DEVELOPMENTAL STUDY OF SEX DIFFERENCES IN SPATIAL, VERBAL, AND LOGICAL REASONING ABILITY

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CHAPTER I

INTRODUCTION AND REVIEW OF LITERATURE

Over the past several decades, investigators have consistently found that the sexes differ on a variety of cognitive measures. Where differences are found, females typically excel on measures of articulation, verbal fluency, and perceptual speed and accuracy whereas males excel in the areas of mathematical ability and spatial ability including field independence. Recent studies reveal indications of a sex difference in favor of males on measures of logical reasoning, particularly at higher levels of functioning.

Spatial ability is generally recognized as the most consistent and pronounced sex difference in cognitive ability and has been linked to sex differences in other cognitive abilities. Little is known about the relationship between spatial and verbal ability and functioning or how the female verbal-ability advantage and the male spatial-ability advantage are related to the development of logical thinking ability.

Due to the apparent importance of spatial ability in cognitive functioning, it is the primary focus of the review of the literature. The review includes a brief discussion of some of the problems encountered in measuring and defining spatial ability. A selective review of the evidence for sex differences in cognitive abilities follows. The relationship between spatial ability and other cognitive abilities is discussed. In keeping with the developmental focus of the present study, factors that appear to be involved in the maturation and organization of cognitive abilities are also considered. Finally, possible biological and environmental determinants of performance on cognitive measures are briefly reviewed. In order to present an overview of the nature-nuture controversy, all factors known to the author to affect cognitive functioning are presented. However, the discussion focuses mainly on those factors most relevant to the present study.

Considerations in Defining and Measuring Spatial Ability

Interest in spatial ability can be traced to Thorndike's observation in the early 1920's that performance on a block counting task did not correlate highly with what was called general intelligence. Over the years, the concept of spatial ability has come to cover a wide range of skills including auditory localization, perceptual closure, visual discrimination, and non-verbal reasoning. Spatial ability has been measured by an equally wide variety of tests (Fairweather, 1976; Myers, 1967).

The Problem of Definition

Some investigators have suggested that spatial ability is comprised of several distinguishable factors. For example, French (1951) identified three factors which he termed perceptual, orientation, and visualization. Spatial perception was defined as the ability to perceive and compare spatial patterns accurately and orientation as the ability to remain unconfused by the presentation of the pattern in various orientations. The ability to manipulate objects mentally was referred to as spatial visualization.

Other researchers have argued that French's three factors are not separate abilities but rather artifacts of differing degrees of complexity or organization required in spatial problem-solving tasks (Eliot and Fralley, 1976). A comparison of tests designed to measure different spatial factors revealed that correlations were higher between measures of different factors by the same author than between measures by different authors that reportedly tap the same factor (Borich and Bauman, 1972).

Eliot (Eliot and Salkind, 1975) suggested that the lack of knowledge about spatial ability necessitates the use of a definition that incorporates various meanings. Imagery has been linked to spatial representation. According to Durio (1976), imagery is both product and process and "can be involved in all decoding, encoding, and cognitive construction processes of figural or spatial content (p. 234)." For the purposes of the present paper, the term spatial ability is used in a general way to encompass all factors associated with the representation of space.

The Problem of Measurement

The measurement of spatial ability is complicated by several problems. One of these is prevalent use of inappropriate and inadequate instruments. Vandenberg (1975) has questioned the widespread use of paper-and-pencil measures and recommended that we should follow Piaget and others and design "performance" tests of spatial ability.

Vandenberg stressed the need for new and better measures of children's spatial ability. The failure to find sex differences prior to adolescence may be due to this lack of appropriate measures for young children (Eliot and Salkind, 1975; Fairweather, 1976).

Vandenberg (1975) also cautioned that some tests, which have been inappropriately labeled as spatial, actually require minimal if any spatial ability. He cited Raven's Progressive Matrices, various form boards, mazes, and the Kohs blocks as examples of tests which may be solved verbally. Results obtained with such tests may have contributed to the conflicting findings concerning sex differences on spatial measures.

Most studies of sex differences in spatial ability have focused on the phenomenon of sex differences per se (Eliot and Fralley, 1976). This approach has contributed little to our understanding of how spatial ability interacts with or influences other cognitive processes.

It is not possible to overcome or correct all of these measurement problems in one study. The design of the present study will be influenced by the apparent need for a developmental and multivariant approach, as well as the need to explore active (performance) versus paper-and-pencil measures of ability.

Developmental Sex Differences in Cognitive Abilities

There is considerable evidence to show that sex differences exist in spatial ability and in several other abilities such as mathematical ability, verbal ability, and logical thinking ability which have been linked to spatial ability. Any general discussion of sex differences in the cognitive area must be tempered by developmental considerations. Tasks and situations that provide a basis for prediction of superior performance by one sex at one age might lead to predictions of no difference between the sexes at another age and even a reversal of the sex difference at still another age.

What follows is primarily a review of the evidence for developmental sex differences in several cognitive abilities. The discussion will include some evidence for the existence of sex differences per se, as well as findings on the relationship between spatial ability and other cognitive abilities.

Spatial Ability

Evidence of male superiority over females in tasks that measure spatial ability is plentiful (Anastasi, 1958; Garai and Scheinfeld, 1968; Kagan and Kogan, 1970; Kogan, 1972; Maccoby, 1966; Maccoby and Jacklin, 1974; Sherman, 1967; and Tyler, 1965). A male advantage in spatial ability has been observed in the Stanford Binet (Buffery and Gray, 1972) and the Wechsler intelligence tests (Hutt, 1972), as measured by performance on the block design, object assembly, and picture completion subscales.

Yen (1975) found males more proficient than females on other measures of spatial ability such as form boards, mental rotations, and paper folding. Guilford (1967) in a summary of factorial studies of sex differences concluded that males score higher than females on the Street Gestalt Completion, the Guilford-Zimmerman Spatial Orientation, the Guilford-Zimmerman Spatial Visualization, Porteus Maze, Match Problems and Gottschaldt Embedded Figures.

According to Maccoby and Jacklin (1974), spatial ability is the most consistent and differentiating ability between the sexes.

> Male superiority on visual-spatial tasks is fairly consistently found in adolescence and adulthood but not in childhood. The male advantage on spatial tests increases through high school years up to a level of about .40 of a standard deviation (pp. 351-352).

Cohen (1976) investigated sex differences in spatial orientation and spatial visualization in elderly men and women. Males scored higher than females on both measures. Both sexes were low on the ability to imagine spatial displacement or movement in reference to an outside figure.

Field Independence

Field independence has been identified as a critical dimension in problem-solving ability (Maccoby and Jacklin, 1974). A number of investigators have found sex differences in favor of males on various measures of field independence in subjects from eight years of age through adulthood (Anastasi, 1958; Kagan and Kogan, 1970; Sherman, 1967; and Tyler, 1965). Females have been found to be more field independent than males in a few studies of preschool children (Coates, 1972; 1974).

Witkin (1954) reported that males are better than females on the Rod and Frame Test (RFT) which is one measure of field independence. The subject is seated in a special chair in a totally dark room and presented with an illuminated rod and frame, each of which can be manipulated independently. The experimenter tilts either the frame or the chair or both and asks the subject to adjust the rod to the vertical position. The perceptually-bound (field dependent) individual takes an overall, Gestalt-like orientation as compared to the field independent person who responds analytically to the situation, or to portions of the problem in isolation from the total context.

Some conflicting findings have been reported. For example, Pitbaldo (1976) in a study which involved vertical adjustment of a luminous line while viewing it from a laterally titled body position found that women performed as well as men.

Problem-Solving Ability and Strategies

Allen (1974) in a study of sex differences in spatial problem-solving styles found that spatial tests elicit different problem-solving strategies which may not be equally efficient. Males reported using strategies that were judged to be more efficient and more abstract than those reported by females. According to their reports, females switched to more concrete methods or to guessing after attempting unsuccessfully to use more abstract stragegies.

Guttentag (1973) looked at sex differences in the use of sequential and parallel strategies in problem-solving. The sequential strategy required using a single search rule whereas the parallel strategy required use of multiple search rules. Sequential processing is thought to be analytical and verbal in nature whereas parallel processing is spatial or synthetic. Men were significantly more efficient than women in using both strategies. Both sexes were better in parallel processing than in sequential processing.

Sex differences were reported in one investigation of developmental changes in strategies used to solve permutation problems (Leskow and Smock, 1970). Males and females at 12, 15, and 18 years of age were given five tasks varying on representational level (symbolic and object) and associative structure either ordered or unordered. No effect of age was found for males on tasks involving objects or for females on tasks involving symbolic patterns. Males scored higher than females on both the ordered and unordered tasks involving objects, significantly higher on the symbolic, ordered task, and about the same on the symbolic, unordered task. Sex differences were attributed to the type of strategies used rather than to differences in cognitive competence.

Males were also reported to have greater breadth of categorization, another aspect of analytic ability, in subjects ranging from children age eight to adults (Crandall, 1965; Kogan and Wallach, 1964; Pettigrew, 1958; Wallach and Caron, 1959; and Wallach and Kogan, 1965).

According to Maccoby and Jacklin (1974), boys are not more analytical than girls. However, Keller (1975) reports a trend in favor of males. He found the difference between boys and girls in analytic responses increased from first to third grade. Seven- and eight-year-old boys gave more analytical responses on the Conceptual Style Test than females, and scored higher on the Children's Embedded Figures Test (CEFT) (Stanes and Gordon, 1973).

Logical Thinking Ability

Hutt (1972) has claimed that males are superior on tasks involving reasoning or logical manipulation of concepts regardless of the problem content. Fennema (1974) concluded that when sex differences in cognitive function are found, boys are favored on measures that deal with "higher level cognitive tasks" and girls are favored when "lower level cognitive tasks" are tapped.

Piaget (1967) proposed four stages in the development of logical thought and behavior: sensorimotor, preoperational, concrete operations, and formal operations. Each new stage rooted in a previous stage and continued into the next stage, reflects a change in the way in which the child organizes and adapts to the environment. According to Piaget's theory of logical thinking, both synthetic and analytic processing are involved in logical thinking.

Recent studies revealed indications of a sex difference in favor of males on Piagetian tasks (Graybill, 1975; Keating and Schaefer, 1975; Lawson, 1975; Ross, 1976; and Thomas, Jamison, and Hummel, 1973). The male advantage is most apparent in the transition from concrete to formal operations and at high ability levels (Keating and Schaefer, 1975). Graybill (1975) found that girls begin to lag behind boys in logical ability at about 11 years of age and fall further behind boys at ages 13 and 15. None of the females in Graybill's study were functioning at the formal thought level, although they had been identified as highly successful students.

These findings are interesting in light of a statement by Inhelder (Tanner and Inhelder, 1958) regarding a male advantage.

> If we compare two groups of boys and girls of the same age we do not in fact observe any significant differences in the development of logical functions. On the other hand we note slight differences in the formation of spatial representation, for example when it is a question of transformations and development of geometric solids. Moreover, we note that these differences which are very little pronounced among young children, take on greater importance with age (p. 63).

Mathematical Ability

The sexes do not differ greatly in their ability to master quantitative skills and concepts prior to age 10 or 11, at which age males begin to excel on mathematical measures (Aiken, 1971; Leder, 1974; and Maccoby and Jacklin, 1974). A National Assessment of Educational Progress (NAEP) (1976) report on eight learning areas showed that males generally do better in mathematics than females at several ages. At age nine, females and males were found to have equal ability in addition, subtraction, multiplication, and division, but males were superior on geometry and measurement. At age 13, females and males were equal on consumer mathematics as well as variables and relationships but males scored higher on measures of probability and statistics and increased their advantage on measures of geometry and measurement. By age 17, males outperformed females in all mathematical content areas assessed.

Hilton and Berglund (1974) conducted a longitudinal study of sex differences in mathematical achievement. They administered the Sequential Test for Educational Progress (STEP) and School and College Achievement Test (SCAT) tests to a nationwide sample of fifth grade children and then again when the students were in the seventh, ninth, and eleventh grades. They divided the students into two groups, those with high "academic achievement orientation and curriculum" and those with "practical orientation and curriculum." The number of mathematics courses was held constant for males and females within the two groups. Analysis of the fifth grade scores revealed no sex difference in the mean scores, however, those students who were later identified as academically oriented had higher mean scores than the practical orientation group. Results of the subsequent testing at higher grade levels revealed that males had successively higher mean scores than females in both academic groups. Similarly, data from Project Talent cited in

Maccoby and Jacklin (1974), which equated the sexes on the number of mathematics courses taken, revealed that males had substantially higher average scores on mathematical measures.

The Graduate Record Examination (GRE) developed for senior undergraduates has different norms for the sexes for mathematical and verbal tasks. While the mathematical norms show a large difference favoring males, the verbal norms show only a slight difference favoring females.

Verbal-Linguistic Ability

Support for the conclusion that women are superior to men in at least some verbal skills is strong but not without conflicting evidence (Broverman, Klaiber, Kobayashi, and Vogel, 1968; Fairweather, 1976; Garai and Scheinfeld, 1968; and Hutt, 1972). The sex difference on verbal measures is not as great as the sex difference in spatial ability (Maccoby and Jacklin, 1974).

Moore (1967) concluded that linguistic development runs a steadier course from infancy on for females. He also reported that linguistic measures administered as early as 18 months of age were highly predictive of IQ at later ages for females but not for males. The development of the sex difference in verbal ability appears to follow a pattern different from that for spatial, analytical, logical thinking, and mathematical ability which peak during adolescence.

Females read better than boys at ages 9, 13, and 17 and faster at ages 9 and 13 (NAEP, 1976). Gunderson (1976) cites findings that suggest that boys have more reading problems than girls. Over ninety percent of the children referred to reading clinics in the United States are males. Stevenson, Parker, Wilkinson, Hegion and Fish (1976) found that reading was more dependent upon memory than on either language development or abilities tapped by Piagetian tasks.

Organization of Cognitive Abilities

The pattern of cognitive abilities changes both quantitatively and qualitatively with age and by sex (Anastasi, 1974; Very and Iacono, 1970). The organization of cognitive abilities follows the general pattern described by Werner (1948). That is, cognitive functioning changes from a global, undifferentiated ability into a complex pattern of differentiated abilities.

Very and Iacono (1970) administered a battery of 27 tests including measures of inductive reasoning, deductive reasoning, estimative ability, numerical facility, perceptual speed, spatial relations, verbal and mathematics achievement to 203 seventh graders. Factor analysis yielded five cognitive factors for females and seven for males. Very and Iacono noted that the female factors were less clearly defined than the male factors. The male factors had either higher loadings and/or more appropriate tests loading, that is, a greater number of tests designed to measure a specific characteristic. In prior research, Very (1967) obtained 8 factors for females and 10 factors for males at the college level. They interpreted these findings to mean that qualitatively, the male pattern of abilities differentiates earlier and to a greater extent than the female pattern. Quantitatively, females scored as well or better than males on some measures.

There is evidence which suggests that the more clearly differentiated abilities for each sex are those in which that sex excels (Anastasi, 1974; Hyde, Geringer, and Yen, 1975). Typically, females excel on verbal tests and exhibit higher intercorrelations between verbal measures and lower correlations between verbal and other types of measures. On the other hand, males exhibit evidence of trait differentiation on mathematical and spatial measures (Anastasi, 1974).

A case in point is the Hyde et al. (1975) study. A battery of tests including measures of spatial ability, field independence, non-geometrical mathematical problem-solving, vocabulary, creativity, and achievement motivation were administered to 81 college undergraduates. Factor structures, based on correlation matrices and common-factor analysis were compared for females, males, and the total sample. Spatial ability, field independence, and mental arithmetic measures loaded on a spatial ability factor for the pooled sample. The relationship between spatial ability and field independence and mental arithmetic was stronger for males than for females as indicated by both correlational and factor analyses. Sex differences in the factor structure were interpreted to be due for the most part to a spatial factor. Spatial ability appeared to be related to a wider variety of tasks for males than for females.

Relationship of Spatial Ability to Other Cognitive Abilities and Processes

It appears that when spatial ability is controlled, sex differences on a variety of tasks disappear. Geringer and Hyde (1976) reported that sex differences on the Piagetian water-level task disappeared when the spatial ability of fifth and twelfth graders was controlled. Similarly, Sweeney (1953) found no sex differences in problem-solving and mathematical ability when subjects were equated on a test of spatial visualization. Hyde et al. (1975) eliminated significant sex differences in the Rod and Frame Test and mental arithmetic by controlling for spatial ability. Leskow and Smock (1970) equated males and females on both nonverbal ability and arithmetic achievement but still found sex differences in the ability to solve permutation problems. They speculated that the ability to process spatial relational changes may have been a component factor.

Spatial and Verbal Processes

It appears that verbal and spatial tasks require different processes for their solution. People who are skilled in solving spatial problems are not necessarily proficient in solving verbal problems and vice versa (Olson, 1975). Furthermore, it appears that individuals not only exhibit different patterns of ability but often solve the same problem in different ways. Day (1972) found that people with high spatial and low verbal ability have a flat recall curve on a digit recall task, whereas those individuals possessing high verbal ability and low spatial ability show the classical bowed, serial position effect.

Kail and Siegel (1977) investigated sex differences in retention of verbal and spatial characteristics of stimuli. Sets of five or seven letters were presented in a 4 x 4 matrix to males and females in grades 3, 6, and college. They were asked to recall either the names of the letters, the positions of the letters, or both letters and positions. Females at all levels had greater recall for letters than for positions, while males exhibited equal recall of letters and positions. Also, they found that both sexes at all age levels processed the verbal and spatial information separately.

Olson (1975) speculated that

> . . . spatial processes are called upon in solving verbal problems whenever either the information exceeds the limitations of short-term memory, and whenever the 'semantic system' under consideration is not sufficiently structured in terms of a finite set of alternatives which are contrastively organized around a basic set of features (p. 81).

Olson summarized his discussion on the relationship between linguistic and spatial processes with the conclusion that the problem-solving strategy an individual adopts depends on the nature of the task, its complexity, and the individual's ability to employ either spatial or verbal processing.

Reading poses an interesting problem for researchers interested in the relationship between verbal and spatial processing and verbal and spatial content. Brooks (1970) concluded that spatial and verbal systems are complementary but that interference between the two systems occurs when the same system is used for both internal processing and for external responding.

Fleck (1972) investigated the relationship of field dependence/independence and verbal mediation/non-mediation to Piagetian conservation ability in kindergarten, first and second grade males. Verbal mediation (i.e., internalized symbolic representation) was thought to be related to the ability to organize responses to aspects of the stimulus situation. He found a significant positive relationship between field independence and the ability to conserve, whereas the hypothesized verbal mediation influence was not found.

The current cultural emphasis on language processes and the resultant tendency to equate intelligence with verbal ability has been noted by several authors (Olson, 1975; Olson and Bruner, 1974; and Ornstein, 1978). Ornstein (1978) made the observation that: "When we say that someone has a great mind, we mean that he or she has a great mouth, is good at inference, verbal retention, and reasoning (p. 76)."

Olson (1975) speculated that this focus on verbal ability may have a profound effect upon intellectual development by suppressing the development of spatial ability. Consistent with this notion is the observation that girls typically read better, more and at an earlier age than boys, but also have poorer spatial ability.

Activity seems to play a crucial role in the development of motor skills and in the development of intelligence (Olson, 1970; Olson and Bruner, 1974; and Piaget, 1967). Olson (1970) argues that activity provides information in the form of perceptual cues. Activities in different process areas such as language, number systems, etc., require different perceptual information. For example, the information needed to recognize an object (i.e., screwdriver) differs from that which is needed to draw it, name it, to discriminate it from other objects, or to use it to tighten a screw. Although language aids in specifying and selecting alternatives, it is not equivalent to motor activity.

Expressing a prevalent viewpoint that mental operations and problem-solving depend upon the dual functioning of both spatial and linguistic systems, McGuiness and Pribram (1978) argue that cognitive systems are the outgrowth of basic "perceptual processes" and "perceptual-motor integration" (p. 24). They maintain that sex differences are due in part to a male bias toward active intention and a female bias toward communicative intention. For example, males typically respond to an object by providing its action whereas females name a quality of the object.

Sources of Variance in Performance on Spatial and Verbal Measures

While it is generally accepted that males excel on spatial measures and females excel on verbal measures, the explanations that have been offered for these sex differences are highly speculative and much debated. While it is difficult to separate biological and environmental factors in any real sense, for the purpose of discussion such a distinction is maintained in the following sections.

Biological Factors

Arguments for biological and hereditary determinants of spatial ability are based on a possible sex-linked recessive gene, sex hormones, physical maturation, and brain lateralization. The investigations have included studies of large populations, cross-generational groups, clinical populations, and twins.

Sex-Linked Inheritance. According to Eliot and Fralley (1976), O'Conner was the first researcher to propose that spatial ability was an inherited sex-linked recessive trait. O'Conner's work in the 1940's received little attention until Stafford (1963) reported similar findings from cross-generational studies. Hartlage (1970), Bock and Kolakowski (1973), Vandenberg (1966, 1967, and 1969), and Yen (1975) have reported findings of a genetic component of spatial ability. The X-linked recessive trait hypothesis would predict that the inheritance pattern of (XO) individuals would be more like that of normal males (XY) than normal females (XX), and they should exhibit relatively greater spatial ability. Money (1963, 1964) studied spatial ability in (XO) individuals with Turner's Syndrome but his findings did not support the hypothesis. Whether this was an artifact of the severe general deficit associated with Turner's Syndrome is not clear.

Sex Hormones. Broverman, Klaiber, Kobayshi, and Vogel (1968) proposed a theory relating sex hormones to intellectual functioning. They hypothesized that sex differences in cognitive abilities, specifically the female advantage on perceptual-motor tasks that measure speed and accuracy, and the male advantage on perceptual restructuring and inhibitory tasks, are due to the differential effect of the "sex" hormones, estrogens and androgens. The argument has appeal in that sex differences in many cognitive abilities do not appear or reach a significant level until adolescence.

McGuinness and Pribram (1978) have continued the sex hormone argument. They speculate that hormonal differences and differing muscular organization between the sexes produce differential behavior in the sexes.

Physical Maturation. Waber (1976) tested the hypothesis that physical maturation is instrumental in the development of sex differences on spatial and verbal measures. Early-maturing individuals of both sexes performed less well than late-maturing individuals on spatial measures, but the groups did not differ on tests of verbal ability. Greater hemispheric lateralization as measured by a dichotic listening task was found for late maturers of both sexes among the older adolescents studied. Waber's findings did not support the prevalent argument that females owe their greater early academic success to their faster rate of development.

Brain Lateralization. New techniques have stimulated interest and research in the neurophysiological factors, in particular brain lateralization, thought to be involved in the development of spatial ability. While a relationship between sex differences and brain hemisphere specialization is generally accepted, there are disagreements over the exact nature of the relationship. Several important, interrelated issues arise out of the controversy.

Some researchers argue that the hemispheres are specialized for spatial and verbal material, and that sex differences are the result of dominant or lack of dominant hemispheric functioning. Evidence based primarily upon studies of individuals with damage to either the right or left hemisphere led to the conclusion that the left hemisphere is specialized for language whereas the right hemisphere responds to spatial stimuli (Eliot and Fralley, 1976; Gloning and Hof, 1969; Harris, 1975; and Luria, 1973).

Other researchers contend that the functioning of the hemispheres is specialized not for type of material but rather for spatial or verbal processing, and that sex differences are the result of biological and/or environmental factors that predispose the sexes toward different types of processing.

Galin and Ornstein (1972) devised a cap which allows the experimenter to take EEG readings of a subject while he/she is performing various tasks. Ornstein (1978) studied 10 subjects who were asked to write letters, arrange wooden blocks to match a pattern, and mentally think their way through the two tasks. Alpha rhythms (interpreted as indicating a decrease in information processing in the brain area being tapped) revealed that the left hemisphere was more involved when the subject was performing the verbal tasks than when performing the spatial ones. In another study (Ornstein, 1978), lawyers and ceramists were monitored while they performed verbal and spatial tasks. Lawyers exhibited more left hemispheric activity regardless of the task than did the ceramists.

Ornstein (1978) concluded: "that the brain's hemispheres are not specialized for different types of material (verbal and spatial) but for different types of thought (analytical and spatial) (p. 733)."

The dominant role of the left hemisphere in processing verbal material seems to be established by age four or five years for both sexes (Kimura, 1963). The development of the specialized functioning of the right hemisphere is less clear. Witelson (1976) tested 200 right-handed males and females, six to fourteen years of age. The subjects simultaneously handled two objects with unfamiliar and irregular shapes but were not able to see them. They then attempted to visually identify the objects from a display of several similar objects, including those they had explored. The sexes did not differ in total accuracy but the males were significantly better with their left than with their right hand. Since information from the left hand is processed by the right hemisphere, and since males were more proficient at this task with their left hand from age six on, and since females did equally well with both hands until age thirteen, Witelson concluded that the specialized functioning of the right hemisphere is greater and occurs earlier in males. Other researchers found greater specialization for spatial tasks for males as early as five years of age (Kimura, 1969; Knox and Kimura, 1970). However, Buffery (1971) found that at age three or four, females were more lateralized than males on a spatial task, that required the subject to draw, simultaneously and with eyes closed, a circle with one hand and a square with the other. The conflicting findings may have resulted from the use of different tasks and/or different age subjects.

On the basis of Buffery's findings, Buffery and Gray (1972) argued that spatial and verbal skills are represented bilaterally in males and unilaterally in females. In other words, males process spatial and verbal stimuli with both hemispheres whereas females are left-hemisphere dominant. An opposing view is offered by Levy and Sperry (cited in Woodruff, 1978). They postulate greater hemisphere specialization for males. Most of the evidence seems to support the Levy-Sperry position. McGlone and Kertesz (1973) found that damage to the right hemisphere resulted in lower scores for males than for females on a spatial task, indicating greater lateralization for spatial ability in males. In a later study, McGlone (1978) reported that males showed more severe impairment in both verbal and spatial ability with damage to the left and right hemispheres, respectively, than did females. Adolescent and adult males appeared to be more lateralized than females on a verbal dichotic listening task (Lake and Bryden, 1976).

The relationship between lateralization and spatial and verbal ability is not clear. Waber (1976) reported a relationship between rate of maturity at puberty, lateralization, and ability. She found that late maturers of both sexes had greater left-hemisphere lateralization as measured by a dichotic listening task and higher scores on a battery of spatial tasks than early maturers. Late and early maturers did not differ on measures of verbal ability.

Levy's (1969) suggestion that interference or competition occurs when visual-spatial processing and verbal processing occur in the same hemisphere may provide an explanation of Waber's findings. Following Levy's line of reasoning, visual-spatial processing may be interferred with (lower spatial scores) in subjects (early-maturers) who are less well lateralized for language, whereas their language ability may not be affected as they process language in both hemispheres.

Ornstein (1978) stated that while either hemisphere can process both spatial and verbal stimuli, more efficient functioning results when the left hemisphere is used to process sequential, detailed (analytic) information and the right hemisphere to process synthetic wholes or relationships between elements. He speculated that the specialized functioning of the hemispheres may have evolved to reduce interference between the two types of processing.

McGlone and Davidson (1973) commented on competition between verbal and non-verbal functions served by the same hemisphere. They concluded that while their findings could not be adequately explained by competition, it appeared that left hemispheric processing of spatial material, more typical of female subjects, resulted in poorer performance on spatial tasks. While localization of verbal and nonverbal skills within the same hemisphere tended to decrease spatial scores, this trend was not statistically significant. On the other hand, Tucker (1976) found that the analytic-synthetic incompatibility suggested by Levy (1969) was more apparent for males than females. He reported that males relied upon the right hemisphere for a synthetic spatial visualization task, whereas females used both hemispheres. Both sexes used both hemispheres on a perceptual analysis task.

Another line of evidence for the specialized functioning of the hemispheres comes from studies of autistic children. Blackstock (cited in Gray, 1978) argued that left hemisphere damage may be one cause of autism. The argument is based in part on the observation that the autistic child's musical and spatial visualization abilities, usually associated with right hemispheric functioning, is not impaired. For example, art, mathematics, mechanical, directions, paths, etc., were among the savant abilities exhibited by autistic children studied by Rimland (1978).

Blackstock believes that trying to make autistic children communicate normally may not be in the best interest of the child. A case in point is Nadia, an autistic child who exhibited extraordinary artistic ability at a young age. The artistic ability diminished when she was encouraged to develop verbal communication skills (Selfe, 1978).

Environmental Factors

Various environmental arguments have been offered as explanations for the differential spatial ability of the sexes. Culture, training and education, masculinity-femininity, socio-economic status, birth order and sex of siblings, activity level and preference, and multiple social factors have been suggested.

Culture. Cross-cultural and subcultural studies, based on Witkin's and Berry's work, have tested the hypothesis that spatial ability, specifically field independence, is a function of the cultural restrictions placed differentially on the sexes. Kagan and Kogan (1970) in a review of cultural studies found support for the notion that fewer restrictions result in a greater field independence. Ridgeway (1977) in a study of the patterns of environmental adjustments underlying field independence found that field independence in women was related to rejection of the social environment, whereas field independent males held the social environment in high regard.

Urban subjects have been found to be more field independent than individuals living in rural settings (Dawson, 1967; Deregowski, 1968; and Hudson, 1970). This finding has been interpreted to mean that additional factors such as education are involved in the development of spatial ability (Mitchelmore, cited in Eliot and Fralley, 1976).

Training and Education. Several researchers have offered the observation that the typical school curriculum does little to develop spatial ability (Brinkman, 1966; Mendicino, 1958; and Olson and Bruner, 1974). At the college level, field dependence/independence may be related to curriculum. According to one study, students in liberal arts are more field dependent than students in mathematics, physics, and chemistry. Males in science were most field independent, females in science and males in liberal arts scored similarly and lower than the science males but higher than liberal arts females, who were found to be the most field dependent (DeRussy and Futch, 1971).

Blade and Watson (1955) found significant increases in spatial test scores of males after a year of engineering courses. Also, they found that high performance on spatial measures was as good a predictor of success in engineering as high performance on a mathematics test.

There have been attempts to assess the effects of training on spatial ability. Most studies have been conducted with adults and have not considered long term effects of training.

The scores of college freshmen, identified as having low spatial ability, were raised significantly by a series of twelve lessons on spatial perception (Van Voorhis, cited in Eliot and Fralley, 1976). Brinkman (1966) administered the Differential Aptitude Tests (DAT) of spatial relations to two groups of eighth graders. One group received training in pattern folding and object manipulation. The trained group scored significantly higher on the second administration of the DAT. A similar study, involving the use of videotaped lessons paralleling tasks on spatial tests resulted in gains on the parallel tasks but did not appear to result in transfer learning to other tests supposedly measuring the same ability (Wolfe, 1970). Elliot and McMichael (1963) conducted a study in which one group received didactic training, whereas the other group received practice in addition to the didactic training. The group which received both practice and training exhibited a significant but transient increase on a measure of field independence.

Smith and Schroeder (1979) investigated the effects of instruction on spatial ability of fourth grade boys and girls. They reported no sex difference on the Spatial Visualization Abilities Test (SVAT), which is similar to the Form Board Test. The SVAT requires subjects to manipulate puzzle pieces in various arrangements until the required pattern is formed. Both sexes profited from instruction involving spatial ability.

Masculinity-Femininity. An investigation of the relationship of masculinity and femininity to field independence revealed that high-masculine males and high-feminine females, as determined by scores on the Guilford-Zimmerman Masculinity-Femininity Scale, were more field dependent than subjects with relatively non-traditional sex-role identities (Arbuthnot, 1975).

Socio-Economic Status. Performance on spatial measures has a lower correlation with social class than does performance on either vocabulary or general intelligence measures (Guilford, 1967; Nuttin, cited in Eliot and Salkind, 1975). Vandenberg (1975) speculated that the low correlation of social class and spatial ability may be due to insignificant differences in social class experiences related to the development of spatial ability; little or no difference between the social classes in inheritance of spatial ability, and/or the mixing effect of marriage between the classes.

Birth Order and Sex of Siblings. Cicirelli (1975) investigated the effect of interaction with an older sibling or mother on the spatial problem-solving behavior of a young child. In the condition where the child worked alone on the practice task, children with an older brother had higher scores than children with an older sister. The children who were assisted on the practice task by their older brother showed no improvement. Cicirelli interpreted these findings to mean that while an older brother stimulates a younger child's cognitive development, he creates a situation for the younger child in which help on a task is unacceptable. In a review of the literature, Cicirelli referred to findings which suggested that children with male siblings were superior on IQ and achievement measures to children with female siblings. He noted that students with a female sibling had higher language scores than those with a male sibling.

Roodin, Broughton, and Vaught (1974) reported that birth order and family size had no effect upon field dependence and that sex of sibling had only a limited effect. However, Reighard and Johnson (1973) found that males performed better than females on the RFT and that first-born children performed better than later-born children or an only child.

Activity Level and Preference. It has been argued that the male advantage in manipulating spatial relationships may be due to a higher level of aggressiveness, activity, and mobility in males observed in early childhood (Maccoby and Jacklin, 1974; Sherman, 1967). The play activities of females appear to include fewer spatial components than the play activities of boys (Fennema, 1974).

This argument has been taken a step further by the suggestion that since females use symbols better and at an earlier age than males, they are encouraged to advance more rapidly from concrete representation to abstract, symbolic representation. As a consequence, girls may lack the essential concrete experiences necessary for the development of spatial ability (Fennema, 1974; Sherman, 1967).

Fogelman (1969) suggested that the mechanical play interests of boys and the literary or aesthetic interests of girls are reinforced by society and carried over in the preference for active learning by males and passive or verbal learning by females. Support for this argument can be found in the following diverse investigations.

A Piagetian test of conservation of quantity utilizing an "active" and "passive" procedure was administered to 174 six- and seven-year-olds. The "active" group manipulated the materials themselves, whereas the "passive" group observed the experimenter carry out the manipulations. Females were found to do better when they watched while males were more successful when they manipulated the materials (Fogelman, 1969). Similarly, Graybill (1975) observed that high school females enrolled in science classes did not manipulate equipment as much as males. In the experimental situation, females often asked permission of the experimenter to carry out the necessary manipulations of the equipment and exhibited difficulty in using the apparatus.

Keogh (1971) found that while male and female children did not differ in their ability to copy patterns on a paper and pencil task, they differed greatly in their ability to copy the same patterns by walking them out under various conditions. Males were more successful in the walking tasks and were observed to walk the patterns in parts or sections, whereas females tried to walk the patterns in one continuous line. Keogh suggested that pattern walking, which involves abstraction and organization of the parts from an embedding field, is another correlate of field dependence/independence. It appears that males and females use different perceptual strategies in the organization of space. Similarly, Cohen (1976) reports that older men appeared to be more proficient than older women in making spatial judgements in relation to body position.

Lawson (1975) reported sex differences in concrete and formal operational reasoning ability on paper and pencil and manipulative tasks. High school males performed significantly better than females on manipulative reasoning tasks. While the sexes differed less on paper and pencil reasoning tasks, males performed better than females. More males than females were functioning at the formal operational level.

Coates, Lord, and Jakabovies (1975) looked at field dependence/ independence in relation to the social and non-social play of the sexes at the preschool level. It was found that for both sexes, field dependent children were more social, whereas field independent children preferred solitary play. Girls who engaged in social block play were found to be field independent, whereas boys who engaged in social block play were found to be field dependent suggesting that the same activity may provide a different experience for boys and girls.

Held and Heins (1963) in a study involving cats concluded that perceptual learning was based on self-produced movement. Active cats were more successful than passive cats on perceptual tasks. A study of physical activity in relation to field dependence/independence indicated physically inactive individuals were more field dependent than physically active individuals (Svinicki, Bundgarrd, Schwenjohn, and West Gor, 1974).

Multivariant Social Factors. Alexander and Eckland (1974) conducted a longitudinal investigation of sex differences in educational process. Ability appeared to be considerably more important for the continuing educational progress of men, whereas social factors had considerable effect upon the progress of women. Educational attainment of women remained lower than males when status background variables, ability, curriculum, the influence of significant others, and college plans were controlled statistically.

Summary

The study of spatial ability has been complicated by the lack of a clear conceptual definition, the use of inappropriate measures, and the lack of appropriate measures for young children. Despite these problems, researchers have consistently found a male advantage on tasks requiring manipulation of spatial relationships. Given the general maturational advantage of females, the male superiority in spatial ability is even more striking.

Sex differences in problem-solving ability and style, logical thinking ability, mathematical ability, and verbal ability have been reported. The female verbal-ability advantage and the male spatial-ability advantage appear to be related to sex differences found in problem-solving ability and style, logical thinking ability, and mathematical ability.

Activity seems to play a crucial role in the development of cognitive skills and thus intelligence (Olson and Bruner, 1974; Piaget, 1968). It has been argued that the male advantage in spatial relationships is due to a higher level of aggressiveness, activity, and mobility observed in early childhood (Maccoby and Jacklin, 1974; Sherman, 1967). In addition, it has been suggested that since females use symbols better and at an earlier age than males, they are encouraged to proceed more rapidly from concrete representation and motor activity to abstract, symbolic representation and passive activities. Consequently, females may lack the essential concrete experiences necessary for the development of spatial ability.

The current educational and cultural emphasis on language and the resultant practice of equating intelligence with verbal ability has been noted (Olson and Bruner, 1974). The typical school curriculum does little to develop spatial ability (Brinkman, 1966). Thus, spatial ability appears to be one important aspect of cognitive functioning, and one that has been almost totally overlooked. Furthermore, it appears that the cultural and educational emphasis on verbal ability may have a profound effect upon overall intellectual development by suppressing the development of spatial ability, particularly for females (Olson, 1975). This implies that the female superiority in verbal ability may be purchased at the cost of the development of other abilities, namely, mathematical and logical reasoning capacities.

Sex differences in verbal and spatial ability appear to be the result of hereditary and biological factors as well as environmental ones. There appears to be a sex difference in the lateralized processing of verbal and spatial information. One intriguing idea here is that there may be an active interference between spatial and verbal processing that may be related to sex differences in the degree of lateralization (Woodruff, 1978).

The development of sex differences becomes significantly apparent during adolescence. The organization of cognitive abilities changes both quantitatively and qualitatively with age and by sex. Individuals appear to utilize their best developed and most differentiated abilities in problem-solving.

There has been an increasing concern and interest in recent years in the enhancement of children's cognitive development, and in the maximization of individual potential. Spatial ability appears to offer an interesting avenue to that goal. For that reason, sex differences in the development of spatial ability in relation to other cognitive abilities constitute an interesting and important area for research.

CHAPTER II

RESEARCH DESIGN

There have been numerous isolated investigations of sex differences in cognitive abilities. The present study represents the first effort to study the relationship between verbal, spatial, and logical thinking ability as a function of age and sex. The relationship of verbal and spatial ability to logical reasoning was assessed with both passive (paper and pencil) and active (hands-on) measures of the reasoning. The question of a possible trade-off between verbal and spatial ability, that is, superior ability in one process being purchased at the expense of the other, was investigated. Sex, age, and ability differences in the processing of verbal and spatial information were investigated for their relationship to brain laterality and specialized hemispheric functioning.

The research was conducted in two phases. This chapter includes for each phase: (a) a discussion of purposes and hypotheses, (b) a description of the subjects and strategies used in selection of subjects, and (c) a description of the instruments, administration and scoring procedures, and design.

Phase I

Purpose

The purpose of Phase I research was to explore the relationship between the three cognitive abilities that appear to be most critical to general intellectual functioning. There was an interest in identifying possible sex differences, developmental trends, and sex differences within developmental trends, as these were related to the three abilities and the interrelationships among them. Accordingly, the empirical goal of the study was to investigate the interrelationship between paper-and-pencil measures of verbal ability, spatial ability, and logical reasoning as a function of age and sex.

Hypotheses

Given the considerable evidence for a male advantage on tasks that measure spatial ability (Anastasi, 1958; Garai and Scheinfeld, 1968; Kagan and Kogan, 1970; Kogan, 1972; Maccoby and Jacklin, 1974; Sherman, 1967; and Tyler, 1965) it was predicted that males would score higher than females in spatial ability. Evidence of female superiority on verbal tasks (Broverman, Klaiber, Kobayashi, and Vogel, 1968; Fairweather, 1976; Garai and Scheinfeld, 1968; Hutt, 1972; and Maccoby and Jacklin, 1974) provided the basis for predicting that females would score higher than males in verbal ability. Evidence of a sex difference in favor of males on Piagetian tasks (Graybill, 1975; Keating and Schaefer, 1975; Lawson, 1975; Ross, 1976; and Thomas, Jamison and Hummel, 1973), led to the prediction that males would score higher than females in logical reasoning ability, when assessed by means of Piagetian tasks.

Developmental theory (Werner, 1948) and evidence from factor analytic studies (Very and Iacono, 1970; Very, 1967) which suggests that cognitive functioning changes from a global, undifferentiated ability into a complex pattern of differentiated abilities would provide a basis for predicting that spatial ability would be independent (uncorrelated with) of verbal ability. However, if there is a trade-off between verbal and spatial ability as suggested in the literature (Sherman, 1967; Olson, 1975), there would be a negative correlation between verbal and spatial ability. There was no obvious way to choose between these alternative predictions at the outset of the study.

Given the evidence that performance differences on a variety of tasks (e.g., the Piagetian water-level task, the Rod and Frame Test, mathematical and problem-solving measures) disappear when spatial ability is controlled (Geringer and Hyde, 1976; Hyde, Geringer, and Yen, 1975; and Sweeney, 1953), it was predicted that spatial ability would have a strong, positive correlation with logical reasoning ability.

While verbal ability is commonly associated with intelligence (Ornstein, 1978; Olson and Bruner, 1974) no evidence of a strong relationship between verbal ability and logical reasoning has been found. However, if logical reasoning tasks are similar to other problem-solving tasks that can be solved by either verbal or spatial means (Vandenberg, 1975; Day, 1972; and Allen, 1974) then verbal ability should be helpful in a logical reasoning task. Therefore, it was predicted that verbal ability would have a positive but lower correlation with logical reasoning than spatial ability.

These predictions imply that subjects with high ability regardless of sex will tend to have high reasoning scores. However, since males on the average should score higher than females on spatial ability and logical reasoning, the spatial-reasoning relationship should be stronger and more typical of males; and the verbal-reasoning relationship would be weaker and more typical of females. To the extent that verbal and spatial ability are independent of each other (separate abilities), and are both positively correlated with logical reasoning, it follows that spatial ability and verbal ability together should be a better predictor of logical reasoning than either spatial or verbal ability alone.

It was expected that performance on all three measures would improve with age. Developmentally, a female advantage on the verbal measure was expected to be evident at the fourth grade level, to be less at the eighth grade level, and to disappear at the college level. In the case of spatial ability, it was expected that a male advantage would be evident at the fourth grade level, but would not be statistically significant until the eighth grade. This male advantage was expected to continue to increase at the college level.

If logical reasoning performance is rooted mainly in spatial ability such that verbal ability is not an important factor, then one would expect that males and females would be equal on logical reasoning at the fourth grade and that males would have the advantage at the eighth grade and college levels. However, if both abilities are important (that is, if logical reasoning problems can be solved either spatially or verbally), then one would predict a female advantage at the fourth grade level, no sex difference at the eighth grade level, and a male advantage at the college level.

The above predictions concerning performance on a logical reasoning task may be influenced by the task itself. For example, a paper-and-pencil measure would lend itself more than a manipulative task to the use of verbal processes and a possible learning style which should favor females more than a manipulative task. In this case, the predicted outcomes shift toward a greater female advantage at the fourth grade, diminishing at the eighth grade, and perhaps disappearing or giving way to a male advantage at the college level.

Subjects

The 231 subjects for Phase I were selected from fourth and eighth grade classes in the Stillwater (Oklahoma) Public Schools and from the introductory psychology course at Oklahoma State University. The fourth grade subjects were 30 males and 38 females enrolled in three classes at one elementary school. The eighth grade subjects were 53 males and 46 females enrolled in four sections of a required, non-ability-grouped science course. There were 33 male and 31 female university subjects enrolled in introductory psychology. All subjects were volunteers; the university students received extra credit for participation.

The fourth grade, eighth grade, and college levels were selected on the assumption that these three age groups would offer the best opportunity to detect critical developmental changes in verbal, spatial, and logical reasoning ability. The elementary school selected was recommended by a school-district administrator as offering a representative sample of fourth graders with a wide range of abilities. The eighth grade sample was drawn from the only middle school (grades 6, 7, and 8) in the city and also included a wide range of abilities and socio-economic backgrounds. Although the investigator had heard informally that eighth grade students might present some problems in terms of gathering reliable data, this did not appear to be the case in the present study. A brief, informal review of the data with the classroom teacher yielded no surprises in terms of student ability. The introductory psychology course provided a wide range of majors on campus.

Instruments

Measures of verbal, spatial, and logical reasoning ability were selected on the basis of three criteria: age appropriateness, time required for administration, and ease of administration.

Wide Range Vocabulary Test. The Wide Range Vocabulary Test (WRVT), Form B, (Atwell and Wells, 1937) was selected as the verbal measure. Instructions to the subjects and a sample item are presented in Appendix A. The test is not presented in full in Appendix B because it is copyrighted material and can be obtained elsewhere. The test met the age-range requirement as it is appropriate to use with ages eight years through adults. No data on reliability or validity were found. However, the test was described as useful for preliminary screening (Buros, 1949). One deviation from the standard, untimed procedure for administration was that the test was timed. Available information indicated that the test could be completed in 10 minutes under normal circumstances (Buros, 1949). Subjects were allowed 15 minutes, which was sufficient time for 85 percent of the subjects either to complete the 100-item measure or to reach a termination criterion of six consecutive errors. Nevertheless, this imposed time limit may have impaired performance to some degree. The test has procedures for both group and individual administration. A scoring system based on the standard procedure for individual administration, which recommends testing be stopped when six words in succession are failed, was used. The format of the WRVT presents words in order of difficulty. No items were scored that occurred after six successive errors were made. Omissions, more than one response per item, and incorrect responses were scored as errors. The subject's test score was the number of correct responses.

Surface Development Test. The Surface Development Test (SDT), (French, Ekstrom, and Price, 1963), a measure of spatial visualization, requires mental folding of parts of a two-dimensional pattern to form a three-dimensional object. A sample item and instructions to subjects are presented in Appendix A. Vandenberg (1969) identified this test as one that cannot be solved by verbal process.

The test was selected for use in the study after an extensive search of the available instruments yielded no measure which better met all the criteria for selection. No information on the reliability and validity of the instrument was given in the Manual for a Kit of Reference Tests for Cognitive Factors (French, Ekstrom, and Price, 1963 1963). Although the authors of the test recommend it for use with ninth graders through college seniors, it has been used (Vandenberg, 1969) with subjects as young as 12 years of age. The standard administration procedure involving written instructions was used with eighth grade and college subjects. The test had not been used previously with fourth graders and the written instructions were judged by the investigator and the classroom teachers to be too difficult for the fourth grade subjects. Accordingly, the standard instructions were given orally and accompanied by a demonstration with a large cardboard pattern identical to the sample item in the written instructions.

The test has two parts, each with six drawings. There are five questions on each drawing. The subjects were allowed the standard amount of time, six minutes for each part. The standard scoring procedure was followed. The score was the number of correct responses minus the number of incorrect responses multiplied by .14, a correction factor for guessing, based on the average number of possible answers. The maximum score possible was 60.

Logical Reasoning. The measure of logical reasoning consisted of items selected from Gray's (1973) Test of Logical Thinking (TOLT), a written test based on the work of Jean Piaget. For the fourth grade, there were six items, three at each of substages I (beginning) and II (complete) of the concrete (C) operational stage. Nine items, three at each of substage II of the concrete operational stage and substages I and II of the formal (F) operational stage, were selected for the eighth grade and college subjects. Test items, which differed for the three age groups, assessed the reasoning areas of exclusion, proportion, and combination. There was one item in each of the three reasoning areas at each substage. The test items and instructions to the subjects are presented in Appendices A and B.

Gray (1973) reported KR_{20} estimates of reliability for the three subscales and the total test. The substantial correlations: .87 for combination, .88 for exclusion, .91 for proportion, and .94 for the total test, indicated acceptable inter-item reliability. All of the above coefficients were significant at the .005 level. Convergent validity values for the relationship between the written problems and the traditional manipulative tasks of Piaget were reported: .19 ($\underline{p}$ <.05) for exclusion-pendulum, .42 for proportion-balance, and .47 combination-chemical. The heterotrait-monomethod validity values were .497 for balance-pendulum, .62 for chemical-pendulum, .64 for chemical balance, .60 for proportion-exclusion, .49 for combination-exclusion, and .66 for combination-proportion. Heterotrait-heteromethod values were .37 for proportion-pendulum, .36 for combination-pendulum, .42 for combination-balance, .36 for exclusion-balance, .26 for exclusion-chemical, and .48 for proportion-chemical. All of the validity coefficients were significant at the .005 level with the exception of exclusion-pendulum as noted. Although these values were not consistently high, they were better than those reported for other written measures of logical reasoning.

The administration and scoring procedures were modified from those reported by Gray. The original TOLT was not timed and scoring was based on numerous items within each of the three areas of logical reasoning being tapped. In the present study, fifteen minutes were allowed for completion of the test. The logical reasoning score was the total number of correct responses multiplied by a weighting factor for difficulty (1 for C-I, 2 for C-II, 3 for F-I, and 4 for F-II). Thus, the maximum possible total score for eighth grade and college level subjects was 27 and 9 for fourth graders. Scores for the sub-scales of exclusion, proportion, and combination were calculated for each subject in the same manner.

Procedure

The experimenter, a female graduate student, was the same for all three groups. For the fourth grade, the three instruments were administered to the entire group in the regular classroom. The spatial measure was given first, followed immediately by the verbal measure. The logical reasoning task was given approximately one hour later.

The test battery was group administered in its entirety to the eighth graders during one of four class periods in the regular classroom. The order of the tests for the eighth graders was spatial, logical reasoning, verbal.

The college students participated in small groups in a seminar room of a classroom building. The test battery was administered in its entirety to each group at one of eight scheduled times outside of class. The order of the tests was logical reasoning, spatial, verbal.

Design

The design for Phase I was multiple factor with repeated measures. Sex and Grade were the between-subjects factors and the scores on the WRVT, the SDT, and the logical reasoning task were treated as a within-subjects factor.

Phase II

Purpose

Phase II research was conducted to investigate the relationship between level of verbal and spatial ability, as determined in Phase I, and logical reasoning as measured by a manipulative (hands-on) Piagetian task as a function of age and sex. This phase allowed the comparison of active and passive measures of reasoning for their relationship to verbal and spatial ability and their relationship to ability level, sex, and age.

While it is generally accepted that brain laterality is related to sex differences in cognitive abilities (McGuinness and Pribram, 1978), the nature of this relationship is not clear. Therefore, an additional purpose of Phase II was to investigate the relationship between brain laterality (hemispheric functioning) as measured by a dichotic listening task and a haptic discrimination task and spatial and verbal ability as a function of age and sex. The dichotic listening task was designed as a behavioral measure of verbal (left hemispheric) functioning whereas the haptic discrimination was used to tap spatial (right hemispheric) functioning.

Hypotheses

Based on Lawson's (1975) findings that the sex difference favoring males on logical reasoning was greater with manipulative than paper-and-pencil tasks and on Fogelman's (1969) findings of sex differences in the active and passive conditions of a conservation task, it was expected that males at all ages would score higher than females on the Piagetian hands-on measure of logical reasoning. In addition, it was expected that the male advantage would increase with age, and to a greater extent on the hands-on measure than on the paper-and-pencil task. Following the argument that activity is associated with spatial ability and passivity with verbal ability (Sherman, 1967), it was predicted that performance on the active and passive measures of logical reasoning would be related to sex differences in verbal and spatial ability.

The relationship between brain laterality and spatial and verbal ability is not yet clearly understood. The question is whether optimum cognitive functioning is the result of bilateral (both hemispheres) or unilateral (one-hemisphere) processing of information. Ornstein (1978) argues that more efficient functioning results when the left hemisphere is used to process sequential, detailed information and the right hemisphere is used to process synthetic wholes or relationships. Similarly, Levy (1969) has suggested that interference occurs when visual-spatial processing and verbal processing occur in the same hemisphere. It would appear, therefore, that better performance would be found in individuals with an established dominant right hemisphere for spatial processing and dominant left hemisphere for verbal processing.

Several alternative hypotheses related to sex differences in hemispheric functioning emerge and there is no clear-cut evidence to support one over the others. If Witelson (1976) is correct, the specialized functioning of the right hemisphere for spatial stimuli, as measured by the haptic discrimination task, will be greater and occur earlier in males. On the other hand, if Buffery (1971) is correct, females will be more lateralized for spatial ability.

According to Kimura (1967), there should be no sex difference in the dominant role of the left hemisphere in processing verbal stimuli as measured by the dichotic listening task. However, if Lake and Bryden (1976) are correct, males will be more lateralized than females on the verbal dichotic listening task.

Still another hypothesis is offered for the relationship between spatial and verbal ability and hemispheric functioning. Waber (1976) has shown that for both sexes, left-hemispheric lateralization as measured by a dichotic listening task is positively correlated with spatial scores and not correlated with verbal scores.

Subjects

Separate spatial and verbal means were computed for both sexes at each of the three age levels in Phase I. These were used to determine "high" and "low" ability subjects for Phase II. Subjects who scored above the mean were classified as high and those below the mean as low in ability. Forty subjects (20 males, 20 females) at each grade level were selected as follows: 10 high-verbal, high-spatial (HvHs); 10 high-verbal, low-spatial (HvLs); 10 low-verbal, high spatial (LvHs); and 10 low-verbal, low-spatial (LvLs). Each ability group contained equal numbers of males and females. The top-scoring five subjects in each of the ability categories were selected to participate in Phase II. Tables I and II in the Results Chapter present the characteristics of Phase II subjects by ability levels, sex, and grade level.

Due to absenteeism, some substitutions and modifications were necessary. A final total of 118 subjects participated in Phase II as follows. There were 40 fourth grade subjects, five males and five females in each of the four ability groups, ranging in age from 9 years, 6 months to 10 years, 5 months with a mean age of 10 years, 1 month. There were 40 eighth grade subjects with a mean age of 14 years, 2 months, and a range of 13 years, 5 months to 15 years, 5 months. By ability group, there were five males and four females in the HvHs group; six males and six females in the HvLs group; four males and six females in the LvHs group; and five males and four females in the LvLs group.

The 38 college students ranged in age from 17 years, 5 months to 20 years, 5 months, with a mean age of 19 years. There were five males and five females in the HvHs, HvLs, and LvLs groups and four of each sex in the LvHs group.

Instruments

A spatial and a verbal measure of hemispheric functioning and a hands-on Piagetian logical reasoning task were administered individually to Phase II subjects. Criteria for selection of these instruments were the same as in Phase I. Phase II testing was completed within 14 to 44 days following Phase I testing.

Haptic Discrimination Task. The haptic discrimination task and procedure were adapted from Witelson (1976). The task required the subject to palpate simultaneously, out of view, pairs of different random wire shapes for 12 seconds each. Each stimulus wire in a pair was examined with the index and middle fingers of one hand. The subject then attempted to identify the two shapes from a visual display containing six such shapes (including the two that comprised the stimulus pair). The stimulus pairs and corresponding recognition displays are presented in photographically reduced form in Appendix E. The score was the number of shapes correctly identified as a function of the hand (right or left) used to explore it.

The materials consisted of 12 corrugated cardboard panels, 9½ inches (24.4 cm.) x 7½ (19.4 cm.) upon each of which two different, randomly shaped wire objects were mounted (glued). The objects (see Appendix E) were made of 12-inch (30.75 cm.) lengths of steel wire, 1/8 inch (.5 cm.) in diameter. The subject's view of the materials was prevented by placing the boards in a box, 8 inches (20.5 cm.) x 8 inches (20.5 cm.) x 11 inches (28 cm.), open at the ends to allow the subject to reach in and perform the task. To assure that the subject used only the middle and index fingers, elasticized, terry cloth bands were placed around the subject's closed hands.

All subjects were given four practice trials on which feedback about their performance was provided. The practice trials were followed by 11 test trials. The first eight test trials were presented in the same order and manner to all subjects. The ninth trial was a replication of a pair from a previous trial. The specific trial chosen for replication was varied systematically across subjects. On trials 10 and 11, the stimulus panels were rotated so that the subject palpated the wire shapes from two previous trials with the opposite hands. These rotations were also varied systematically across subjects. No feedback was given on any of the test trials.

Dichotic Listening Task. The task consisted of 12 groups of four pairs of dichotically presented words. After each group of four pairs of words, the subject reported, in any order, all the words he/she could remember.

The first trial was a practice trial and trial 12 was a repeat of the four pairs presented on the fifth trial. Ten trials (trials 2 through 11) were scored with a maximum score of 40 being possible for each ear. Since it was not possible to obtain auditory records or to conduct auditory screening tests, subjects were asked if they had any known hearing problems. Five subjects reported that at some previous time ear infections, etc., had caused temporary hearing difficulty but no permanent hearing loss. No subject was eliminated from the study because of hearing problems.

The dichotic listening task was adapted from a procedure used by McGlone and Davidson (1973). The task words were selected from established word association norms (Palermo and Jenkins, 1964) and were matched for number of syllables and letters, had the same primary associate for both sexes and for all three age groups and had low (1 to 4) or no associative connection to any other word in the same four-pair group.

Two audio tapes were made to assure that the findings could not be attributed to a particular set of words. The specific word pairs for each tape are presented in Appendix E. In addition, placement of the earphones was counterbalanced to control for any volume imbalance between earphones.

Piagetian Task. A test of proportional reasoning as measured by a balance-beam task was administered following the procedure reported by Inhelder and Piaget (1958). The task was structured in such a way as to "force the question of proportionality" (p. 164).

The apparatus consisted of a meter stick (balance beam); a metal stand and balance clamp (fulcrum); wire hangers; and two weights at each of 100 grams, 50 grams, 20 grams, and 10 grams. The original numbering on the meter stick was covered and the stick was renumbered from 1 to 9 symmetrically at equidistances on both arms starting from the center axis of the balance. A photograph of the apparatus is presented in Appendix E.

The subject first was shown the meter stick in a state of balance without any weights. The experimenter then explained that the subject would be given various weights and asked to place them on one arm such that they would balance the weight(s) placed by the experimenter on the other arm. The subject was asked to explain his/her reasoning for the placement before the experimenter released the balance. Each subject was given six trials involving two 1:1 and one of each of 1:2, 2:1, 1:3, and 2:5 distance and weight ratios. These trials entailed working with weight reversals, equal weights and equal distances, and unequal weights and unequal distances. The specific task problems are presented in Appendix D.

The subjects' responses were categorized as being preoperational II (P-II), concrete I (C-I), concrete II (C-II), formal I (F-I), and formal II (F-11) according to Piaget's (1958) criteria:

P-II. Subject balances on basis of symmetry; non-systematic adding and subtracting to achieve balance; no concept of further equals heavier.

C-I. Subject understands weights must be equal to be balanced; ability to equalize weights or distances but not simultaneously; no mention of ratio or proportionality; can solve 1:1 ratio.

C-II. Subject coordinates weight with distance; use of multiplication to solve problem; reverses.

F-I. Subject reverses easily; clearly cross multiplies to solve problem; uses terms of proportion or ratio in explanation.

F-II. Solves problems successfully; can state law in some form (i.e., work, force, pull, weight, distance). The maximum possible score for the hands-on Piagetian task was 5, ranging from 1 for a P-II response to 5 for an F-II response.

Other Variables. Several additional variables identified in the review of literature and thought to be related to spatial ability were recorded for each subject in Phase II: birth order, sex of siblings, handedness, and eye-hand dominance as measured by sighting through a cylinder. Major field of study was also recorded for the college subjects.

General Experimental Procedure

A research trailer with three rooms was used in the collection of Phase II data with the fourth and eighth grade subjects. The college data were collected in a seminar room in a classroom building, as in Phase I.

In order to minimize possible disruption of the school schedule and to complete the testing within two to three days, as requested by the schools, assistance was required of three additional doctoral-level graduate students to serve as experimenters. Standard procedures for administering the three tasks were formulated and practiced prior to testing. The assistant experimenters all had training and experience in conducting research and coursework in Piagetian theory. They had no knowledge of the ability classification of the subjects.

For the fourth grade subjects, the order of administration of the tasks (haptic discrimination, dichotic listening, Piagetian reasoning) was the same for all subjects. The testing required about 30 minutes per child, 10 minutes for each task. The same female experimenter (author) administered the haptic task to all the subjects. A male experimenter administered the dichotic listening task, assessed handedness and eye-hand dominance, and collected information on the age and sex of siblings. A second female experimenter administered the Piagetian task to the fourth grade subjects.

The order of administration of the tasks was randomly varied for the eighth graders as it was necessary to test three subjects at the same time in order to complete the testing in the time period requested by the school. The same male and female experimenters who administered the dichotic listening task and the haptic discrimination task to the fourth graders also presented these tasks to the eighth-grade subjects. A third female experimenter administered the Piagetian task.

The author administered the entire battery to the college student sample. The order of the tasks was the same for all subjects: data on handedness, eye-hand dominance, and siblings were collected first, followed by the haptic discrimination task, the dichotic listening task, and the Piagetian task, in that order.

Design

The design for Phase II was similar to that of Phase I. Ability grouping was a between-subjects factor, as were Sex and Grade. The variables of interest (haptic discrimination--left-hand, right hand; dichotic listening--right-ear, left-ear correct responses and intrusions; and hands-on logical reasoning) were treated as within-subjects factors, with each being analyzed via a separate analysis of variance.

CHAPTER III

RESULTS

This chapter presents the analyses of data collected in Phase I and Phase II. The results are presented separately for each phase. The statistical analyses were essentially the same for both phases. Repeated measures analyses of variance were computed using the BMDP2V procedure (Dixon, 1975). The unweighted-means solution modification of the Tukey ratio for unequal cell sizes was used for individual means comparisons (Kirk, 1968). The GLM procedure of the Statistical Analysis System (SAS) (Barr, Goodnight, Sall, and Helwig, 1976) was used for all analyses of variance not involving repeated measures. The Pearson *r* statistic was used to determine the extent of correlation between the ability measures. Multiple regression (R^2) was used to determine the predictive value of sex, age, verbal and spatial ability for performance on the logical reasoning tasks. Both correlation procedures were computed using SAS computer programs. The Chi-Square statistic was used to test frequency data in several places.

Phase I

Sex and Grade Differences on Ability Measures

Phase I results are summarized in Tables I and II. Table I presents the means and standard deviations of the subjects' scores on the three ability measures separately for each sex and grade. Table II, in the same fashion, presents maximum scores, ranges, medians, and, for the WRVT, normative data.

TABLE I

ABILITY MEANS AND STANDARD DEVIATIONS[a]
FOR PHASE I SUBJECTS

Sex and Grade	$\underline{N}$	WRVT		SDT		Logical Reasoning	
Male							
4	30	31.67	(13.36)	9.94	(5.39)	4.50	(2.46)
8	53	41.36	(15.93)	22.26	(13.51)	8.81	(4.79)
C	33	65.39	(10.30)	35.01	(16.21)	11.97	(5.27)
Female							
4	38	29.71	(11.98)	7.75	(4.17)	4.95	(2.71)
8	46	43.20	(12.95)	18.47	(10.05)	6.85	(4.75)
C	31	65.26	(9.02)	29.83	(13.49)	11.52	(4.23)

[a]Shown in parentheses.

A repeated measures analysis of variance was performed on the ability scores, following the design presented in Table I. This analysis revealed that both Grade, $\underline{F}$ (2,225) = 146.50 and Ability Measure, $\underline{F}$ (2,450) = 1.084.91 were both highly significant, $\underline{p} < .0001$, whereas the Sex main effect was not significant, $\underline{p} < .132$. The Sex X Ability Measure interaction bordered on statistical significance, $\underline{F}$ (2,450) = 2.76, $\underline{p} < .06$. The interaction between Grade and Ability Measure, $\underline{F}$ (4,450) = 4.62 was highly significant, $\underline{p} < .0001$. No other interactions were significant ($F < 1$). To determine the basis for the

TABLE II

RANGE AND MEDIAN DATA FOR PHASE I SUBJECTS

Sex and Grade	N	WRVT (Maximum score = 100) Range	WRVT Median[a]	SDT (Maximum score = 60) Range	SDT Median	Logical Reasoning (Maximum score = 27)[b] Range	Logical Reasoning Median
Males							
4	30	4-59	29.5	.6-29.86	9.92	0-7	2
8	53	5-74	44.0	.1-52.02	19.64	0-20	9
C	33	42-83	67.0	2.9-60.00	34.76	4-23	13
Females							
4	38	6-67	29.5	.3-17.82	7.75	0-9	5
8	46	23-66	40.5	2.26-43.88	18.47	0-18	7
C	31	31-77	66.0	3.48-54.58	29.83	2-19	11

[a]The age norms (median scores) on the WRVT are: (10 years-31, 14 years-52, and 19 years-79).

[b]The maximum score for fourth graders was 9.

significant effects obtained in the analysis of variance, a series of individual comparisons was performed. The results of these comparisons are summarized for each ability measure in the following paragraphs.

Wide Range Vocabulary Test. Males and Females did not differ significantly on the Wide Range Vocabulary Test. Comparisons of female performance across grade levels revealed that eighth grade females scored significantly higher than fourth grade females, q (2,225) = 8.01, $p < .01$, and that college females scored significantly higher than eighth grade females, q (2,225) = 13.10, $p < .01$. Similar results were found for males. Eighth grade males performed significantly better than fourth grade males, q (2,225) = 5.67, $p < .01$ and college males scored significantly higher than eighth grade males, q (2,225) = 14.28, $p < .01$.

Surface Development Test. Although males at all ages scored higher than females on the SDT, the difference was significant only for college subjects, q (2,225) = 3.12, $p < .05$. Within sex comparisons revealed that eighth graders scored significantly higher than fourth grade subjects, q (2,225) = 7.32, $p < .01$ and q (2,225) = 6.37, $p < .01$, for males and females, respectively. College males scored significantly higher than eighth grade males, q (2,225) = 7.57, $p < .01$ as did their female counterparts, q (2,225) = 6.75, $p < .01$.

Logical Reasoning. Males and females did not differ significantly on the logical reasoning task. College females scored significantly higher than eighth grade females, q (2,225) = 2.77, $p < .05$. Eighth grade females' performance did not differ significantly from that of fourth grade females. A different pattern was found for males. The mean difference between eighth grade and college males was not significant whereas the mean difference between fourth and eighth grade males, $\underline{q}$ (2,225) = 2.6, $\underline{p} < .06$, approached statistical significance. For both sexes, scores of college students were significantly higher than those of fourth graders, $\underline{q}$ (2,225) = 3.90, $\underline{p} < .01$, and $\underline{q}$ (2,225) = 4.44, $\underline{p} < .01$, for females and males, respectively. Differences between fourth graders' performance and that of either eighth grade or college students are perhaps best viewed as an artifact of the task and scoring system that allowed a maximum score of 9 points for fourth graders and 27 points for the other two groups.

Similar to Gray's (1973) findings, a stage-related hierarchy of performance on the subscales of exclusion and combination was obtained. As Table III shows, the numbers of correct responses decreased as the level of difficulty increased. Insomuch as there was only one problem within each level and category, the numbers of correct responses shown for a given problem are equal to the numbers of subjects who successfully solved that problem. As Gray also found, the proportion subscale did not yield differences appropriate to the developmental stages of logical reasoning. Gray attributed this finding in part to the effect of past learning without understanding. In the present study, the findings may be a result of timing the task as 32 percent (2 fourth graders, 45 eighth graders, and 25 college students) of the subjects did not complete all the items. This finding suggests that the imposed time limit was of little consequence for the fourth graders, who had fewer and easier problems than the eighth grade and college subjects.

TABLE III

LOGICAL REASONING TASK: NUMBERS OF CORRECT RESPONSES FOR EACH PROBLEM CATEGORY AND DEVELOPMENTAL LEVEL

Grade and Sex	Exclusion				Proportion				Combination			
	C-I[a]	C-II	F-I	F-II	C-I	C-II	F-I	F-II	C-I	C-II	F-I	F-II
Fourth												
Female	30	14	NA[b]	NA	15	16	NA	NA	25	24	NA	NA
Male	23	14	NA	NA	8	10	NA	NA	22	17	NA	NA
Eighth												
Female	NA	25	6	1	NA	21	26	3	NA	31	12	3
Male	NA	31	9	0	NA	37	38	7	NA	44	17	1
College												
Female	NA	25	12	4	NA	14	10	24	NA	24	15	2
Male	NA	29	14	5	NA	13	14	24	NA	30	13	3

[a]C-I = beginning concrete operations stage.
C-II = completed concrete operations stage.
F-I = beginning formal operations stage.
F-II = completed formal operations stage.

[b]NA = a substage not assessed.

Sex and Grade Relationships Between Abilities

Verbal and Logical Reasoning Ability. The correlation between verbal ability and logical reasoning was significant for both males, $\underline{r} = .58$, $\underline{p} < .0001$, and females, $\underline{r} = .67$, $\underline{p} < .0001$. The proportion of total variance explained for females, $r^2 = .45$ was somewhat higher, therefore, than for males, $r^2 = .34$.

The relationship between verbal ability and logical reasoning considered separately by sex and grade is shown in Table IV. The table shows that the correlation between verbal ability and logical reasoning decreased at the college level for females but increased for males.

TABLE IV

CORRELATION BETWEEN VERBAL AND LOGICAL ABILITY

Sex and Grade	N	r	Significance Level
Males			
4	30	.45	.01
8	53	.33	.05
C	33	.58	.001
Females			
4	38	.55	.001
8	46	.52	.001
C	31	.37	.05

Spatial and Logical Reasoning Ability. The correlation between spatial ability and logical reasoning also was significant for both males, $r = .61$, $p < .001$, and females, $r = .63$, $p < .001$. The proportion of variance explained for males was $r^2 = .37$ and $r^2 = .40$ for females.

As shown in Table V, the correlation between spatial ability and logical reasoning was practically nonexistant for both males and females at the fourth grade level. The correlation increased greatly for both males and females at the eighth grade, but more so for females. The degree of correlation continued to increase for males at the college level, but declined for females.

TABLE V

CORRELATION BETWEEN SPATIAL AND LOGICAL ABILITY

Sex and Grade	N	r	Significance Level
Males			
4	30	.10	NS
8	53	.43	.01
C	33	.50	.01
Females			
4	38	.05	NS
8	46	.58	.0001
C	31	.40	.05

Verbal Ability and Spatial Ability. The relationship between verbal and spatial ability differed for males and females as Table VI shows. The association was essentially nonexistant at the fourth grade for both males and females. At the eighth grade, the correlation increased for both sexes but was significant for females only. At the college level, the relationship was significant for males only.

Predictive Value of Spatial and Verbal Ability. Multiple regression with sex, grade, verbal ability, and spatial ability was computed. Spatial ability was the best single predictor of logical reasoning ability, $R^2 = .39$, followed closely by verbal ability, $R^2 = .38$. Grade, $R^2 = .28$, was higher than sex, $R^2 = .01$. Verbal ability and spatial ability together explained a slightly higher proportion of the variance in logical reasoning ($R^2 = .49$) than either spatial or verbal ability alone.

TABLE VI

CORRELATION BETWEEN SPATIAL AND VERBAL ABILITY

Sex and Grade	N	r	Significance Level
Males			
4	30	.05	NS
8	53	.20	NS
C	33	.42	.01
Females			
4	38	.11	NS
8	46	.47	.001
C	31	.32	NS

Summary

Males and females did not differ significantly on the WRVT or the written logical reasoning measures. Males out-performed females on the SDT at all ages, but the difference was significant at the college level only. For both males and females, performance on all three measures improved significantly with age. Performance of females on the logical reasoning task increased significantly between eighth grade and college, while that of males did not.

There was a strong positive correlation between verbal ability and logical reasoning ability for both males and females. For males, the degree of association was moderately high at the fourth grade level, declined at the eighth grade, and increased substantially at the college level. For females, the association was moderately high at the fourth and eighth grades but declined substantially at the college level.

The degree of correlation between spatial ability and logical reasoning was also moderately high for both males and females. For both sexes, the correlation between spatial ability and logical reasoning was quite low and nonsignificant at the fourth grade but increased substantially at the eighth grade level. The degree of correlation continued to increase for males at the college level but decreased for females.

A positive relationship between verbal and spatial ability was found for both males and females but was significant at different ages. For males, the association was significant at the college level, whereas it was significant at the eighth grade level for females.

Spatial ability was virtually identical to verbal ability as a predictor of logical reasoning performance for both sexes. Verbal and spatial ability together explained slightly more variation than either spatial or verbal ability alone.

Phase II

Ability Group Differences

Table VII presents the distribution of Phase I subjects within each of the four Phase II ability groups (HsHs, HvLs, LvHs, and LvLs). Table VIII presents the means and standard deviations of scores on the WRVT and the SDT for the actual Phase II sample by ability group. An analysis of variance confirmed that the high and low verbal ability groups were significantly different, $\underline{F}\ (3,94) = 113.83$, $\underline{p} < .0001$; as were the high and low spatial ability groups, $\underline{F}\ (3,94) = 75.42$, $\underline{p} < .001$. Comparisons between the two high verbal ability groups and between the two low verbal ability groups revealed that these groups did not differ significantly on the WRVT (HvHs versus the HvLs, $\underline{q}$ $(3,94) = .35$; LvHs versus LvLs, $\underline{q}$ $(3,94) = 1.40$). Comparisons of the two high and two low spatial ability groups also yielded nonsignificance (HvHs versus LvHs, $\underline{q}$ $(3,94) = 3.35$; HvLs versus LvLs, $\underline{q}$ $(3,94) = .87$).

TABLE VII

ABILITY GROUP SUMMARY: NUMBERS OF PHASE I SUBJECTS OBSERVED WITHIN EACH PHASE II ABILITY GROUP

Sex and Grade	N	Ability Group			
		HvHs	HvLs	LvHs	LvLs
Males					
4	30	5	8	11	6
8	53	13	18	9	13
C	33	11	10	5	7
Females					
4	38	6	13	9	10
8	46	12	8	8	18
C	31	9	8	5	9

The effect of Sex was significant for the spatial measure, $\underline{F}$ $(1,94) = 14.22$, $\underline{p} < .003$ but not for verbal ability ($F < 1$), due to the fact that males scores were higher than those of females on the SDT. Grade was highly significant for spatial, $\underline{F}$ $(2,94) = 124.47$, $\underline{p} < .0001$, and verbal, $\underline{F}$ $(2,94) = 230.05$, $\underline{p} < .0001$, indicating that performance on both measures increased with age. The interaction between Sex and Grade was not statistically significant for either the verbal ($\underline{p} < .16$) or spatial

TABLE VIII

SUMMARY OF PHASE II ABILITY GROUPS BY SEX AND GRADE: MEANS AND STANDARD DEVIATIONS[a]

Sex and Grade	Ability Group	N	WRVT		SDT	
Male						
4	HvHs	5	43.40	(4.67)	15.13	(8.30)
	HvLs	5	50.40	(8.17)	5.01	(3.37)
	LvHs	5	29.40	(.89)	12.80	(1.71)
	LvLs	5	16.80	(7.69)	5.06	(2.37)
8	HvHs	5	60.80	(7.46)	44.68	(7.47)
	HvLs	6	56.00	(3.22)	12.19	(8.49)
	LvHs	4	27.75	(9.07)	34.10	(11.12)
	LvLs	5	35.40	(3.51)	14.94	(5.44)
C	HvHs	5	76.60	(5.03)	55.00	(8.70)
	HvLs	5	74.00	(3.32)	25.67	(3.93)
	LvHs	4	56.75	(8.66)	50.01	(9.97)
	LvLs	5	53.00	(6.08)	14.63	(10.82)
Female						
4	HvHs	5	39.00	(5.52)	12.04	(4.02)
	HvLs	5	49.20	(13.37)	6.48	(1.03)
	LvHs	5	25.20	(2.59)	11.94	(3.63)
	LvLs	5	24.40	(2.07)	4.32	(2.91)
8	HvHs	4	63.00	(4.08)	31.60	(8.19)
	HvLs	6	55.83	(5.34)	11.08	(4.29)
	LvHs	6	38.67	(3.67)	25.12	(8.07)
	LvLs	4	39.25	(1.50)	12.78	(7.26)
C	HvHs	5	71.80	(1.92)	39.34	(7.44)
	HvLs	5	73.00	(3.94)	19.80	(4.74)
	LvHs	4	62.00	(2.00)	39.77	(5.95)
	LvLs	5	51.60	(13.24)	18.82	(8.70)

[a]Shown in parentheses.

($\underline{p} < .09$) measure. The Sex X Ability Group interaction was significant only for the SDT, $\underline{F}$ $(3,94) = 3.96$, $\underline{p} < .01$, due to the females in the LvLs ability group having higher scores than the males in the same group. The Grade X Ability Group interaction was significant for the WRVT, $\underline{F}$ $(6,94) = 4.55$, $\underline{p} < .0004$, and resulted from the HvHs group being lower than the HvLs group at the fourth grade while the LvLs group was higher than the LvHs group at the eighth grade. The Grade X Ability Group interaction on the SDT was also significant, $\underline{F}$ $(6,94) = 7.85$, $\underline{p} < .0001$ and was due to the eighth grade LvLs group being higher than the HvLv group.

Sex and Grade Differences on Phase II Tasks

Haptic Discrimination Task. Trials 9-11 were originally included as a reliability check. Due to a possible learning effect and a fatigue factor on the repeated trials, reliability was assessed using the even-odd split-half estimate of inter-item reliability (Nunnally, 1967) for trials 1-8. Data for the first eight trials grouped by age and sex are presented in Appendix G. Inspection of the data revealed that some trials were more difficult than others. Separate estimates for the right and left hands are shown in Table IX. The r_{kk} values were generally low which indicate that the test was too short or that the items had little in common. It was observed that some subjects had difficulty remembering which hand felt which member of the pair of objects.

Correlational analyses revealed little relationship between haptic performance and verbal or spatial ability. The correlation between spatial ability and left-hand scores on the haptic discrimination task was non-significant for males at all three grades and significant only for college females, $r = .46$, $p < .05$. The correlation between spatial ability and right-hand scores was not significant for males at any grade level and was significant for females at the eighth grade only, $r = .49$, $p < .05$. Verbal ability was significantly correlated with right-hand haptic scores at the eighth grade level for both males, $r = .49$, $p < .05$, and females, $r = .47$, $p < .05$, but was not correlated with left-hand scores at any age for either sex.

TABLE IX

RELIABILITY OF HAPTIC DISCRIMINATION TASK

Sex and Grade	N	Right Hand r_{kk}	Left Hand r_{kk}
Males			
4	20	.35	.13
8	20	.37	.54*
C	19	.04	.18
Females			
4	20	.68**	.77**
8	20	.19	.35
C	19	.00	.46*

*$p < .05$.

**$p < .01$.

A two-point (or greater) difference between hand scores served as the criterion for classifying individuals as being lateralized. Separate Chi-Square analyses for males and females revealed that the frequency of lateralized subjects did not differ significantly as a function of high or low spatial ability ($\chi^2 < 1$).

There were 14 left-handed and 2 ambidextrous subjects in the sample. Analysis of variance revealed that performance of these subjects did not differ significantly, ($F < 1$), from that of right-handed subjects; therefore, handedness was not treated separately in subsequent analyses.

The means and standard deviations of numbers of correct responses for the haptic discrimination task are summarized separately for each hand by sex, grade, and ability group in Table X. An analysis of variance revealed that Grade Level, $F\ (2,94) = 23.09$, $p < .0001$, and Ability Group, $F\ (3,94) = 2.60$, $p < .05$, were significant. The main effects of Sex and Hands were not significant ($F < 1$). Significant interactions were found for Hands X Sex, $F\ (1,\ 94) = 6.27$, $p < .01$, and Hands X Sex X Grade, $F\ (2,94) = 4.26$, $p < .01$. No other interactions were significant.

Comparisons for the right hand across grades revealed that eighth graders scored significantly higher than fourth graders, $q\ (2,94) = 3.79$, $p < .01$ and that college subjects scored significantly higher than eighth graders, $q\ (2,94) = 3.99$, $p < .01$. With the left hand, eighth graders did not differ significantly from fourth graders in accuracy. College subjects outperformed eighth graders, $q\ (2,94) = 5.03$, $p < .01$ and fourth graders, $q\ (2,94) = 7.15$, $p < .01$.

The HvHs ability group scored significantly higher than the LvLs ability group, $q\ (2,94) = 3.85$, $p < .01$. No other ability group comparisons were significant.

TABLE X

NUMBERS OF CORRECT RESPONSES ON HAPTIC DISCRIMINATION TASK: MEANS AND STANDARD DEVIATIONS[a]

Sex and Grade	Ability Group[b]	Right-Hand		Left-Hand	
Males					
4	HvHs	2.40	(1.82)	2.60	(1.52)
	HvLs	2.20	(1.48)	2.00	(1.22)
	LvHs	1.60	(.55)	2.40	(.89)
	LvLs	1.60	(.55)	1.60	(.89)
8	HvHs	3.00	(1.58)	3.60	(1.14)
	HvLs	3.33	(2.58)	2.50	(1.38)
	LvHs	1.50	(.58)	3.00	(1.41)
	LvLs	1.60	(.89)	4.80	(1.10)
C	HvHs	4.60	(1.34)	4.60	(1.14)
	HvLs	2.60	(1.52)	4.00	(1.58)
	LvHs	3.75	(2.22)	4.50	(2.52)
	LvLs	3.80	(.84)	4.20	(2.59)
Females					
4	HvHs	1.80	(1.79)	2.40	(.89)
	HvLs	2.40	(1.34)	3.00	(1.73)
	LvHs	2.60	(2.70)	3.80	(2.05)
	LvLs	1.60	(1.52)	1.40	(1.52)
8	HvHs	4.75	(2.22)	3.50	(1.00)
	HvLs	3.66	(1.37)	2.00	(1.10)
	LvHs	3.33	(.82)	2.66	(1.37)
	LvLs	2.25	(1.71)	1.50	(.58)
C	HvHs	4.20	(1.64)	5.00	(1.00)
	HvLs	4.20	(1.92)	3.60	(2.41)
	LvHs	4.50	(1.29)	4.25	(2.50)
	LvLs	4.20	(.84)	3.40	(1.52)

[a]Shown in parentheses.

[b]N's for each group are given in Table VIII.

The Hands X Sex interaction resulted from females being significantly better than males with the right hand, $q\ (2,94) = 2.90$, $p < .05$. The sexes did not differ significantly in accuracy with the left hand and there was no significant overall difference between hands for either sex.

The Hands X Sex X Grade interaction is illustrated in Figure 1. Males were consistently but not significantly more accurate with their left hand, except at the eighth grade, $q\ (2,94) = 3.22$, $p < .05$. Females were more accurate with the left hand at the fourth grade, significantly more accurate with the right hand at the eighth grade, $q\ (2,94) = 3.22$, $p < .05$, and nonsignificantly more accurate with the right hand at the college level.

Dichotic Listening Task. Table XI shows separate estimates of inter-item reliability for the right ear and left ear made using the even-odd, split-half method. The moderately high r_{kk} values suggest that the instrument is reasonably internally consistent.

An analysis of variance revealed that performance of left-handed and ambidextrous subjects did not differ significantly from that of right-handed subjects, ($F < 1$), therefore, the subjects' scores were pooled across handedness for further analysis. Data from Phase II testing are presented in Appendix F.

Analyses of variance were computed to determine the effects of the counter-balancing factors of earphone placement and tape. Table XII gives the means for earphone placement for the right and left ears. Earphone placement was not significant, ($F < 1$) and, therefore, was disregarded in further analysis.

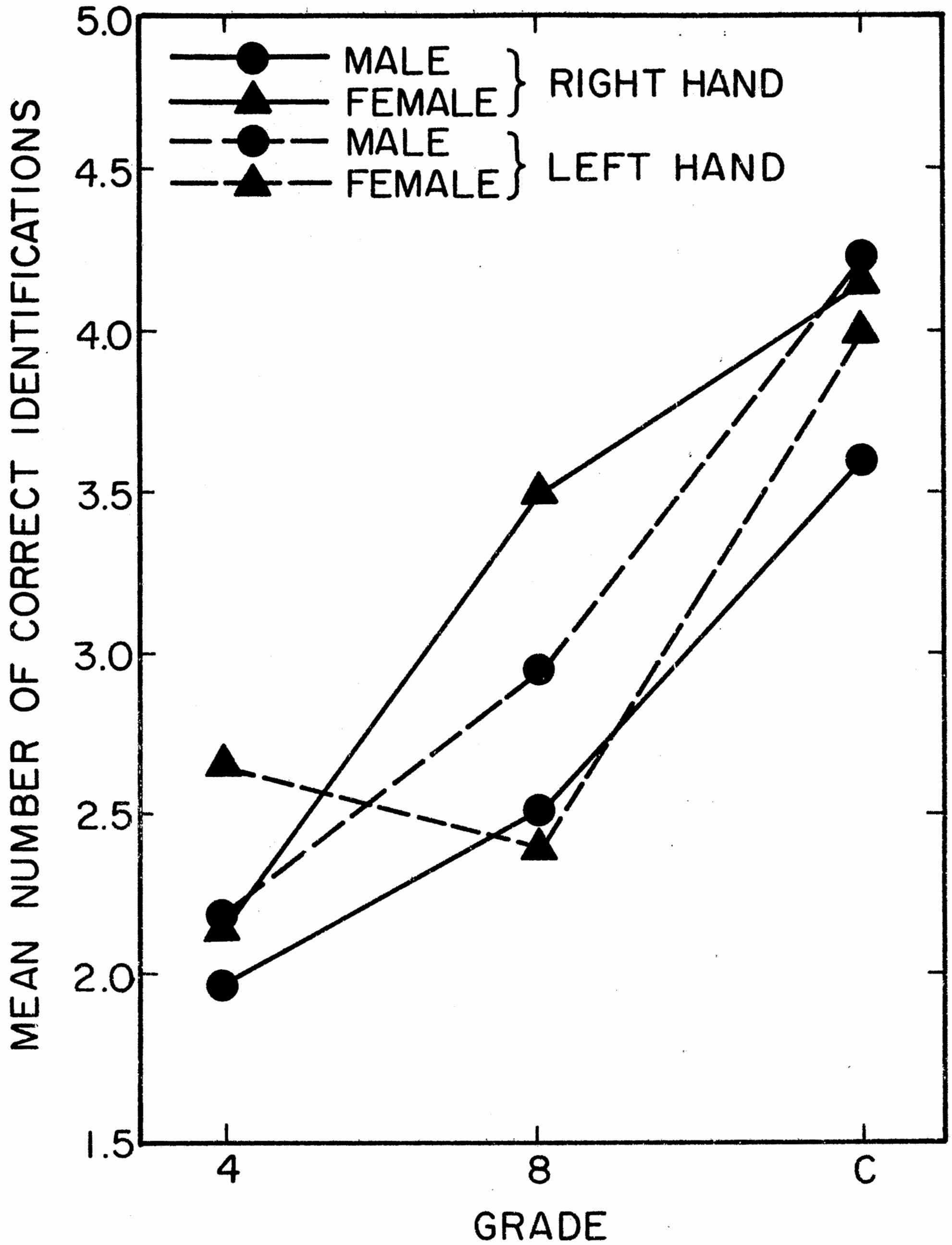

Figure 1. Mean Accuracy Scores for Right and Left Hands on the Haptic Task as a Function of Sex and Grade

TABLE XI

RELIABILITY OF DICHOTIC LISTENING TASK

Sex and Grade	N	Right Ear r_{kk}	Left Ear r_{kk}
Males			
4	20	.18	.55*
8	20	.77**	.55*
C	19	.84**	.84**
Females			
4	20	.78**	.69**
8	20	.76**	.74**
C	19	.59**	.88**

*$p < .05$.

**$p < .01$.

TABLE XII

NUMBERS OF CORRECT RESPONSES ON THE DICHOTIC LISTENING TASK AS A FUNCTION OF EARPHONE PLACEMENT AND EAR: MEANS AND STANDARD DEVIATIONS[a]

Earphone Placement (control phone)	N	Right Ear		Left Ear	
Right Ear	58	14.85	(5.22)	15.33	(5.03)
Left Ear	60	15.58	(5.21)	13.94	(4.43)

[a]Shown in parentheses.

The analysis of variance for tape differences revealed a significant effect for Tape, $\underline{F}$ (1,106) = 13.35, $\underline{p} < .001$, indicating that tape 2 was easier than tape 1. Table XIII gives the means for right ear and left ear by tape. There also was a significant Ears X Tape interaction, $\underline{F}$ (1,106) = 4.64, $\underline{p} < .04$. As may be seen in Table XIII, this interaction was due to the greater difference between right- and left-ear scores on tape 1. Whether this right-ear superiority on the more difficult tape reflects a left-hemisphere advantage with verbal material or merely an artifact of tape 1 is not known. Since tape effects per se were of no special interest in the research problem, tape was not included as a factor in further data analysis.

TABLE XIII

NUMBERS OF CORRECT RESPONSES ON THE DICHOTIC LISTENING TASK AS A FUNCTION OF TAPE AND EAR: MEANS AND STANDARD DEVIATIONS[a]

Tape	N	Right Ear		Left Ear	
1	60	14.42	(5.23)	12.16	(4.52)
2	58	16.29	(4.62)	16.59	(4.22)

[a]Shown in parentheses.

Mean numbers of correct responses and standard deviations are summarized in Table XIV for males and females at the three grade levels in each ability group. An analysis of variance revealed that Grade, $\underline{F}$

TABLE XIV

NUMBERS OF CORRECT RESPONSES ON THE DICHOTIC LISTENING TASK AS A FUNCTION OF EAR, GRADE, SEX, AND ABILITY GROUP: MEANS AND STANDARD DEVIATIONS[a]

Sex and Grade	Ability Group	Right-Ear		Left-Ear	
Males					
4	HvHs	11.40	(5.98)	11.60	(2.61)
	HvLs	15.60	(3.21)	14.40	(4.04)
	LvHs	13.40	(3.29)	11.80	(4.09)
	LvLs	11.60	(3.36)	10.80	(2.39)
8	HvHs	15.40	(3.78)	16.00	(4.18)
	HvLs	11.00	(3.63)	13.33	(4.03)
	LvHs	10.75	(3.50)	15.25	(5.91)
	LvLs	13.40	(4.04)	10.00	(4.85)
C	HvHs	19.00	(6.56)	20.00	(5.70)
	HvLs	21.60	(5.41)	21.40	(4.10
	LvHs	15.25	(4.72)	13.25	(4.65)
	LvLs	15.00	(5.24)	18.20	(5.54)
Females					
4	HvHs	11.20	(7.79)	10.40	(4.67)
	HvLs	15.40	(3.65)	13.20	(3.90)
	LvHs	12.00	(4.06)	9.80	(3.77)
	LvLs	11.20	(6.53)	8.80	(4.21)
8	HvHs	20.75	(5.50)	16.25	(7.27)
	HvLs	12.67	(6.38)	14.17	(6.01)
	LvHs	14.83	(5.81)	13.50	(6.83)
	LvLs	12.25	(4.35)	13.00	(3.92)
C	HvHs	22.40	(6.07)	20.60	(7.27)
	HvLs	20.20	(3.63)	18.20	(5.36)
	LvHs	21.00	(5.35)	17.50	(2.08)
	LvLs	17.20	(4.21)	17.00	(3.39)

[a]Shown in parentheses.

[b]N's for each group are given in Table VIII.

(2,94) = 27.49, $\underline{p} < .0001$ and Ability Group, $\underline{F}$ (3,94) = 3.94, $\underline{p} < .01$ were significant. Sex ($\underline{F} < 1.00$) and Ear main effects ($\underline{p} < .21$) were not significant. None of the interactions were significant: Sex X Grade, $\underline{p} < .28$; Grade X Ability Grouping, $\underline{p} < .09$; Ears X Sex, $\underline{p} < .09$; Ears X Grade X Ability, $\underline{p} < .41$; no other interaction approached significance (all $\underline{F}$s < 1.00).

College students were significantly more accurate with the right ear than were eighth graders, $\underline{q}$ (2,94) = 7.23, $\underline{p} < .01$, and fourth graders, $\underline{q}$ (2,94) = 8.60, $\underline{p} < .01$. While eighth graders were more accurate with the right ear than fourth graders, the difference was not statistically significant. Comparisons of left-ear performance revealed significant differences between all three grades at the .01 level. The respective Tukey values were $\underline{q}$ (2,94) = 5.14 for fourth and eighth graders, $\underline{q}$ (2,94) = 9.98 for eighth graders and college, and $\underline{q}$ (2,94) = 15.12 for college and fourth graders. As may be seen in Table XIV, performance improved consistently across the grade levels.

There was no difference in accuracy as a function of ear for either sex nor did males and females differ significantly in their right- and left-ear scores. Figure 2 shows that females were consistently more accurate with the right ear whereas males fluctuated between greater accuracy with the right and left ear. College females scored significantly higher than fourth graders only for the right ear, $\underline{q}$ (2,94) = 3.63, $\underline{p} < .05$ and left ear, $\underline{q}$ (2,94) = 3.72, $\underline{p} < .01$. College males scored significantly higher than fourth graders only for the left ear, $\underline{q}$ (2,94) = 3.11, $\underline{p} < .05$.

Mean comparisons between ability groups revealed that subjects with high verbal ability were better at this task than subjects with

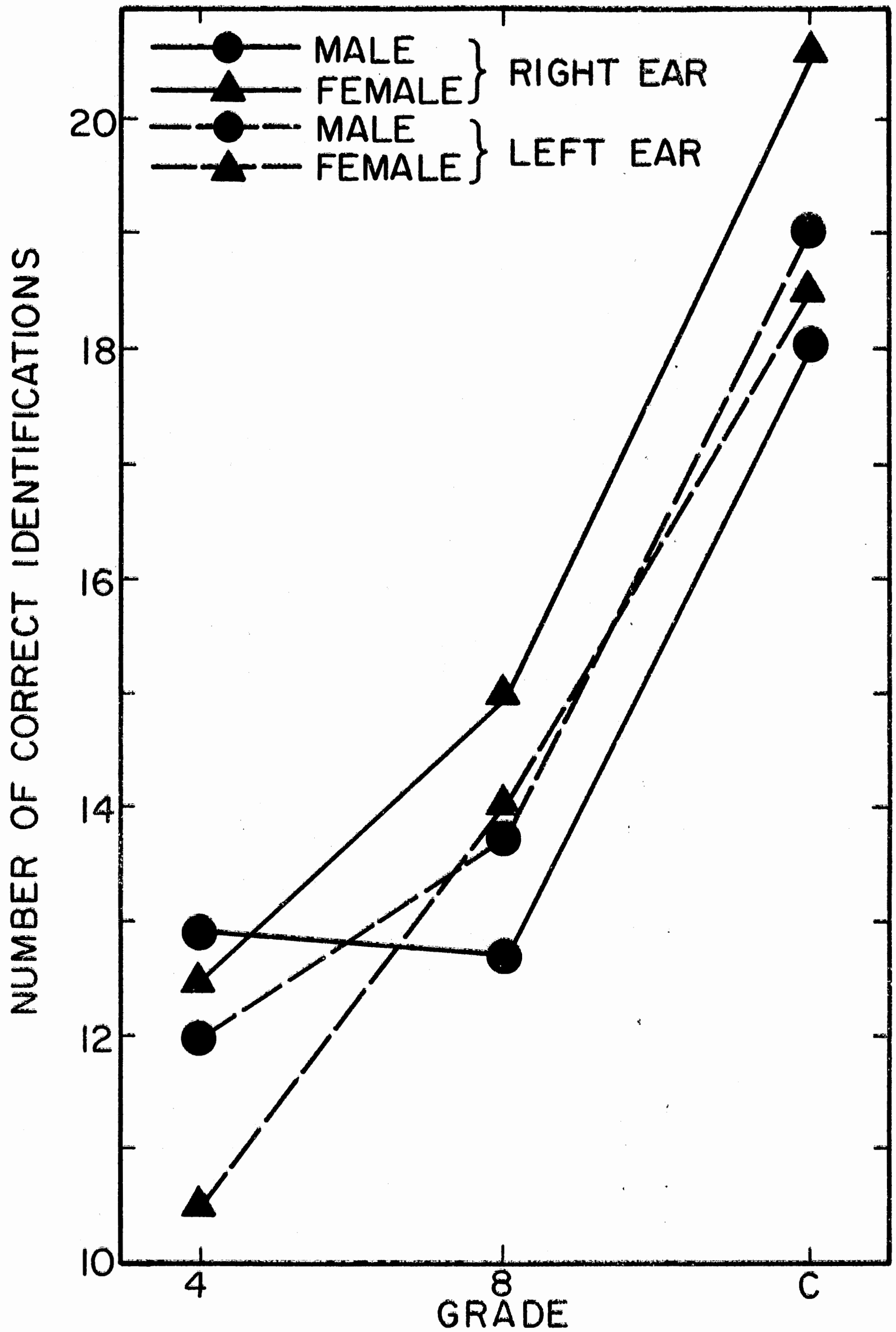

Figure 2. Mean Numbers of Correct Responses for the Right and Left Ears on the Dichotic Listening Task as a Function of Sex and Grade

low verbal ability. The HvHs subjects scored significantly higher than the LvLs subjects, $\underline{q}$ (2,94) = 3.54, $\underline{p} < .05$. The HvLs group also outperformed the LvLs group, $\underline{q}$ (2,94) = 3.17, $\underline{p} < .05$. No other ability-group comparisons were statistically significant.

Intrusions (overt incorrect responses) were of four basic types: words from previous trials, some alternate form of the stimulus word, associates, and blends of two stimulus words. An analysis of variance of the intrusion data revealed no significant main effects or interactions for Sex, Grade, or Ability Group.

A significant correlation between left-hemispheric lateralization (right-ear scores) and spatial ability was obtained for college females only, $\underline{r} = .56$, $\underline{p} < .05$. A correlation between right-ear scores and verbal ability was obtained for college males only, $\underline{r} = .51$, $\underline{p} < .05$. Neither spatial nor verbal ability correlated with left-ear scores for either sex at any grade level.

Of the 30 females classified as having low spatial ability, 22 did not show hemisphere lateralization on the dichotic listening task. A five-point (or greater) difference between ear scores served as the criterion for classifying individuals as being lateralized. Of the 29 high spatial ability females, 15 were lateralized. Eight of the 28 males with high spatial ability were lateralized as compared with 12 of the 31 males with low spatial ability. Separate Chi-Square analyses for males and females revealed that for females only, the frequency of lateralized subjects differed significantly depending upon whether or not they were high or low in spatial ability ($\chi^2 = 3.90$, d.f. = 1, $\underline{p} < .05$).

Hands-On Logical Reasoning Task. The Pearson r correlation between scores on the hands-on task and the proportion subscale score on the written measure was .49, $p < .0001$ for males and .47 $p < .001$ for females. The association, which increased with age for both males and females reached significance at the college level only, $r = .49$, $p < .05$ and $r = .67$, $p < .01$ for college males and females, respectively.

An analysis of variance with Sex, Grade, and Ability as the between between-subjects variables and Hands-on Logical Reasoning as the within-subjects variable was calculated. Table XV presents the mean correct responses and standard deviations. Grade, $F(2,94) = 18.18$, $p < .0001$, Sex, $F(1,94) = 11.11$, $p < .001$, and Ability Group, $F(3,94) = 13.11$, $p < .0001$ were highly significant. No interactions were significant.

TABLE XV

NUMBERS OF CORRECT RESPONSES ON THE HANDS-ON LOGICAL REASONING TASK: MEANS AND STANDARD DEVIATIONS[a]

Sex and Grade	Ability Group[b]							
	HvHs		HvLs		LvHs		LvLs	
Males								
4	3.60	(.45)	3.40	(.89)	3.00	(.50)	2.60	(.71)
8	4.00	(.55)	3.00	(.55)	4.00	(.71)	3.00	(.89)
C	4.80	(.40)	4.40	(.63)	4.25	(.42)	3.00	(.63)
Females								
4	3.80	(.45)	2.40	(.55)	2.80	(.45)	3.00	(.00)
8	3.50	(.58)	2.83	(.75)	2.67	(.82)	2.50	(.58)
C	4.40	(.50)	3.20	(.84)	3.50	(1.73)	3.20	(1.30)

[a]Shown in parentheses.

[b]N's for each group are given in Table VIII.

Males scored higher than females on the hands-on measure of logical reasoning at all ages tested and the difference reached statistical significance at the eighth grade, $\underline{q}$ (2,94) = 2.84, $\underline{p} < .05$ and college level, $\underline{q}$ (2,94) = 3.34, $\underline{p} < .05$. Performance improved significantly with age. College students scored significantly higher than fourth graders, $\underline{q}$ (3,94) = 6.75, $\underline{p} < .01$, and eighth graders, $\underline{q}$ (3,94) = 6.10, $\underline{p} < .01$. Eighth graders did not differ significantly from fourth graders.

College males scored significantly higher than eighth grade males, $\underline{q}$ (3,94) = 4.16, $\underline{p} < .05$, and fourth grade males, $\underline{q}$ (3,94) = 6.09, $\underline{p} < .01$. No other grade comparisons for males were significant. Fourth grade females scored higher than eighth grade females but the difference was not significant. College females scored significantly higher than both fourth grade females, $\underline{q}$ (3,94) = 3.65, $\underline{p} < .05$, and eighth grade females, $\underline{q}$ (3,94) = 4.68, $\underline{p} < .01$.

The HvHs ability group scored significantly higher than the HvLs group, $\underline{q}$ (4,94) = 6.58, $\underline{p} < .01$, the LvHs group, $\underline{q}$ (4,94) = 5.64, $\underline{p} < .01$, and the LvLs group, $\underline{q}$ (4,94) = 8.96, $\underline{p} < .01$. The HvLs group did not differ significantly from the LvHs or the LvLs groups, nor did the LvHs group differ significantly from the LvLs group.

A significant positive correlation between spatial ability and the hands-on measure of logical reasoning was found for eighth grade males, $\underline{r} = .65$, $\underline{p} < .01$; college males, $\underline{r} = .62$, $\underline{p} < .01$; and college females, $\underline{r} = .49$, $\underline{p} < .05$. Verbal ability also was positively correlated with the hands-on measure in fourth grade males, $\underline{r} = .65$, $\underline{p} < .01$; college males, $\underline{r} = .63$, $\underline{p} < .01$; and college females, $\underline{r} = .47$, $\underline{p} < .05$.

Multiple regression with sex, grade, verbal ability, and spatial ability revealed that spatial ability was the best single predictor of performance on the hands-on task, $R^2 = .30$. The R^2 values for the other variables were .21 for verbal, .11 for grade, and .05 for sex. Verbal and spatial ability together was the best two-variable predictor, and explained 34 percent of the variance on this measure. Verbal ability, spatial ability, and sex constituted the best three-variable predictor of performance, $R^2 = .38$.

<u>The Relationship Between Written and Hands-on Measures of Logical Reasoning</u>. Table XVI summarizes the Pearson *r* correlations among verbal and spatial ability measures and performance in the two logical reasoning tasks for Phase II subjects.

As may be seen in Table XVI, the correlations differed for males and females and by grade level. The relationship of spatial and verbal ability to logical reasoning was task specific, particularly for the younger subjects. At the fourth grade, verbal, but not spatial ability, was correlated with both measures of logical reasoning for males; whereas, the only significant correlation found for females was between verbal ability and the paper-and-pencil logical reasoning task. For eighth graders, spatial ability more than verbal ability was strongly correlated with logical reasoning. Spatial ability was strongly correlated with both measures of logical reasoning for males and with the paper-and-pencil task for females. The only significant correlation between logical reasoning and verbal ability at the eighth grade level was found for males on the paper-and-pencil task. Both verbal and spatial ability were correlated with both measures of logical reasoning for college males; for females, verbal and spatial ability were correlated with performance on the hands-on task only.

TABLE XVI

SUMMARY OF CORRELATIONS BETWEEN VERBAL, SPATIAL, AND LOGICAL REASONING MEASURES

	Grade and Sex					
	Fourth		Eighth		College	
	Males (n=20)	Females (n=20)	Males (n=20)	Females (n=20)	Males (n=19)	Females (n=19)
Measures	r	r	r	r	r	r
Verbal and P-Logic[a]	.51*	.62**	.45*	.29	.74***	.41
Verbal and A-Logic[b]	.65**	.03	-.02	.28	.63**	.47*
Spatial and P-Logic	.15	-.10	.50*	.58**	.66**	.41
Spatial and A-Logic	.37	.38	.65**	.14	.62**	.49*
P-Logic and A-Logic	.52*	-.13	.23	.25	.65**	.71***
Verbal and Spatial	.17	.01	.10	.15	.50*	.41

[a]P-Logic = Passive measure of logical reasoning (Paper-and-Pencil).

[b]A-Logic = Active measure of logical reasoning (Hands-on).

* = $p < .05$.

** = $p < .01$.

*** = $p < .001$.

The two measures of logical reasoning were significantly correlated for fourth grade males and college males and females. Verbal and spatial ability were correlated for college males.

Other Variables. A 3 x 2 Chi-Square analysis was used to determine whether the numbers of males having high or low spatial ability differed significantly as a function of the sex of their older sibling(s) and no older siblings. Subjects were classified as either those with only an older sister, those with both an older brother and sister, and those with no older siblings. A similar analysis was computed for female subjects. The resultant values for females ($\underline{\chi}^2 < 1$) and males ($\underline{\chi}^2$ = 3.41, d.f. = 2) were not significant. Also, separate Chi-Square analyses for males and females revealed no significant differences in the frequency of subjects with high and low spatial ability as a function of the four eye-hand dominance possibilities (right hand-right eye, right hand-left eye, left hand-left eye, and left hand-right eye) ($\underline{\chi}^2 < 1$).

Summary

Haptic Discrimination Task. Females were significantly better than males with the right hand at the eighth grade level only. The sexes did not differ with the left hand and there was no significant difference between hands for either sex. Performance with the right hand increased significantly with grade level. While performance improved with grade level for the left hand also, differences in performance were significant only between the college subjects and the younger groups. The only significant ability group difference observed was between the HvHs and LvLs groups, with the HvHs group scoring higher.

The only significant correlations between spatial ability and performance on the haptic task was on the left-hand scores of college females and the right-hand scores of eighth grade females. An association between verbal ability and right-hand scores only was found for both eighth grade males and females.

Dichotic Listening Task. Males and females did not differ significantly in performance with either the right or left ear. Performance on the auditory task improved significantly with age. The HvHs ability group performed significantly better than the other ability groups and the HvLs group outperformed the LvLs group. The only significant correlations between ability and task performance were between verbal ability and right-ear scores for college males. Significantly more females with low spatial ability than with high spatial ability were not lateralized with respect to right versus left ear dominance.

Hands-on Logical Reasoning Task. Males scored higher than females on the hands-on measure of logical reasoning, and the male advantage was significant at the eighth grade and college levels. Performance improved with age. The HvHs ability group performed significantly better than the other ability groups.

Spatial ability correlated with the hands-on measure of logical reasoning for eighth grade and college males and college females. Verbal ability correlated with the hands-on measure for fourth grade and college males and college females. Spatial ability emerged as the best single predictor of performance on the hands-on logical reasoning task.

Written and Hands-on Measures of Logical Reasoning. Performance on the active logical reasoning task correlated positively with that on the passive (written) measure for both males and females. The correlation was significant at the fourth grade and college levels for males and at the college level for females. Spatial ability correlated with both logical reasoning measures for eighth grade and college males, but with only the written measure for eighth grade females and only the hands-on task for college females.

Verbal ability correlated with both logical measures for fourth grade males but only with the written measure for fourth grade females. At the eighth grade, verbal ability correlated only with paper and pencil performance and only for males. Verbal ability was highly correlated with both measures of logical reasoning for college males and moderately correlated with hands-on performance for college females.

Significant correlations between the hands on and paper-and-pencil tasks were found for fourth grade and college males and college females. Verbal ability correlated with spatial ability for college males only.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

This chapter considers the research questions of Phase I and II in light of the findings. The findings are discussed in relation to previous research and current theoretical understanding of sex differences in cognitive processes.

Phase I

Research Questions

What is the Nature of Sex Differences in Spatial, Verbal, and Logical Reasoning Abilities? Consistent with previous findings (e.g., Maccoby and Jacklin, 1974), a male advantage in spatial-visualization ability was the most substantial sex difference obtained in the study. The expected female verbal-ability advantage and predicted male advantage in logical reasoning were not obtained.

The nonsignificant male advantage at the fourth grade on the WRVT was surprising in light of previous research (Maccoby and Jacklin, 1974) which reported either a female advantage or no sex difference. Whether this tendency for males to do slightly better than females in the verbal area was a result of sampling or of the instrument employed is not clear. In an informal discussion, the fourth grade classroom teachers indicated that a disproportionate number of males were identified as having high verbal ability by the district testing program. On the other hand, McGuinness and Pribram (1978) have noted that vocabulary measures typically do not yield sex differences except in studies with very large samples.

The absence of a significant sex difference on the written logical reasoning measure may have been related to the more passive and verbal nature of the task. This issue will be discussed further later in the chapter.

Is There a Trade-off Between Verbal and Spatial Processes Or Are They Independent? The present data provided no evidence of a trade-off between verbal and spatial ability as suggested by Olson (1975). The low correlation between verbal and spatial ability obtained for both sexes at the fourth grade level would indicate that these abilities initially are independent of one another. However, the higher positive correlations at later ages between verbal and spatial ability suggest that these abilities may become interrelated in the course of development. These results conflict with the findings of factor analytic studies (Very and Iacono, 1970; Very, 1967) indicating that the abilities become differentiated during the course of development. Similarly, the present results would not be consistent with that aspect of developmental theory (Werner, 1948) which suggests that cognitive functioning changes from a global, undifferentiated ability into a complex pattern of differentiated abilities.

Given that verbal and spatial abilities were both found to correlate positively with logical reasoning, as well as with each other, it might be argued that the verbal and spatial instruments merely provided two estimates of the same thing. However, we should remember that spatial ability was originally identified as a separate ability because it did not correlate with other measures of general intelligence. Also, there is nothing in the WRVT or SDT tasks that would appear to draw on a common ability of the subject, other than intelligence in the most general sense. Therefore, the explanation that the WRVT and the SDT are simply measuring the same ability is not a very logical or satisfying one.

Thus, the present data provided no support for either the "trade-off" or the independent processes alternative. The finding that verbal and spatial processes may become progressively interrelated in development was both unexpected and interesting. Perhaps, as Werner (1948) suggested, abilities do become hierarchically integrated in the final stages of development. At any rate, this finding would have important theoretical and practical implications, if it proves to be reliable. For that reason, an early replication effort would appear to be in order.

What is the Role of Verbal and Spatial Ability in Logical Reasoning? The relationship between verbal ability and reasoning was stronger for females than for males only at the eighth grade. This finding lends little support to the prediction that the verbal ability and reasoning relationship would be more typical of females. The finding that the correlation between spatial ability and logical reasoning increased in strength for males at the college level but decreased for females, provided the only support for the hypothesis that the relationship between spatial ability and logical reasoning would be stronger and more typical of males.

As predicted, verbal ability and spatial ability explained a slightly greater proportion (10 percent) of the variance on the written logical reasoning task than either verbal or spatial ability alone.

Both verbal and spatial ability appear to be equally good predictors of reasoning performance on the paper-and-pencil task.

The predicted female advantage in reasoning at the fourth grade, diminishing at the eighth grade, and perhaps disappearing or giving way to a male advantage at the college level were not obtained. The predictions were based on the reasoning that a paper-and-pencil measure would lend itself more than a manipulative task to the use of verbal processes, and involve a more passive learning style that should favor females.

It was also assumed that females would enjoy a verbal advantage at the fourth grade that would diminish with development, while males would enjoy a progressively greater spatial advantage with development.

As noted earlier, spatial ability and verbal ability were found to be equally good predictors of reasoning performance. Given this finding, it is surprising that males did not outperform females as they exhibited superior spatial ability and equal verbal ability. It is not clear whether both sexes used verbal processing on the task with equal efficiency or whether males tended to use spatial ability whereas females were more likely to use verbal processing. This latter possibility suggests that reasoning tasks may often be solved by verbal and/or spatial means. This point will be considered further a bit later.

<u>Are there Developmental Sex Differences</u>? As expected performance on all three measures improved with age. The developmental pattern for males and females on the WRVT was virtually identical. The same was true for the SDT, with the male advantage increasing with age. The developmental pattern on the logical reasoning task appeared to differ for males and females. Eighth grade females' performance differed

significantly from college but not fourth grade females whereas eighth grade males resembled college males more than fourth graders. Given that the sexes performed comparably at the fourth grade and college levels, the nonsignificant male advantage observed at the eighth grade suggests that females may have a slower rate of development of logical reasoning. The argument for a slower rate of female development in any ability is difficult to explain. One possibility is that verbal and spatial ability may have different critical periods of development in relation to logical reasoning. Differential expectations, activities, etc., for the sexes may interact with biological processes to result in an apparent retardation of logical development for females. Whether females have a slower rate of development but eventually reach the same level as males, or have a lower final level of development is an important question. Graybill (1975) found that females lagged behind males beginning at about age 11 years and fell further behind at ages 13 to 15. No previous research evidence is available for adults. Further research with a non-college adult sample may be needed to clarify this issue. Phase II data from the specialized hemispheric functioning tasks may have a bearing on this question and they will be discussed in the next section.

Phase II

Research Questions

<u>What is the Nature of the Sex Difference on an Active Logical Reasoning Task</u>? As predicted, (based on Lawson, 1975 and Fogelman, 1969) males scored higher than females on the hands-on measure of logical reasoning. The data provided some support for the predicted

relationship of the active and passive measures of logical reasoning to sex differences in verbal and spatial ability. While verbal and spatial ability proved to be equally good predictors of performance on the paper-and-pencil measure of logical reasoning, spatial ability was the better predictor of performance on the hands-on measure. These findings would appear to account for the male advantage on the manipulative reasoning task which reached statistical significance at the eighth grade and college levels. It appears that spatial ability can become an important component of reasoning at higher levels of functioning (more complex problems) for individuals who possess the ability. The likelihood of having spatial capability seems to increase with age. A significant positive correlation between spatial and manipulative reasoning ability was found for eighth grade and college males and college females. Similarly, the correlation between the abilities (spatial and logical reasoning) increased substantially with age on the paper-and-pencil task. The developmental pattern for males and females on the active measure was similar to that of the paper-and-pencil measure, again suggesting that females may have a slower rate of development of logical reasoning. The finding of greater sex differences at the eighth grade than at the college level would argue against the idea that females have a lower final level of reasoning ability which they reach earlier.

What is the Relationship Between Verbal and Spatial Ability and Specialized Hemispheric Functioning? The hypothesis that specialized functioning of the right hemisphere for spatial stimuli would be greater and occur earlier in males was partially supported. Superior left-hand performance on the haptic task was found only for males but was significant only at the eighth grade level. These findings were generally consistent with Witelson's (1979) results showing left-hand superiority for males in the age range of 6 to 12 years. On balance, however, the data from the haptic task provided little evidence for a general right hemispheric dominance.

Neither hemisphere emerged as dominant in the processing of verbal stimuli. Females were consistently more accurate with the right ear in the dichotic listening task whereas males shifted from greater right-ear accuracy at the fourth grade to greater left-ear accuracy at the eighth grade and college levels. This finding conflicts with the results of previous studies (McGlone and Davidson, 1973; Witelson, 1976) showing the right ear to be dominant in processing verbal stimuli for both sexes. Similarly, it is not in agreement with the Lake and Bryden (1976) finding that males are more lateralized than females on the verbal dichotic listening task.

Surprisingly, the predicted relationship between right hemisphere processing (left-hand performance) and spatial ability was found only for college females, and the relationship between right-ear scores and verbal ability was found only for college males. Could these findings be an artifact of the instruments? Although the haptic and dichotic listening tasks were designed to tap functioning in opposite hemispheres, it appears that this did not happen. Regardless of task (spatial or verbal) males tended to use the right hemisphere (left-hand, left-ear) and females tended to use the left hemisphere (right-hand, right-ear). This is an intriguing finding that would not appear to be due solely to peculiarities of the instruments used. One possible explanation is that the sexes may develop a response bias or preference for using one problem-solving approach (verbal or spatial) over another. If so, that would account for the finding that the sexes tended to use different hemispheres regardless of the nature of the task. The failure to find significant correlations of spatial or verbal ability with performance on the tasks designed to tap hemispheric functioning could be interpreted to mean that verbal processing is not restricted to the left hemisphere, or spatial processing to the right hemisphere. Alternatively, and more likely, is the possibility that the so-called "spatial" and "verbal" lateralization tasks do not measure only the specific process (or specific hemisphere) they were designed to measure, but in fact can be solved either spatially or verbally, which is to say via either hemisphere.

These considerations suggest a need to exercise caution in interpreting the results of studies employing lateralization measures. In this connection, it might be helpful to assess the validity of behavioral measures of lateralization in conjunction with an electroencephalogram. Measures of brain activity via EEG recordings would help to substantiate the apparent relationship between overt activity and underlying hemispheric processing.

Conclusions and Implications

The study examined the interrelationships between spatial, verbal, and logical reasoning ability, and the level of verbal and spatial ability in relation to performance on an active measure of logical reasoning and tasks designed to tap brain hemisphere functioning.

The only quantitative evidence for sex differences found in this study was a male advantage in spatial ability and on the hands-on logical reasoning task. Performance on the hands-on task was related to the sex difference in spatial ability. This finding would appear to explain the greater sex difference found with active, manipulative tasks as compared to paper-and-pencil tasks noted by other researchers (e.g., Fogelman, 1969; Lawson, 1975; and Keogh, 1971).

As expected, performance on all measures improved with age. The apparently different developmental pattern for the sexes on both measures of logical reasoning poses an interesting problem for future research.

The failure to find expected correlations of verbal and spatial ability with performance on the dichotic listening and haptic discrimination tasks, respectively, and the finding that females tended to use the left hemisphere and males the right hemisphere regardless of task, suggest the need to reexamine theories of brain lateralization that relate more effective cognitive functioning and sex differences in cognitive abilities to specialized hemispheric functioning.

The study provided direct empirical evidence to link spatial ability with logical reasoning. The predictive value of both spatial and verbal ability in relation to performance on logical reasoning tasks underscores the importance of giving greater attention to the development of spatial ability. This recommendation would seem to be particularly appropriate to school curriculua that so typically emphasize verbal processes and skills and virtually ignore the development of spatial ability.

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APPENDIX A

INSTRUCTIONS TO SUBJECTS FOR PHASE I MEASURES

Instructions for Written Logical Reasoning Task

You are going to do some problems. Some present facts and you have to make a conclusion. Some ask you to complete a drawing and some are like arithmetic problems. If you cannot answer a question, skip it and go on to the next one. If you have time you can come back to it. You will have 15 minutes to complete the test. (Instructions were identical for all three age groups.)

Instructions for Wide Range Vocabulary Test

The standard instructions presented in the Manual of Directions (Atwell and Wells, n.d.) were given to all subjects.

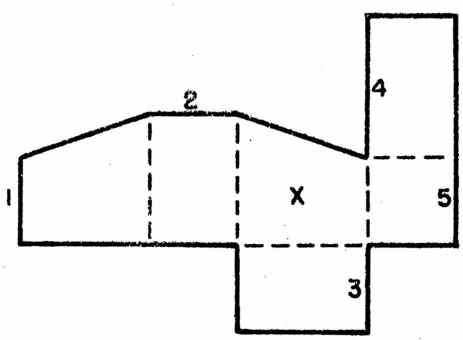
> Distribute the tests and instruct the subjects to fill in the space at the top of the page. Then say, 'In this test you are to underline the word at the right which will best complete the sentence. To illustrate: 'A <u>Street</u> is a -- field, hill, road, stream, path.' Which one of these words tells what a street is? (Pause, to let examinees respond.) 'Road' tells what a street is. A line should be drawn under 'road' to show that it is the correct answer. Now do the others this way. If you are not sure, guess. When you have finished the first page, turn over the test and go right on.'

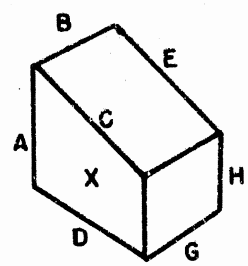
Name ______________________________

SURFACE DEVELOPMENT TEST — VZ-3

In this test you are to try to imagine or visualize how a piece of paper can be folded to form some kind of object. Look at the two drawings below. The drawing on the left is of a piece of paper which can be folded on the dotted lines to form the object drawn at the right. You are to imagine the folding and are to figure out which of the lettered edges on the object are the same as the numbered edges on the piece of paper at the left. Write the letters of the answers in the numbered spaces at the far right.

Now try the practice problem below. Numbers 1 and 4 are already correctly marked for you.





1:	H
2:	
3:	
4:	C
5:	

NOTE: The side of the flat piece marked with the X will always be the same as the side of the object marked with the X. Therefore, the paper must always be folded so that the X will be on the outside of the object.

In the above problem, if the side with edge 1 is folded around to form the back of the object, then edge 1 will be the same as edge H. If the side with edge 5 is folded back, then the side with edge 4 may be folded down so that edge 4 is the same as edge C. The other answers are as follows: 2 is B; 3 is G; and 5 is H. Notice that two of the answers can be the same.

Your score on this test will be the number of correct letters minus a fraction of the number of incorrect letters. Therefore, it will not be to your advantage to guess unless you are able to eliminate one or more of the answer choices as wrong.

You will have 6 minutes for each of the two parts of this test. Each part has 2 pages. When you have finished Part 1 (pages 2 and 3), STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

APPENDIX B

TEST MATERIALS FOR PHASE I

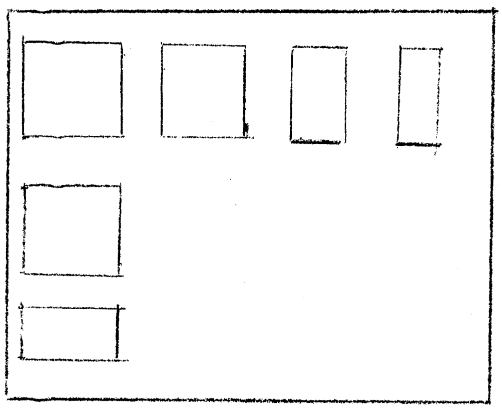
Copyright laws do not permit the reproduction of the Wide Range Vocabulary Test or the Surface Development Test. The items used in the written logical reasoning tasks are taken directly from the Test of Logical Thinking (TOLT), (Gray, 1973). The reader is referred to Gray (1973) for the complete TOLT.

Fourth Grade Items

1. George is taller than Bill
   Bill is taller than Harold
   Harold is taller than Carl

   Is George taller than Carl?

2. Complete the following drawing.



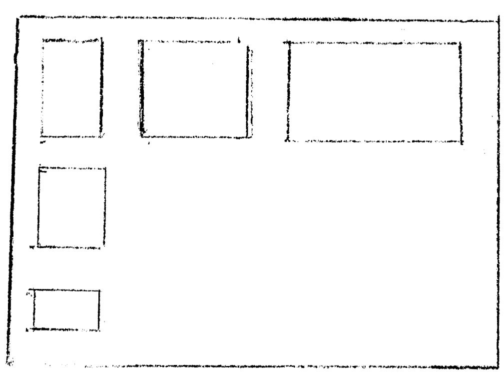
3. A coach has a choice of four players. He wants to give each player the same chance of making the team. He lets each player play for one week.

   How many weeks will the coach need if each player is to have the same chance of making the team?

4. Bob is the richest of four men; Jim the next richest; Lloyd, the next richest; and Tim the next richest. The richest man owns the smallest car; the next richest man the next smallest car, and so on.

   Who owns the smallest car?

5. Complete the following drawing.



6. A group of friends decide to go dancing. There are three men (Al, Bob, and Chuck) and three women (Louise, Marsha, and Nancy). Each man wants to dance with each woman.

   Write all of the possible man-women couples of dancers there could be if each man danced with each women.

Eighth Grade Items

1. Joe is the fastest of four men; Bill, the next fastest; Ken, the next fastest; and Dave the next fastest. The fastest man has the smallest feet; the next fastest man, the next smallest feet, and so on.

   Who has the second smallest feet?

2. All of the following sentences are true. What must happen for Alvin to go to the store?

   Mary comes home, it rains, Mike is not here and Alvin does not go to the store.

   Mary does not come home, it does not rain, Mike is here, and Alvin does not go to the store.

   Mary does not come home, it rains, Mike is not here, and Alvin goes to the store.

   Mary comes home, it does not rain, Mike is here, and Alvin goes to the store.

3. John and Chip each buy a bag of candy. In John's bag, there are 12 pieces of hard candy and 20 mints. In Chip's bag, there are 9 pieces of hard candy and 15 mints.

   Who has the best chance of grabbing a piece of hard candy when he takes a piece of candy from his bag?

4. A boy goes to an ice cream store and asks for four different ice cream sodas (chocolate, lemon, strawberry, and vanilla). They are served one at a time. The next day, he asks for the same sodas, but in a different order. Write all of the possible ways that the sodas could be served to the boy.

5. All of the following sentences are true. What must happen for John to talk to Luke?

   Paul sings, Jill screams, the police are correct, and John talks to Luke.

   Paul does not sing, Jill does not scream, the police are correct, and John talks to Luke.

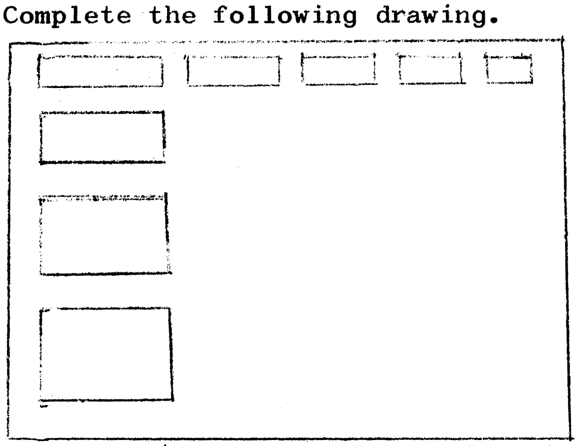
   Paul sings, Jill does not scream, the police are not correct, and John does not talk to Luke.

6. Two groups of children are going swimming. Teachers are going with them and will watch them. The first group is made up of 12 children and 2 teachers. The second group is made up of 18 children and 3 teachers.

   In which group is each teacher in charge of the fewest children?

7. A baseball manager has three pitchers (Sam, Tom, and George) and two catchers (Bill and Frank). The manager wants to find the best pair of pitcher and catcher. Write all the possible pairs of pitcher and catcher there could be if each pitcher threw to each catcher.

8. Complete the following drawing.



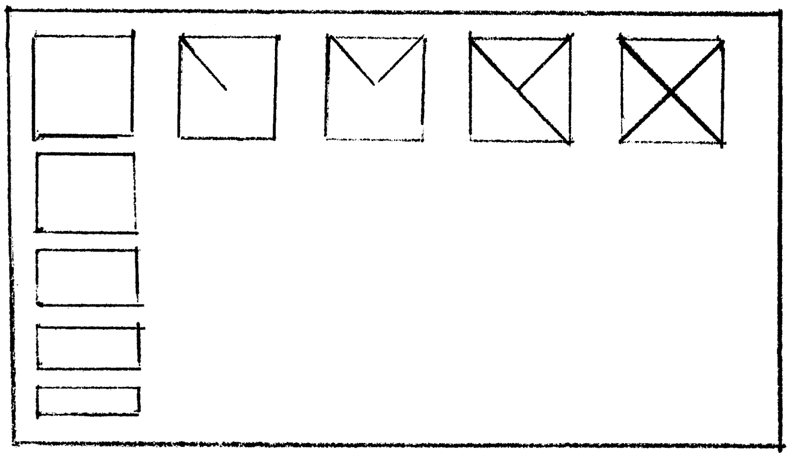
9. Six boys (Andy, Charlie, David, Mike, Paul, and Sam) are going to play tennis. Each boy wants to play every other boy in a game. Write all of the possible games that could be played if each boy played every other boy.

College Level Items

1. Gene is the best of four baseball players; Alan, the next best; Walt, the next best; and Rich, the next best. The best player is the shortest; the next best player, the next shortest, and so on.

   Who is the third shortest?

2. Complete the following drawing.



3. In a Chinese restaurant the menu has two columns listing the things that can be ordered. Column A has duck, fish, peanuts, and rice. Column B has apples, bread, chicken and ham. Only one pair of items, one from Column A and one from Column B, can be chosen at any one time. Write all of the possible pairs of food that could be made if each food in Column A was chosen with each food in Column B.

4. All of the following sentences are true. What must happen for Sam to be on vacation?

   John is going with his friends. Tom is walking through a village, Bob is not going fishing, and Sam is on vacation.

   John is not going with his friends, Tom is walking through a village, Bob is going fishing, and Sam is on vacation.

   John is going with his friends, Tom is not walking through a village, Bob is not going fishing, and Sam is not on vacation.

5. At quitting time, the workers of a factory leave through two doors. At door one, 12 women and 18 men will leave. At door two, 18 women and 27 men will leave. One person leaves each door at the same time. From which door does one have the best chance of seeing a woman leave first?

6. Eight football teams are going to play each other. Each team will play every other team. Write all of the possible games that could be played if each team played every other team.

7. All of the following sentences are true. What must happen for there to be good weather?

   Charlie is swimming, Dave is not boating, Ken is playing in the sand, and there is good weather.

   Charlie is not swimming, Dave is boating, Ken is playing in the sand, and there is not good weather.

   Charlie is not swimming, Dave is boating, Ken is not playing in the sand, and there is good weather.

   Charlie is swimming, Dave is not boating, Ken is playing in the sand, and there is not good weather.

8. Fred buys 3 tickets in a raffle, and a total of 75 tickets are sold. Bob buys 2 tickets in another raffle, and a total of 50 tickets are sold. Who has the best chance of winning his raffle?

9. Four companies (Chrysler, Delco, Frigidaire, and Nabisco) are going to have offices on the first four floors of a new building. Each company may choose any of the floors for its offices. No two companies can be on the same floor. Write all of the possible ways that the companies' offices could be arranged on the floors.

APPENDIX C

RAW DATA FOR PHASE I

Symbols and Abbreviations for Table XVII

GR	Grade (4 = Fourth Grade, 8 = Eighth Grade, C = College)
SX	Sex and identification number (M = Male, F = Female)
CV	Verbal Ability Category (1 = Low, 2 = High)
CS	Spatial Ability Category (1 = Low, 2 = High)
CL	Logical Reasoning Ability Category (1 = Low, 2 = High) (Paper and pencil task)
CI	Concrete Operational, beginning stage
CII	Concrete Operational, complete stage
FI	Formal Operational, beginning stage
FII	Formal Operational, complete stage
VER	Score for WRVT (verbal ability)
SPA	Score for SDT (spatial ability)
LOG	Score for Logical Reasoning (paper and pencil)
E	Exclusion (score for exclusion subscale)
P	Proportion (score for proportion subscale)
C	Combination (score for combination subscale)

TABLE XVII

PHASE I DATA

GR	SX	CV	CS	CL	CI	CII	FI	FII	VER	SPA	LOG	E	P	C
4	M1	1	1	1	1	0	0	0	20	6.42	1	1	0	0
	M2	1	1	2	3	3	0	0	24	7.46	9	3	3	3
	M3	2	1	2	2	2	0	0	51	7.90	6	3	0	3
	M4	1	2	1	1	1	0	0	28	12.64	3	0	1	1
	M5	2	2	2	3	3	0	0	38	12.60	9	3	3	3
	M6	2	1	1	2	1	0	0	33	6.74	4	1	0	3
	M7	1	1	1	1	1	0	0	28	9.22	3	3	0	0
	M8	2	1	1	2	1	0	0	32	7.38	4	1	0	3
	M9	1	2	2	3	3	0	0	18	12.64	9	3	3	3
	M10	2	1	2	2	2	0	0	37	3.00	6	3	0	3
	M11	1	2	1	0	0	0	0	27	13.08	0	0	0	0
	M12	1	2	2	2	2	0	0	29	10.74	6	3	0	3
	M13	1	1	1	0	0	0	0	4	2.56	0	0	0	0
	M14	1	1	1	1	1	0	0	16	6.42	3	2	0	1
	M15	2	2	1	2	1	0	0	46	29.86	4	1	0	3
	M16	1	1	1	2	0	0	0	20	2.46	2	1	0	1
	M17	1	2	1	2	1	0	0	30	12.02	4	1	0	3
	M18	1	2	1	1	1	0	0	30	13.26	3	1	0	2
	M19	2	2	2	1	3	0	0	41	9.92	7	2	2	3
	M20	2	1	2	0	3	0	0	51	8.70	6	2	2	2
	M21	2	2	2	3	3	0	0	50	11.06	9	3	3	3
	M22	1	2	1	2	0	0	0	30	15.36	2	1	0	1
	M23	1	2	1	2	1	0	0	19	11.94	4	3	0	1
	M24	2	1	2	3	3	0	0	59	4.84	5	3	0	2
	M25	2	1	1	1	1	0	0	54	.60	3	3	0	0
	M26	1	2	2	2	2	0	0	25	14.10	6	0	3	3
	M27	2	1	2	2	2	0	0	36	8.68	6	1	2	3
	M28	1	2	1	3	0	0	0	10	10.98	3	1	1	1
	M29	1	2	1	3	0	0	0	22	13.26	3	1	1	1
	M30	2	2	2	3	2	0	0	42	12.20	7	1	3	3
4	F1	1	2	1	0	1	0	0	6	12.04	2	2	0	0
	F2	2	1	2	3	2	0	0	38	7.46	7	1	3	3
	F3	1	1	1	1	1	0	0	22	7.64	3	1	2	0
	F4	1	2	1	0	2	0	0	25	17.82	4	2	0	2
	F5	1	2	1	1	2	0	0	21	9.48	5	1	2	2
	F6	1	2	1	1	0	0	0	22	9.92	1	1	0	0
	F7	1	2	1	1	0	0	0	24	10.74	1	1	0	0
	F8	1	1	1	1	0	0	0	11	3.96	1	1	0	0
	F9	2	1	2	3	3	0	0	30	4.34	9	3	3	3
	F10	2	1	2	2	2	0	0	34	3.78	6	3	0	3
	F11	1	1	1	1	0	0	0	23	2.76	0	0	0	0
	F12	1	1	1	2	2	0	0	23	3.34	6	0	3	3
	F13	1	1	1	0	1	0	0	19	6.32	2	1	0	0
	F14	2	1	2	3	3	0	0	32	4.92	9	3	3	3
	F15	1	2	2	3	3	0	0	29	8.46	9	3	3	3
	F16	1	2	1	2	1	0	0	21	9.84	4	3	0	1

TABLE XVII (Continued)

GR	SX	CV	CS	CL	CI	CII	FI	FII	VER	SPA	LOG	E	P	C
	F17	2	1	2	3	2	0	0	34	7.20	7	3	1	3
	F18	2	1	2	2	3	0	0	34	5.72	8	3	2	3
	F19	2	1	2	3	3	0	0	67	6.48	9	3	3	3
	F20	2	1	2	2	2	0	0	34	6.42	6	3	0	3
	F21	2	1	1	3	0	0	0	31	7.64	3	1	1	1
	F22	1	2	1	3	1	0	0	26	12.74	5	1	1	3
	F23	2	1	1	1	0	0	0	31	3.00	1	1	0	0
	F24	1	1	1	0	2	0	0	24	7.56	4	2	0	2
	F25	2	1	2	3	3	0	0	52	4.82	9	3	3	3
	F26	2	2	1	2	1	0	0	45	17.82	4	0	3	1
	F27	2	2	1	2	0	0	0	31	10.18	2	1	0	1
	F28	2	1	1	2	1	0	0	30	6.32	4	1	0	3
	F29	1	1	1	2	1	0	0	24	2.72	4	1	0	3
	F30	2	2	2	3	3	0	0	41	14.48	9	3	3	3
	F31	2	2	2	3	2	0	0	42	9.84	7	3	1	3
	F32	2	1	2	2	2	0	0	55	7.20	6	3	0	3
	F33	1	1	1	1	2	0	0	8	.30	5	0	2	3
	F34	1	2	1	3	1	0	0	23	10.98	5	1	3	1
	F35	1	1	1	1	2	0	0	26	7.04	5	3	2	0
	F36	2	2	1	2	1	0	0	36	7.90	4	1	0	3
	F37	1	1	1	1	1	0	0	25	.84	3	1	0	2
	F38	2	2	2	3	3	0	0	30	14.40	9	3	3	3
8	M1	2	1	1	0	3	1	0	55	16.80	9	2	5	2
	M2	1	1	1	0	2	0	0	33	11.48	4	2	0	2
	M3	2	1	2	0	1	2	2	57	13.78	16	0	7	9
	M4	2	2	1	0	2	1	0	57	45.88	7	0	2	5
	M5	2	1	2	0	3	2	0	54	21.50	12	2	5	5
	M6	1	1	1	0	2	2	0	26	15.62	10	2	3	5
	M7	1	2	1	0	0	0	0	26	24.62	0	0	0	0
	M8	1	1	1	0	2	0	0	41	20.44	4	2	0	2
	M9	2	2	1	0	1	1	1	74	32.16	9	0	7	2
	M10	2	2	1	0	2	2	0	49	26.76	10	0	5	5
	M11	1	1	2	0	3	2	0	35	19.64	12	2	5	5
	M12	1	2	1	0	2	2	0	23	48.86	10	2	3	5
	M13	1	1	2	0	3	2	0	6	10.64	12	5	5	2
	M14	1	2	2	0	3	1	1	29	52.02	13	2	9	2
	M15	2	1	2	0	3	2	0	53	9.84	12	5	5	2
	M16	2	2	2	0	3	2	0	43	26.34	12	2	5	5
	M17	1	1	1	0	0	0	0	32	7.62	0	0	0	0
	M18	2	1	1	0	2	0	0	44	14.40	4	0	2	2
	M19	2	1	1	0	3	1	0	55	10.56	7	2	5	2
	M20	2	1	2	0	2	2	1	61	3.88	14	0	5	9
	M21	2	2	1	0	2	1	0	45	26.34	7	0	2	5
	M22	1	2	1	0	3	1	0	41	36.44	9	2	5	2
	M23	1	1	1	0	1	0	0	5	3.60	2	0	2	0
	M24	2	2	1	0	2	1	0	48	24.66	7	0	5	2
	M25	2	1	1	0	0	0	0	58	15.48	0	0	0	0
	M26	2	1	1	0	0	1	0	45	17.20	3	0	3	0

TABLE XVII (Continued)

GR	SX	CV	CS	CL	CI	CII	FI	FII	VER	SPA	LOG	E	P	C
	M27	2	1	1	0	3	0	0	62	20.32	9	2	5	2
	M28	2	1	2	0	2	3	0	54	13.34	10	3	5	5
	M29	2	2	1	0	2	2	0	44	46.28	10	0	5	5
	M30	2	2	2	0	3	2	0	47	33.60	12	2	5	5
	M31	1	1	1	0	1	0	0	16	15.54	2	0	2	0
	M32	2	2	2	0	3	2	2	56	45.30	20	2	9	9
	M33	2	2	2	0	3	1	1	58	52.02	13	2	9	2
	M34	1	1	2	0	3	2	0	28	.10	12	2	5	5
	M35	1	1	1	0	0	1	0	12	10.54	3	0	3	0
	M36	1	1	1	0	3	1	0	15	11.62	9	2	5	2
	M37	2	1	2	0	2	1	1	47	12.62	11	0	5	6
	M38	2	2	1	0	3	1	0	45	23.18	9	2	5	2
	M39	2	2	2	0	2	2	1	50	34.44	17	5	3	9
	M40	2	1	2	0	2	1	1	57	20.88	11	0	9	2
	M41	2	1	2	0	2	1	1	54	14.40	11	2	3	6
	M42	1	2	2	0	3	2	0	37	23.52	12	5	5	2
	M43	2	1	1	0	2	1	0	42	19.06	7	0	5	2
	M44	1	2	2	0	3	2	0	27	22.38	12	2	5	5
	M45	1	2	2	0	3	2	0	39	46.88	12	5	5	2
	M46	1	1	1	0	1	0	0	13	13.26	2	2	0	0
	M47	1	2	1	0	2	0	0	21	26.50	4	0	2	2
	M48	1	1	1	0	3	0	0	36	15.50	6	2	2	2
	M49	2	2	2	0	3	2	2	59	48.02	20	5	9	6
	M50	2	1	1	0	2	0	0	56	14.34	4	2	0	2
	M51	2	1	1	0	1	0	0	53	1.58	2	2	0	0
	M52	2	1	1	0	2	2	0	44	16.68	10	3	5	2
	M53	1	2	2	0	3	2	0	25	21.24	12	5	5	2
8	F1	2	1	1	0	2	1	0	63	13.08	7	0	5	2
	F2	2	2	2	0	2	3	0	66	27.32	13	3	5	5
	F3	2	2	1	0	3	1	0	53	33.88	9	2	5	2
	F4	1	1	1	0	3	1	0	31	17.48	9	2	2	5
	F5	1	1	1	0	2	0	0	32	12.90	4	2	0	2
	F6	1	1	1	0	2	0	0	40	13.80	4	2	0	2
	F7	1	2	1	0	2	0	0	37	19.62	4	2	0	2
	F8	1	1	1	0	2	0	0	30	9.84	4	2	0	2
	F9	1	1	1	0	1	0	0	43	4.32	2	2	0	0
	F10	2	2	1	0	1	1	0	57	27.58	5	0	3	2
	F11	1	2	2	0	3	2	1	32	29.74	16	2	9	5
	F12	2	2	2	0	3	2	0	65	35.16	12	5	5	2
	F13	1	1	1	0	0	0	0	26	9.20	0	0	0	0
	F14	2	2	2	0	1	1	2	64	27.62	13	0	7	6
	F15	2	1	1	0	2	1	0	47	8.34	7	2	3	2
	F16	1	1	1	0	3	1	0	30	12.06	9	2	5	2
	F17	2	2	1	0	2	1	0	58	23.08	7	2	3	2
	F18	2	2	1	0	1	2	0	48	24.88	8	3	3	2
	F19	2	1	1	0	3	1	0	52	10.66	9	2	2	5
	F20	1	2	1	0	2	1	0	40	20.04	7	0	2	5
	F21	2	2	1	0	2	1	0	58	30.78	10	0	5	2

TABLE XVII (Continued)

GR	SX	CV	CS	CL	CI	CII	FI	FII	VER	SPA	LOG	E	P	C
	F22	1	1	1	0	0	0	0	31	11.50	0	0	0	0
	F23	2	1	1	0	2	2	0	47	13.26	10	2	5	3
	F24	1	1	1	0	0	0	0	37	18.38	0	0	0	0
	F25	1	1	1	0	0	0	0	40	16.68	0	0	0	0
	F26	2	1	2	0	3	2	0	61	13.96	12	2	5	5
	F27	1	1	1	0	2	0	0	28	10.98	4	0	2	2
	F28	2	2	1	0	2	2	0	62	39.58	10	0	5	5
	F29	2	1	1	0	1	0	0	57	15.18	2	2	0	0
	F30	1	2	1	0	1	0	0	31	19.62	2	2	0	0
	F31	2	1	1	0	2	1	0	50	3.20	7	2	3	2
	F32	2	1	1	0	0	1	0	52	10.38	3	0	3	0
	F33	1	2	2	0	3	2	0	41	39.62	12	2	5	5
	F34	1	1	1	0	0	0	0	28	6.38	0	0	0	0
	F35	1	1	1	0	1	1	0	40	2.26	5	0	3	2
	F36	1	2	2	0	3	2	0	40	21.78	12	5	2	5
	F37	1	2	1	0	2	2	0	42	19.92	10	3	5	2
	F38	1	2	1	0	1	0	0	24	18.50	2	0	2	0
	F39	1	1	1	0	0	0	0	31	14.40	0	0	0	0
	F40	1	1	1	0	1	1	0	27	17.82	5	0	3	2
	F41	1	1	1	0	1	1	0	30	2.64	5	2	3	0
	F42	2	2	2	0	3	2	1	65	43.88	16	2	5	9
	F43	2	2	2	0	0	2	3	46	23.76	18	4	7	7
	F44	1	1	1	0	1	0	0	23	17.52	2	0	2	0
	F45	2	2	1	0	3	1	0	48	24.04	9	2	5	2
	F46	1	1	1	0	2	2	0	34	12.76	10	5	3	2
C	M1	2	2	2	0	2	2	2	73	57.72	18	9	7	2
	M2	1	2	1	0	2	1	1	59	54.00	11	2	4	5
	M3	2	1	2	0	2	2	1	66	18.34	14	5	4	5
	M4	2	2	2	0	3	2	1	83	60.00	16	2	9	5
	M5	2	2	1	0	1	1	0	69	52.86	5	0	0	5
	M6	2	1	1	0	2	0	1	71	23.74	8	2	4	2
	M7	2	2	2	0	2	2	1	73	40.62	14	5	4	5
	M8	2	2	1	0	2	0	1	66	35.30	8	2	4	2
	M9	2	1	2	0	2	2	1	71	31.14	14	2	7	5
	M10	2	1	2	0	1	2	2	77	27.30	16	3	7	6
	M11	2	2	1	0	1	3	0	72	39.58	11	3	3	5
	M12	2	2	2	0	3	3	2	81	60.00	23	9	9	5
	M13	1	2	2	0	3	1	1	61	54.30	13	2	9	2
	M14	2	2	2	0	2	2	2	71	35.44	18	9	7	2
	M15	2	2	1	0	3	0	1	74	57.72	10	2	6	2
	M16	2	1	2	0	2	1	2	73	25.06	15	9	4	2
	M17	2	1	2	0	2	2	1	78	20.90	14	2	7	5
	M18	2	1	1	0	2	0	1	67	22.02	8	2	4	2
	M19	2	1	2	0	2	2	1	67	31.60	14	5	4	5
	M20	1	1	1	0	2	0	0	62	31.44	4	0	2	2
	M21	1	2	1	0	2	1	1	44	35.16	11	2	7	2
	M22	1	1	1	0	2	0	1	57	16.92	8	2	4	2

TABLE XVII (Continued)

GR	SX	CV	CS	CL	CI	CII	FI	FII	VER	SPA	LOG	E	P	C
	M23	1	2	2	0	2	2	1	60	44.86	14	5	7	2
	M24	1	1	1	0	2	1	1	42	34.92	11	2	0	9
	M25	2	1	2	0	3	1	1	68	20.18	13	2	6	5
	M26	2	2	2	0	3	3	2	71	35.44	23	5	9	9
	M27	1	1	1	0	2	0	0	46	7.82	4	2	2	0
	M28	1	1	1	0	2	0	0	54	15.10	4	2	0	2
	M29	2	2	2	0	3	2	2	67	55.44	20	9	9	2
	M30	2	1	2	0	3	1	1	69	34.76	13	5	6	2
	M31	1	1	1	0	2	0	0	54	15.90	4	2	2	0
	M32	1	2	2	0	3	2	0	63	56.58	12	5	5	2
	M33	1	1	1	0	2	0	0	49	2.90	4	2	2	0
C	F1	2	1	2	0	3	2	1	66	14.60	16	5	6	5
	F2	1	2	2	0	3	1	1	63	42.44	13	5	6	2
	F3	1	1	2	0	2	2	2	62	23.44	18	6	7	5
	F4	2	2	2	0	2	2	1	75	37.60	14	2	7	5
	F5	1	2	1	0	1	1	1	63	46.74	9	0	4	5
	F6	2	2	2	0	3	2	1	67	51.16	16	5	9	2
	F7	2	1	1	0	3	0	1	71	21.48	10	2	6	2
	F8	1	1	1	0	1	1	1	65	27.46	9	5	4	0
	F9	2	2	2	0	2	1	3	67	47.58	19	6	4	9
	F10	2	1	1	0	3	0	1	73	23.02	10	2	6	2
	F11	2	2	2	0	3	1	2	71	33.48	17	6	6	5
	F12	2	1	1	0	2	1	1	74	28.34	11	5	4	2
	F13	1	1	2	0	2	3	1	62	22.90	17	5	7	5
	F14	1	1	1	0	1	2	0	46	20.20	8	3	2	3
	F15	1	1	2	0	2	2	1	65	20.58	14	2	7	5
	F16	2	2	1	0	1	1	1	66	46.16	9	2	4	3
	F17	1	2	1	0	2	0	0	59	36.30	4	2	0	2
	F18	1	2	1	0	3	0	1	62	39.16	10	2	6	2
	F19	2	1	1	0	3	1	0	76	23.30	9	2	2	5
	F20	1	1	1	0	1	0	0	31	3.48	2	2	0	0
	F21	1	1	2	0	0	2	2	57	24.08	14	7	4	3
	F22	2	2	1	0	2	1	1	71	34.44	11	3	6	2
	F23	2	2	2	0	2	0	2	67	54.58	12	2	4	6
	F24	2	2	2	0	3	1	1	72	52.00	13	2	9	2
	F25	1	1	1	0	2	2	0	60	17.38	10	5	3	2
	F26	2	1	2	0	3	2	0	72	23.44	12	2	5	5
	F27	2	2	2	0	2	3	1	70	39.16	17	3	9	5
	F28	1	1	1	0	1	1	0	63	7.50	5	5	0	0
	F29	2	1	1	0	2	0	1	77	14.60	8	0	6	2
	F30	2	1	1	0	1	0	1	67	14.62	6	2	4	0
	F31	1	2	2	0	2	2	1	63	33.58	14	2	7	5

APPENDIX D

INSTRUCTIONS TO SUBJECTS FOR PHASE II MEASURES

Instructions for Haptic Discrimination Task

This task requires that you feel two wire shapes, one with your left hand and one with your right hand at the same time. You can use only the index and middle fingers. These bands will help you to use just these fingers (DEMONSTRATE). Now you try. (Trial P1). In the actual test you will not be able to see the objects and you will have 12 seconds to feel the objects, then I will ask you to identify the shape that you felt with your right hand and the shape that you felt with your left hand out of a display like this (Show). Let's do some practice trials (P 2, 3, 4).

Instructions for Dichotic Listening Task

This is a listening task. You will hear one word in your right ear and a different word in your left ear. There will be four pairs of words and then a tone. At the tone, I will stop the tape and ask you to tell me as many of the 8 words that you heard as you can. There will be 12 sets of four pairs of words. The first one is a practice trial. Tell me if the tape is too loud or not loud enough. Do you have any known hearing problem? What ear? Any questions?

Instructions for Balance Task

I am interested in how people work on this task. There are several different ways to approach it. I am most interested in how you do them. Don't worry about getting the right or wrong answer, this is not a test. As you work, I will ask you questions about what you are doing. I will record your answers on this sheet.

(present weights and call attention to the balance in equilibrium). Now I am going to place this 20 gram weight here. (let go of arm) See what happened. Using your 20 gram weight, what can you do to make it straight? Why did you put the weight there? (let go of the arm).

Now I am going to hang the 50 gram weight here (7). Where will you hang your 50 gram weight to make the bar balance? Why? (let go of the arm).

Next, I am going to hang the 100 gram weight here (4). Where will you hang the 50 gram weight to make it balance? Why? (let go of the arm).

If I hang my 50 gram weight here (8) where will you hang the 100 gram weight to make the bar balance? Why? (let go of the arm).

I am going to hang 30 grams of weight here (3). I want you to make the bar balance using the 10 gram weight. Why did you hang the weight there (let go of arm).

I am hanging the 20 gram weight here (5). I want you to use the 50 gram weight. Why did you hang the weight there? (let go of arm).

What did you learn from working with the balance? or Can you explain how the balance works?

APPENDIX E

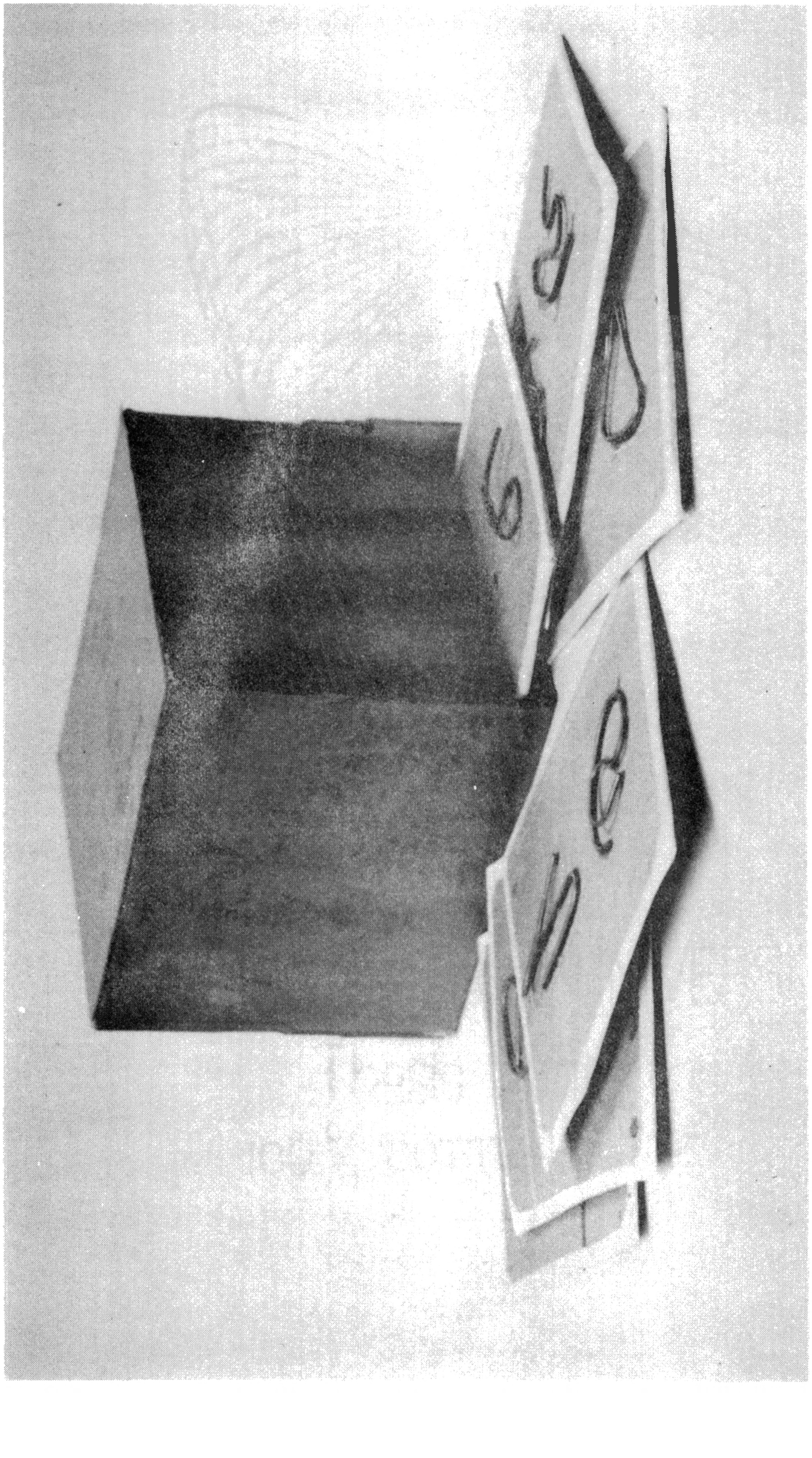
TEST MATERIALS FOR PHASE II

Word List for Tape 1

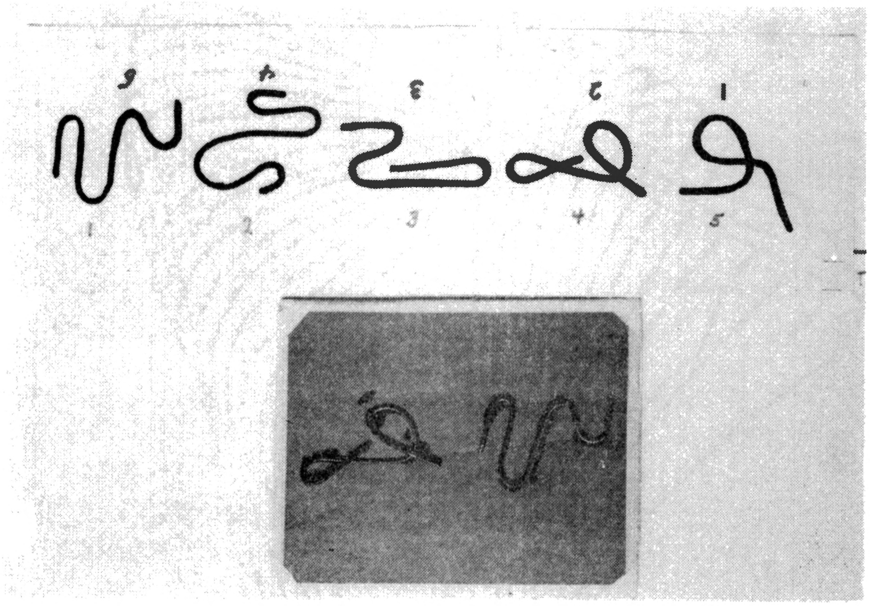
Practice Trial		Trial 5		Trial 9	
1. anger	eagle	1. girl	jump	1. dream	speak
2. become	doctor	2. street	where	2. square	priest
3. swift	stove	3. chair	swift	3. boy	now
4. whiskey	fingers	4. on	ah	4. earth	stove
Trial 2		**Trial 6**		**Trial 10**	
1. dark	stem	1. younger	working	1. trouble	command
2. man	joy	2. only	river	2. bath	king
3. soft	tell	3. spider	carpet	3. hungry	window
4. at	am	4. lamp	salt	4. numbers	because
Trial 3		**Trial 7**		**Trial 11**	
1. cry	get	1. always	butter	1. high	they
2. house	stand	2. from	moon	2. sour	loud
3. sell	this	3. how	sit	3. sleep	white
4. thinner	running	4. faster	doctor	4. fingers	thirsty
Trial 4		**Trial 8**		**Trial 12**	
1. baby	over	1. slow	come	1. younger	working
2. is	me	2. eating	needle	2. only	river
3. quiet	heavy	3. justice	blossom	3. spider	carpet
4. rough	fruit	4. cold	guns	4. lamp	salt

Word List for Tape 2

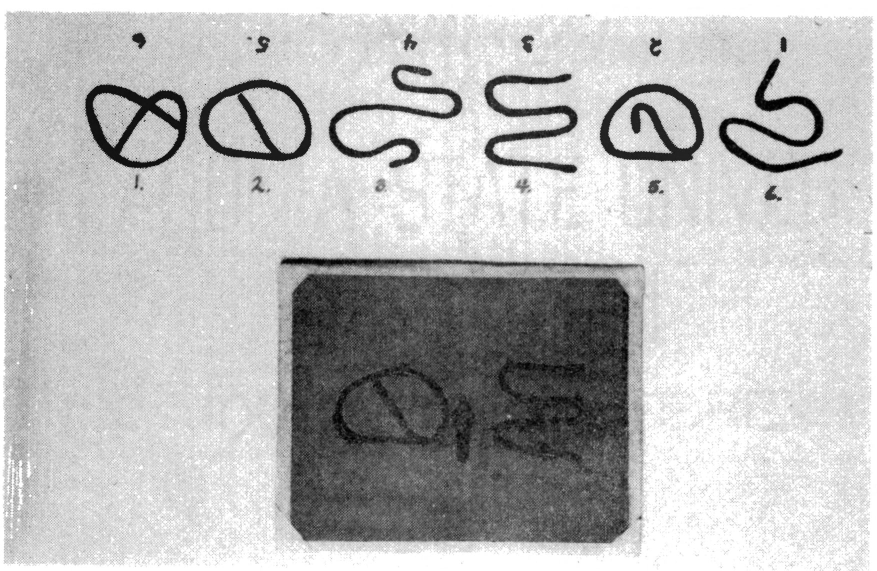
Practice Trial		Trial 5		Trial 9	
1. dark	stem	1. joy	his	1. sell	high
2. man	joy	2. stand	rough	2. from	girl
3. soft	tell	3. yellow	hotter	3. earth	priest
4. at	am	4. come	long	4. they	salt
Trial 2		**Trial 6**		**Trial 10**	
1. anger	eagle	1. cars	lamp	1. cry	man
2. become	doctor	2. slowly	hammer	2. house	sleep
3. swift	stove	3. ah	if	3. lift	soft
4. whiskey	fingers	4. butter	hungry	4. on	am
Trial 3		**Trial 7**		**Trial 11**	
1. smooth	dream	1. scissors	mountain	1. sour	hard
2. cold	king	2. quickly	kittens	2. slow	tell
3. city	baby	3. always	window	3. thirsty	because
4. now	sit	4. speak	chair	4. get	boy
Trial 4		**Trial 8**		**Trial 12**	
1. bed	how	1. cottage	comfort	1. cars	lamp
2. moon	jump	2. needle	spider	2. slowly	hammer
3. woman	faster	3. light	fruit	3. ah	if
4. stem	loud	4. dogs	bath	4. butter	hungry



Haptic Discrimination Task Apparatus

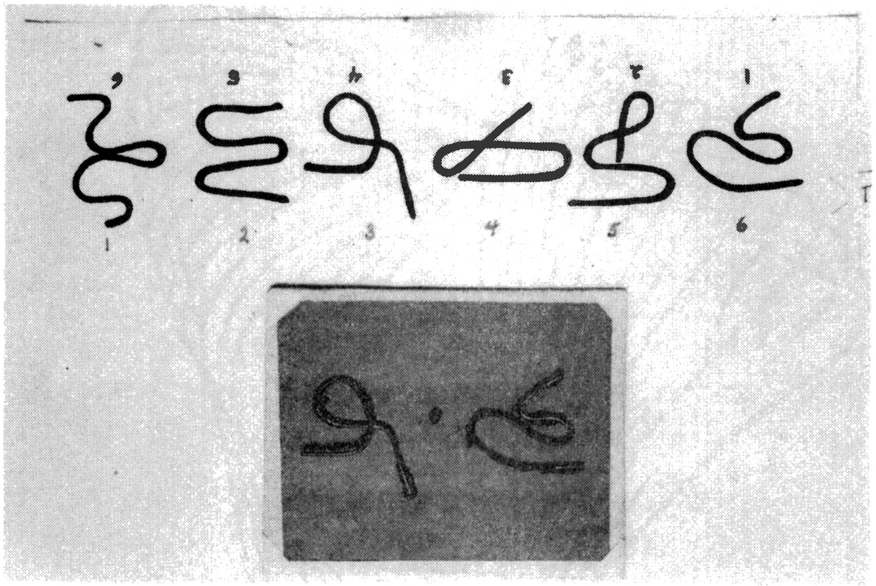


Practice Trial 1*

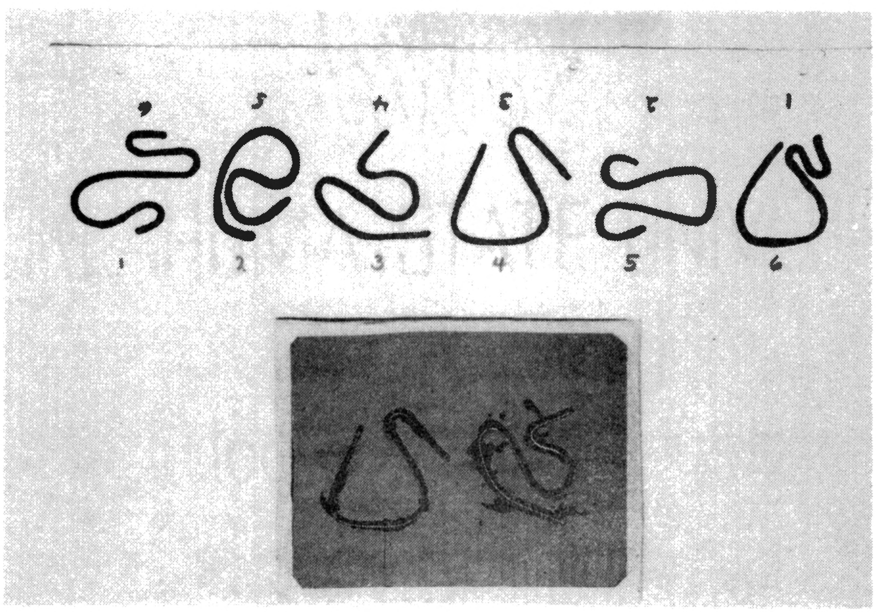


Practice Trial 2

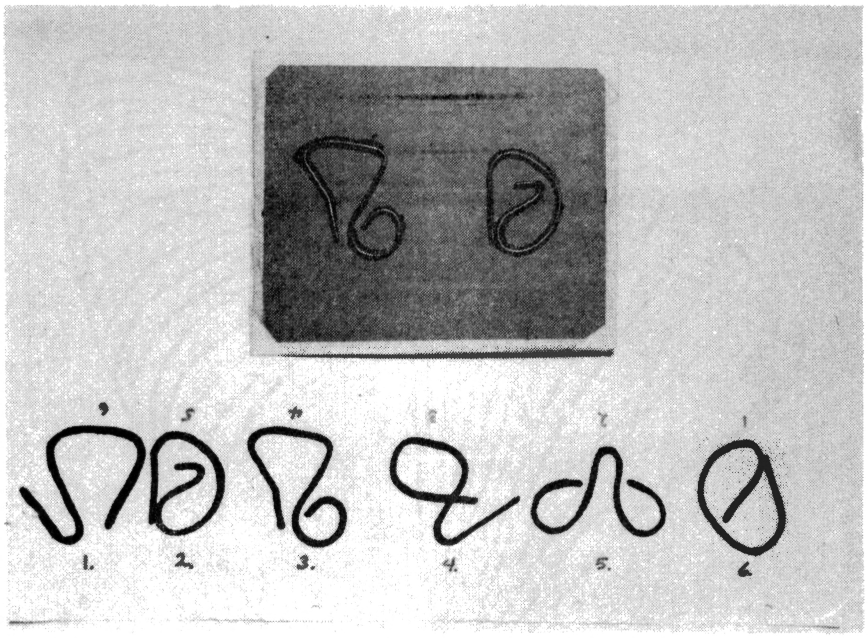
*The photographs are reduced 20 percent.



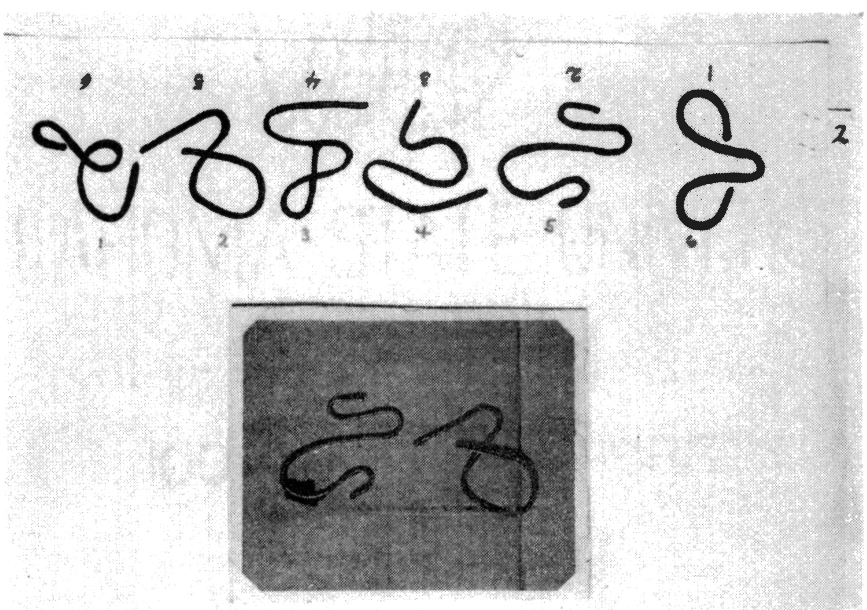
Practice Trial 3



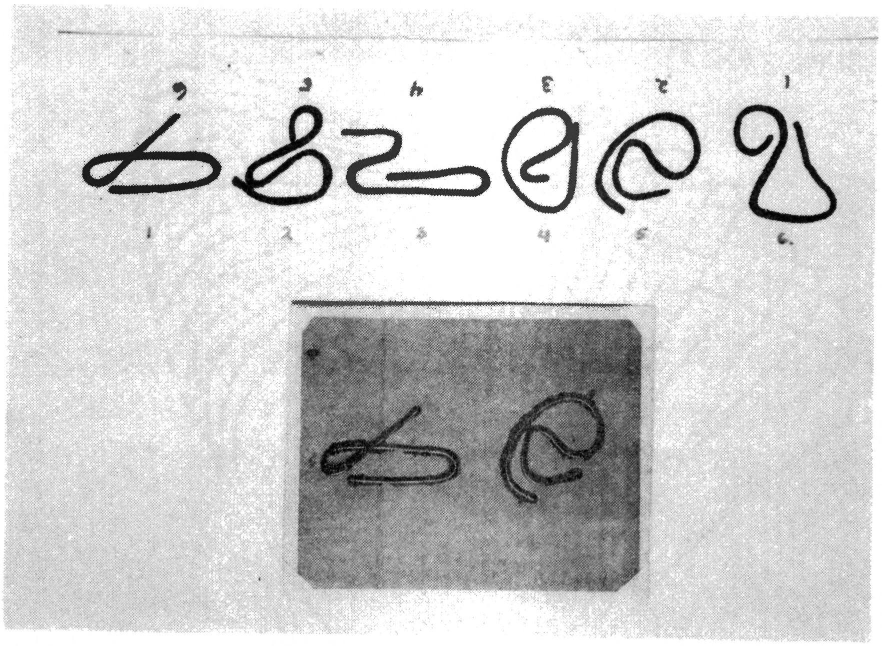
Practice Trial 4



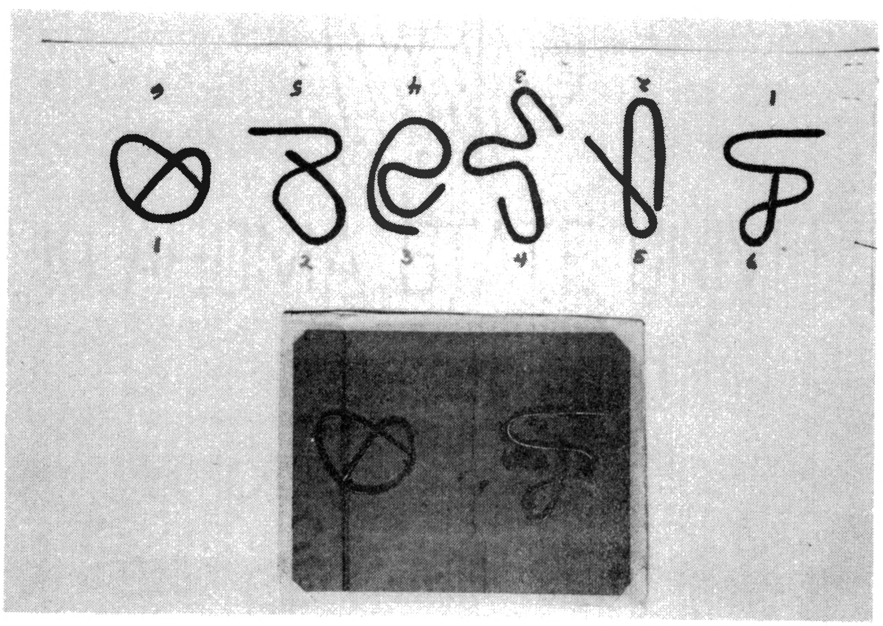
Trial 1



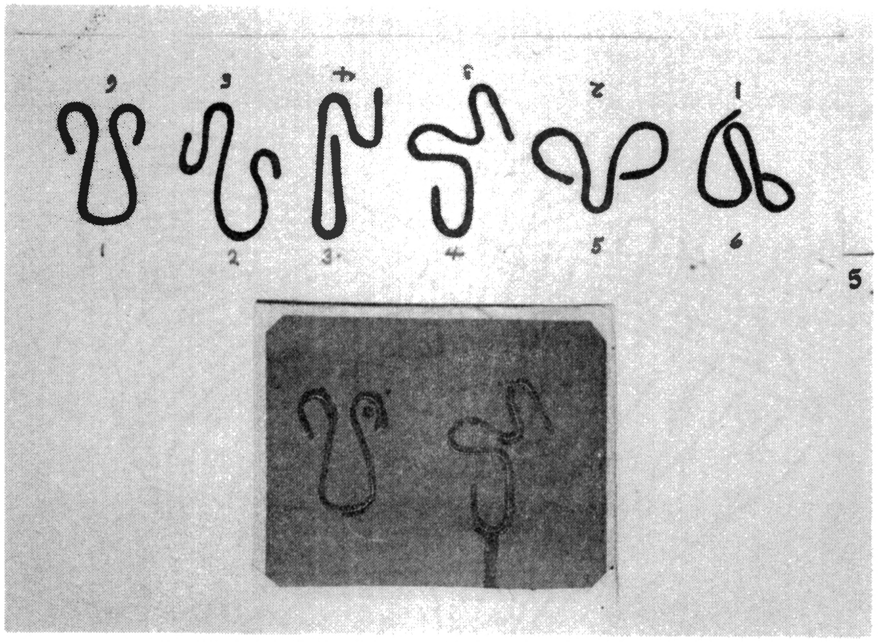
Trial 2



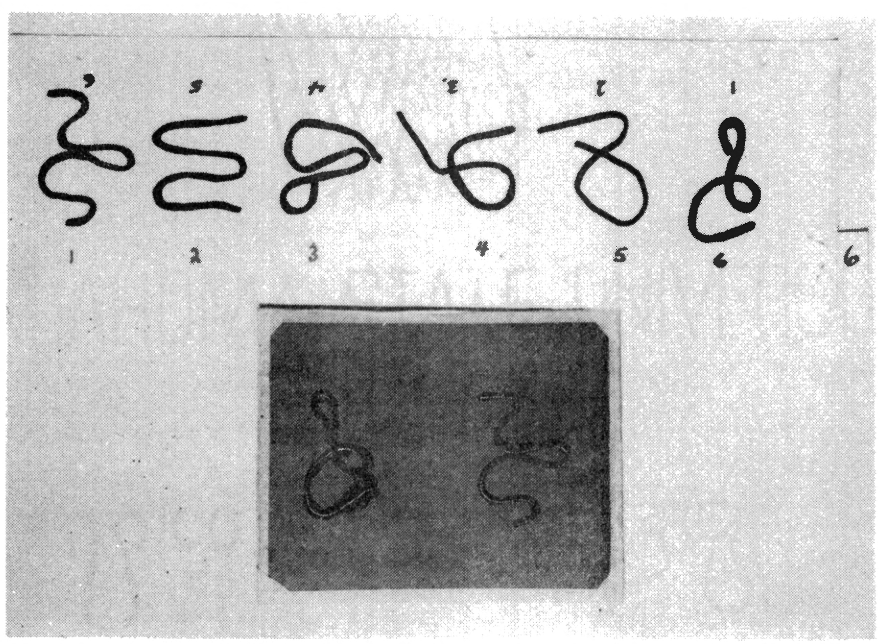
Trial 3



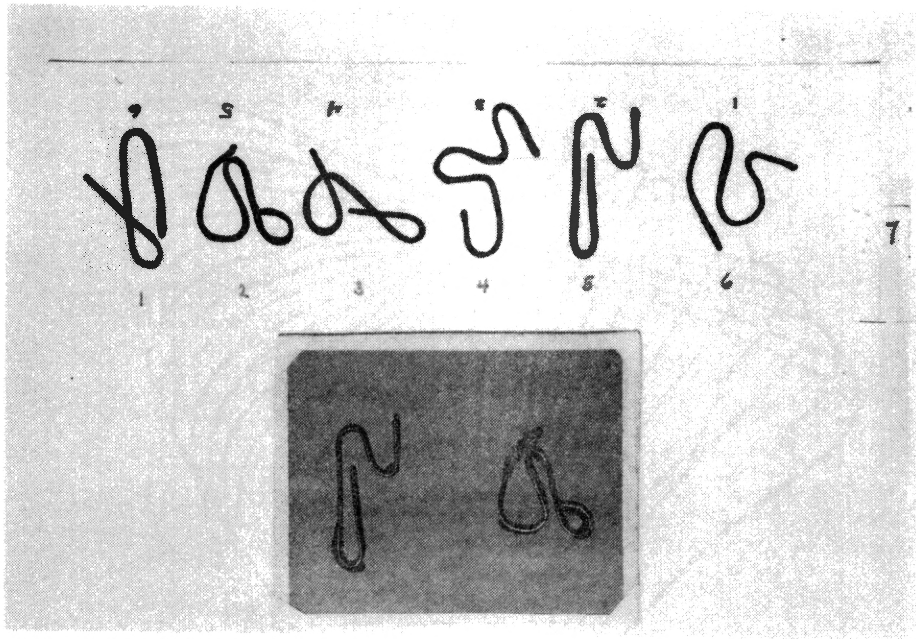
Trial 4



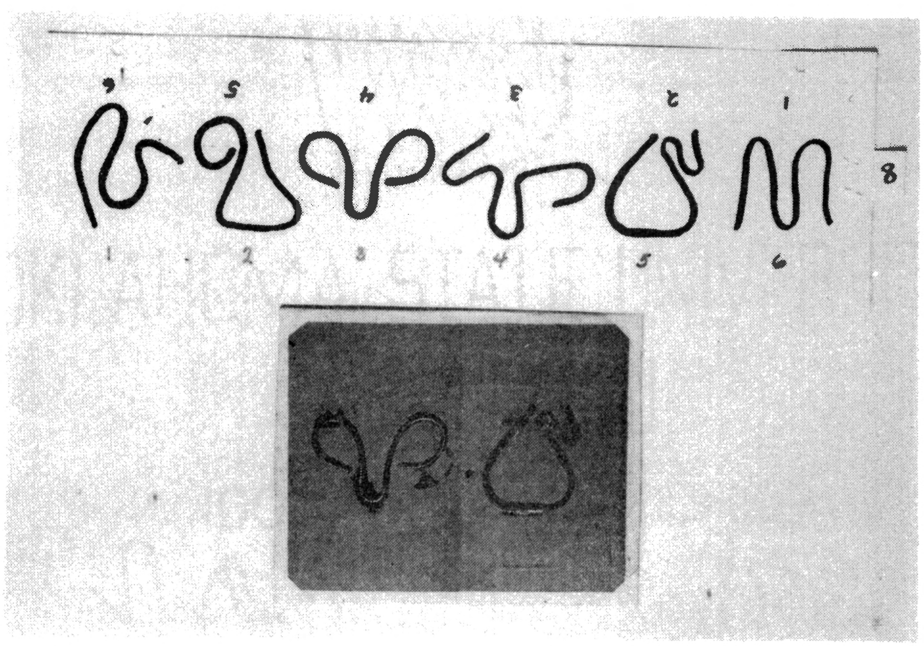
Trial 5



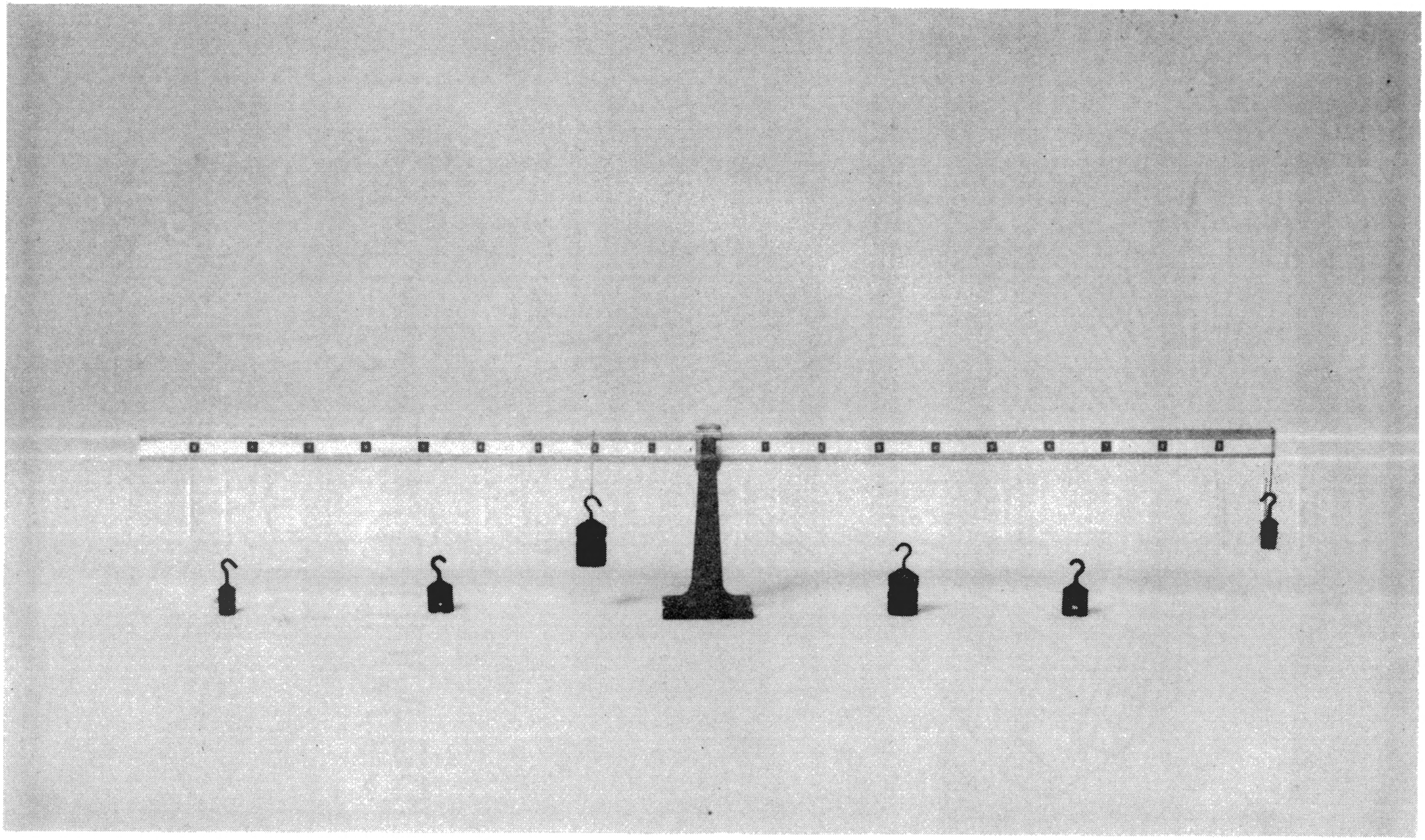
Trial 6



Trial 7



Trial 8



Piagetian Hands-on Logical Reasoning Task Apparatus

APPENDIX F

RAW DATA FOR PHASE II

Code Sheet

Column Number	Variable Name	Variable Value
1	Grade	C = College 8 = Eighth grade 4 = Fourth grade
2	Sex	M = Male F = Female
3-4	Identification number (from Phase I)	
6-8	Age-in-months	
9	Handedness	1 = right 2 = left
10	Sighting	1 = right hand, left eye 2 = right hand, right eye 3 = left hand, left eye 4 = left hand, right eye
11	Tape	Number 1 Number 2
12	Earphone Placement	1 = right 2 = left
13	Hearing Loss	1 = No 2 = Yes
14	Right Hand Score	
15	Left Hand Score	
16-17	Right Ear Score	
18-19	Left Ear Score	
20-21	Intrusion Score	
22	Hands-on logical reasoning score	
23	Number of younger brother(s)	
24	Number of younger sister(s)	
25	Number of older brother(s)	
26	Number of younger sister(s)	
27-28	Major (college only)	1 = Business 2 = Pre-Veterinarian Med. 3 = Engineering 4 = Journalism 5 = Pre-Medicine 6 = Hotel Restaurant & Management 7 = Special Education 8 = Political Science 9 = Home Economics 10 = Sociology 11 = Pre-Nursing 12 = Undecided

Column Number	Variable Name	Variable Value
29-44	Haptic Discrimination Task Trials 1-8. The right-hand score is first (column 29) followed by left-hand score (column 30)	0 = incorrect response 1 = correct response
46-75	Dichotic Listening Task Trials 2-11. The right ear score is first (column 46) followed by the left ear score (column 47) and intrusions (column 48).	

TABLE XVIII

PHASE II DATA

HvHs	4M05	1	18121110110101040000	0000000100000000	012001120121111220201111111102
	4M15	1	2T122115218160440100	0000111010011010	210310210130310220220031202121
	4M19	1	192312132214101630000	0100101001000010	004032211210114120301111202211
	4M21	1	25242212313120740100	1101011001000000	120311112101120210101031120201
	4M30	1	29121112502102030100	0101110100100001	012004002021012112013110300000
HvLs	4M03	1	28122112214130631100	0100011000000010	111301300040210210112011220021
	4M20	1	16121212219090640200	0000000110000110	210022121140031031121110112010
	4M24	1	17112213112161541001	0000101001000010	121202022202051221112022220222
	4M25	1	15121110114200930100	0100000000000000	111223302402111300121212101222
	4M10	1	21132114419140930100	1000011101001110	230310102120132310023302210310
LvHs	4M12	1	19121211115140631001	0010010000000000	011120410310230110202020121111
	4M17	1	17122212315111641021	1000010100110000	202121012303201211211012143211
	4M18	1	16121112309061530100	0100001000010011	001103112102102220112101011111
	4M22	1	24122111217170930022	0000010010010000	220031310013130230112201312320
	4M04	1	16121222311111521010	0100110000000010	003003212300111131212021120112
LvLs	4M16	1	19122212106141630001	0000100011000000	002121130113111321020120210121
	4M02	1	24121111150909300111	0100001000000000	211300021031310301112101020021
	4M13	1	25112121213110810000	0100001100000000	011112101032102100211112202211
	4M14	1	20121212312081131000	0101000000101001	011020110201111133112021021110
	4M01	1	28122212112120630101	1001000000000010	111020212202120220110101110120

TABLE XVIII (Continued)

HvHs	4F26	123121114205142040100	1111000010001000	0031020220021111030020083201011
	4F27	125142110210071440100	0000000101000000	012211101021012211102102201111
	4F30	119141213224150441011	0010110010000001	021122311410320210310320320210
	4F31	116122210212130730001	0101000000000000	01221102110012123020011121 1120
	4F36	1151211112405131740002	00000100001011010	00210211110400122300131020222013
HvLs	4F02	119122113217121920010	0011101001000000	12011211130343113112312032213218
	4F19	124121214216091131000	0001101000000011	102201211201103220220210311122
	4F20	116242211209111823011	0000100101000000	012212121012210112221003113012
	4F25	123121111317151020010	0100000101100000	11331111120122320121211310121
	4F32	119122113618190830000	0011010101101101	211320022240022310130410221112
LvHs	4F04	121121210213090931011	0001010000000000	200012111201201120111002120101
	4F06	120122211418081030010	0100000001010011	211201010201123211200112311310
	4F07	121111112217100920010	1100000100000010	00110202211120112003000111111
	4F15	124122117712160130100	1011110111111111	020111310030010130120100310220
	4F22	126241213410061331000	1000011101110000	01401221020002201200103100001
LvLs	4F12	125122212420160930011	0000010101100110	11141103241022032011203210420
	4F03	1171211114104061730001	0000001000111010	0030030210111200032003101200012
	4F29	121122111015090531001	0000000000000010	0322000311101101200210120100220
	4F35	119121211111060930000	0000000000000110	102020300200012101011201111111
	4F37	119122210106071530200	0000010000000000	01110202110201311010000012202

TABLE XVIII (Continued)

	1–4	6	7–26	29–45	46–75
HvHs	8M09	1	75121113510171042100	01000111000111110	011320022041122120022100121301
	8M49	1	691221112413101540002	00100101010000011	114101111201102113121210121221
	8M33	1	74121214318210341313	00011111000011010	2202302223203302201211211120
	8M32	1	65122215417182041001	10100111100011101	311122231115113322113221230122
	8M04	1	65121111219141040020	00000100110000000	2101111220321210302021221222121
HvLs	8M15	1	65122114406142042000	01000110001111011	121202022004004112130022022121
	8M20	1	86121215217190930100	10100111110000010	211131221330220220121130212103
	8M25	1	78122227411101930010	11101011101111001	1202011120041122211230211032020
	8M40	1	66121113312091331000	01110011100000010	012301011102211220012102211121
	8M05	1	70242111111171321000	00010000000000000	121012122102122130211022220221
	8M51	1	65211110109111730222	00000000000010000	0030131210311031120222102102022
LvHs	8M47	1	69121211215161240000	00000101000000010	112203211211132120120321121121
	8M22	1	67122212212131440101	00100101000001000	111021004102102320122112140310
	8M12	1	73122112309230440001	00010000100001101	120130121211131130110040020121
	8M07	1	86121211507091640020	00010000011110101	013102112211021110002012111112
LvLs	8M17	1	66122222508170630100	00000111011110100	111011121110111130121021020220
	8M02	1	74121110513101332000	00000101000110101	000003211230210321102112012212
	8M11	1	74122112619051031100	01010111010100010	210110002211301102301103400220
	8M48	1	68121212512061231141	01011101010001000	000001210211101121201211202014
	8M08	1	72122212315121930021	00010100000101100	11320211332212121111023112320

TABLE XVIII (Continued)

HvHs	8F02	168121113426090630122	0000010111111000	111311211310211310211310410301
	8F10	165122114422230431001	0011010100111010	120230220320310230221231321231
	8F14	181121214222220540001	1011000100001010	230221230321121321211210330230
	8F42	182241118413111540000	1010101011111111	103111122122220211112102240112
HvLs	8F31	172122212421240631010	0010011101000001	230212221210231520240131231320
	8F01	171112116107140720011	1011001000101010	021121012201001110020021130210
	8F26	166121213213121631022	0000100001100011	100113121312120114301003221031
	8F29	169242221421109132001	0011110000001010	012121120201111211202012003210
	8F32	163121114105081840013	1100001000101000	004210030121112003011005101001
	8F19	164242113219180630011	0011110101000000	320221130301230310201132121120
LvHs	8F33	167121214119090620001	0000011010001010	200111220201120220201201301221
	8F11	169122214305161730011	0110010110100010	121031022202203030013022022211
	8F36	169121133182009300010	0001110000011010	121320220240320022122123110122
	8F07	162122114113221440003	1100001010001000	030121102222124331121131222130
	8F20	169121212421090720010	0011000110000111	201111300301220131300121400112
	8F37	182121213413051220001	0001110000001101	201003310211111111011010022211
LvLs	8F06	163122210218140921100	0000000101000000	220111311211041400103031211310
	8F25	173311113208091231010	0010011100100000	003102201120202120020002111021
	8F35	165122114113181430010	0010001010110000	121222032311123111121220023210
	8F24	165122212110111722001	1000000001000010	112005120103103222010003212121

TABLE XVIII (Continued)

	1–4	6–44	46–75
HvHs	CM01	2381411114423152640010010111101110001110010	1222223313314321312222113213323
	CM04	244142116524261151020011110011110111001111	431321330212212241330141222231
	CM07	224121211330813205111110110100101000011100	0030222212210122212111013013013
	CM12	247122216522222095010000211111101010101010	1302201111412221331212231231330
	CM15	240121111461824125011101110001111010111101	2322212332313202211242121201141
HvLs	CM06	2232221135242806404000111010100011011100	3403202212423313313301110231230
	CM09	23312121142417115100000300010101100100000	2023301312313112123113313102112
	CM10	24612221522822095010002000000101111011110	3212403222420320322220222321321
	CM16	23013111261520225111003010101111000100110	1032133300424212120322204033130
	CM17	23412211231720093001104010111000000000111	1212200412211213013200222321221
LvLs	CM02	23312121351207111402010500010011101011011	1103021211020100022011102021121
	CM13	229122217522151040001061111101110011110	3122022202121111311230131311320
	CM21	2241211121121312411010101000100000000010	0022111202212012201211113021112
	CM32	2393412137151817510100710011111101010101	1113141113330222221322111022231
LvHs	CM20	233141111581209243001110100001011101000111	2011111130321112122113203104203
	CM33	228142213419230930000011101111101011111	231230212203121240230140321211
	CM31	2141422145211808310000101111011100001011	4111222301123202202112311111320
	CM27	2281411143081912200100801000110001011110	111211121040022121021121122112
	CM28	2221422131152211400000100100001000000010	2302121311221212222100132031

TABLE XVIII (Continued)

		6–44	46–75
HvHs	CF04	210121113414232750001080101001110001100	024024232232204322142221123133
	CF11	2321221165232107511000900111101111011011	340321230202320330233141240220
	CF22	226121215621151342153011111100101101101	300122320221212320212320123113
	CF24	223112212631270444000004010101111010010001	421331230321320340340330321420
	CF27	22324111542311064011010101100111110010010	3013212113204111300011121210210
HvLs	CF10	225112111652622033002207110111100111111010	230231320212230410330310330220
	CF30	2231212142201411420001010010001100001011	2032123213112202212121222220112
	CF19	242132221571923083010001101110101011111111	023230320131221320330212131220
	CF26	2261111113161106410010100000100100000101	1203012211101111210021210211201
	CF29	2241121115120211340011121010101000001100	140113221033212321230312321320
LvHs	CF02	22411121342717065002109100001110100100	302210410321330320211320230222
	CF05	2232422165212006410110210111111011000111	420211131311221220320131121220
	CF17	2221211115722180711000091000000110101010	130211211131311330220311211321
	CF31	228121214714151341213010111101110101011	012121221301103231201022120231
LvLs	CF13	2241112155221909410010110000110110111111	320330122211231330101123301330
	CF14	236111114216200841001121000010011101001	0211201313212203202212211111122
	CF20	225122213212121310040110000110100100110	013202220021121212111111111211
	CF21	2292421114521190441000120011010100101001	0122303113202202202202032022 1
	CF03	2391222253151508312000100000101110110011	012302120308211202100310222330

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APPENDIX G

HAPTIC TASK DATA BY TRIAL

Symbols and Abbreviations for Table XIX

GR	Grade (4 = Fourth Grade, 8 = Eighth Grade, C = College)
S	Sex (M = Male, F = Female)
T	Trial
R1	Response 1 (order of possible responses)
DK	Did not know
CR	The correct response for each hand by trial is underlined.

TABLE XIX

HAPTIC TASK DATA BY TRIAL

			Right Hand							Left Hand						
GR	SX	T	R1	R2	R3	R4	R5	R6	DK	R1	R2	R3	R4	R5	R6	DK
4	M	1	0	2	8	4	3	3	0	4	0	2	3	10	0	1
4	F	1	2	3	4	4	4	2	1	5	3	4	2	5	0	1
8	M	1	3	2	5	4	5	1	0	8	1	3	2	6	0	0
8	F	1	0	2	1	6	8	3	0	2	3	9	2	3	0	1
C	M	1	0	1	3	9	3	2	1	3	0	2	2	10	1	1
C	F	1	1	0	1	11	5	1	0	2	2	7	2	6	0	0
4	M	2	6	1	4	2	6	1	0	2	4	3	3	4	3	1
4	F	2	4	5	4	3	3	1	0	3	4	2	1	7	2	1
8	M	2	3	6	9	1	0	0	0	3	1	3	5	7	1	0
8	F	2	3	10	6	1	0	0	0	3	0	0	5	8	4	0
C	M	2	3	6	6	1	1	1	1	4	0	1	1	11	2	0
C	F	2	3	8	2	1	4	1	0	3	2	2	3	9	0	0
4	M	3	3	4	2	1	6	4	0	9	4	4	3	0	0	0
4	F	3	0	5	4	3	5	2	1	8	5	0	4	1	1	1
8	M	3	1	6	0	7	3	3	0	15	3	0	1	1	0	0
8	F	3	2	3	3	5	6	1	1	10	3	2	3	1	1	1
C	M	3	0	4	1	3	8	2	1	13	4	0	1	0	0	1
C	F	3	0	3	1	4	8	2	1	12	4	1	2	0	0	0
4	M	4	1	5	0	4	1	9	0	6	7	4	1	1	0	1
4	F	4	3	5	3	2	3	4	0	8	5	1	1	1	4	0
8	M	4	3	5	2	1	1	9	0	12	2	3	0	2	1	1
8	F	4	0	3	2	3	3	9	0	8	5	0	1	2	3	1
C	M	4	1	3	0	1	3	11	0	12	3	0	1	1	1	1
C	F	4	1	1	0	0	4	12	1	12	4	1	0	1	1	0
4	M	5	1	5	3	4	3	3	1	5	5	1	3	3	3	0
4	F	5	1	6	2	3	3	5	0	10	5	2	0	1	2	0
8	M	5	1	5	0	5	2	7	0	6	5	1	2	1	5	0
8	F	5	1	4	2	8	1	4	0	1	9	1	1	1	2	0
C	M	5	1	5	1	6	4	2	0	9	4	2	1	3	0	0
C	F	5	1	2	2	10	0	4	0	10	4	0	1	2	2	0
4	M	6	3	2	3	0	5	6	1	2	1	8	3	2	4	0
4	F	6	6	1	4	4	3	2	0	2	2	3	2	6	5	0
8	M	6	5	2	5	0	3	4	1	5	1	3	0	2	9	0
8	F	6	9	0	3	0	1	7	0	3	3	6	3	0	5	0
C	M	6	5	2	6	2	2	2	0	4	1	4	2	0	8	0
C	F	6	7	3	3	1	2	2	1	4	0	5	0	2	8	0

TABLE XIX (Continued)

			Right Hand							Left Hand						
GR	SX	T	R1	R2	R3	R4	R5	R6	DK	R1	R2	R3	R4	R5	R6	DK
4	M	7	1	3	7	3	2	4	0	5	5	4	1	2	3	0
4	F	7	2	6	8	1	0	2	1	3	2	3	5	4	3	0
8	M	7	2	9	5	2	1	1	0	4	5	2	1	7	1	0
8	F	7	1	11	3	3	1	1	0	6	3	1	4	3	3	0
C	M	7	1	11	1	3	1	2	0	0	1	6	1	11	0	0
C	F	7	0	14	3	0	1	1	0	2	0	4	3	8	2	0
4	M	8	1	2	0	5	9	2	0	4	9	3	1	1	2	0
4	F	8	1	5	1	2	9	1	1	3	5	6	5	1	0	0
8	M	8	1	3	0	7	8	1	0	5	3	7	4	0	1	0
8	F	8	1	3	1	2	11	1	1	3	7	5	3	2	0	0
C	M	8	1	1	0	3	14	0	0	5	6	8	0	0	0	0
C	F	8	2	3	0	1	11	2	0	2	2	12	1	1	1	0

VITA[2]

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