced, or limited in its performance when reading was attempted with the right hand. Consequently, at the beginning and intermediate stages of learning to read braille, the right hemisphere is considered to be the best primary cognitive processor of braille configurations; the left hemisphere is considered to contribute strongly as a secondary cognitive processor at the same stages when the spatial information is transformed for verbal processing. And when

the speed and accuracy of braille reading is increased exemplary of advanced stages of reading, the spatial configurations may become less important, thus facilitating motor and cognitive dominance by the linguistic-verbal left hemisphere.

Toward a Theory of Functional Hand Asymmetry in Braille Reading

In recent years there have been several attempts to explain how the hemispheres process information and the nature of the asymmetries involved. Of particular interest for this study was the meaning of the asymmetry with regard to left hand superiority while reading braille. In general, inferences have been made about braille reading based on braille letter learning experiments that have observed only part of the reading process over varying experimental conditions (Wagner, 1976; Rudel et al., 1977). To date, many of the theoretical models derived from these experiments do not explain the total braille reading process in a comprehensive way; that is, in the school situation, where a child is asked to read and remember varying combinations of dot configurations with the index fingers of both hands simultaneously, the reader must make several decisions continuously about the information to be processed. Consequently, none of the theories really attempts to provide a functional theory for what appears to be the simultaneous and continuous tactual reactions induced by the joint movements of both index fingers while actually reading.

Since visual learning requires that the child simultaneously and continuously transform spatial signs into verbal equivalents, followed by linking the written material to meaning via memory both verbal and auditory (Mackworth, 1972), exploring an alternative strategy of describing a

model or theory derived from existing knowledge about the visual reading system might account for the new information acquired from this study and might bring together some of the theoretical viewpoints currently being considered with regard to tactual reading processes. Therefore, this section summarizes existing relevant viewpoints on hemispheric specialization and hand asymmetries; describes, where appropriate, memory and information processing concepts found during visual reading; and discusses a dual coding theory that attempts to operationalize the functional cognitive processing strategies of braille readers based on a preference for a particular hand.

Hand asymmetry in terms of cerebral mechanisms. According to one view, hand asymmetries can be attributed to the initial preprocessing operations for a particular stimulus (Bryden and Allard, 1976; Witelson, 1974). This theory is based, in part, on the "structural prepotency" of the hemispheres for a specific type of stimulus. That is, because the right hemisphere is known to organize and perform more global, gestalt (spatial) types of processing and the left hemisphere does more analytic, naming (verbal) processing, a two stage process was conceived. In the initial phase, the stimulus is normalized and attention is focused on the relevant characteristics. Then, the target stimulus is actually identified and named. This theory is consistent with the strong transfer effects which result from the contralateral connections for the visual, auditory and tactile systems (e.g., Kimura, 1967). Consequently, on a braille reading task (assumed to be more spatial in nature) where reading might be done primarily by the right hand, the information encountered would be either distorted, retarded or left in incomplete or unidentifiable form as a consequence of having to cross the corpus callosum to the

linguistic mediating left hemisphere before the spatial relationships of the configurations could be added for complete identification.

Another viewpoint originates from theories which propose that hemispheric asymmetries are determined by the nature of the task or response method required. Kinsbourne (1973) argues in his "attentional set" theory that depending on the task or response method prescribed, one hemisphere becomes activated, focusing attention toward the contralateral side, while activation of the other hemisphere is inhibited. So conceivably on a braille reading task where both hands are stimulated simultaneously or when the hands alternate while reading, because the task strongly favors the translation of the spatial aspects of the code, the right hemisphere would be activated, the performance of the left hand would be facilitated, and the left hemisphere would be inhibited.

A similar theory detailed earlier and espoused by Levy et al. (1972) again focuses primarily on the task or response method. She suggests that given the particular input and the ultimate response method, both hemispheres will compete for processing the stimulus information. One hemisphere will dominate and the other hemisphere will be inhibited from functioning at a particular stage of the processing because of the structural prepotent hierarchy of the hemispheres. The hierarchy is likely to change if the subject is exposed to extensive practice or experience. For example, when a braille reader reads silently with both hands simultaneously, depending on his level of skill, his left hand might be called the reading hand. This is inferred because the right hemisphere would be monitoring the spatial changes, in the configurations. Likewise, if the reader reads aloud, the right hand or left hemisphere might dominate the motor pathways because of the phonological cues and the verbalizing involved. In summary then, it appears that hand asymmetries for braille reading may be explained by several theoretical viewpoints especially if the incoming information can be determined to be more spatial than verbal.

Modes of the Acquisition Process

In this study, a majority of the subjects chose to read the braille materials with their left hands. This implies that the cognitive processes for these subjects operated to maintain a particular kind of decoding which has proven to be the "best" for tactial reading success. In this regard, it therefore may be inferred that hemispheric asymmetries are more sensitive to (1) the type of processing and (2) the pattern configuration effects rather than to the type of stimulus (White and White, 1975). Memory and information processing literature that describes stages or phases in the visual reading system and the corresponding similarities found during tactial reading will be used to further substantiate this contention.

Basically, there are three stages in the memory system: a sensory register, a short-term memory, and a long-term memory. Several investigators have studied the first phase of the memory system for both the visual and tactile systems to determine the capacity for coding information. Sperling (1960) concluded from experiments on brief visual stimulation that the available information from the presentations fades rapidly, within one or two seconds after exposure. However, the visual information stored in immediate memory was likely to last two or three times as much as the decay rate, thereby demonstrating that the sensory register allowed a limited but consistent amount of information to be retained over short periods of time. Similarly, Bliss, Crane, Link and Townsend

(1966) and Bliss and Crane (1969) found that the sensory registering process in the tactial system for both sighted and blind subjects was capable of recording several stimuli on the palms and fingers of both hands (in these experiments, the tactile space was 24 stimulus points roughly corresponding to a visual field). They also demonstrated that the sensory register decay rate was about one or two seconds, yet most of the subjects could remember and identify four or more stimulus positions.

Neisser (1967) has argued that the ability to name four or five items would take considerably longer than the one or two seconds to have registered and thus proposed that information must have been transferred to a more permanent form of storage - an iconic storage or short-term memory. Moreover, within this storage process, input is either discarded or recorded into meaning at a highly abstract level and then transferred into long-term memory. Therefore, any difference in performance between visual and tactile reading would be largely a result of (1) the non-optimum presentation of stimuli to the sense organs (Hampshire, 1975) or (2) the non-optimum means of translating the stimulus set through the sensory organs. In the case of braille reading the latter concern would translate as hemisphere hand to difficulties rather than an inferiority of the processing capabilities of the sensory neural system. But, at a fundamental level, the two modes of reading are very similar but differ mainly as a function of the compatibility between the stimulus and the sense organs being used.

In recent years, considerable progress has been made to optimize the presentation of stimuli for blind people by exploiting the cutaneous sense as one sensitive to rhythm as opposed to spatial cues to increase the reception of symbols. This has been largely accomplished by the optacon

which has altered the "code" problems through advances in technology (Moore and Bliss, 1975).[1] In the optacon system, the left hand is used as the principle receptor organ and the right hand is used only to detect and monitor the flow of information to the left hand. Because of this relationship, the two hands must be more dependent on each other to complete the "information circuit" provided by the electrical probe. So, by default or as a consequence of the limitations of information intake, the left hand has taken over the function of the primary and secondary receptor which was once performed by both hands during the braille reading; and for the most part, the left hand is still directly related to optimizing the type of cognitive processing involved in the decoding tactually presented symbols, particularly reading symbols used by the blind. It would seem then that, the translation of information to the brain must be related to how familiar the left hand is with the spatial structures of configurations of the normal alphabet letters, so that the right hand can move the probe more rapidly from letters to words.

Morton (1964) and other researchers studying visual recognition during reading have emphasized the importance of familiarity and its role in the decoding process and reading speed (Mewhort, 1967; Lott and Smith, 1970; and Krueger, 1970). He selected redundancy as the most important aspect of familiarity and redundancy translates as the probability that one item will follow another. In this respect, he asserted that the

[1]The optacon is a compact portable, electronic reading instrument that uses a miniature camera to convert regular inkprint into vibrating tactile form via electronic impulses. The left hand of the reader feels the tactile facsimile of the original image or letters as the right hand moves the camera across a line of print.

efficient reader is capable of capitalizing on the linking probabilities among letters, words, phrases and even sentences such that the length of the eye-voice span in words could possibly reach up to the eight order or more. He also added that poor or less skilled readers never really get a chance to build up the highly overlearned associations that aid in predicting these probabilities. From this perspective, increases in the recognition of letters and words would depend on the degree of familiarity and redundancy achieved by the reader. And as an indication of the effectiveness of the decoding process, reading speed should be highly correlated with increasing pattern perception skills (i.e., identifying the size and shape of the letters).

In braille word recognition research using blind subjects, Nolan and Kederis (1969) found further support for Morton's association: reading speed follows greater familiarity with the linking components between letters and words. They demonstrated that familiar words were recognized for sooner than unfamiliar words by their faster readers. This familiarity factor became an added advantage for faster readers, for as the number of characters increased sometimes five to seven characters in length, integration and early recognition of the words increased. This was primarily due to the amount of information often found in the stems and beginnings of many words allowing for quick recognition of the whole word. Slower readers did not appear to have as firm a grasp on the same phonological cues as did the faster readers and they made more errors. As a result, unfamiliarity with certain braille prefixes and suffixes must lead to processing difficulties associated with word forms as Bürklen (1917) suggested.

Ashcroft (1960), for example, enumerated three problem areas that

produced errors in braille reading particularly reading of slow and less skilled readers: (1) perceptual problems (missed dot errors, added dot errors, and word ending errors); (2) orientation problem (reversal errors); and (3) meaning problems (association errors and gross substitutions). These problems or errors signify information processing difficulties but not necessarily modality differences with specific reference to the hemispheres. In this respect, Briggs (1974) has suggested that the potential for errors or confusion in the recognition of letters or characters points toward bi-modality or dual coding conflicts where an individual may chose to encode tactually and recode aurally for recall or vice versa. Furthermore, Briggs (1974) suggests that bi-modality, auditory and visual confusions reflect strategy-contingent recoding difficulties rather than stimulus modality-specific encoding problems.

The results from the current study demonstrate that at least two or more strategies or approaches to braille reading are indicative of as many types of processing as the memory matching process will generate. The pattern configuration effects in the form of errors or conflicts in information processing are also considered to be a function of the memory matching process, for it is assumed that the least amount of interference in the process of reading will determine the effectiveness of the reading, in terms of speed and accuracy of recall and the preferred style that the reader adopts.

Hand Preference and Dual Coding in Braille Reading

The preceding sections have outlined the present theoretical viewpoints on the cerebral mechanisms involved in the acquisition of hand asymmetries and the similarities between the memory matching processes

of the visual and tactual sensory modalities. At this point, the preference for a particular hand and the specific type of competitive hemispheric hierarchy indicative of cognitive processing should be examined more closely to speculate on the actual strategies used for decoding the memory representations. By way of illustration, a few of the more consistent patterns of reading as examples of the approaches used by these subjects will be outlined.

First, it appeared that some people approached the braille code in terms of its spatial configurations. They probably processed the braille configurations in a parallel coding manner, since it is suspected that the readers looked for spatially-identical, physically-identical forms using phonological cues to aid in their differentiation. These people start off being slow left hand preferring readers who do not use the potential capabilities of the right hand effectively. They do, however, appear to use a left hand, right hemisphere, left hemisphere strategy to encode the configurations and become almost exclusively fast left hand preferring readers, who make very few detectable errors. This is an effective approach.

The reading style of these people is consistent with the theories presented earlier which predicted a left hand superiority in tactual perception based on the necessity to code spatial information initially. This procedure would require the pre-processing mechanisms to focus attention towards the spatial cues as a function of right hemisphere dominance of the motor response hierarchy, temporarily inhibiting the processing of verbal cues at the same motor response level.

However, from the braille reading histories and the demonstrated reading competencies of these people, it is also quite obvious they

process verbal cues at some other memory level. At what level and to what degree verbal cues interact as an integrated part of the present theoretical viewpoints is unclear. As was suggested earlier, perhaps, verbal coding is facilitated by auditory coding of phonological cues which account for the integrated simultaneous code-ability of nonverbal and verbal cues. This would require a formalization of a bi-modality coding perspective in the present theoretical framework to accommodate the dual processing capabilities of both hemispheres. Dual coding in this instance would assume that listening to a verbal message and the haptic perception of the message could be done synchronically to aid in the differentiation of similar feeling words. This approach obviously eliminates the need for reading with both hands simultaneously, but it is important to note, that the possibility of dual coding would allow for continuous processing of a series of perceptual information forms and its recall without apparent inhibition during the process.

Second, there also appeared to be people who identified verbal or linguistic meanings initially and more consistently than the spatial cues. These people appear to be the slow right hand preferring readers and they seemed to overlook the synthesizing capabilities of the left hand. It is speculated their approach to the braille code was to look for characters that were nominally-identical and physically-different in a serial coding process. This was also an effective strategy because comparing both groups of slow readers with left and right hand preferences, the right preferrers read faster with their right hand at the more complex level of reading.

The cognitive processing of these readers does indeed imply that the left hemisphere maintains dominance over the memory matching hierarchy

and facilitates inhibitory functioning of the right hemisphere. However, the formal inhibition of the opposite hemisphere must be questioned, since the information is only coming through the right hand-left hemisphere channel. It seems more plausible to propose that this approach to reading forces the cognitive processing of the internal representations of spatial information to re-organize where the reorganization of the information from the form given in immediate perception must be transformed to a more abstract form initially. In other words, reading the verbal messages and imagining the spatial relationships described by those messages seems likely to produce conflict for these readers. A dual coding interpretation of this type of conflict may be that a perceptual task (imagining the forms) and a concurrent verbal memory task involving the same modality produces interference. The current theories as presented imply that the competition leading to information processing conflicts are only inter-hemispheric, while in this case, it could be suggested that competition may also be intra-hemispheric at the modality level. The information made available for this type of reading does not appear to be acquired simultaneously, but rather it is performed by temporal and successive ordering of the braille configurations which is theoretically distinct from the first style of reading described above.

Finally, a third group of readers seem to overcome both the inter- and intra-hemispheric conflicts and achieve an integration of both parallel and serial processing. These people appeared to be the fast right hand preferring readers, who demonstrated left hand superiority in braille reading. Their hemispheric hierarchy expresses less competition and more functional independence between the hands. Because of this, their level of braille reading skills must involve understanding and integrating the

spatial (parallel) and the alphanumerical (serial) aspects of the word patterns. If these readers were once slow right hand preferring readers, it might be assumed that the right hemisphere is involved in a re-emphasis of the gestalt of the word cues and the left hemisphere is not inhibited but facilitates processing, whereby the total process leads to better word comprehension. The independence with which each hand functions at this level of reading suggests the hemispheres can also function independently, are interconnected and overlap in their ability to analyze nonverbal and verbal relationships without substantial interference or inhibition.

In a sense, this third group processes information in what Paivio (1971) describes as operationally parallel functioning, since the functional overlap is between the nonverbal and verbal systems. The mental operations are independent in that the outline of the configuration can be imagined and the counting of the dots can be started from any direction; but the independence is restricted because optimum efficiency is only obtained if in the process of moving around the figure serial processing is imposed on the pattern.

From the cognitive processes described for the three approaches, it seems reasonable to expand the present theoretical conceptualizations, since at least two of the very basic assumptions supporting the hierarchical origin of hand asymmetries can be questioned: one of the spatial cues being processed initially for the most efficient means of handling spatially organized material, and the other suggesting competition between the two hemispheres for control of the motor pathways, where activation of one hemisphere would produce inhibition in the other.

Both the first and the second approaches indicate that the braille

code can be encoded initially using verbal cues, whose hierarchical structure is characteristic of the sequentially organized linquistic system. In other words, the symbolic processes are functionally linked to an auditory motor system or to some immediate transformation to abstract representations of the word concepts that are available to either hemisphere. The ability to function in this way implies that there exists within the nonverbal and verbal system the capacity for bi-modality processing or dual (hemispheric) coding. With this in mind, the hemispheres can be functionally independent: one can be active without the other and they can be active concurrently without mutually inhibiting the other causing conflicts and interference.

In addition to the relative hemispheric independence demonstrated by the first two approaches the third example emphasizes, the functional interconnectedness of the hemispheres where the activation of one hemisphere or system can activate the other depending on the situation or task requirements. This ability also appears to be related to an increase in reading skills but it again assumes the cognitive perception and memory processes involve dual coding. The nonverbal spatial configurations are simultaneously available for recall and the linguistic information that is super-imposed on the spatial image of the dots such as grammatical transformations must be organized sequentially so that thinking during braille reading is a continuous and synchronic interaction of both nonverbal and verbal processes.

Consider for example, the skilled braille reader who is reading for speed, perhaps reading a novel. Since his right hand is proficient at reading and he is right handed, taking advantage of the greater mobility of the right hand for this task would seem reasonable. However, for the

skilled braille reader, who may be reading professional journals, technical journals, or more difficult reading materials where abstract words are encountered, reading speed may be less critical, as the adult readers in the Hermelin and O'Connor (1971b) study demonstrated. Instead, the left hand may be used because closer attention might be required to decode the complex arrangements of individual characters and the spatial variations to gain comprehension. As implied, the contractions and words should require greater reliability on the left hand's ability to decode the spatial configurations but once this is accomplished the reader may shift back to reading with the right hand.

Now, if in the act of reading a child does not make this distinction and tends to read fast and only with the right hand (taking advantage of its greater mobility), thereby rushing through reading material as children are often inclined to do, then it is reasonable to predict that errors in orientation, perception, and meaning as noted by Ashcroft (1960) will occur as a result of the reader relying more heavily on an insufficient or limited reservoir of spatial configurations or grammatical transformations. This is perhaps what was suggested by the analysis of errors on the single letter identification task and the type of blindness result. However, the preponderance of two or more almost equally effective approaches to the reading of braille, points to the suggestion by Bradshaw, Gates and Nettleton (1977) that neither hemisphere is exclusively specialized for a particular function but rather cooperates its serial and parallel processing on the basis of degree and strategic approach as opposed to a functional specialization that is rigid.

It is suggested that the memory processes that enable an individual to haptically scan a spatially organized series of verbal stimuli like

braille, are on a continuum that is interfaced with the specialization properties of each hemisphere, e.g. the gestalt and analytic processing. And it is likely that the current theories and the dual coding theory represent a hierarchy where developmental changes manifest themselves, in the attainment of increasing braille skills, vis-a-vis hand preference and the ability for abstract thinking. Since braille reading competence appears to be correlated with sensori-motor abilities (tactual and auditory), and the capacity for abstract conceptualizations, understanding the memory processes that interfere with the acquisition of meaning, such as perceptual and orientation errors and their relationship to the functional distinction between the verbal and nonverbal symbolic systems, seems to be a fruitful area for new research.

APPENDIX A

HANDEDNESS QUESTIONNAIRE

APPENDIX A

HANDEDNESS QUESTIONNAIRÈ

Score

NAME ______________________________

HAND

1. Which hand do you favor in braille typing? The stronger one?
2. In which hand do you hold a stylus?
3. Which hand do you draw with?
4. Which hand to you throw with?
5. In which hand do you hold a scissors?
6. Which hand do you use to comb your hair? Brush it?
7. In which hand do you hold a knife without a fork?
8. In which hand do you hold your toothbrush?
9. In which hand do you hold a knife with a fork?
10. In which hand do you hold a spoon?
11. In which hand do you hold a screwdriver?
12. In which hand do you hold a hammer?
13. In which hand do you hold your cane?
14. Which hand do you reach out with to open a box? a Door?
15. Which hand do you put in your coat first?
16. In which hand do you hold a cup?
17. What foot do you kick a ball with?
18. Which hand do you use to bowl with?
19. On which side do you line up to play golf? To bat a baseball?
20. Which hand do you use to trace a braille map?

APPENDIX B

HISTORY OF BLINDNESS QUESTIONNAIRE

APPENDIX B

HISTORY OF BLINDNESS QUESTIONNAIRE

NAME______________________________ Date of Birth__________

Age__________

1. Do you remember when you became blind?

2. Do you remember what caused it?

3. Some blind people feel more comfortable talking to other blind people, others feel comfortable talking to sighted people. How do you feel?

4. How long have you studied braille?

5. Who taught you to read braille?

6. Did you learn different methods?

7. Do you read with one finger? two fingers? left or right?

8. Do you think you read better with your left or right fingers or are there no differences?

9. Do you use different methods for different tasks?

APPENDIX C

INSTRUCTIONS FOR EXPERIMENT I

APPENDIX C

INSTRUCTIONS FOR EXPERIMENT I

HI __________, MY NAME IS __________. I'M FROM MSU. I WOULD LIKE YOU TO READ SOME LETTERS AND SENTENCES. FIRST, I'M GOING TO PLACE A SHEET OF BRAILLE LETTERS OF THE ALPHABET IN FRONT OF YOU. AND I WANT YOU TO READ EACH OF THE LETTERS IN THE LINE OUT LOUD. READ THE WAY YOU USUALLY DO, THE WAY YOU DO BEST. AND READ AS FAST AS YOU CAN AND TRY NOT TO MAKE ANY MISTAKES. THE LETTERS AREN'T IN THE ORDER A,B,C,D,E. I'VE MIXED THEM UP. ANY QUESTIONS? REMEMBER READ ALOUD. ALL RIGHT (Pause). THAT WAS FINE, NOW I'M PUTTING ANOTHER LIST OF LETTERS IN FRONT OF YOU. THIS TIME THE LETTERS ARE PRINTED IN A VERTICAL COLUMN, SO YOU'LL HAVE TO READ FROM THE TOP OF THE PAGE TO THE BOTTOM. AGAIN, READ THE LIST ALOUD USING YOUR NORMAL READING STYLE. READ AS FAST AS YOU CAN AND TRY NOT TO MAKE ANY MISTAKES. ANY QUESTIONS? READY, (Put <u>S</u>'s finger on dot, start recorder, start timing with 'begin'). BEGIN.

(Note every error the subject makes by striking the letter on the code sheet. Record time at the bottom of the list on the code sheet. Note which hand and finger the <u>S</u> read with.)

THAT WAS FINE. NOW I'D LIKE YOU TO READ ANOTHER LIST. BUT THIS TIME USE THE MIDDLE FINGER OF YOUR __________ HAND. I WILL PUT YOUR FINGER ON THE DOT JUST ABOVE THE FIRST LETTER. (Put finger on dot. Check to see the <u>S</u> is using the appropriate finger.) ANY QUESTIONS? REMEMBER READ ALOUD AS FAST AS YOU CAN AND TRY NOT TO MAKE ANY MISTAKES. STOP AT THE END OF THE LIST AND WAIT UNTIL I START YOU AGAIN. (Start recorder, starting timing with 'begin'). READY WITH YOUR __________ MIDDLE FINGER, BEGIN. (Note every error the subject makes by striking the

letter from the list. Record time at the bottom of the list on the code sheet.) GOOD, NOW SWITCH TO THE MIDDLE FINGER OR YOUR __________ HAND.

(Check to see that the subject has changed fingers.) REMEMBER READ AS FAST AS YOU CAN TRYING NOT TO MAKE ANY MISTAKES. STOP WHEN YOU FINISH AND WAIT UNTIL I START YOU. ANY QUESTIONS?

(Turn page; start recorder; start timing with 'begin'.) READY WITH YOUR __________ MIDDLE FINGER, BEGIN. (Note every error the subject makes by striking the letter from the list. Record time at the bottom of the list on the code sheet.)

THAT'S FINE. NOW SWITCH TO THE MIDDLE FINGER OF YOUR __________ HAND.

(Check to see that the subject has changed fingers.)

The same procedure was then followed for the other fingers.

APPENDIX D

EXPERIMENT I CODE SHEET

APPENDIX D

EXPERIMENT I CODE SHEET

PRACTICE	CONTROL	1	2	3	4	5	6
C	L	Y	A	J	H	W	I
P	I	M	Z	N	M	Y	R
I	Q	B	V	D	V	C	A
F	A	C	H	H	Q	R	Z
H	Z	R	B	K	R	A	L
Y	C	W	I	F	I	Q	W
E	N	O	M	Z	X	N	C
L	W	F	C	Q	G	T	S
O	M	N	Y	C	T	G	E
M	S	X	T	W	N	V	U
R	X	P	L	I	U	J	J
Z	B	S	O	A	Z	L	N
N	G	I	S	U	W	D	Y
G	D	Z	G	B	C	X	P
K	J	L	F	L	P	U	M
V	V	D	Q	M	E	K	H
T	F	Q	K	T	L	Z	G
W	K	E	N	E	F	E	V
A	H	K	R	R	J	I	D
J	P	T	U	Y	O	O	T
X	U	J	J	O	K	M	F
U	O	H	W	V	Y	F	X
B	E	U	P	P	S	H	B
D	R	V	D	S	A	S	K
S	Y	A	X	G	D	P	Q
Q	T	G	E	X	B	B	O
E / T							

APPENDIX E

INSTRUCTIONS FOR EXPERIMENT II

APPENDIX E

INSTRUCTIONS FOR EXPERIMENT II

YOU DID VERY WELL. NOW LET'S DO SOMETHING DIFFERENT. BEFORE YOU WERE JUST READING ALPHABET LETTERS. NOW I'D LIKE YOU TO READ SENTENCES. I'VE PUT A PARAGRAPH WITH THREE SENTENCES IN FRONT OF YOU. THE PARAGRAPH ASKS A QUESTION. I'D LIKE YOU TO READ THE PARAGRAPH IN YOUR NORMAL WAY, BUT THIS TIME DON'T READ OUT LOUD. READ TO YOURSELF. UNDER THE PARAGRAPH ARE FOUR WORDS. READ ALL FOUR WORDS AND FIND THE WORD THAT BEST ANSWERS THE QUESTION. SAY THAT WORD OUT LOUD. ANY QUESTIONS? READY, BEGIN. (Pause, wait for subject to read and answer the first paragraph.) THE WORD 'DOOR' IS THE BEST ANSWER FOR PARAGRAPH ONE. (Pause, any questions.) NOW HERE'S ANOTHER PARAGRAPH. THIS TIME I WANT YOU TO READ IT OUT LOUD. REMEMBER READ ALL FOUR WORDS AND FIND THE WORD BELOW THAT BEST ANSWERS THE QUESTIONS AND SAY IT OUT LOUD. ANY QUESTIONS? (Put finger on dot.) READY, BEGIN. (Pause, wait for subject to read and answer the second paragraph.) THE WORD 'ELEPHANTS' BEST COMPLETES THE SECOND PARAGRAPH. (Pause.) ANY QUESTIONS?

GATES - MACGINITIE READING TESTS

Survey - D, Form 2, Part 1

Speed and Accuracy

SAMPLES:

1. MARY PULLED AND TRIED TO TURN THE KNOB. SHE COULD NOT TURN IT. IT WAS A COLD DAY TO BE LOCKED OUTSIDE. WHAT WAS MARY TRYING TO OPEN?

   BOX BAG [DOOR] SAFE

2. THE HUGE ANIMALS WALKED SLOWLY, SWINGING THEIR TRUNKS FROM SIDE TO SIDE. THEY HAD BIG FLOPPY EARS AND LONG WHITE TUSKS. THESE ANIMALS WERE

   TIGERS DEER LIONS [ELEPHANTS]

(1-6)

NOW THAT YOU UNDERSTAND THE DIRECTIONS, I'D LIKE YOU TO READ __________ SOME MORE PARAGRAPHS FOR ME IN YOUR NORMAL READING STYLE. YOU ARE TO READ AND ANSWER EACH PARAGRAPH AS FAST AS YOU CAN. REMEMBER TO FIND THE WORD THAT BEST ANSWERS THE QUESTIONS OR COMPLETES THE PARAGRAPH AND SAY IT OUT LOUD. STOP AFTER YOU GIVE YOUR ANSWER AND WAIT UNTIL I TELL YOU TO START AGAIN. ANY QUESTIONS? REMEMBER TO WORK AS FAST AS YOU CAN TRYING NOT TO MAKE MISTAKES. READY? (Start recorder, start timing with 'begin'.) BEGIN. (Stop when subject gives his response. Record time and error, if one is made.)

GOOD, NOW WHEN I SAY BEGIN YOU ARE TO READ __________ THE THIRD PARAGRAPH AT THE BOTTOM OF THE PAGE. AS FAST AS YOU CAN TRYING NOT TO MAKE A MISTAKE. REMEMBER TO ANSWER OUT LOUD. STOP AFTER YOU GIVE YOUR ANSWER AND WAIT. ANY QUESTIONS? READY? (Start recorder, start timing with 'begin'.) BEGIN. (Stop when subject gives his response. Record time and error, if one is made and turn the page of the subject's manual.)

1. THE EMPIRE STATE BUILDING IS NEW YORK CITY'S TALLEST OFFICE BUILDING. IT IS A SKYSCRAPER OF 102 STORIES, COMPLETED IN 1931. THIS BUILDING IS VERY

   SMALL   ORDINARY   [HIGH]   UNBALANCED

2. A JELLY FISH IS SHAPED RATHER LIKE AN UMBRELLA, USUALLY WITH TRAILING TENTACLES. IT SWIMS WITH RHYTHMIC CONTRACTIONS OF ITS BODY. IN WHAT DOES IT LIVE?

   EARTH   AIR   SKY   [SEA]

3. SOME ESKIMO WINTER HOUSES ARE MADE OF SNOW AND ICE. WHEN THE SHORT ARCTIC SUMMER COMES, AND THE WEATHER GETS WARMER, THESE HOUSES MAY

   [MELT]   BURN   GROW   BLOW UP

ALRIGHT, NOW YOU'RE GOING TO READ THE NEXT PARAGRAPHS __________, USING YOUR NORMAL READING STYLE. READ AS FAST AS YOU CAN TRYING NOT TO MAKE A MISTAKE. REMEMBER READ __________. AND WAIT FOR ME, AFTER YOU FINISH THE PARAGRAPH. ANY QUESTIONS? READY? (Start recorder, start timing with 'begin'.) BEGIN.

(Stop, when subject gives his response. Record time and errors. if they are made.)

GOOD, WHEN I SAY BEGIN YOU'RE TO READ THE NEXT PARAGRAPH __________, USING YOUR NORMAL READING STYLE. READ AS FAST AS YOU CAN TRYING NOT TO MAKE A MISTAKE. REMEMBER READ __________. WHEN YOU FINISH AND WAIT FOR ME TO START YOU AGAIN. ANY QUESTIONS? READY? (Start recorder, start timing with 'begin'.) BEGIN.

(Stop when subject gives his response. Record time and errors, if they are made.)

FINE, WHEN I SAY BEGIN YOU'RE TO READ THE NEXT PARAGRAPH __________, USING YOUR NORMAL READING STYLE. READ AS FAST AS YOU CAN TRYING NOT TO MAKE A MISTAKE. REMEMBER READ __________. STOP WHEN YOU FINISH. ANY QUESTIONS? READY? (Start recorder, start timing with 'begin'.) BEGIN.

(Stop when subject gives his response. Record time and errors, if they are made. Turn page of subject's manual.)

4. ENGLISH AND FRENCH ARE BOTH OFFICIAL LANGUAGES IN CANADA. MANY ROAD MARKERS AND OTHER SIGNS THERE ARE WRITTEN IN BOTH FRENCH AND

LATIN   CANADA   [ENGLISH]   CHINESE

5. THE NATIVES IN SOME TROPIC AREAS USE COCONUTS FOR FOOD AND FIND MANY USES FOR THE LEAVES OF THE COCONUT PALM. FOR THEM, THE COCONUT PALM IS

[VALUABLE] NEW USELESS TROUBLESOME

6. BOBWHITES BELONG TO THE QUAIL FAMILY. THEIR REDDISH-BROWN FEATHERS WITH SPECKLED MARKINGS MAKE THEM DIFFICULT TO SEE IN THE WORDS. THEY ARE

SQUIRRELS FISH [BIRDS] TREES

(7-30)

THAT WAS FINE. NOW I HAVE A SECOND SET OF PARAGRAPHS THAT ARE VERY SIMILAR TO THE ONES YOU HAVE ALREADY READ. BUT THIS TIME I'D LIKE YOU TO READ THESE PARAGRAPHS WITH DIFFERENT FINGERS. I'LL TELL YOU WHICH FINGER AS WE GO ALONG.

LET'S PRACTICE WITH THE PARAGRAPHS IN FRONT OF YOU. USING THE MIDDLE FINGER OF ONE OR YOUR HANDS READ THE PARAGRAPH AT THE TOP OF THE PAGE AND STOP. (Pause, note which hand the subject uses to practice with first.)

FINE, NOW READ THE NEXT PARAGRAPH WITH THE SAME FINGER. (Pause.)

O.K., NOW READ THE LAST PARAGRAPH WITH THE SAME FINGER. (Pause, when the subject completes the third paragraph turn the page of his booklet.)

ALRIGHT, NOW SWITCH TO THE MIDDLE FINGER OF YOUR OTHER HAND AND READ THE PARAGRAPH AT THE TOP OF THE PAGE, (Pause).

NOW READ THE NEXT ONE WITH THE SAME FINGER (Pause). AND NOW THE LAST ONE AT THE BOTTOM OF THE PAGE (Pause).

(When the subject completes the paragraph, turn the page of his manual so that paragraph 7 is next to be read.)

The same procedure was then followed for the next 24 paragraphs.

APPENDIX F

EXPERIMENT II CODE SHEET

APPENDIX F

EXPERIMENT II CODE SHEET

CONTROL: ( )

1	2	3	4	5	6	7	8	9	10	11	12

ERRORS

TIMES

☐ Fingers together

☐ Fingers apart

☐ Left finger

☐ Right finger

☐ Lip movement

REMARKS

TRIAL 1: ( )

1	2	3	4	5	6	7	8	9	10	11	12

ERRORS

TIMES

☐ Lip movements

☐ Other

☐

☐

☐

REMARKS

TRIAL 2: ( )

1	2	3	4	5	6	7	8	9	10	11	12

ERRORS

TIMES

☐ Lip movements

☐ Other

☐

☐

REMARKS

APPENDIX G

T-TESTS FOR LETTER IDENTIFICATION AND

PARAGRAPH READING

APPENDIX G

Table G1. Results of t-tests for mean times and errors during the letter identification task by sex of subject and hand.

Sex of Subject	Mean Time (in seconds)				Mean Errors			
	Left	Right	t	df	Left	Right	t	df
Boys	41.57	56.28	1.30	13	5.35	6.57	1.07	13
Girls	83.84	55.15	- .70	12	7.75	6.69	- .31	12
Combined	61.92	55.74	- .30	26	6.51	6.62	.06	26

Table G2. Results of the t-tests between the mean difference scores in seconds for the left and right hand paragraph reading conditions by sex.

Sex	Difference Means Right	Difference Means Left	t	df
Boys	357.64 (σ=302.41)	204.50 (σ=202.04)	1.44	13
Girls	220.23 (σ=141.98)	159.61 (σ=139.67)	1.24	12
Combined	291.48 (σ=244.80)	182.88 (σ=173.82)	11.82	26

APPENDIX H

RIGHT AND LEFT HAND DIFFERENCES FOR VERBALIZATION TRIALS ON PARAGRAPH READING

APPENDIX H

Table H1. Results of the t-tests between right and left hand performance in the silent and aloud condition of the paragraph reading task.

Condition	Group	Difference Means (in seconds) Right	Left	t	df
	Boys	162.50 (σ=154.32)	94.35 (σ=102.59)	1.30	13
Silent	Girls	106.61 (σ= 67.38)	79.23 (σ= 67.69)	1.24	12
	Combined	135.59 (σ=121.70)	87.07 (σ= 86.23)	1.64	26
	Boys	195.14 (σ=152.94)	110.14 (σ=102.02)	1.55	13
Aloud	Girls	113.61 (σ= 78.94)	80.38 (σ= 91.62)	1.18	12
	Combined	155.88 (σ=127.65)	95.81 (σ= 96.48)	1.92	26

APPENDIX I

MEAN DIFFERENCE SCORES FOR PARAGRAPH READING AS A FUNCTION OF SEX AND RATE OF READING

APPENDIX I

Table I1. Results of the t-tests between the mean difference in seconds for the silent and aloud conditions for the right and left hand performances on the paragraph reading task as a function of sex and rate of reading.

Hand	Group	Rate of Reading	Difference Means (in seconds) Silent	Aloud	t	df
Right	Boys	Fast	74.14 (σ= 37.99)	100.28 (σ= 50.55)	-3.30*	6
		Slow	250.85 (σ=178.70)	290.00 (σ=164.71)	-1.35	6
	Girls	Fast	67.71 (σ= 27.23)	71.71 (σ= 42.34)	- .42	6
		Slow	152.14 (σ= 73.60)	162.58 (σ= 86.48)	- .51	5
Aloud	Boys	Fast	52.14 (σ= 16.55)	77.00 (σ= 35.09)	-2.15	6
		Slow	136.57 (σ=135.54)	143.28 (σ=136.96)	- .53	6
	Girls	Fast	46.28 (σ= 26.83)	41.42 (σ= 28.18)	1.27	6
		Slow	117.66 (σ= 82.71)	125.83 (σ=120.78)	- .16	5

(*$p < .05$)

APPENDX J

MEAN DIFFERENCE SCORES FOR PARAGRAPH READING AS A FUNCTION OF VERBALIZATION, HAND PREFERENCE, AND RATE OF READING

Table J1. Results of the t-tests between silent and aloud conditions in the paragraph reading task as a function of verbalization, hand preference and rate of reading.

Hand	Hand Preference	Rate of Reading	Difference Means (in seconds) Silent	Aloud	t	df
Right	Right	Fast	73.20 (σ= 28.46)	80.00 (σ= 52.61)	- .47	4
		Slow	74.60 (σ= 39.38)	82.20 (σ= 57.92)	- .33	4
	Left	Fast	138.50 (σ= 63.92)	168.16 (σ= 97.41)	1.20	5
		Slow	290.33 (σ=170.76)	316.00 (σ=149.57)	- .97	5
Left	Right	Fast	39.60 (σ= 22.15)	53.40 (σ= 47.21)	- .80	4
		Slow	194.00 (σ=154.70)	213.00 (σ=177.78)	- .31	4
	Left	Fast	61.83 (σ= 27.50)	71.16 (σ= 35.51)	-1.32	5
		Slow	93.16 (σ= 48.11)	86.33 (σ= 38.38)	.49	5

APPENDIX K

T-TESTS FOR SUBJECTS PREFERRING HANDS EQUALLY

APPENDIX K

Table K1. Results of the t-tests for effect of hand and verbalization for the subjects who preferred each hand equally.

Condition	Difference Means (in seconds) Right	Left	t	df
Silent	69.80 (σ= 38.79)	50.60 (σ= 17.06)	1.23	4
Aloud	98.60 (σ= 56.55)	62.00 (σ= 36.87)	1.46	4

Table K2. Results of the t-tests for effect of verbalization and hand for the subjects who preferred each hand equally.

Hand	Difference Means (in seconds) Silent	Aloud	t	df
Right	69.80 (σ= 38.79)	98.60 (σ= 56.55)	-2.69*	4
Left	50.60 (σ= 17.06)	62.00 (σ= 36.87)	- .94	4

(*p < .05)

APPENDIX L

INDIVIDUAL DIFFERENCES--EXPERIMENT I

APPENDIX L

Table L1. Mean reading times and percent differences for 3 columns of braille letters in the aloud reading conditions as a function of behavioral hand preference in the single letter identification task.

Preferred finger for Braille-reading	S#	Age	Mean reading time in sec./column of 26 letters Middle finger Left	Right	Percent difference	
MALES (N=14)					Faster Hand	
Left	1131	10	34	40	L	17.7%
Index (N=7)	1241	18	20	58	L	190.0%
	3031	16	56	68	L	21.4%
	4051	15	37	47	L	27.0%
	4111	17	36	57	L	58.3%
	2191	11	40	42	L	5.0%
	2201	15	38	43	L	13.2%
Left and Right	2071	17	33	27	R	22.2%
Index (N=3)	3011	18	43	30	R	43.3%
	1161	15	49	37	R	32.4%
Right	3151	13	28	38	L	35.7%
Index (N=4)	4181	13	46	40	R	15.0%
	1171	18	34	41	L	20.6%
	2091	20	36	28	R	28.6%
FEMALES (N=13)						
Left	1142	16	22	38	L	72.7%
Index (N=5)	3042	18	27	30	L	11.1%
	3122	17	37	41	L	10.8%
	3222	15	24	35	L	45.8%
	4262	16	29	41	L	41.4%
Left and Right	1082	11	29	36	L	24.1%
Index (N=2)	2022	20	25	34	L	36.0%
Right	2252	12	39	38	R	2.6%
Index (N=6)	4212	13	37	46	L	24.3%
	4272	18	245	73	R	235.6%
	2062	14	96	57	R	68.4%
	1232	18	32	37	L	15.6%
	1102	14	31	34	L	9.7%

APPENDIX M

ANOVAs FOR TYPE OF BLINDNESS AND SEX

APPENDIX M

Table M1. Results of the analysis of variance for the paragraph reading difference scores of congenital and adventitiously blind males and females.

Source	MS	df	F
Sex (A)	5555.55	1,26	<1
Type (B)	6408.79	1,26	<1
A x B	18281.08	1,26	<1

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