122
117
THS

THESIS

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 00814 9944

LIBRARY
Michigan State
University

This is to certify that the

thesis entitled

A DEVELOPMENTAL STUDY OF HAND SPECIALIZATION USING A DICHHAPTIC PERCEPTION TASK

presented by

Arthur Pomerantz

has been accepted towards fulfillment of the requirements for

M.A. degree in Psychology

Lauren Julius Harris
Major professor

Date May 7, 1980

O-7639

MICHIGAN STATE UNIVERSITY

OVERDUE FINES:
25¢ per day per item

RETURNING LIBRARY MATERIALS:
Place in book return to remove charge from circulation records

D 25 1992

A DEVELOPMENTAL STUDY OF HAND SPECIALIZATION USING A DICHHAPTIC PERCEPTION TASK

By

Arthur P. Pomerantz

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Psychology

1980

ABSTRACT

A DEVELOPMENTAL STUDY OF HAND SPECIALIZATION
USING A DICHHAPTIC PERCEPTION TASK

By

Arthur P. Pomerantz

This study was an investigation of age and sex differences in right hemisphere lateralization of spatial abilities as indexed by performance on a tactile discrimination task. Seven-, 11-, and 15-year-old right-handed children (N=61) were asked to feel pairs of nonsense shaped forms, simultaneously, and then to identify them on a visual display.

The results showed nonsignificant left-hand advantages for the seven- and 11-year-olds; a significant left-hand advantage for the 15-year-old girls; and a nonsignificant right-hand advantage for the 15-year-old boys.

The results, for girls, support Witelson's (1976) conclusion that in girls, right-hemisphere specialization for tactual discrimination develops late. The boys' results, however, fail to confirm Witelson's finding of a left-hand advantage in boys and no hand asymmetries in girls. Differences between the current and previous studies may reflect differences in stimulus attributes, type of subject response and other procedural details.

ACKNOWLEDGMENTS

I would like to thank Lauren Harris, the chairman of my thesis committee and academic advisor, for his careful attention to the preparation and writing of this thesis and for his enlightening comments and discussions. I am grateful also to the other members of my committee, Ellen Strommen and John McKinney, for their helpful suggestions.

I also wish to express thanks to Roger Buldain for his assistance in the data analysis and to Bill Bukowski for his suggestions and advice.

Finally, I am grateful to my family and friends for their encouragement and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The purpose of the present study was to investigate age and sex differences in cerebral lateralization of spatial abilities as indexed by performance on a tactile discrimination task. I shall present a brief overview of research in cerebral lateralization and then review studies in hemispheric specialization for tactual perception. This review will include developmental research as well as studies of normal and brain-damaged adults. A discussion of sex differences in cognitive functions follows, and three theoretical positions proposed to account for such differences are outlined.

Cerebral Lateralization: Background

Studies of cerebral lateralization in the 19th century focused on the function of the left hemisphere and were based mainly on the effects of injury or disease in that hemisphere on speech production and comprehension. The prepoccupation with the "major" hemisphere continued (with some notable exceptions) until the post-World War II period, probably because lesions of the left side of the brain produced more obvious behavioral changes (i.e., disruptions in language) than lesions of the right side.

Nonetheless, investigators as far back as Hughlings Jackson speculated on the specialized role of the right hemisphere, which Jackson had characterized as being concerned with "perception" or "visual imagery" (Jackson 1932/1874). Since then, studies of patients with right-hemisphere lesions have indicated deficits in a variety of visuo-spatial tasks and in the ability to remember music, faces, and nonsense shapes (Milner, 1971). Such findings are thought to reflect right-hemisphere specialization for these capacities.

The reliance on clinical populations for subjects also persisted until the middle of the 20th century when the emergence of new experimental techniques and devices made it easier to investigate cerebral asymmetries in normal individuals. One of these techniques is dichotic listening, in which different auditory stimuli are presented simultaneously to the two ears and the subject is tested for recognition or recall. Since contralateral connections are stronger or more direct than ipsilateral ones, a right ear advantage for verbal stimuli, for example, implies a left-hemisphere superiority for processing this kind of material. An analagous rationale underlies the method of half-field presentations of visual stimuli.

Researchers employing these techniques usually find a right ear or right-visual field superiority for the recognition of words, digits, and stimuli presented in a temporally patterned sequence. Left-ear advantages have been found for the perception of animal sounds and environmental sounds (Knox & Kimura, 1970). For musical stimuli, ear asymmetries of different direction have been found depending on the precise stimulus attributes and the kind of processing required. When rhythmic and time factors are stressed, a right-ear advantage is more likely to appear, whereas presentation of melodies tends to produce left-ear advantages (Gates & Bradshaw, 1977). Left hemi-field superiority has been demonstrated for the visual perception of spatial configurations (Kimura, 1969) and faces (Geffen, Bradshaw & Wallace, 1971; Pirozzolo & Rayner, 1977), for the judgement of depth (Durnford & Kimura, 1971), and for identification of line orientation (Kimura & Durnford, 1974).

The dual nature of the two hemispheres has been characterized in many different ways. The left hemisphere has been described as logical, verbal, analytic, symbolic, propositional, and concerned with temporal processing. Its counterpart has been conceptualized as visuo-spatial, perceptual, nonverbal, synthetic, holistic, appositional, and involved in parallel processing (Bogen, 1969). To characterize the left hemisphere as verbal and the right as nonverbal, however, is simplistic since both hemispheres in most individuals are probably capable of both types of processing, to some extent. Furthermore, dichotic listening and visual half-field presentation studies indicate that certain aspects of the verbal or nonverbal stiumli produce the ear or hemi-field asymmetries. Schwartz and Tallal (1980), for example, discovered that the time dependent, acoustic qualities of speech but not the phonemic characteristics bring out a right-ear advantage.

Studies of Hemispheric Specialization in the Somesthetic Modality

Studies with Neurological Patients

In contrast to experiments involving vision or audition, there has been little research dealing with lateral asymmetries in tactual perception, and most of this research has been with subjects suffering from neurological disorders.

Semmes, Weinstein, Ghent, and Teuber (1960) tested war veterans with penetrating brain injuries on point localization, sense of passive movement, two-point discrimination, and touch-pressure thresholds. When comparing subjects with right-hemisphere lesions with those with lesions of the left side, they found that the number and severity of deficits in the contralateral hand was nearly equal for the two groups. Right-handed deficits were correlated more highly with damage to the left-hemisphere sensori-motor region than were left-hand deficits to localization of right-hemisphere lesions in the corresponding region. This result led the authors to propose that right-hemisphere representation of sensory and motor capacities is more diffuse than that of the left hemisphere.

Subjects with left-hemisphere lesions in this study showed greater left-hand sensory impairment than the group with right-hemisphere damage showed for the right hand. The experimenters therefore concluded that the left hemisphere has more ipsilateral sensori-motor influence than the right. This conclusion is supported by reports from neurologists that left-hemisphere lesions often produce bilateral manual defects (such as bilateral finger agnosia) whereas right hemisphere lesions usually do not (Critchley, 1953).

Corkin, Milner and Rasmussen (1964), on the other hand, found that the two hemispheres did not differ significantly with respect to control over ipsilateral sensation.

Boll (1974) administered a battery of tactile-perceptual tests (tactile finger localization, fingertip number writing perception, and tactile form recognition) to patients with lateralized brain lesions. Patients with right-hemisphere lesions made more errors than those with left-side lesions. Right-cerebral lesions produced greater deficits in the contralateral hand than left-cerebral lesions and in the ipsilateral hand as well.

This finding supports the view that the right hemisphere is specialized for tasks of this kind. It also conflicts with the earlier reports of greater or equal left-hemisphere control over ipsilateral sensori-motor functions. This discrepancy may be partially the result of Semmes et. al.'s (1960) use of subjects who had suffered penetrating head wounds, whereas Boll's (1974) study also included people with cerebro-vascular disease. Boll suggested this as a possible confounding factor, along with the complexity of the tasks involved and the precise location of the lesions. These studies illustrate some of the problems inherent in interpreting research with neurologically atypical subjects.

Semmes (1965) reported that brain-damaged individuals with astereognosis (same sample of veterans in 1960 study) sometimes showed impairment of tactual shape discrimination without deficits in tactual acuity, sensitivity, or localization or in discrimination of texture or size. She felt that a general spatial factor entered into those performances which require discrimination of spatial arrangements--regardless of modality. This explanation was bolstered by the finding, in a second part of the experiment, that subjects who did well on a test of visual-spatial orientation (walking through paths represented on maps) discriminated shapes tactually as well as did controls, while those who did poorly on the test were also impaired in discriminating shapes.

DeRenzi and Scotti (1969) had brain-damaged subjects palpate the edges of a wooden geometrical shape and then visually identify its equivalent among an array of five other shapes. Reaction time was used as the dependent measure. Subjects with right-hemisphere damage were significantly slower than those with lesions on the left side.

Fontenot and Benton (1971) gave subjects with unilateral brain damage a task in which they were required to specify the direction of moving tactile stimulation applied to the palms of their hands. Patients with lesions of the right hemisphere had significantly lower scores with both hands than control subjects without cerebral disease, whereas the subjects with left-hemisphere damage showed significant deficits (relative to the control group) only in the right hand. The results were seen as providing support for the role of the right hemishpere in the mediation of spatial perception in the tactile modality.

Similar conclusions were reached in studies of patients who had undergone cerebral commisurotomies. Levy-Agresti and Sperry (1968) asked these patients to match three-dimensional forms held in the left or right hand with drawings of these shapes as they would appear if they had been unfolded and placed onto a flat surface. Left hand performance was "much superior" to the right, and the authors reported that the method used by the subject was different depending upon which hemisphere was being used. This was inferred from the degree of difficulty the subject experienced with different types of problems. Levy-Agresti and Sperry concluded that the left hemisphere is specialized for "logical, analytic computer-like processing" and the "minor" hemisphere excels at Gestalt, wholistic perception.

Franco and Sperry (1977) presented a similar kind of visuo-tactile matching test [as used by Levi-Agresti and Sperry (1968)] to commisurotomized patients, but varied the stimuli to include geometric discriminations in Euclidean, affine, projective, and topological space. Left hand superiority depended on the type of stimulus being felt. The two hands were nearly equal with Euclidean shapes, for example, whereas the greatest left-hand advantage appeared for the topological forms.

Milner and Taylor (1972) gave commisurotomized patients a delayed match-to-sample task involving nonsense-shaped wire figures and found clear left-hand superiority in six out of seven subjects. Milner and Taylor viewed this as a demonstration of right hemisphere specialization for the perception and recall of spatial patterns.

Control subjects with cortical lesions but intact commissures performed at a superior level with both hands, indicating that both hemispheres are necessary for such tasks, with the right having a predominant role.

Studies with Normal Adults

There are problems in generalizing from clinical populations to normal individuals, For example, the injury or disease producing the lesion may well have a wide range of effects besides impairing the function associated with the cortical area of interest. "Split brain" patients, for instance, not only undergo surgery to sever the corpus callosum, but usually have a history of very severe Grand Mal epilepsy as well. Thus, it is of obvious value to use neurologically intact individuals in this area of research.

A relatively small number of studies have been conducted to determine hand asymmetry in tactile perception in normal subjects. Gardner (1942) had adults sort corks of varying sizes and shapes using one hand at a time. There was a modest right-hand advantage when size was the criterion. Gardner also arranged letters made of cord upon a cardboard background and tested for manual asymmetries in speed of reading with the fingers. He found a left-hand advantage, suggesting that the letters were being processed as spatial stimuli.

Nebes (1971b) had college students palpate an arc and then estimate the size of the complete circle from which it came. He found no significant differences between the hands for college students, though in an earlier study, commisurotomized individuals had shown a left-hand advantage for this task (Nebes, 1971a).

Benton, Levin, and Varney (1973) found a left-hand superiority for the perception of the direction of tactile stimulation applied to the palms of the hands. This stimulation was of brief duration and consisted of lines very close in orientation. In a similar study which suggested that the complexity of the task is a crucial factor in some cases, Umilta et al. (1974) presented subjects with a visual equivalent to this line orientation task on a tachistoscope, but at several levels of difficulty. Left-visual field superiority was exhibited only in the most difficult task in which the slopes of the lines differed very little from one another. This difficulty factor may help explain why manual asymmetries in tactile perception often do not show up with normal subjects when one hand is tested at a time.

Using the same task as Benton, Levin, and Varney (1973), Varney and Benton (1975) showed that the presumed right-hemisphere role in spatial perception in the tactile modality does not hold for left-handers and that familial handedness is a significant and independent factor. They found that right-handers having no familial sinistrality (FS-) performed significantly better with the left hand, whereas right-handers with familial sinistrality (FS+) showed no difference in performance between the hands. As for left-handers, FS- subjects performed at equal levels with the two hands whereas FS+ subjects performed significantly better with the right hand. A high percentage of right-handed subjects, however, did not conform to the pattern of a left-hand advantage (34%), and familial handedness did not fully account for these deviations.

Developmental Studies: Braille

There have been a few developmental studies of hemispheric specialization for tactual perception, the majority being studies of manual differences in reading braille letters.

As early as 50 years ago there was speculation as to which hand is superior for braille reading in blind people (Smith, 1929). There was no universal agreement as to which hand was "the eye of the blind" in these early and, for the most part, inadequately reported studies.

Hermelin and O'Connor (1971) rediscovered this avenue of research and found that right-handed blind children were faster and more accurate when reading braille with the left hand than with the right. They had subjects use their middle fingers in order to reduce the effects of practice, since the index finger is predominantly used by the blind for braille. With adults, no differences in speed were found, but fewer errors were made with the left hand. Even though the stimuli were linguistic in this instance, Hermelin and O'Connor reasoned from the fact of left-hand superiority that the braille characters were treated as spatial configurations which must first be analyzed by the right hemisphere prior to being analyzed by the left hemisphere.

The use of the less practiced middle finger did not eliminate the possibility that the left-hand advantage resulted from greater practice with this hand. Therefore, at least three studies were carried out using naive, sighted individuals to circumvent this complicating factor.

Rudel, Denckla, and Spalten (1974) trained right-handed, sighted 7- to 14-year old children to read braille, and discovered a left-hand superiority by age 11 in boys, but only by age 13 in girls. Boys younger than 11 showed no hand differences while girls age 7-8 showed a right-hand advantage. The authors suggested from this latter result that girls, at least at this age, employ processes associated with the left hemisphere (e.g. verbal, analytical) for tactile discim-inations.

Feinberg and Harris (1975; cited in Wagner and Harris, 1976) conducted a braille study with sighted adults and found small left-hand superiorities, but no sex differences in magnitude. A possible sex-difference in strategy, however, was indicated by the finding that females who showed a large right-hand superiority tended to have higher overall learning scores, while the reverse was true for males.

Harris, Wagner, and Wilkinson (1976) found left-hand superior-ities in sighted 8-13 year-old children as well as in college stu-dents. Among the eight year-olds, left-hand superiority was more marked for boys than for girls, but no other sex differences were found. Subsequently, a re-analysis of these data failed to confirm even this sex difference (Wagner & Harris, 1979).

Braille studies, then, generally disclose a left-hand advantage in recognition of these stimuli, but the sex difference found by Rudel et al. (1974) has not been found by others.

Developmental Studies: Dichhaptic Perception Task

Braille configurations are not purely spatial stimuli, since they comprise an alphabet. "Dichhaptic" presentation of nonsense shapes represents a more direct attempt to test lateral specialization for nonverbal, spatial, tactual functions.

Witelson (1975) devised this tactile version of the dichotic listening technique in which subjects felt two different nonsense shapes simultaneously with the two hands. (The objects were hidden from view.) Subjects then were asked to identify the stimuli from among several similar shapes in a visual display. Witelson assumed [by generalization from the structural (Kimura's) model for dichotic listening] that having the subjects process objects with both hands at the same time would create a competition between the hemispheres, thereby maximizing input to the contralateral hemisphere. The dependent measures were accuracy and frequency of first response in indentifying the objects. Witelson does not explain why she used frequency of first response as a dependent measure. Perhaps it was because a first response measure would be less likely to reflect the effects of an attention set.

The subjects were normal, right-handed boys and girls, ages 5-13 years.

The results showed sex and age differences as well as a sex x age interaction. For boys there was a significant ($p<.05$) left-hand advantage at ages 6-7 and 10-11. At ages 5 and 12-13 there was a left-hand advantage significant at the $p=.10$ level but no difference in accuracy between the hands for the 3 and 4 year-olds. On first response, boys showed a left-hand advantage ($p<.05$) at ages 5-11. No differences were found at ages 3, 4, and 12-13 for this measure.

For the girls there were no significant hand differences except for a right-hand advantage for the 4-year-olds. (Rudel et al., 1974, also found a right-hand advantage in one of their groups of girls, but the children in this case were somewhat older than Witelson's 4-year-olds.) The oldest girls in Witelson's (1975) study showed a nonsignificant left-hand advantage.

In an earlier study, this time with boys only, Witelson (1974) found a significant ($p=.05$) left-hand advantage in accuracy for nonsense shapes for children at ages 6.4-7.4, 9.5-11.4, and 12.0-14.3. These were significant differences despite small sample sizes (N's of 7, 5, and 14, respectively). Witelson gave the same boys a test of tactile perception of letter shapes and failed to find hand differences at any age tested (6-14 years).

The procedure in Witelson's studies was to have the subject identify the correct stimuli in the display by pointing with the hand earlier designated (during pretest trials) by the experimenter as the response hand. When a right hand response was called for, there were no significant differences between the two hands, but with a left-hand response, identification of objects perceived with the left hand was better than with the right. Witelson (1974) suggested that instructions to respond with one hand or the other focuses attention on the corresponding perceptual field so that instructions to respond with the left hand could have enhanced right-hemisphere processing for the task, whereas use of the right hand would have a balancing effect by enhancing left-hemisphere activation.

LaBreche, Manning, Goble and Markman (1977) used Witelson's dichhaptic task to measure hemispheric asymmetry in congenitally and profoundly deaf children whose average age was 15 years. The authors reasoned that because the congenitally deaf depend greatly on nonverbal learning functions and employ linguistic systems that are visuo-spatial in nature, deaf individuals may have a greater degree of bilateral representation of spatial functions than hearing people. They do not discuss the more plausible possibility that cerebral organization is the same, but that there might be differences in strategies employed by deaf and hearing people. Therefore, it was thought that the deaf children would show either a left-hand advantage or equal performance with both hands. The results did not confirm these expectations. The 15-year-olds showed no significant difference between the hands, what difference there was being in favor of the right hand. What is more, a comparison group of hearing children (average age 17 years) showed a significant <u>right</u>-hand advantage. The authors suggested that verbal mediation might have occurred (particularly since the subjects were older than Witelson's, 1975) in trying to explain these results. They concluded that, at least within the tactual modality, the cerebral organization of congenitally deaf and hearing individuals is not differentially influenced by such ever differences in experience as might be associated with deafness or normal hearing.

Cioffi and Kandel (1979) presented seven-, nine-, 11-, and 12-year-old children with tactile stimuli of three kinds: words, bigrams, and nonesense shapes. The stimuli were presented simultaneously to the two hands as in the Witelson testing procedure. The result was that both boys and girls identified nonsense shapes better with the left hand and words with the right hand. A right-hand advantage was found among girls and a left-hand advantage among boys for recognition of the bigrams. The authors inferred that the bigrams were generally processed by boys as shapes whereas girls tended to process them as words. So, Witelson's (1975) finding of a sex difference did not show up on the nonsense-shapes task, but there was a sex difference in processing of the bigrams. This latter result is in accord with the view that cognitive processes are organized differently in boys and girls.

Flanery and Balling (1979) repeated Witelson's (1975) study with first, third, and fifth graders and adults. In addition to using Witelson's dichhaptic procedure (two hands simultaneously), they had a second condition in which subjects felt a nonsense figure with a single hand. The fifth graders and adults were more accurate in identifying objects presented to the left hand, but no hand difference appeared for the younger groups. Unlike Witelson, they found no sex differences. The two procedures, dichhaptic and single hand, yielded similar results.

Cranney and Ashton (1980) administered Witelson's dichhaptic task to deaf children, as well as to hearing children and adults.

They found no significant differences between the left-hand and right-hand scores of any of the groups. In all of the groups, except the younger group of deaf children, the average right-hand score was greater than the average left-hand score.

Finally, Dawson, Farrow and Dawson (1980) tested first and sixth graders and undergraduates on the dichhaptic task, using Witelson's (1975) nonverbal stimuli, presented in four different orientations. Shapes were identified by having subjects call out the number of the labeled choice stimulus. Like Witelson (1975), they found a significant sex x tactual field interaction. Ten-year-old boys, but not girls, tended to have higher scores for the left hand.

The six dichhaptic studies reviewed here present an inconsistent pattern of findings. Most, though not all of these studies, show a left-hand advantage for perception of nonsense shapes and among these two show such an advantage for boys and not girls.

The Development of Cerebral Lateralization: Theory

It generally has been assumed that at birth, the two cerebral hemispheres have equal potential for the sub-serving of cognitive functions. A correlary to this view was that lateralization is absent or largely absent during infancy and develops gradually with the development of language (Lenneberg, 1967).

This view was based partly on reports that damage to the left hemisphere in childhood produces less severe and more transient language deficits than similar injury during adulthood (Lenneberg, 1967). It has been thought that the earlier the age at which the injury is suffered, the less severe is its effect upon language development. Part of the problem with such evidence is that the kinds of brain damage suffered by children are usually not equivalent to the adult cases and most researchers have used adult aphasia symptoms as the basis for comparison of cerebral injury in children and adults. Thus, a valid comparison is not made.

Further evidence for bilateral language representation in children comes from reports of right hemisphere damage producing language deficits in pre-school children (Lenneberg, 1967).

Until very recently, most investigators have agreed that handedness was not clearly or permanently established in early childhood and this was thought to reflect incomplete lateralization in the first several years of life.

A more current view is that cerebral lateralization is present from birth. That early left hemisphere insult produces less severe aphasias than later damage may reflect the greater plasticity of the less complex, immature brain rather than less complete lateralization. Moreover, it is by no means certain that age, per se, is related to greater degree of recovery from central nervous system injury (St. James-Roberts, 1979). It is more likely that age interacts with a constellation of other factors in influencing recovery from brain damage.

Reports of right hemisphere damage causing aphasia in children (Lenneberg, 1967) have been criticized on several grounds (Kinsbourne, 1975). For example, the damage often may not have been limited to the right hemisphere and language disruption was not always reliably reported. In any case, the hemispheric equipotentiality theory does not adequately account for the greater disruption of language development caused by left-hemisphere injury in infancy as compared to right-hemisphere injury.

Furthermore, for tests such as dichotic listening and tachistoscopic presentations of visual stimuli, the magnitude of the asymmetries found has generally not been found to increase as a function of age.

Evidence for early cerebral lateralization comes from a number of other sources as well. Turkewitz (1976) found that infants turn towards visual, auditory, and tactile stimuli presented to the right side of their perceptual field more frequently than stimuli presented to the left side.

Caplan and Kinsbourne (1976) and Hawn (1978) reported that infants as young as two to three months of age hold a rattle or wood bar-bell in the right hand for a longer period of time than in the left. Previous studies which reported shifts in handedness in infants (Gesell & Ames, 1947, for example) may have involved unreliable or age-inappropriate techniques for measuring predisposition to handedness in young children.

Corroborating evidence for lateralization in infancy also comes from studies showing that verbal stimuli produce greater electrical cortical responses from the left hemisphere of infants than the right

(Molfese, 1973) and ear differences in dishabituation to dichotically-presented sounds (Entus, 1975; Glanville, Best, & Levenson, 1977).

If cerebral lateralization is present from birth, how do proponents of this view account for findings, such as Witelson's (1974), that boys show a left-hand advantage on the dichhaptic task at age 6 but girls do not? Harris and Witelson (1977) note a growing tendency among psychologists to interpret all such tasks as absolute measures of the degree of cerebral specialization for the spatial or verbal function that the test is presumed to represent. These tasks, however, may not simply index changes in lateral organization, but reflect changes in the types of processes individuals will invoke to solve particular problems. Laterality may be more or less constant during childhood--cognitive competence for various types of skills is not. The results of different tests of laterality also depend importantly on the unique qualities of the sensory mode involved. The haptic sense, for example, may be inherently more spatial in operation than other senses because of its limitation in taking in information, thus requiring a temporal-spatial mode of analysis best served by right-hemisphere systems.

Sex Differences

The inconsistent reports of sex differences in the tactile perception studies behoove us to take a closer look at the topic of sex differences in cerebral organization.

Sex Differences in Cognitive Abilities

Women generally exhibit better performance than men on a variety of language-oriented or predominantly left-hemisphere tasks, whereas men excel at visual-spatial skills, skills usually linked to the right hemisphere. Women are, on the average, superior to men in areas of verbal skill such as speed of articulation, fluency, and grammar. Throughout childhood, girls reach various milestones of linguistic development ahead of boys and reveal fewer problems with and better average skill in reading (Harris, 1977). Women are also better at fine motor coordination, including precise temporal regulation of motor repetitions (finger tapping, Wolff & Hurwitz, 1975), and rapid processing of detailed perceptual information (Maccoby & Jacklin, 1974).

Males outperform females on such spatial tests as visual and tactual mazes, the rod-and-frame test, and map-reading, as well as recall and detection of shapes and mental rotations (see Harris, 1978, for review). Broverman, Klaiber, Kobayashi and Vogel (1968) propose that the type of tasks males excel at are those requiring inhibition of immediate response and they have developed a hormonal theory to explain the sex differences along this activation-inhibition dimension.

Sex Differences in the Development and Degree of Lateralization

Several theories have been advanced to account for sex differences in performance on cognitive and perceptual tests. A brief discussion of the more plausible of these theories (after Harris, 1978) follows.

Bilateral language representation in females. One explanation for the well-established pattern of sex differences in cognitive skills posits that language functions are lateralized to a lesser extent in females than in males. The supposition in this theory seems to be that spatial skills suffer by the intrusion of linguistic processes into the right hemisphere. Language function in the right hemisphere, according to this view, may interfere with the supposed diffuse organization of that hemisphere which Semmes (1968) saw as essential to spatial analysis. Characterization of the right hemisphere as more diffuse in organization than the left is suggested by studies showing that impairment on tests of spatial orientation is related to locus of injury only in the left hemisphere and not in the right (Semmes, Weinstein, Ghent, & Teuber, 1960).

If this theory is valid, then other groups known to be less well lateralized with respect to language should also show deficits in spatial ability. Left-handers are such a group. Levy (1969) tested male graduate students on the WAIS and found that the left-handers performed significantly worse on the performance scale than the right-handers, but approximately equal on the verbal part. In Nebes' (1971b) study with college students, left-handers had more difficulty than right-handers matching a segment of an arc to the circle to which it belonged.

More recent studies have not supported these early findings of a spatial deficit in left-handers. Briggs, Nebes, and Kinsbourne (1976) found that left and mixed handed college students achieved lower full-scale I.Q. scores (WAIS) on the average than right-handers. The difference in average scores was small but significant. Unlike Levy (1969), they did not find that left handed individuals do worse on the performance part of the WAIS than right handers but not on the verbal part. Heim and Watts (1976) gave verbal, numerical, and perceptual tests to a large sample (N=2165) of children and adults. The authors meant to improve on methodological flaws in Levy's (1969) study, including the small, select group of subjects used (graduate science students), and the "cognitive dichotomy" set up between performance (visuo-spatial) and verbal (including numerical) test groupings. Heim and Watts (1976) found no evidence that left-handers perform less well on tests of visuo-spatial skill. Others (Newcomb & Ratcliff, 1973; Fagan-Dubin, 1974; Hardyck, Petrovich, & Goldman, 1976; Hardyck, 1977) have also found no deficit in left-handers on spatial or performance tests.

Some investigators have looked for differences in spatial skill as a function of strength of lateralization among right-handers only. Zoccolotti and Oltman (1978) investigated the relationship between degree of lateralization and spatial ability in right-handed men, ages 18-30. Men who performed well on embedded figures tests and the rod-and-frame test showed right hemi-field superiorities in recognition of tachistoscopically presented letters, but those who had poorer scores on the spatial tests did not show visual field asymmetries. Among right-handers, Kail and Siegel (1978) found a positive correlation between strength of handedness and more accurate recall of spatial information in the right visual field for women, but a negative correlation for men.

It seems, then, that the relationship between degree of lateralization and spatial skill is not firmly established. Therefore, this avenue of research does not unequivocably support the theory of bilateral language representation in females as an explanation of sex differences in cognition.

Some studies with neurological patients can be interpreted as lending support to this theory. Lansdell (1961) found that women's performance on a proverb comprehension test did not change after left-hemisphere surgery, but men's scores declined. In a second study, Lansdell (1962) administered the Graves Design Test to men and women before and after surgery to remove the right or left temporal lobe (for purposes of relief of epilepsy). The Graves Design Test was designed to measure art appreciation but has a strong spatial component. Among those who underwent left-hemisphere surgery, men's scores rose and women's declined. For those who had the right temporal lobe removed, men's scores declined, women's rose.

McGlone (1978) tested right-handed patients with unilateral brain damage on the WAIS. Males showed a decrement on the verbal subtests after left-hemisphere damage and lower scores on the performance subtests after right-hemisphere injury. In females, verbal and performance I.Q. scores were not significantly different after left or right hemisphere injury.

In dichotic listening studies, right-handed males have shown a greater right-ear superiority than right-handed women (Lake & Bryden, 1976). Men also display a stronger right-field superiority for verbal stimuli presented in a tachistoscope (Kimura, 1969; Kail & Siegel, 1978).

Earlier right-hemisphere specialization in males. The previously mentioned studies by Rudel et al. (1974) and Witelson (1975) suggest that boys may develop earlier right-hemisphere specialization for spatial functions than girls.

Studies measuring evoked potential recordings from the two hemispheres (Molfese, 1973) and dishabituation to dichotically presented stimuli (Entus, 1975; Glanville, Best & Levenson, 1977) have indicated right-hemisphere specialization for the perception of nonverbal sounds in infants. No sex differences were reported in these studies. Shucard et al. (1979), however, measured evoked auditory potentials from three-month-old infants while musical and verbal stiumli were played and did find a sex difference. With both types of sounds, seven of eight boys showed a higher amplitude of right than left response. The pattern was reversed in girls, among whom seven of eight produced higher amplitude responses from the left than the right hemisphere.

The few studies which have compared boys and girls on asymmetries in visual half-field or dichotic presentations of nonverbal sounds have found no significant differences. Marcel and Rajan (1975), for example, reported no sex difference for recognition of faces in seven-to nine-year-old children. Piazza (1975) presented environmental sounds dichotically to three- to five-year-old children and found a similar left-ear advantage for boys and girls.

Research with monkeys indicates that man may not be the only primate in whom males and females follow different developmental schedules for higher nervous system organization. Goldman, Crawford, and Stokes (1974) studied the performance of Rhesus monkeys with bilateral, prefrontal lesions on an object discrimination reversal task and on spatial, delayed-response problems. Males were impaired on these behavioral tests at 2½ months of age, but females did not show comparable impairment until 15-18 months of age.

Strategy differences. An alternative theory to the ones which propose differences in lateralization is that females rely primarily upon linguistic modes of processing whereas males prefer right-hemisphere strategies. Of course, these different theories are not mutually exclusive--a greater degree or earlier onset of lateralization may predispose an individual to favor one hemisphere (cognitive process) over another.

Many of the aforementioned studies, cited in support of a neurological model, also can be interpreted to conform with the strategy theory. This is particularly true of some of the braille studies, since braille configurations apparently can be treated as either spatial or verbal stimuli. In the study by Rudel et al. (1974), for example, the right-hand advantage for the youngest girls could mean that they are processing the braille characters using linguistic skills.

The Lansdell (1962) experiment also employed stimuli which are readily processed by either verbal or spatial means. The drop in score among women who had had left-hemisphere surgery could mean that they depend more on this hemisphere (language) to make aesthetic judgments of art, and that males use more purely spatial means of analysis.

Mellone (1944) gave seven-year-old children a variety of ostensibly spatial tests, such as block counting and identifying the mirror image of a picture. Factor analyses suggested that the girls were drawing upon verbal capacities to solve the same problems that the boys were processing (sometimes more efficiently) spatially.

In summary, there is evidence to support theories of differences in the degree and ontogeny of neurological organization as well as differences in preferred strategies as underlying the observed sex differences in cognitive abilities.

Place of Proposed Study in the Literature

The purpose of the present study was to provide additional evidence bearing on the question of hand differences in tactile perception of spatial stimuli in normal children of different ages. More specifically, this study was intended to clarify some of the conflicting results obtained by Witelson (1975) and other researchers using the dichhaptic perception task, especially with regard to the question of age and sex differences.

Four of the studies using the dichhaptic procedure were published only after the present research began (Flanery & Balling, 1979; Cioffi & Kandel, 1979; Cranney & Ashton, 1980; Dawson et al. 1980). The relationships among these studies and the present one and the implications of their disparate findings will be analyzed in the Discussion section. At the time the current experiment was designed, only Witelson's (1975) and one other study had been done, and the main concern of the current study therefore was to use stimuli that were less verbalizable than Witelson's (1975) and to eliminate the specification of the response hand to the subject from the procedure.

METHOD

Subjects

The subjects were first, fifth and ninth graders from a public elementary and high school in a local suburban area. There were 10 first-grade boys and 11 girls, 8 fifth-grade boys and 13 girls, and 9 ninth-grade boys and 10 girls. The average age for the first-grade boys was 6:8 and for the first-grade girls, 7:0. For the fifth-grade boys and girls, average ages were 11:1 and 10:9, respectively, and for the ninth-graders 15:1 for the boys and 14:9 for the girls.

Only right-handed subjects were included in the study. Handedness was determined by asking the children to perform five common actions (Annett, 1970) and noting which hand was used. Only subjects who reported using their right hand for at least four out of five of the tasks were included in the study.

Informed consent forms were given to the parents of prospective participants along with a statement explaining the purposes and procedures of the study. (See Appendix A.)

Stimuli

The stimuli consisted of irregularly shaped styrofoam forms, approximately 1½ x 1½ x 3/16 inches in size. Pairs of stimuli, spaced 4" apart, were glued to an 8" x 10" cardboard backing. Witelson stated that her stimuli were sufficiently meaningless and unfamiliar so as to make verbal mediation almost impossible (see Figure 1).

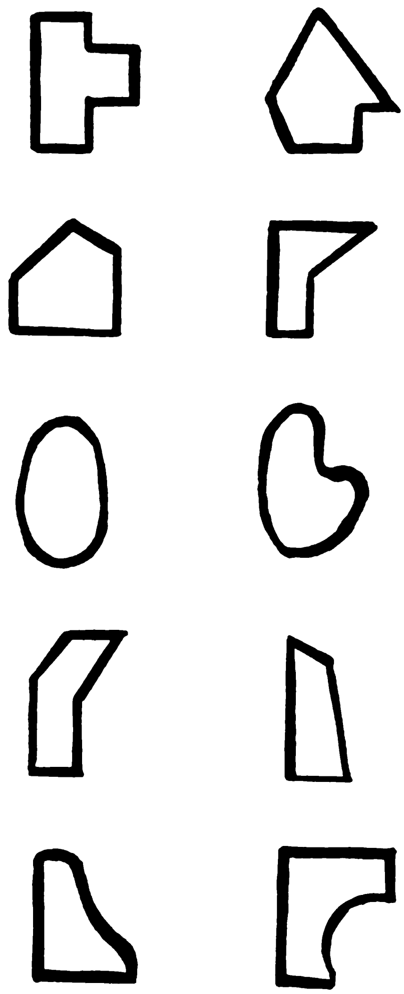

Figure 1.--The 5 pairs of nonsense shapes used by Witelson (1974).

Some of the forms, however, were quite familiar (e.g. an oval) and some of the pairs differed in terms of features that could be easily encoded verbally. Therefore, for the current study, a set of shapes was designed so as to minimize the chance for linguistic processing, thereby maximizing the likelihood of gestalt perception. For the seven- and 11-year olds, the same stimuli were used (see Figure 2), but two new pairs of stimuli were substituted for two of the old ones with the 15-year-olds (see Figure 3). This was done after pre-testing suggested that the forms used with the younger children would be too easy for the 15-year-olds.

Procedure

Subjects were asked to feel a stimulus with each hand, simultaneously, for 10 seconds. The nonsense shapes were concealed from the subject's view behind a box-like construction (see Figure 4). In light of evidence that there is no ipsilateral control for fine movements of the digits (Brinkman & Kuypers, 1972), the subjects' arms were contrained by placing them through the holes pictured in the testing apparatus to prevent gross movements which could produce ipsilateral feedback. Also, subjects were asked to use only the middle and index fingers of each hand. The experimenter demonstrated the procedure to the child.

Immediately after the 10-second exploration period, subjects were asked to point to the correct stimuli from a visual display. The forms in the display were arranged randomly, and the positions of the correct stimuli varied randomly from trial to trial.

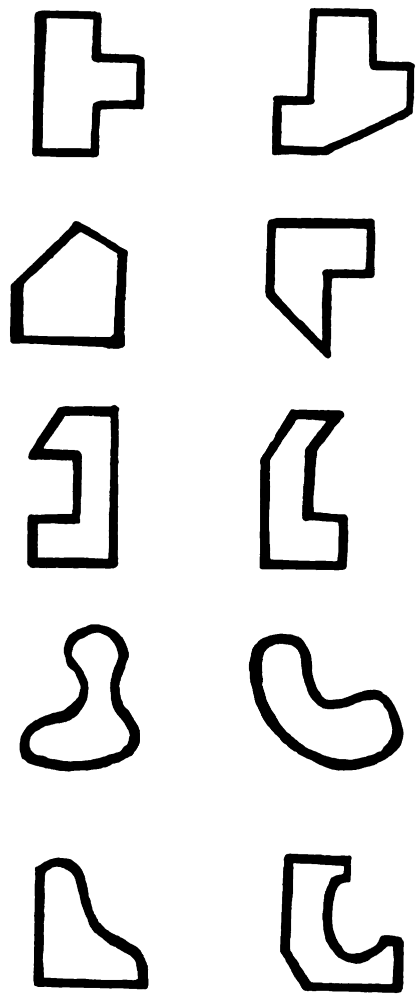

Figure 2.--Stimuli used in the present study for the nine- and 11-year-old children.

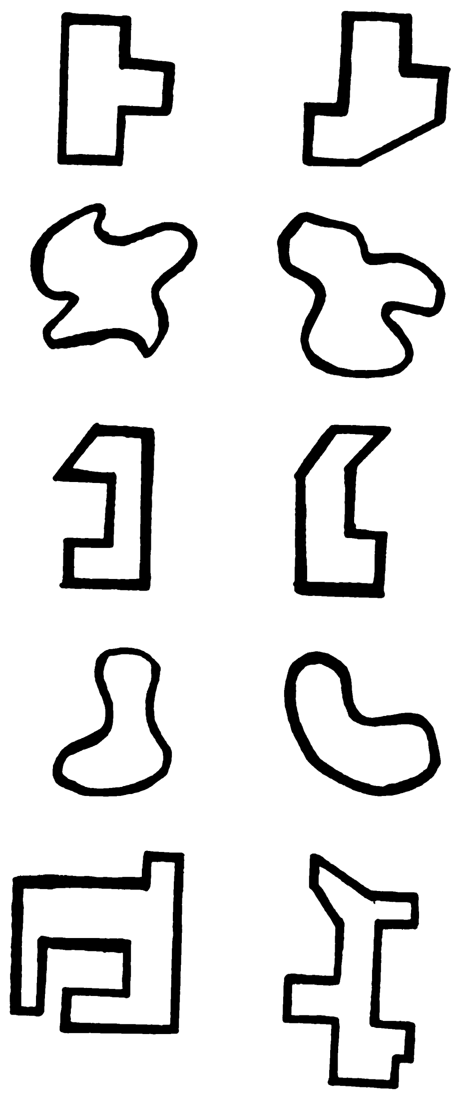

Figure 3.--Stimuli used in the present study, for 15-year-olds.

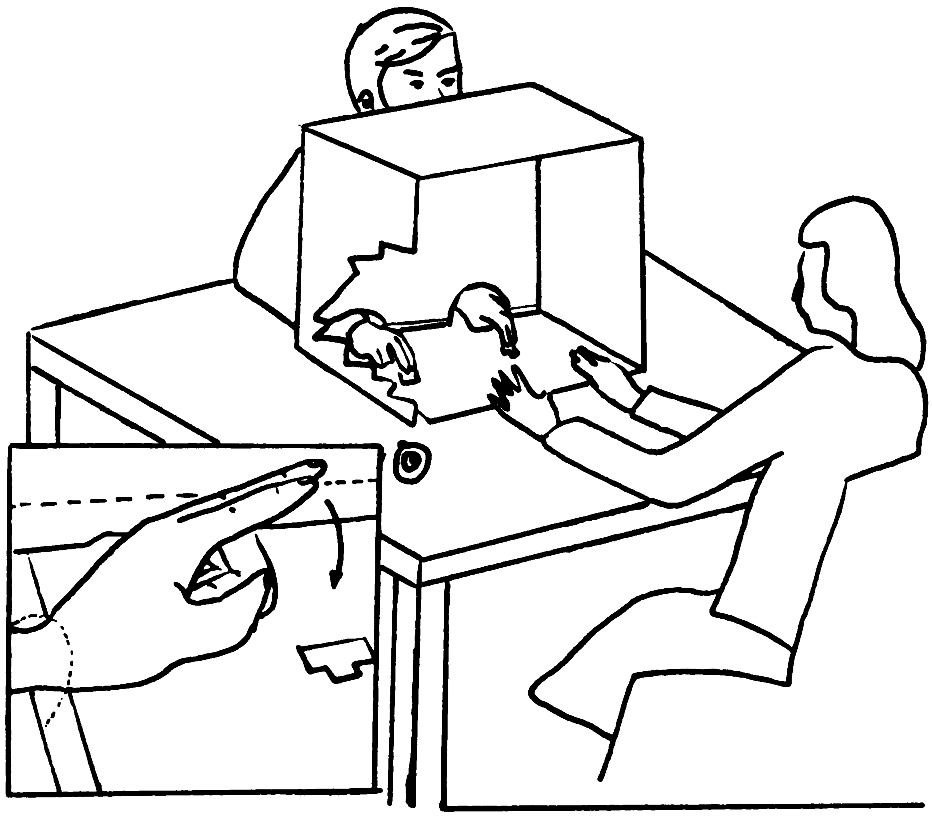

Figure 4.--The testing situation for the two-hand tactile perception task, devised by Witelson (1974).

There were five choice stimuli in the display, the two correct ones and three distractors. No time limit was given for each response, but a child who did not know the correct stimulus for a particular hand was asked to guess. As in Witelson's (1974) study, knowledge of results was not given.

Earlier I suggested that in Witelson's (1974) study, the required use of a particular hand as the response hand may have created a bias in attention to the corresponding perceptual field, resulting in enhancement of left hemisphere processing in the case of a right-hand response or right hemisphere processing for a left-hand response. Witelson (1974) reported that although all her subjects were right-handed, when they were instructed to use the right hand, they often spontaneously tried to use the left. In the present study it was thought preferable to let an intitial perceptual asymmetry influence motor output, rather than to let the influence work in the reverse direction (as Witelson's procedure seems to have done). Therefore, subjects were not restrained in the use of one hand or the other as the response hand in the current experiment.

Each subject was given 10 trials. Each stimulus pair was presented twice, once to the left hand and once to the right. The stimulus pairs were counterbalanced so that half the subjects were given one set of stimuli to the left hand for the first five trials, with the presentation reversed for the others. Subjects were given 10 practice trials to teach them to explore the two shapes simultaneously with just two fingers of each hand while keeping the wrists immobile. The stimuli used in the practice trials differed from those used during the main part of the study. Knowledge of results was provided.

RESULTS

Comparison of Left and Right Hand Scores

The average scores for left and right hand for the dichhaptic task, over 10 trials, are summarized in Table 1. For all groups

Table 1: Mean Number of Correct Right and Left Hand Scores and T-tests for Each Age X Sex Group and All Groups Combined

Age	Males		Females	
	Left	Right	Left	Right
7	7.10	6.40	6.09	5.50
	t<1.0 (N.S.)		t<1.0 (N.S.)	
11	6.75	6.12	7.38	6.92
	t<1.0 (N.S.)		t<1.0 (N.S.)	
15	5.66	6.00	6.50	5.40
	t<1.0 (N.S.)		t=2.69 (p<.05)	

Note: For all groups combined, t<1.0.

except the 15-year-old boys, the stimuli felt with the left hand were identified more often than those felt with the right hand. For the 15-year old boys, the difference was in the reverse direction. T-tests (Table 1) disclosed that the hand difference reached significance only for the 15-year-old girls ($p<.05$). When hand scores for all groups were combined, the hand difference was not significant ($t<1.0$).

Scatterplots, depicting right hand score vs. left hand score for each subject, are shown in Figures 5, 6, and 7. In all groups except the seven- and 15-year-old girls, there was no obvious preponderance of scores with a right or left hand advantage. This is confirmed in Table 2, which shows the number of subjects with left or right hand advantages grouped by age and sex.

Table 2: Number of Subjects Showing Superior Performance with Left or Right Hand, Grouped by Age and Sex

Age	Males		Females	
	R > L	L > R	R > L	L > R
7	4	5	3	6
11	5	4	4	5
15	4	3	1	7

Analysis of Group Effects

Simple Difference Between the Hand Scores

A multivariate ANOVA was performed using overall difference scores between the hands and difference between the hands in first response as dependent measures. These were the same measures used

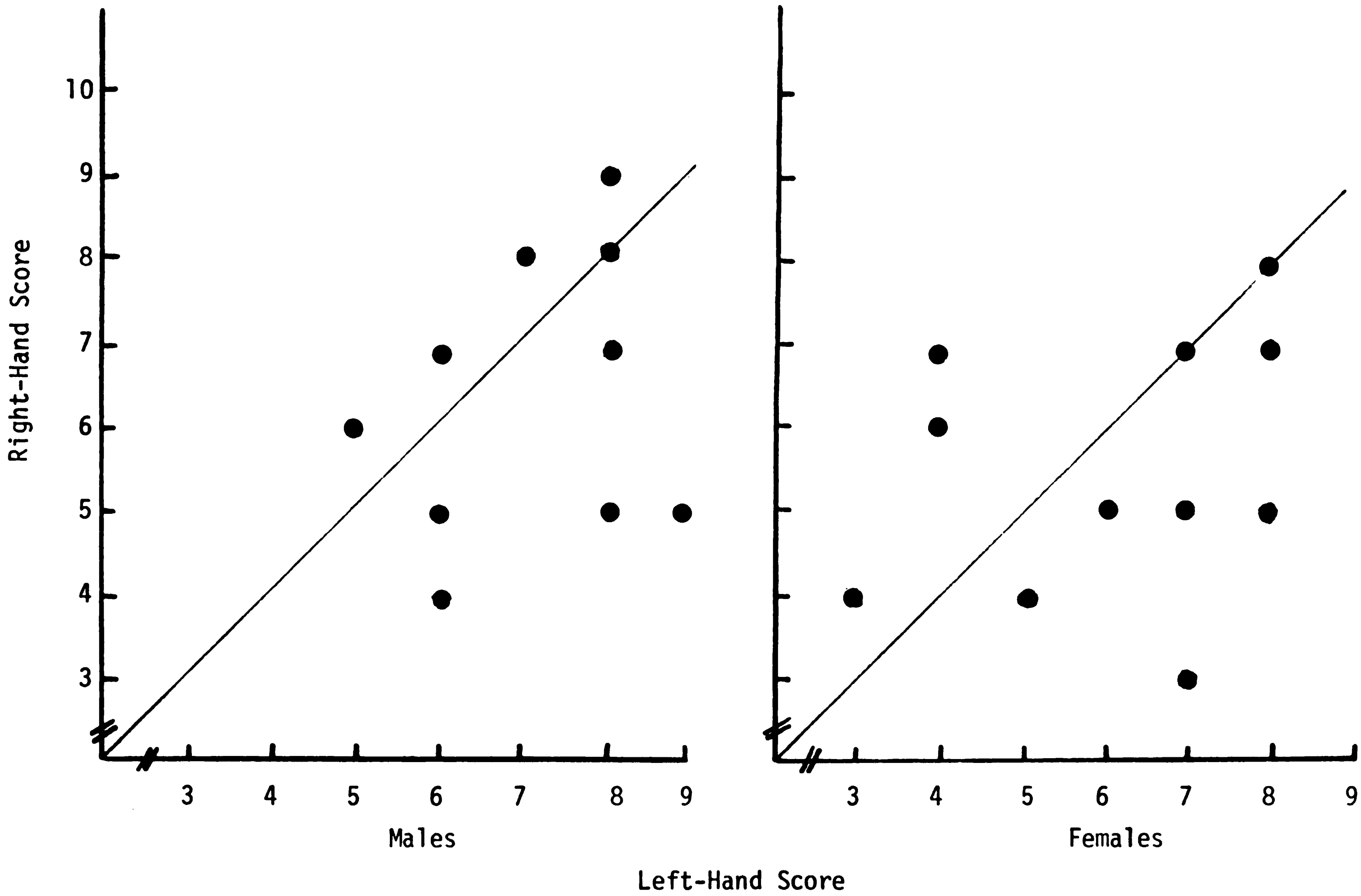

Figure 5.--Scatter-plot of left- versus right-hand responses for seven-year-olds.

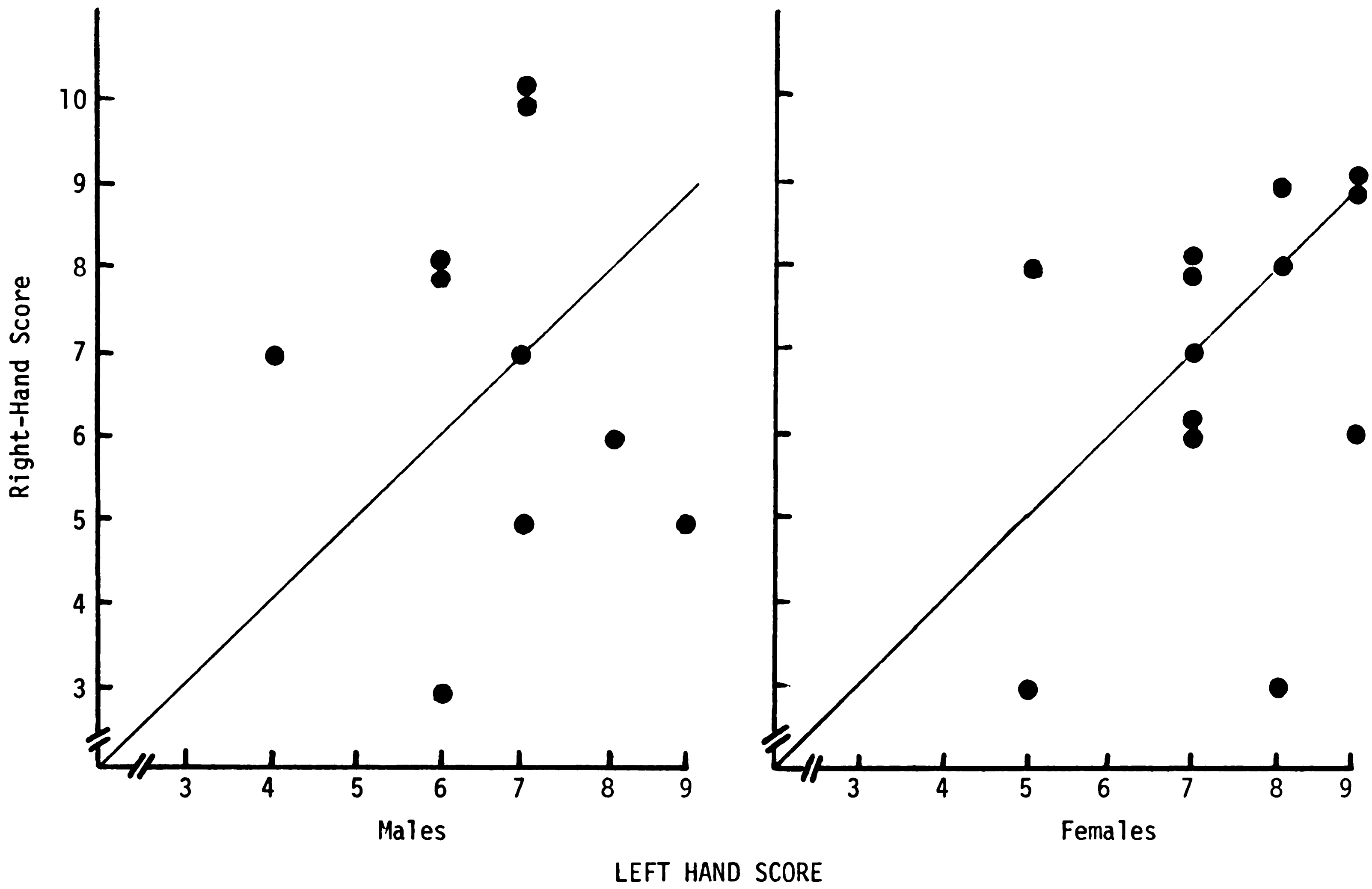

Figure 6.--Scatter-plot of left versus right-hand responses for 11-year-olds.

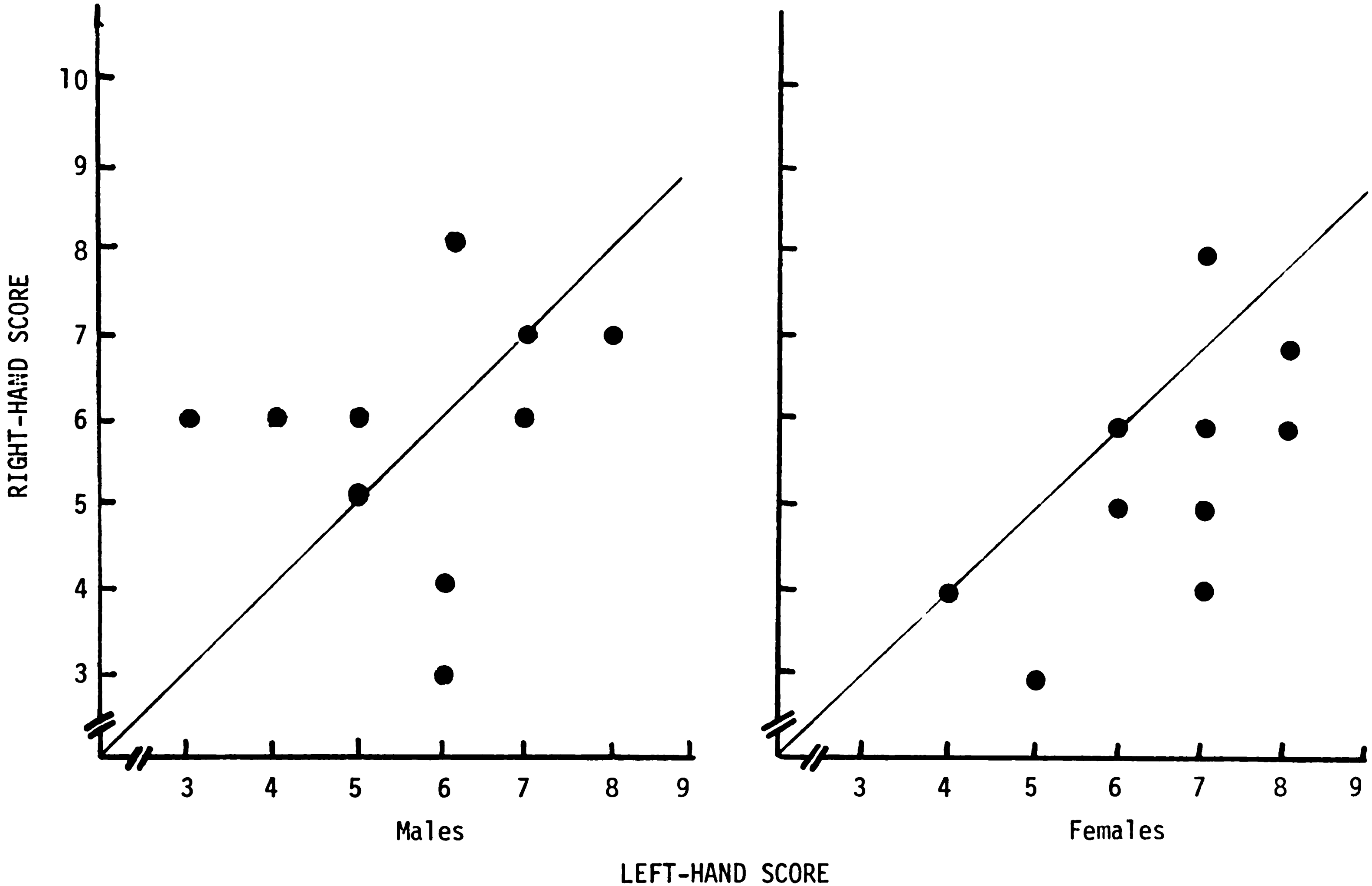

Figure 7.--Scatter-plot of left- versus right-hand responses for 15-year-olds.

by Witelson (1975). The effects of Age, Sex, Order and Block were tested with mutivariate F-ratios. Block was the variable denoting first or second set of five trials for each subject. (The five stimulus pairs were presented twice--with the hands reversed on the second set of trials.) The "Order" variable referred to whether a set of five stimuli was presented to the left hand first or to the right.

When difference scores between the hands was the dependent variable (Table 3), the main effects found were for Sex ($F=4.08$), $p<.05$) and Order ($F=6.21$, $p<.05$). The only significant interaction was Age x Sex ($F=3.62$, $p<.05$).

For the seven-and 11-year-olds, the hand asymmetries were in the same direction for both boys and girls; there were nonsignificant left-hand advantages for all groups. For the 15-year-olds, the boys showed a nonsignificant right-hand advantage ($t<1.0$) and the girls a significant left-hand advantage. Therefore, the significant Sex effect in the ANOVA seems to have been a result of this difference in the oldest age group. The Age x Sex interaction reflects the change in boys from a nonsignificant left-hand advantage in the younger groups to a nonsignificant right-hand advantage in the 15-year-olds and the increase in girls from a nonsignificant left-hand advantage in the younger groups to a larger, significant left-hand advantage in the 15-year-olds.

Although the stimuli presented initially to the left hand were designed to be roughly comparable to those presented to the right,

Table 3: ANOVA for Simple Difference Scores in Identification of Left and Right Hand Stimuli

SOURCE	d.f.	F	p	SOURCE	d.f.	F	p
AGE	2	.555	.578	BLOCK	1	.711	.403
SEX	1	4.08	.049	AGE x BLOCK	2	.196	.822
ORDER	1	6.21	.016	SEX x BLOCK	1	2.00	.163
AGE x SEX	2	3.62	.034	ORDER x BLOCK	1	.001	.982
AGE x ORDER	2	1.43	.247	Age x Sex x Block	2	.125	.883
SEX x ORDER	1	.417	.521	AGE x ORDER x BLOCK	2	.102	.904
AGE x SEX x ORDER	2	.340	.714	SEX x ORDER x BLOCK	1	1.77	.188
				AGE x SEX x ORDER x BLOCK	2	.181	.835

the two different orders of presentation were given so as to counterbalance any effects related to overall differences in stimulus attributes between the two groups. For Order of presentation 1, the average simple difference score was -.03, a slight left-hand advantage, whereas for Order 2, the average simple difference score was -.36, a larger left-hand advantage. Therefore, given the significant Order effect, the subjects had greater left hand advantages under Order 2 than 1.

Table 4 shows that when left and right-hand scores are compared by a t-test for each cell, three of the groups show significant

Table 4: Mean Left and Right Hand Scores and T-tests for Each Age by Sex Group and All Groups Combined for Order 2

Age	Males		Females	
	Left	Right	Left	Right
7	7.2	6.4	6.8	5.8
	t=1.48 (N.S.)		t=2.24 ($p<.05$)	
11	6.6	6.0	7.2	5.7
	t=1.07 (N.S.)		t=2.61 ($p<.05$)	
15	5.3	5.8	6.4	5.4
	t=1.0 (N.S.)		t=2.22 ($p<.05$)	

Note: For all groups combined, t=2.86 ($p<.05$)

left-hand advantages and for the combined groups there is a significant left-hand advantage as well. It is not clear why the second Order of presentation should have produced more left-hand advantages than the first Order. Either there has been some sampling error, or one of the sets of five stimuli presented to the left or right hand inexplicably initiated a verbal mediation strategy more reliably than the other, thus negating the presumed left-hand superiority for this task.

There were no significant main or interaction effects when the difference in number of initial responses between the hands was used as the dependent variable (Table 5).

Phi Coefficient Scores

In dichotic listening studies, a simple difference score has been found to be an inadequate measure of asymmetries because it does not take accuracy into account. A second measure, R-L/R+L (Studdert-Kennedy & Shankweiler, 1970), has been reported to be negatively correlated with overall accuracy. When a subject's accuracy exceeds 50%, the maximum value of this index decreases sharply. Therefore, an alternative measure of laterality was computed in this study--the phi coefficient ($R-L/\sqrt{(R+L)2T-(R+L)}$; Kuhn, 1976). In the phi coefficient formula, R and L stand for the number of correct right and left hand responses, respectively, and T represents the number of trials given to a subject. This measure is designed to give a more accurate estimate than other such indices of the lateral asymmetry shown on a given task by taking account of

Table 5: ANOVA for Simple Difference Between-the-Hands Scores in Frequency of First Response

SOURCE	d.f.	F	p	SOURCE	d.f.	F	p
AGE	2	.074	.929	BLOCK	1	.056	.813
SEX	1	.001	.981	AGE x BLOCK	2	.837	.439
ORDER	1	.009	.926	SEX x BLOCK	1	.001	.976
AGE x SEX	2	.021	.979	ORDER x BLOCK	1	.332	.567
AGE x ORDER	2	1.39	.258	AGE x SEX x BLOCK	2	.736	.484
SEX x ORDER	1	3.25	.077	AGE x ORDER x BLOCK	2	.237	.790
AGE x SEX x ORDER	2	.651	.526	SEX x ORDER x BLOCK	1	.490	.487
				AGE x SEX x ORDER x BLOCK	2	.319	.728

the overall level of performance. The coefficients range from -1 to +1, a positive score indicating a right-hand advantage. Mean laterality scores for each group, using this measure, are listed in Table 6.

Table 6: Mean Phi Coefficients for Each Sex at Each Age

Age	Boys	Girls
7	-.08	-.05
11	-.02	-.06
15	.03	-.11

A multivariate ANOVA using phi-coefficient scores instead of simple difference scores were performed on overall hand-difference scores (Table 7) and also hand-difference scores on the first response (Table 8). For this analysis, no significant effects were found at the .05 level for Age, Sex, Block, or Order, or for any of the interactions for either dependent variable.

The Sex x Order interaction for the second dependent variable (difference in first response score) was significant at the $p=.055$ level. This effect is shown in Table 9. As measured by the phi coefficient, when stimuli were given in Order 1, boys tended to have a left-hand advantage for first response and girls a right-hand advantage whereas with Order two, boys had more initial right-hand responses and girls more left-hand responses.

Table 7: ANOVA for Phi Coefficient (corrected for accuracy) Difference Between-the-Hands scores

SOURCE	d.f.	F	p	SOURCE	d.f.	F	p
AGE	2	.210	.811	BLOCK	1	2.73	.104
SEX	1	1.36	.248	AGE x BLOCK	2	2.24	.116
ORDER	1	1.20	.278	SEX x BLOCK	1	1.14	.290
AGE x SEX	2	.71	.494	ORDER x BLOCK	1	.01	.913
AGE x ORDER	2	.76	.471	AGE x SEX x BLOCK	2	1.63	.205
SEX x ORDER	1	.13	.720	AGE x ORDER x BLOCK	2	.45	.635
AGE x SEX x ORDER	2	.13	.877	SEX x ORDER x BLOCK	1	.001	.980
				AGE x SEX x ORDER x BLOCK	2	.24	.784

Table 8: ANOVA for Phi Coefficient Difference Between-the-Hands Scores for Frequency of First Response

SOURCE	d.f.	F	p	SOURCE	d.f.	F	p
AGE	2	.700	.501	BLOCK	1	2.52	.118
SEX	1	1.69	.199	AGE x BLOCK	2	3.04	.057
ORDER	1	.178	.675	SEX x BLOCK	1	1.18	.282
AGE x SEX	2	.669	.517	ORDER x BLOCK	1	.147	.703
AGE x ORDER	2	2.41	.100	AGE x SEX x BLOCK	2	2.56	.087
SEX x ORDER	1	3.86	.055	AGE x ORDER x BLOCK	2	.754	.476
AGE x SEX x ORDER	2	.081	.923	SEX x ORDER x BLOCK	1	.204	.650
				AGE x SEX x ORDER x BLOCK	2	.107	.898

Table 9: Mean Phi Coefficient Scores for Hand Differences in First Response for Males and Females Under Both Orders of Presentation

		Sex	
		Boys	Girls
Order	1	-.01	.02
	2	.12	-.06

There was also a significant (p=.057) Age x Block effect for the second dependent variable using phi coefficient scores. For the seven-year-olds, there was a greater average number of right-hand than left-hand first responses for the first Block of five trials, while on the second Block, left-hand first response scores were higher. The reverse pattern held for the 11- and 15-year olds (Table 10). Age x Sex x Block was significant at p=.087 for the

Table 10: Mean Phi Coefficient Scores for Hand Difference in First Response at Each Age for Each Trial Block

		Block	
		1	2
Age	7	.07	-.06
	11	-.08	.05
	15	-.07	.19

second dependent variable. None of the other Between- and Within-subject main effects or their interactions was significant for either dependent variable ($p > .10$)

In summary, when phi coefficient scores were used, the significant main effects of Sex, Order and the interaction of Age and Sex found for the simple difference scores (when difference between the hands scores was the dependent variable), did not appear. In fact, for phi coefficient scores there were no significant effects at the .05 level. However, marginally significant ($p < .10$) interactions of Sex x Order, Age x Block and Age x Sex x Block were found for the dependent variable of hand differences in initial response, whereas there were no significant main or interaction effects for this second dependent variable when simple difference scores were analyzed.

Scores Summed Across Hands

Overall accuracy in hand scores did not differ for boys and girls ($t < 1.0$). As Figures 8, 9, and 10 indicate, there was no obvious relationship between overall performance and whether an individual was better with one hand or the other.

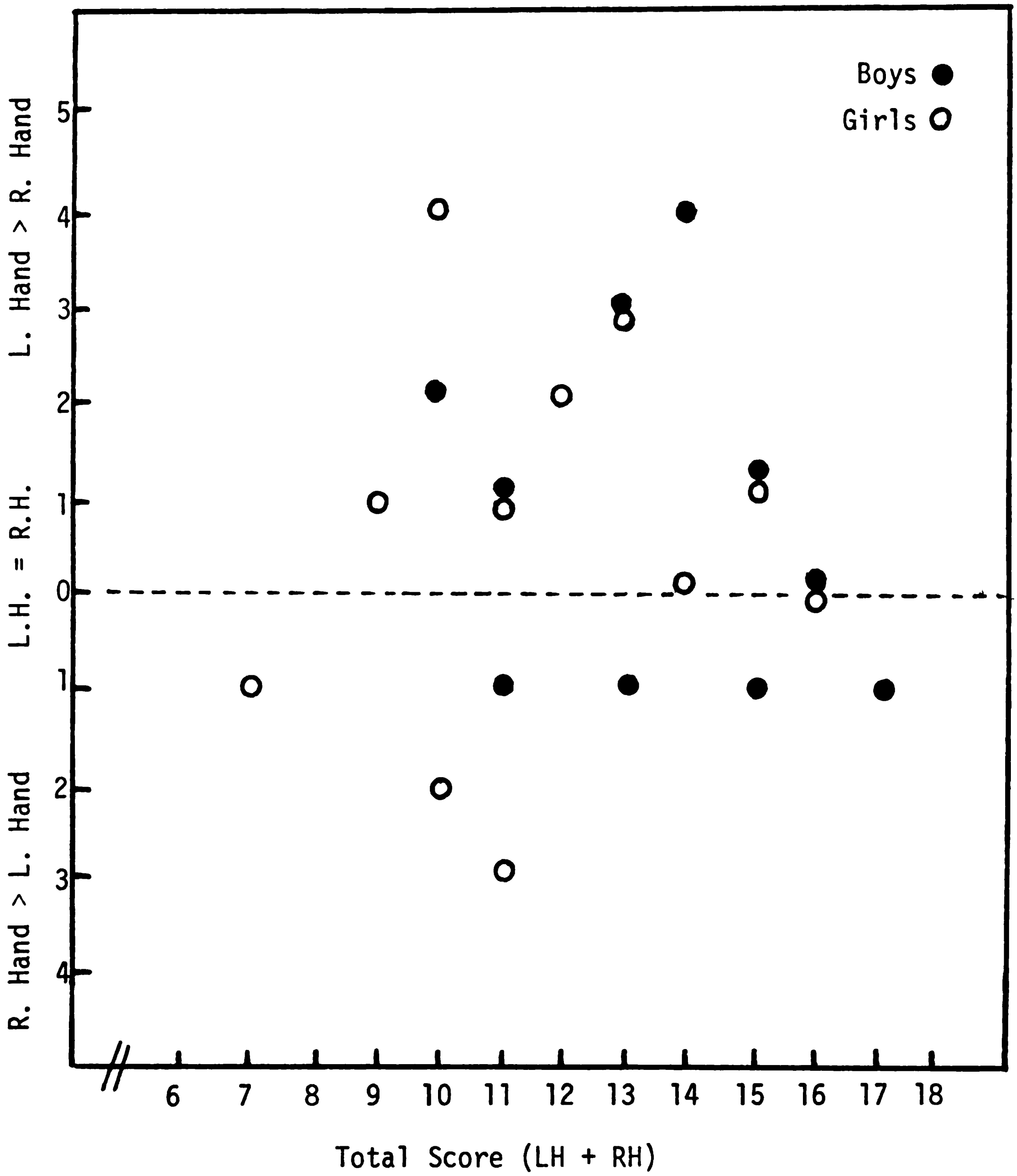

Figure 8.--Relationship between difference between-the-hands scores and total scores in 7-year-olds.

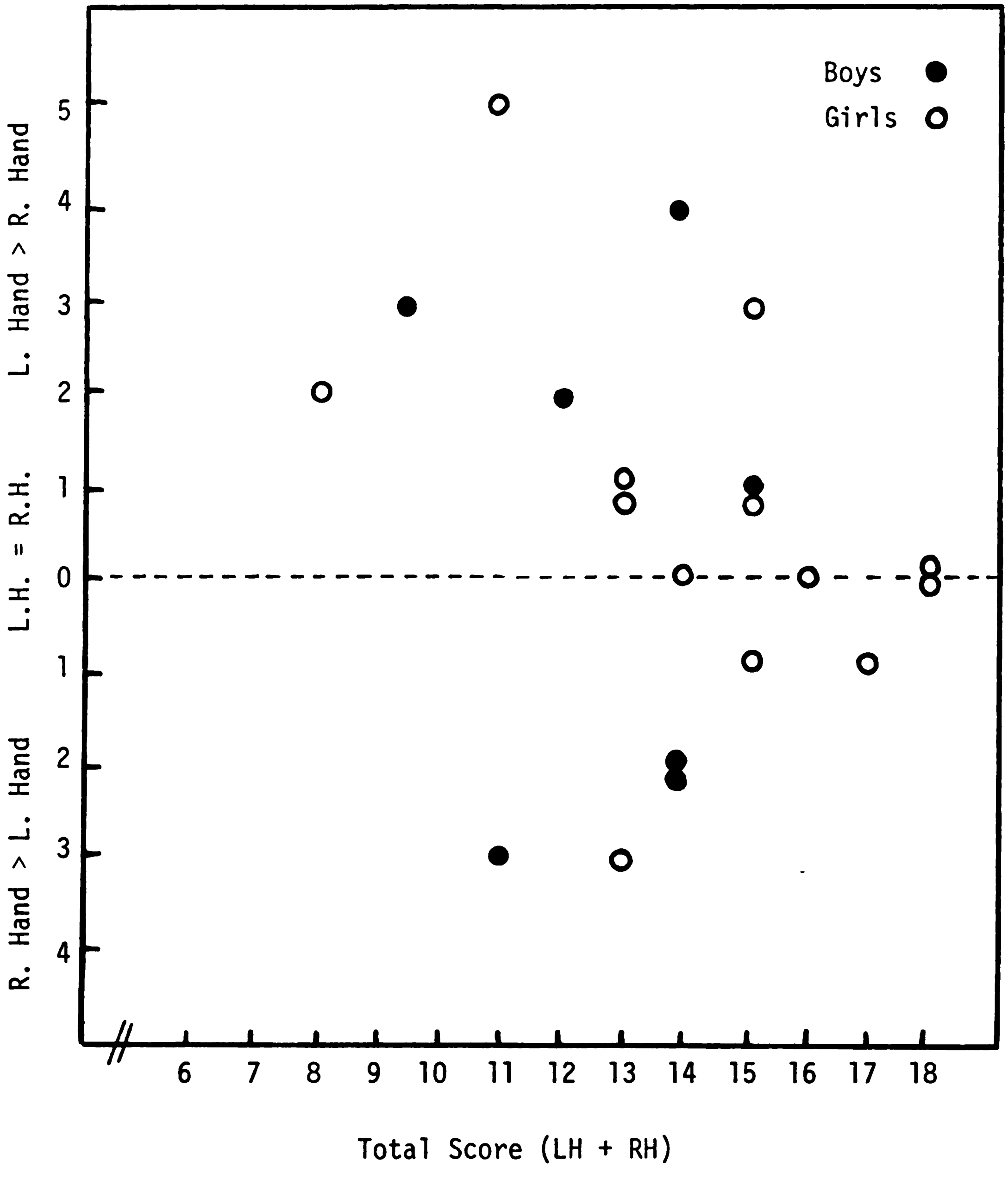

Figure 9.--Relationship between difference between-the-hands scores and total scores in 11-year-olds.

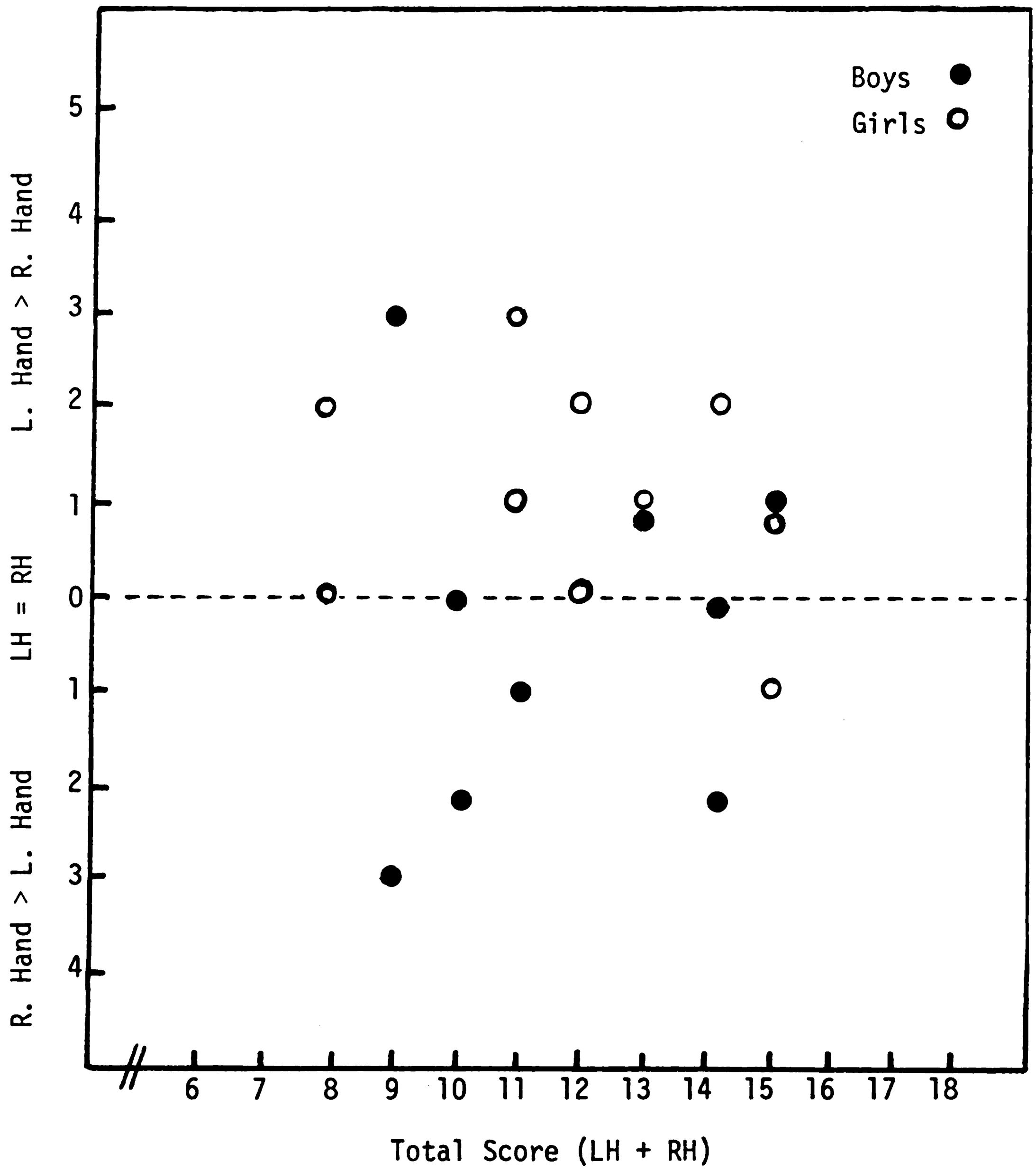

Figure 10.--Relationship between difference between-the-hands scores and total scores in 15-year-olds.

DISCUSSION

As we saw in the Introduction, since the dichhaptic perception task was first devised, several researchers have used this procedure with widely varying results. Some have found a significant left-hand advantage for both males and females (Cioffi & Kandel, 1979; Flanery & Balling, 1979); others have found a significant right-hand advantage for both sexes (LaBreche et al., 1977); still others have found a left-hand advantage for males, but not for some of the female groups (Witelson, 1975; Dawson et al., 1980); and one failed to find any significant hand differences (Cranney & Ashton, 1980).

The results of the current study do not seem to fit clearly with any of the others. The finding of no significant differences between average left and right hand scores (for all groups except one) in the present study, like the results of the Cranney and Ashton (1980) study, obviously are inconsistent with the original Witelson (1974) findings. The Cranney and Ashton (1980) scores, however, were in the direction of a right-hand advantage whereas in the present study, the average left hand score exceeded the right hand score in all groups except the oldest boys. If these left-hand advantages had reached significance, they would not be inconsistent with the results of the two groups who found overall left-hand superiority regardless of sex.

In any case, the current results do not support either Witelson's (1975) or Dawson et al.'s (1980) more recent finding of a sex difference in hand asymmetries on this task. For the seven- and 11-year-old groups, both boys and girls had greater left than right hand scores (though the difference was not significant). For the 15-year-olds, there was a sex difference, but it was the reverse of the direction expected. In this group girls did better with the left hand (the greatest and only significant hand score difference of any group) whereas the boys did better with the right. As already mentioned, this oldest age group probably accounts for most of the significant Sex effect in the ANOVA for simple difference scores. It is difficult to explain this pattern of results among the 15-year-olds in light of current ideas pertaining to the earlier maturation of and preference for right hemisphere modes of processing in males. The boys' right-hand advantage was slight (.34) and not significant ($t<1.0$). The significant left-hand advantage for the oldest girls and its absence in the younger girls is similar to Witelson's (1975) findings of no significant differences in hand scores in seven-, eight-, and 10-year-old girls and the emergence of a modest left-hand advantage at age 13. Thus, the girls' scores, considered alone, are consistent with Witelson's conjecture that in females, right hemisphere function for haptic perception of spatial forms may not mature until early adolescence.

Explanation of Differences in Dichhaptic Perception Studies

Attempts to explain the disparate findings of the groups using Witelson's dichhaptic task should focus on at least five crucial variables (see Table 11).

Table 11: Comparison of Procedures and Results in Studies Using the Dichhaptic Perception Task

	Left Hand Advantage				No Significant Hand Differences		Right Hand Advantage
	Sex Difference		No Sex Differences				
Researcher	Witelson (1976)	Dawson et al. (1980)	Flanery Balling(1979)	Cioffi and Kandel(1980)	Pomerantz (1980)	Cranney and Ashton(1979)	LaBreche et al. (1977)
NONVERBAL STIMULI	Witel-son's	Witelson's rotated in 4 different orientations	Own (randomly generated)	Witelson's	Own	Witelson's	Witelson's
SAMPLE SIZE	25/cell ('76) 9/cell ('74) Average	20/cell	8/cell	19/cell	10/cell	10/cell	12/cell
TYPE OF RESPONSE	Point with hand specified by experimen-ter	Verbal	tactile comparison	Point with each hand to shape felt with that hand	Point with either hand (not specified by experi-menter)	Point with left hand	Point with hand specified by experimenter)
NUMBER OF CHOICE STIMULI	6	6	-	?	5	6	6
AGE	6,8,10,13	6,12,adults	7,9,11,adults	7,9,11,12.5	7,11,15	7,11,4	17

Sample Size

First, the absence of significant hand differences for most groups in the present study and in Cranney and Ashton's (1980) study, in contrast to other studies, might be related to differences in sample size. The former two studies used 10 subjects per cell, whereas three studies finding significant differences had 19 or more (Dawson et al. (1980)--20/cell; Witelson (1975)--25/cell; Cioffi and Kandel (1979)--19/cell). Other researchers, however, found significant differences with sample sizes comparable to those used in the present study (Flanery & Balling (1979)--8/cell), so differences in sample size is a partial explanation at best.

Task Difficulty

The possibility that the task used in the current experiment was too difficult for some or many of the children is unlikely, since average scores for each hand over 10 trials ranged from 5.4 to 7.38, and these are significantly greater than the score expected by chance (=2). It seems equally unlikely that the task was too easy, since the shapes were generally more complex (had more sides) than Witelson's and Witelson's stimuli were used in the LaBreche et al. (1977) and Cioffi and Kandel (1979) studies in which significant hand asymmetries were found. It also may be that the use of five choice stimuli in the current study made the task easier than the other studies, most of which used six choice stimuli. However, the scores for each hand (for 10 trials) in most of the other investigations were similar in magnitude to those in the current study. Witelson's (1974) scores, for example, ranged from 4.5 to 7.0 (averages for each group); the range for each hand in the current study was 5.4 to 7.4.

Stimulus Attributes

The absence of a sex difference in the present study in contrast to the differences found by Witelson (1975) and Dawson et al. (1980) also might be attributable to differences in the stimuli used. As already noted, although Witelson (1974) designed her stimuli to minimize the possibility of verbal mediation occurring, many of her forms seemed easy to label, either in respect to certain features or taken as a whole. The stimuli in the current study were meant to improve upon Witelson's forms by being less easily subject to verbal mediation--more irregular and with fewer outstanding features. (These forms were designed, for the most part, however, in an intuitive, subjective way, and in at least one case, a subject was heard to say to himself that he was "trying to find the one (stimulus) with the sharp corner.") Flanery and Balling (1979) report having had the same aim in mind with their "randomly generated" figures. In neither their study nor the present one were sex differences found. So it may be that some of the girls in Witelson's (1975) experiment tended to process the forms in a manner that drew strongly on verbal mediation, and this information-processing strategy eliminated the left-hand advantage for girls. Thus, the use of stimuli which did not lend themselves easily to dual modes of processing may help account for the failure to find a sex difference in the present study as well as in Flanery and Balling's (1979) experiment.

As noted previously, overall accuracy in hand scores did not differ for boys and girls (t<1.0) and no relationship was found between overall performance and hand asymmetries. If the dichhaptic task and forms used in the present study were drawing upon processing skills associated primarily with the right hemisphere, one would expect to find higher overall scores in subjects showing a left-hand advantage. This was not the case.

In Witelson's (1975) study, boys and girls also had equal overall hand scores, although hand asymmetries appeared in boys and not in girls. If the stimuli and task are truly of a nonverbal nature, the spatial-configurational aspects of the test should put boys at an advantage, since males generally outperform females on tests of spatial ability (even tactual spatial tests such as tactual mazes). Dawson et al. (1980) used Witelson's stimuli, but rotated the shapes in four different orientations, and found a sex difference favoring boys. The requirement that the shapes be mentally rotated is a task which is one of the most consistent and reliable among spatial problems in producing better performance in males than females. Dawson et al.'s procedure therefore may have placed greater demands on the subjects' spatial skills than Witelson's (1975) or the present study, and a higher level of difficulty of the task may be a prerequisite for bringing out sex differences.

The previously mentioned study by Umilta et al. (1974) may be of relevance here. These researchers found a left-field advantage for discrimination of direction of lines presented tachistoscopically only when the task was of sufficient difficulty. Thus, both hemispheres may be capable of fairly easy spatial processing with the superiority of the right hemisphere for this function emerging only when a more demanding problem is presented.

Another explanation of the absence of a sex difference in hand asymmetries in the present study, therefore, is that the task was not of sufficient difficulty to produce left-hand advantages or to reveal the presumed underlying sex difference in spatial skill or right-hemisphere specialization for nonverbal, tactual perception.

If this is so, then how can we account for Witelson's (1975) finding of a sex difference in hand asymmetries but not in overall performance? It could be that the boys in her study merely attended more to the left hand than the right, though why this should occur in her study and not in the present one is not clear. (One possible explanation follows.)

The type of stimulus used does not by itself seem a sufficient explanation of the different results in the various studies named here. Others (Cioffi & Kandel, 1979; Cranney & Ashton, 1980; LaBreche et al., 1977) using Witelson's stimuli have found no sex differences and, in some cases, not even a left-hand superiority.

Type of Response

The type of response elicited in selecting the choice stimuli also might be responsible for producing some of the different outcomes for this experiment. Witelson (1974) found a left-hand advantage when subjects were instructed to point to the correct choice stimulus with their left hand but not when they were told to point with the right hand. Her procedure thus could have set up an attentional bias to the left hand which would create or contribute to a left-hand advantage. Dawson et al. (1980), who also found a left-hand advantage and a sex difference, had subjects name a number associated with the choice stimulus in the array. They implied (without documentation) that this response would not involve unilateral hemispheric activation. Nevertheless, any kind of verbal response might have set up a left hemisphere bias.

In the present study, the subject was not told which hand to use to point to the choice stimulus. If the dominant hand was the one preferred,this could have set up a left hemisphere activation, in turn tending to negate a left-hand advantage. Regrettably, the hand used in responding was not recorded by the experimenter. Flanery and Balling (1979) and Cioffi and Kandel (1980) used what may have been the most neutral kinds of responses, and found no sex differences for perception of nonsense shapes. The former study employed a tactile-comparison response and in the latter subjects pointed to the left-hand stimulus with the left hand and the right-hand stimulus with the right hand. Furthermore, as already noted, in the two studies which found a sex difference, the procedures used may have created a bias towards right-hemisphere processing. So, type of response used might have interacted with sex--setting up an attentional bias more reliably for one sex than the other.

It also is conceivable that type of response interacts with the stimulus employed to lessen or heighten asymmetries in tactual field scores or sex differences in performance.

Use of Linguistic Stimuli in Same Session

There are other possible confounding factors in these investigations. One is whether subjects were given letter forms as well as nonsense shapes to palpate in the same session (as they were in some studies). If there is any kind of difference in preferred strategy or mode of processing (verbal vs. spatial) between the sexes or between individuals, recent experience with a tactile-letter perception task might enhance such a difference. LaBreche et al. (1977), in fact, reported that right-hand advantages for recognition of nonsense shapes attained significance only for those subjects first exposed to letters.

Other Variables

There also seemed to be wide variation in the number of practice trials given (one study reported that a maximum of 25 trials were given, but did not specify an average and others do not report this at all). It seems that a longer period of practice might evoke differences in strategy preferences more reliably than a short one. Other extraneous variables might include whether tests for handedness were performed before or after the test trials and whether the situation was more stressful for the subject in some studies. Subjects under stress might tend to rely on one hemisphere more than the other, as suggested by studies of conjugate lateral eye movements (Gur, Gur, & Harris, 1975).

In summary, the results of the present experiment indicate the need for further study of the reliability and validity of the dichhaptic perception task as a measure of lateral specialization for haptic, spatial perception. It does lend modest support, at least for females, for the hypothesis that right hemisphere specialization for spatial-tactile discrimination increases in childhood.

The hypothesis of earlier right-hemisphere maturation in males than in females for tasks like dichhaptic perception of nonsense shapes is not supported by the current findings. Resolution of these issues awaits additional studies with more systematic control of such intervening variables as stimulus design and type of response. A more fine-grained approach to this task could provide valuable information both about age changes in cerebral specialization for tactile-spatial processes and changes in information-processing strategies.

APPENDICES

APPENDIX A

LETTER SENT TO PARENTS OF SUBJECTS

APPENDIX A

LETTER TO PARENTS OF SUBJECTS

Dear Parent:

I am a second year graduate student in developmental psychology at Michigan State University. As part of the requirement for my Master's thesis, I am conducting a study of children in the 1st, 5th, and 9th grades. The purpose of the study is to learn more about how children process information tactually (through sense of touch) and how such processes change over age. In practical terms this involves having the child feel two irregular-shaped styrofoam forms, hidden from view, and then try to identify the shapes from pictures of several different forms. I also need information about handedness and will obtain this by asking the child to perform a number of simple tasks--writing, throwing a ball, etc. Finally, the foot size of each child will be obtained to provide us with an index of maturation level.

The testing time for each child will be roughly 10 minutes and will take place in a classroom in your child's school.

The study is designed to look at the performance of groups of people (different age groups, males vs. females) and not individuals. Each child is completely anonymous once the data are collected, and the names of the children are not retained or used at any time after that.

The purpose and prodedures of the study will be carefully explained to the child. Participants will be assured that they can quit the experiment at any time. This research has been approved by the St. Johns school system. The Michigan State University Human Subjects Committee also has approved the project as complying with both Federal and University standards for ethical conduct of research.

The cooperation of you and your child in this study would be greatly appreciated. Thank you.

Sincerely,

Arthur Pomerantz

APPENDIX B

INSTRUCTIONS TO SUBJECT

APPENDIX B

Instructions to Subject

Hello. My name is Arthur Pomerantz. I'm a graduate student in psychology at Michigan State University and I'm doing an experiment to find out how well children can recognize objects that they've felt with their hands. I am going to ask you in a couple of minutes to put your hands through the two holes in this board (show board) and to feel a different object with each hand. You won't be able to see the objects because they will be behind this board. The objects are not familiar to you because they'll look something like this (show sample stimulus). I would like you to touch the shapes all over (thoroughly), moving both your hands at the same time. (Experimenter demonstrates, palpating two nonsense shapes simultaneously.) (Let child try it.) Try to form a picture in your mind of what the two shapes look like.

After you have felt the two objects for 10 seconds--I'll tell you when the time is up--take your hands out of the holes in the board. Then I will show you a picture of a group of objects. In this group there will be the two objects you've just been touching and a few that you were feeling (show sample picture of 5 choice stimuli). I want you to point to the pictures of the two objects you have been feeling through the board. If you are not sure which ones they are, make the best guess you can. Do you have any questions? If you have any questions, ask me. O.K. Let's try the first set of shapes.

REFERENCES

References

Annett, M. The growth of manual preference and speed. British Journal of Psychology, 1970, 61, 545-558.

Benton, A.L., Levin, H.S., & Varney, N.R. Tactile perception of direction in normal subjects. Neurology, Minneapolis, 1973, 23, 1248-1250.

Bogen, J.E. The other side of the brain: II. An appositional mind. Bulletin of the Los Angeles Neurological Society, 1969, 34, 135-162 (cited in Corballis, M. & Beale, I., 1976).

Boll, T.J. Right and left cerebral hemisphere damage and tactile perception. Neurophschologia, 1974, 12, 235-238.

Briggs, G.G., Nebes, R.D., & Kinsborne, M. Intellectual difference in relation to personal and family handedness. Quarterly Journal of Experimental Psychology, 1976, 28, 591-601.

Brinkman, J., & Kuypers, H.G.J.M. Splitbrain monkeys: cerebral control of ipsilateral and contralateral arm, hand, and finger movements. Science, 1972, 176, 536-539.

Broverman, D.M., Klaiber, E.L., Kobayashi, Y. & Vogel, W. Roles of activation and inhibition in sex differences in cognitive abilities. Psychological Review, 1968, 75, 23-50.

Buffery, A.W.H. Sex differences in the development of hemispheric asymmetry of function in the human brain. Brain, 1971, 31, 364-365.

Caplan, P.J. & Kinsbourne, M. Baby drops the rattle: asymmetry of duration of grasp by infants. Child Development, 1976, 47, 532-535.

Carmon, A., Belstrom, D.E. & Benton, A.L. Thresholds for pressure and sharpness in the right and left hands. Cortex, 1969, 5, 27-35.

Cioffi, J., & Kandel, G.L. Laterality of stereognostic accuracy of children for words, shapes, and bigrams: a sex difference for bigrams. Science, 1979, 204, 1432-1434.

Corballis, M.C. & Beale, I.L. The psychology of left and right. Lawrence Erlbaum Associates, Hillsdale, N.J., 1976.

Corkin, S., Milner, B. & Rasmussen, T. Effects of different cortical excisions on sensory thresholds in man. Transactions of the American Neurological Association, 1964, 112, 89.

Cranney, J., & Ashton, R. Witelson's dichhaptic as a measure of hemispheric asymmetry in deaf and hearing populations. Neuropsychologia, 1980, 18 95-98.

Critchley, M. The parietal lobes. Hafner Publishing Co., New York, 1953.

Dennis, M., & Whitaker, H.A. Hemispheric equipotentiality and language acquisition. In S. Segalowitz and F. Gruber, (Eds.), Language Development and Neurological Theory. New York: Academic Press, 1977, 93-106.

DeRenzi, E. & Scotti, G. The influence of spatial disorders in impairing tactual discrimination of shapes. Cortex, 1969, 5, 53-62.

Durnford, M. & Kimura, D. Right hemishpere specialization for depth perception reflected in visual field differences. Nature, 1971, 231, 394-395.

Entus, A.K. Hemispheric asymmetry in processing of dichotically presented speech and nonspeech sounds of infants. Paper presented at symposium, "Functional specialization of the cerebral hemishperes in infants and children: new experimental and clinical evidence." L.J. Harris, Chm., Society for Research in Child Development, Denver, Colorado, 13, April 1975 (cited in Harris, L.J., 1977, in press).

Fagan-Dubin, I. Lateral dominance and development of cerebral specialization. Cortex, 1974, 10, 69-74.

Feinberg, R., & Harris, L.J. Sex and handedness differences in braille letter learning. Unpublished research, Michigan State University, 1975 (cited in Wagner, N.M. & Harris, L.J., 1976).

Flanery, R.C. & Balling, J.D. Developmental changes in hemispheric specialization for tactile spatial ability. Developmental Psychology, 1979, 15, 364-372.

Flavell, J.H. Developmental studies of mediated memory. In L.P. Lipsitt and H.W. Reese (Eds.), Advances in Child Development and Behavior (Vol.5). New York: Academic Press, 1970.

Fontenot, D.J. & Benton, A.L. Tactile perception of direction in relation to hemispheric locus of lesion, Neuropsychologia, 1971, 9, 83-88.

Franco, L. & Sperry, R.W. Hemisphere lateralization for cognitive processing of geometry. Neuropsychologia, 1977, 15, 107-114.

Gardner, L.P. Experimental data on the problem of sensory lateral dominance in feet and hands. Psychological Records, 1942, 5, 65-124.

Gates, A. & Bradshaw, J.L. The role of the cerebral hemispheres in music. Brain and Language, 1977, 3, 403-431.

Geffen, G., Bradshaw, J.L. & Wallace, G. Interhemispheric effects on reaction time to verbal and nonverbal stimuli. Journal of Experimental Psychology, 1971, 87, 415-422.

Gesell, A. & Ames, L.B. The development of handedness. The Journal of Genetic Psychology, 1947, 70, 155-175.

Ghent, L. Developemntal changes in tactual thresholds on dominant and nondominant sides. Journal of Comparative and Physiological Psychology, 1961, 54, 670-673.

Glanville, B.B., Best, C.T. & Levenson, R. A cardiac measure of cerebral asymmetries in infant auditory perception. Developmental Psychology, 1977, 13, 54-60.

Goldman, P.S., Crawford, & Stokes. Science, 1974, 186, 540.

Gordon, H.W. Hemispheric asymmetries in the perception of musical chords. Cortex, 1970, 6, 387-398.

Gur, R.E., Gur, R.C. & Harris, L.J. Cerebral activation, as measured by subject's lateral eye movements is influenced by experimentor location. Neuropsychologia, 1974, 12, 213-220.

Hardych, C. Handedness and part-whole relationships: a replication. Cortex, 1977, 13, 177-180.

Hardych, C., Petrinovich, L. & Goldman, R. Left-handedness and cognitive deficit. Cortex, 1976, 12, 266-278.

Harris, A.J. Harris tests of lateral dominance (3rd Ed.). New York: Psychology Corp., 1958.

Harris, L.J. Sex differences in the growth and use of language. In E. Donelson and J. Gullahorn, (Eds.) Women: A psychological Perspective. New York: John Wiley and Sons., 1977, pp. 79-94.

Harris, L.J. Sex differences in spatial ability: Possible environmental, genetic, and neurological factors. In M. Kinsbourne, (Ed.), Hemispheric Asymmetries of Function. Cambridge, England: Cambridge University Press, 1978, 405-522.

Harris, L.J., Wagner, N.M., & Wilkinson, J. Paper presented at the XXI International Congress on Psychology. Paris, France, June 1976, 24-26.

Harris, L.J. & Witelson, S.F. The analysis of congnitive processes in children through the study of hemispheric specialization in different perceptual systems. Society for Research in Child Development, New Orleans, Louisana, March 17, 1977.

Hawn, P. Hand asymmetries in grasp duration and reaching in two- and five-month old human infants. Unpublished Master's Thesis, Michigan State University, 1978.

Heim, A.W. & Watts, K.P. Handedness and cognitive bias. Quarterly Journal of Experimental Psychology, 1976, 28, 355-360.

Hermelin, B. & O'Connor, N. Right and left handed reading of braille. Nature, 1971, 231, 470.

Hiscock, M. & Kinsbourne, M. Selective listening asymmetry in preschool children. Developmental Psychology, 1977, 13, 217,224.

Jackson, J.H. On the nature of the duality of the brain. In J. Taylor (Ed.), Selected writings of John Hughlings Jackson. London: Hodder and Stroughton, 1932, 129-145.

Kail, R. & Siegel, A. Sex and hemispheric differences in the recall of verbal and spatial information. Cortex, 1978, 14, 557-563.

Kimura, D. Spatial localization in left and right visual fields. Canadian Journal of Psychology, 1969, 23, 445-448.

Kimura, D. & Durnford, M. Normal studies on the function of the right hemisphere in vision. In S.J. Dimond and J.G. Beaumont (Eds.), Hemisphere function in the human brain. London: Elek Science, 1974, 25-47.

Kinsbourne, M. The ontogeny of cerebral dominance. Annals New York Academy of Sciences, 1975, 263, 244-250.

Knox, C. & Kimura, D. Cerebral processing of nonverbal fields. Canadian Journal of Psychology, 1969, 23, 445-448.

Kuhn, G.M. The phi coefficient as an index of ear differences in dichotic listening. Cortex, 1976, 12, 450-457.

LaBreache, T.M., Manning, A.A., Goble, W. & Markman, R. Hemispheric specialization for linguistic and nonlinguistic tactual perception in a congenitally deaf population. Cortex, 1977, 13, 184-194.

Lake, D.A. & Bryden, M.P. Handedness and sex differences in hemispheric asymmetry. Brain and Language, 1976, 3, 266-282.

Lansdell, H. The effect of neurosurgery on a test of proverbs. American Psychologist, 1961, 16, 448.

Lansdell, H. A sex difference in effect of temporal lobe neurosurgery on design preference. Nature, 1962, 194, 852-854.

Lenneberg, E. Biological foundations of language. New York: J. Wiley, 1967.

Levy, J. Possible basis for the evolution of lateral specialization of the human brain. Nature, 1969, 224, 614-615.

Levy, J. & Levy, J.M. Human lateralization from head to foot: sex related factors. Science, 1978, 200, 1291-1292.

Levi-Agresti, J. & Sperry, R.W. Differential perceptual capacities in major and minor hemispheres. Proceedings of the National Academy of Sciences, 1968, 61, 1151.

McGlone, J. Sex differences in functional brain asymmetry. Cortex, 1978, 14, 122-128.

McGlone, J. & Davidson, W. The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. Neuropsychologia, 1973, 11, 105-113.

Maccoby, E.J. & Jacklin, C.N. The psychology of sex differences. Stanford, Calif.: Stanford University Press, 1974.

Marcel, T. & Rajan, P. Lateral specialization for recognition of words and faces in good and poor readers. Neuropsychologia, 1975, 13, 489-497.

Mellone, M.A. A factorial study of picture tests for young children. British Journal of Psychology, 1944, 35, 9-16 (cited in Harris, L.J., 1977, in press).

Milner, B. & Taylor, L. Right hemisphere superiority in tactile pattern-recognition after cerebral commissurotomy: evidence for nonverbal memory. Neuropsychologia, 1972, 10, 1-15.

Milner, B. Interhemispheric differences in the localization of psychological processes in man. British Medical Bulletin, 1971, 27, 272-277.

Molfese, D.L. Cerebral asymmetry in infants, children, and adults: auditory evoked responses to speech and noise stimuli. Unpublished doctoral dissertation, Pennsylvania State University, 1973, (cited in Harris, L.J., 1977, in press).

Nebes, R.D. Superiority of the minor hemisphere in commissurotimized man for the perception of part-whole relations. Cortex, 1971a, 7, 333-349.

Nebes, R.D. Handedness and the perception of part-whole relationship. Cortex, 1971b, 7, 350-356.

Newcombe, F. & Ratcliff, G. Handedness, speech lateralization and ability. Neuropsychologia, 1973, 11, 399-407.

Piazza, D. Cerbral lateralization in young children as measured by dichotic listening and finger tapping tasks. Neuropsychologia, 1977, 15, 417-426.

Pirozollo, F.J. & Rayner, K. Hemispheric specialization in reading and word recognition. Brain and Language, 1977, 4, 248-261.

Rudel, R.G., Denckla, M.B. & Spalten, E. The functional asymmetry braille letter learning in normal, sighted children. Neurology, Minneapolis, 1974, 24, 733-738.

St. James-Roberts, I. Neurological plasticity, recovery from brain insult, and child development. In H.W. Reese and L.P. Lipsitt (Eds.), Advances in child development and behavior. New York: Academic Press, 1979, 253-319.

Schwartz, J. & Tallal, P. Rate of acoustic change may underlie hemispheric specialization for speech perception. Science, 1980, 207, 1380-1381.

Semmes, J. A nontactual factor in astereognosis,Neuropsychologia, 1965, 295-315.

Semmes, J. Hemispheric specialization: a possible clue to mechanism. Neuropsychologia, 1968, 6, 11-26.

Semmes, J., Weinstein, S. Ghent, L. & Teuber, H.L. Somatosensory changes after penetrating brain wounds in men. Harvard University Press, Cambridge, 1960.

Shepard, R.N. & Metzer, J. Mental rotation of three-dimensional objects, Science, 1971, 171, 701-703.

Shucard, J.L., Shucard, D.W., Cummins, K.R. & Campos, J.J. Auditory evoked potentials and sex-related differences in brain development. Paper presented at Biennial Meetings of the Society for Research in Child Development, San Francisco, Calif., 1979.

Smith, J.M. Which hand is the eye of the blind? Genetic Psychological Monographs, 1929, 5, 209-252.

Studdert-Kennedy, M. & Shankweiler, D. Hemispheric specialization for speech perception. Journal of the Acoustic Society of America, 1970, 48, 579-594.

Turkewitz, G. The development of lateral differentiation in the human infant. Annals New York Academy of Sciences, 1976 264, 225-238.

Umilta, C. Rizzolatti, G., Marzi, A. Zamboni, G., Franzini, C., Camarada, R., & Berlucchi, G. Hemispheric differences in the discrimination of line orientation. Neuropsychologia, 1974, 12, 165-174.

Varney, N.R. & Benton, A.L. Tactile perception of direction in relation to handedness and familial handedness. Neuropsychologia, 1975, 13, 449-454.

Wagner, N.M. & Harris, L.J. Hand differences in learning braille-like letters in sighted children and adults. Unpublished manuscript, Michigan State University, 1976.

Wagner, N.M. & Harris, L.J. Hand asymmetries in braille learning in sighted nine- and 11-year-olds: a cautionary note on sex differences. Paper presented at Biennial Meetings of the Society for Research in Child Development, San Francisco, March 16, 1979.

Weinstein, S. & Sersen, E.A. Tactual sensitivity as a function of handedness and laterality. Journal of Comparative and Physiological Psychology, 1961, 54, 665-669.

Witelson, S.F. Hemispheric specialization for linguistic and non-linguistic tactual perception using a dichotomus stimulation technique. Cortex, 1974, 10, 3-17.

Witelson, S.F. Age and sex differences in the development of right hemispheric specialization for spatial processing as reflected in a dichotomous tactual stimulation task. Paper presented as part of a symposium, "Functional specialization of the cerebral hemispheres in infants and children: new experimental and clinical evidence." L.J. Harris, Chm., Society for Research in Child Development, Denver, Colorado, April 13, 1975.

Witelson, S.F. Sex and the single hemisphere: specialization of the right hemisphere for spatial processing, Science, 1976, 193, 425-426.

Wolff, P. & Hurwitz, I. Sex differences in finger tapping: a developmental study. Neuropsychologia, 1976, 14, 35-41.

Zoccolotti, P. & Oltman, P.K. Field dependence and lateralization of verbal and configurational processing. Cortex, 1978, 14, 155-163.

MICHIGAN STATE UNIV. LIBRARIES
31293008149944