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ABSTRACT

Investigated was the lateral asymmetry in children's hemispheric brain functioning during performance of Piagetian and curriculum related tasks. Six subproblems were investigated. Eighteen right-handed children, ages six to eight years old, were given electroencephalograms while performing a battery of tasks: Piagetian conservation tasks, Piagetian temporal tasks, spatial tasks, and curriculum related tasks. It was concluded that tasks which had initial visio-spatial components during the stimulus period tended to elicit right hemispheric activity during that period. If that task had verbal or logical components during the subsequent response period, then left hemispheric activity tended to be elicited; high performers tended to show a greater proportion of right hemispheric activity during the subsequent response period. Consistent patterns of hemispheric functioning were identified in children having the same sex and hand-eye dominance. (RH)

AN EEG STUDY: HEMISPHERIC BRAIN FUNCTIONING OF SIX TO EIGHT YEAR OLD CHILDREN DURING PIAGETIAN AND CURRICULUM TASKS WITH VARIATION IN PRESENTATION MODE

by

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This study focused upon investigation of lateral asymmetry in children's hemispheric brain functioning during performance of Piagetian and curriculum related tasks. Six subproblems were investigated: 1) differences in brain functioning within Piagetian tasks, between the initial response period (when subjects were observing phenemona) and the subsequent response period (when subjects were thinking about explanations for their observations), 2) children's asymmetrical hemispheric brain functioning and "conservation" performance between administrations of Piagetian tasks when the presentation modes of the tasks were altered, 3) intercorrelations of children's asymmetrical hemispheric brain functioning between the initial and subsequent responses on Piagetian tasks and responses on spatial, reading, syllogistic logic and mathematical tasks, 4) children's asymmetrical hemispheric brain functioning within a reading task, between the initial response period (when subjects

were reading a passage silently) and the subsequent response period (when the subjects were thinking about comprehension questions concerning the passage), 5) differences in children's asymmetrical hemispheric brain functioning between high and low performers on all tasks, and 6) identification of groups of children with similar patterns of asymmetrical hemispheric brain functioning.

Eighteen volunteer right-handed children ages six to eight years were identified and electroencephalograms were recorded from parietal leads (P3-P4) while each performed a battery of tasks: Piagetian conservation tasks (Conservation of Substance and Conservation of Area), Piagetian temporal tasks (Waterflow and Dollrace), spatial tasks (WISC Block and Rotated forms), curriculum related tasks (reading, syllogistic logic and mental arithmetic).

This data was computer analyzed to provide a log L/R alpha power ratio for each task. Statistical evaluation (p .05) of the hypotheses yielded the following results:

1. (Initial-subsequent responses of tasks) There was significantly greater right hemispheric brain activity measured during the initial response period and significantly greater left hemispheric brain activity measured during the subsequent response period during the subjects performance of the Conservation of Substance and Waterflow tasks.

2. (Task presentation mode) There was: a) significantly greater left hemispheric brain activity measured during the initial response period of the Waterflow task

when presented behind a perceptual screen accompanied by the investigator's verbal time ordering of the event than when presented visuo-spatially, and b) a significant increase in the "conservation" performance scores on the Dollrace task and an increase that approached significance in the performance scores on the Waterflow task following the presentation behind a perceptual screen accompanied by the investigator's verbal description of the time ordering of the event than the performance scores on the two tasks when presented visuo-spatially.

3. (Intercorrelations) There were significant positive intercorrelations between the hemispheric brain waves of a) the initial responses measured during Piagetian and reading tasks, b) the subsequent responses measured during Piagetian and reading tasks and those measured during performance of verbal, logical, mathematical and block design tasks, and c) responses measured during performance of parallel forms of reading, mathematical and spatial tasks.

4. (Silent reading) There were significant differences between the hemispheric brain waves measured during the initial and subsequent response periods of the reading task, indicating that there was a greater proportion of right hemispheric activity during the silent reading than when asked comprehension questions concerning the passage they had read.

5. (High-low performers) High performers on the reading comprehension questions and one Piagetian temporal

task had a significantly greater proportion of right hemispheric brain activity than low performers measured during the subsequent response period of the tasks. A similar pattern was observed between the high and low performers on one Piagetian conservation task at the .16 alpha risk level.

6. (Group patterns) There were three significantly different group patterns of asymmetrical hemispheric functioning-right dominant males (right hand and right eye dominant), mixed dominant males (right hand and left eye dominant), and children who appeared to have reversed hemispheres - and a fourth - right dominant females - which approached significance.

On the basis of these findings it was concluded that tasks (Piagetian and reading) which had initial visuo-spatial components during the stimulus (or encoding) period, tended to elicit right hemispheric activity during that period. If that task had verbal or logical components during the subsequent response (or decoding) period, then left hemispheric activity tended to be elicited. However, high performers on these tasks tended to show a greater proportion of right hemispheric activity during the subsequent response period than low performers indicating that the verbal left hemisphere of the high performers utilized greater ability to tap the visuo-spatial right hemisphere's knowledge about the stimulus. Therefore, the investigator suggests that Piagetian tasks are behavioral measurements of interhemispheric communication and selective inhibition and further, that the ontogeny of Piagetian stages is a behavioral index of maturing neural fibres (between the left and right cerebral hemisphere and from the reticular activating system to the two hemispheres) which facilitate these processes.

It was also concluded that although all but three subjects exhibited similar shifts from right hemispheric functioning to left hemispheric functioning between the stimulus and response of reading and Piagetian tasks, consistent patterns of hemispheric functioning can be identified in children having the same sex and hand-eye dominance. Right dominant boys appeared to have greater proportions of left hemispheric functioning during the verbal subsequent response period, while mixed dominant boys appeared to have greater right hemispheric functioning during the initial visuo-spatial period. However, girls did not have large proportions of left or right hemispheric activity across tasks. These findings were interpreted to indicate that the girls were not as lateralized as the boys.

AN EEG STUDY: HEMISPHERIC BRAIN FUNCTIONING OF SIX TO EIGHT YEAR OLD CHILDREN DURING PIAGETIAN AND CURRICULUM TASKS WITH VARIATION IN PRESENTATION MODE

DISSERTATION

Presented in Partial Fulfillment of the Requirements
for the Degree Doctor of Philosophy in the Graduate
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By

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* * * * * * *

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CHAPTER I

THE PROBLEM

Rationale

Jean Piaget's developmental theory is widely accepted by educators and psychologists as a viable basis for understanding children's cognitive abilities and processes. His research and subsequent theory investigating stages of cognitive development has been replicated around the world (Modgil, 1974), becoming the theoretical foundation of many educational implementation programs (Elkind, 1961; Smedslund, 1961; Wohlwill and Lowe, 1962; Karplus, 1974).

Piaget views the ontogeny of cognitive processes as being characterized by qualitatively different stages: sensorimotor, preoperational, concrete operational, and formal operational (Flavell, 1963; Phillips, 1969; Piaget, 1970). He states that the maturation of neurological structures has a major role in this cognitive development (Piaget, 1970), but the nature of these structures is unknown.

Recent discoveries about functional lateralization of cognitive processes (Ornstein, 1972; Dimond and Beaumont, 1974; Gazzaniga, 1970; Lee et al., 1974; Galin, 1975) suggests a way of investigating the nature of structural brain development which may provide a basis for understanding the differences in the cognitive functioning characteristic of the four stages. Piagetian stages may be viewed as the increasing ability to interpret visuo-spatial events (a right cerebral hemisphere function) in a verbal-logical modality (a left cerebral hemisphere function).

The impetus for the investigation of lateralization of cognitive functioning was provided by the work of Sperry (1964) and his associates (Bogan and Gazzaniga, 1965; Gazzaniga, 1967; Levy, Trevarthen and Sperry, 1972) with commisurotomy patients being treated for epilepsy. In carefully controlled experiments assessing the memory and information processing in each of the disconnected cerebral hemispheres of these patients, they observed remarkable and unexpected results. It became clear that when the corpus callosum was severed these patients had two brains, one (left) which could perform speech, logic, and arithmetic calculations and one (right) which had virtually no speech but could perform spatial and geometric tasks not possible for the other hemisphere.

Other researchers have investigated the possibility that normal subjects, without histories of brain lesions or neurosurgery, also exhibit cerebral functional asymmetry. Summaries of this literature may be found in Galin and Ornstein, 1972; Gazzaniga, 1970; Hilgard and Bower, 1975; Schmitt and Worden, 1974; Wittrock, 1975; and Languis and

Kraft, 1975-1976.

Using an electroencephalograph to measure asymmetrical electrical activity, the left hemisphere has been found to show greater activity when overtly or covertly processing verbal material (Buchsbaum and Fedio, 1969; Matsumuza, et al., 1972; Wood, Goft and Day, 1971; McKee, Humphrey and McAdam, 1971; Galin and Ornstein, 1972, 1974; Doyle, Ornstein and Galin, 1975), logical tasks (Dumas and Morgan, 1975; Dilling, 1975; Morgan, McDonald and Hilgard, 1974; Butler and Glass, 1974), and mathematical computation (Morgan, McDonald and MacDonald, 1971) while the right hemisphere exhibits more activity during visuo-spatial tasks (Morrell and Salamy, 1971; Galin and Ornstein, 1972, 1974; Doyle, Ornstein and Galin, 1975) and imaging (Morgan, McDonald and MacDonald, 1971).

However, there is some evidence of sex differences in lateralization. Women are not as lateralized as men (Buffery and Gray, 1972; Harris, in press) having verbal abilities stored and processed in both hemispheres which causes deficiencies in visuo-spatial abilities (Levy, 1974).

Although signs of cerebral lateralization have been found in infants (Molfese, 1972; Gardner, Schulman and Walter, 1973; Witelson and Pallie, 1974), full lateralization does not occur until later childhood (Krashen, 1975; Krashen and Harshman, 1972; Dorman and Geffner, 1974;

Berlin, et al., 1973) and may continue to develop into senescence (Brown and Jaffee, 1975).

Based upon the developmental studies of myelination cycles, Gazzaniga (1974) postulates that the young child operates as a functional "split-brain," having poor interhemispheric communication of experiences processed in either hemisphere. These commisures start to myelinize rapidly at the age of two, reaching adult maturity between the ages of six and nine (Yakelov & Lecours, 1966).

Harris (1973), Knox and Kimura (1970) suggest that the right hemisphere modality is dominant in young children as evidenced in their spatial orientation to environmental experiences. Piaget (1973) indicates that young children's conception of objective time ordered events are confounded by his spatial concepts. This inability to think logically and sequentially about environmental phenomena may reflect the functional "split brain" properties of young children's thinking. Thus the onset of the concrete operational stage (between six and eight years of age) may be behavioral evidence of the maturation of these commisures, when the spatial reasoning of the right cerebral hemisphere becomes available to the logical sequential left cerebral hemisphere through interhemispheric communication.

On the basis of this theory it is postulated that the initial visuo-spatial observation of a Piagetian task would show greater right hemisphere activity than during logical sequential questioning about the task. Moreover while the preoperational and the concrete operational child would differ little in hemispheric asymmetry on spatial tasks, the concrete operational child would have more left hemisphere activity than preoperational children on logical tasks. It is further postulated that greater left hemisphere activity and successful performance on Piagetian tasks can be elicited by presenting the task behind a screen accompanied by a verbal description of the event.

Problem Statement

Therefore, research is clearly indicated that focuses on investigation of the following problems:

How is right and left hemisphere brain functioning related to Piagetian conservation and temporal tasks in 6- to 8-year-old children?

1. Does the pattern of brain functioning differ between a child's initial response to the presentation of a Piagetian task and the child's subsequent response explaining his answer?
2. How does variation in presentation mode of Piagetian tasks alter a child's brain function and task performance?
3. How is Piagetian developmental stage related to patterns of task performance and brain functioning in children?

4. Are there identifiable independent variables that are related to brain functioning during Piagetian and school related task performance?
5. Are there consistent brain functioning patterns in related and parallel tasks?

Hypotheses

H_1: The L/R alpha power ratio on the initial response will be significantly higher (p .05) than on the subsequent response of Piagetian tasks.

H_2: The L/R alpha power ratio on the visuo-spatial initial response will be significantly higher (p .05) than on the audio-verbal initial response of temporal tasks.

H_3: The L/R alpha power ratio on visuo-spatial subsequent response will not be significantly higher (p .05) than on the audio-verbal subsequent responses of temporal tasks.

H_4: There will be significantly higher performance (p .05) on audio-verbal temporal tasks than visuo-spatial temporal tasks.

H_5: The L/R alpha power ratio of the visuo-spatial initial response on a Piagetian task will be positively correlated (p .05) with other Piagetian visuo-spatial initial responses and with spatial tasks.

H_6: The L/R alpha power ratio of the subsequent response on a Piagetian task will be positively correlated (p .05) with other Piagetian subsequent responses and with verbal and logical tasks.

H_7: There will be no significant differences (p .05) on L/R alpha power ratios between preoperational and concrete operational children during performance of Piagetian tasks.

H_8: There will be no significant differences (p .05) on L/R alpha power ratios between girls and boys during performance of Piagetian tasks.

H_9: The L/R alpha power ratios of parallel forms of the same task will be positively correlated (p .05) with each other.

Definitions

Audio-verbal = phenomenon presented behind a visual screen while experimenter verbally states what is happening. (reports)

Concrete operational children = operationally defined as children who do score well on the performance of Piagetian tasks.

High performance = operationally defined as being able to give an adequate explanation for the solution of the task (see the instrument scoring section of this chapter).

Initial response = response of child when first presented with a task while observing a phenomenon taking place as measured by L/R ratio.

Logical tasks = tasks which have verbal components and require syllogistic or mathematical logic to solve. See Appendix A.

L/R ratio = the relationship expressed as a percentage of the power output of the left cerebral hemisphere divided by the power output of the right cerebral hemisphere measured through 2 homologous electrodes (Parietal 3 - Parietal 4). The power output of a hemisphere is calculated by a combination of (1) alpha wave (7-13 cps) suppression and (2) brain wave amplitude (in microvolts).

Parallel forms = administering a task twice in equivalent forms.

Pre-operational children = operationally defined as children who do not score well on the performance measure of Piagetian tasks.

Spatial tasks = tasks which are visuo-spatial in nature and have no verbal components. See Appendix A.

Subsequent response = response of child after experimenter asks questions concerning the observed phenomenon while child is thinking about and answering these questions as measured by L/R ratio.

Temporal tasks = Piagetian tasks applied without alterations from Lovell and Slater "The growth of the concept of time" in Journal of Child Psychology and Psychiatry, Vol. 1 (1961), pp. 179-190. These tasks have visuo-spatial components and require temporal ordering and verbal reasoning to solve.

Verbal tasks = tasks which have verbal components and require verbal thought to solve or answer. See Appendix A.

Visuo-spatial = phenomenon presented visually in three dimensional space to the child with no verbal accompiment.

Limitations

1. Two factors related to selection of the sample limit the generalizability of the study. First, the sample was selected from among thirty volunteers from two public schools in West Lafayette, Indiana. Second, the sample included a large percentage of children whose parents were either white-collar workers and/or were graduate students, staff, or faculty members of Purdue University. Therefore, the results may be skewed as the result of non-random selection and higher than average socioeconomic and/or educational level of the family.

2. A potentially significant independent variable, hand-eye dominance, was screened, but not blocked, into

the design which resulted in such small cell sizes that statistical analysis assessing sex and hand-eye dominance was inappropriate.

Assumptions

The following assumptions were made in designing this study:

1. That a larger proportion of alpha band waves in one hemisphere indicates inactivity or idling of that hemisphere and alpha blocking or activity in the other hemisphere.
2. That a greater proportion of activity in one hemisphere than the other indicates cognition and attention.
3. That for any given measurement of hemispheric brain waves the inferred cognition present involved the task which was being administered.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

The literature related to the problem under investigation has been organized and summarized in four major sections. The first section is concerned with asymmetrical hemispheric brain functioning theory and research. The second section provides a review of the related EEG studies of hemispheric brain functioning. The third section reviews the EEG research with children. Finally, the fourth section discusses Piagetian theory and research.

Asymmetrical Hemispheric Brain Functioning Theory and Research

The studies in this section are presented in the following order: 1) lesion studies, 2) "split-brain" research, 3) research involving normal subjects, who do not have a history of brain lesions or neurosurgery, 4) developmental research and theory, 5) research which qualifies the application of the brain functioning theory to the general population and, finally, 6) implications of this research and theory for educators.

As early as 1961, Paul Broca, a French pathologist and pioneer in neurosurgery, reported functional asymmetry between the two cerebral hemispheres. Citing the behavior of patients with lesions of the left frontal lobe, Broca (cited in Milner, 1974) postulated that articulated speech was a function of the left cerbral hemisphere. Broca's statement precipitated numerous other reports of patients suffering from loss of language functions in association with damage in the left cerebral hemisphere (Harris, 1975).

In 1874 Hughlings Jackson (cited in Benton, 1972) a British neurologist, reported that damage in the right cerebral hemisphere was associated with loss in visuo-spatial recognition and memory resulting in visuo-spatial disorientation, failure to recognize faces and inability to dress. Following Jackson's observation were other reports of spatial disorders associated with lesions of the right cerebral hemisphere, such as loss of geographic memory and inability to locate objects and self in space (Benton, 1972).

In the years that have followed, these reports have been confirmed and extended. Observations of patients with hemispheric lesions have indicated an association of the left hemisphere with reading, writing, speaking, understanding the spoken word, calculation and analytical tasks and an association of the right hemisphere with visuo-spatial performance such as visual pattern identification, visual closure, spatial orientation, musical pattern and Gestalt, synthetic tasks (Newcombe, 1969; Corkin, 1965; Milner, 1965, 1974). However, the significance of this functional asymmetry was not understood until the later 1960's when R. W. Sperry and his associates began publishing the results of tests performed by "split'brain" patients. These patients had undergone surgical sectioning of the major commissures connecting the two cerebral hemispheres in order to prevent the interhemispheric spread of epileptic seizures (Bogen and Vogel, 1962; Bogan, Fisher and Vogel, 1965).

Based on these findings, Sperry (1969) concluded that ". . . the two hemispheres appear to be independently and often simultaneously conscious, each quite oblivious of the mental experiences of the opposite hemisphere and also of the incompleteness of its own awareness." Levy, Trevarthen and Sperry (1972) explicitly describe their observations of these patients:

> "Recent commissurotomy studies have shown that the two disconnected hemispheres, working on the same task, may process the same sensory information in distinctly different ways, and that the two modes of mental operation involving spatial synthesis for the right and temporal analysis for the left, show indications of mutual antagonism" (Levy, 1970). The propensity of the language hemisphere to note analytical details in a way that facilitates their description in language seems to interfere with the perception of an over-all Gestalt, leaving the left hemisphere''unable to see the woods for the trees.' This interference effect suggested a rationale for the evolution of lateral specialization.

Sperry (1969), Gazzaniga (1967) and Bogan (1971, 1975) have confirmed this evidence. The hemispheres in these "split-brain" patients functioned independently, appeared to sense, perceive and conceptualize independently, yet had specialization of function. The right hemisphere had few words but had little or no impairment in visual discrimination tasks and spatial orientation while the left hemisphere had visual discrimination and spatial impairment but scored well on the verbal subtests of the Weschler and was able to calculate.

Thus began the theory of two states of consciousness, two personalities, within one brain. Each was conceived as having its own system of processing sensory information as well as its own cognitive mode. The role of the commissures then was viewed as that of unifying the two into a single personality, the self.

Following Sperry's discovery a growing body of literature has been accumulating which confirms that the functional asymmetry reported in lesion and split-brain patients is also evident in "normal" people who have intact commissures and no history of brain damage or neurosurgery. Comprehensive reviews o¯ this research and its implications are found in Wittrock (1975), Languis and Kraft (1976), O'Keefe (1975), Berluchhi (1974), Galin (1974), Kimura (1973), Levy (1972), and Dimond and Beaumont (1974).

Investigations into hemispheric brain process with normal persons that are of particular relevance to education have frequently utilized three techniques: dichotic listening, tachistoscopic presentation and reaction time, and electroencephalographic measurement of the brain's electrical activity employing both frequency analysis and the evoked potential. The import of this accumulated research data is briefly discussed in this section.

The dichotic listening technique involves presenting subjects with simultaneous auditory stimuli (one in each ear) and then measuring performance differentials. Because each hemisphere receives information primarily (though not exclusively) from the contralateral ear, better left ear perception indicates right hemisphere superiority and vice versa. Using this technique with normal right handed adults the left hemisphere (right ear) has been found to better perceive and remember 1) digits (Knox and Kimura, 1970; Kimura, 1961, 1967), 2) meaningful words and nonsense words that are easily pronounced, Rirk, 1964; Curry, 1967), 3) syntatic structure (Zurif and Sact, 1969), 4) which of two stimuli came first and 5) fine temporal order judgments, i.e., Morse Code (Shankweiler and Studdert-Kennedy, 1967). The right hemisphere (left ear) is superior in perceiving and remembering 1) melodies (Kimura, 1964), 2) pitch perception (Halperin, Nachshon and Carmon, 1973), 3) sonar signals (Chaney and Webster, 1966), 4) environmental sounds (Curry, 1967), 5) vocal nonspeech sounds, i.e., coughing, laughing and crying (Knox and Kimura, 1970; Kimura, 1973), and 6) intonation contours used to indicate commands, questions and declarative sentences (Blumstein and Cooper, 1974).

Consistent with left hemisphere mediation in the processing of verbal information and the right hemisphere processing of non-verbal information, tachistoscopic studies have shown that the right visual hemifield (left hemisphere) is superior 1) in recognizing words (Mishkin and Forgays, 1952; Mackavey, Curcie and Rosen, 1973; Egeth, 1971 and White, 1969), 2) in letter identification (Kimura, 1966; White, 1974; Marcel, Katz and Smith, 1974) and 3) digits (Hines and Satz, 1974). The left visual hemifield (right hemisphere) is superior 1) in dot enumeration (Kimura, 1966, 1969; McGlene and Davidson, 1973), 2) in utilizing dot sterograms (Kimura and Durnford, 1974) and 3) in facial recognition (Giffen, Gradshaw and Wallace, 1971; Gilbert and Baker, 1973). In addition, although binocular viewing was necessary to elicit the effect, Durnford and Kimura (1971) found that the right hemisphere was also superior in depth perception.

Lateralization of cortical functioning has also been found using an electroencephalograph (EEG) to measure asymmetrical electrical activity in the cerebral hemispheres. The left hemisphere is active when overtly or covertly processing 1) verbal material (Buchsbaum and Fedio, 1969; Matsumuza et al., 1972; Wood, Goft and Day, 1971; McAdam and Whittaker, 1971; Morgan, McDonald and MacDonald, 1971; Galin and Ornstein, 1972, 1974; Doyle Ornstein and Galin, 1975), 2) logical tasks (Dumas and Morgan, 1975; Dilling, 1975; Morgan, McDonald and Hilgard, 1974; Butler and Glass, 1974) and 3) mathematical computation (Morgan, McDonald and MacDonald, 1971; Butler and Glass, 1974; Dumas and Morgan, 1974). The right hemisphere exhibits more activity during 1) visuo-spatial tasks (Morrell and Salamy, 1971; Galin and Ornstein, 1972; 1974; Doyle, Ornstein and Galin, 1975), 2) musical activity (Doyle, Ornstein and Galin, 1975; McKee, Humphrey and MacDonald, 1971) and 3) when imaging various scenes (Morgan, McDonald and MacDonald, 1971; Morgan, McDonald and Hilgard, 1974).

Although little is known about the exact nature of hemispheric functioning in children (Galin, 1976), asymmetrical electrical activity of the hemispheres to verbal and nonverbal stimuli has been reported in infants ranging in age from one week to ten months by Molfese (1972) and has been supported by Gardner, Schulman and Walter (1973) and Witelson and Pallie (1974). Furthermore, structural differences between the two hemispheres are present at birth (Geschwind, 1974; Harris, 1973). However, based on case histories indicating full recovery of language facilities following damage to the left hemisphere, other researchers (Krashen and Harshman, 1972; Dorman and Geffner, 1974, and Berlin et al., 1973) postulate that adult lateralization of function does not occur until later childhood, while Brown and Jaffee (1975) present a convincing theory of lateralization which extends into senescence.

The discrepancy between the reports of lateral specialization at birth or shortly thereafter and the case histories of functional disability following lesions may, in part, be explained by the maturation of the commissure fibres which connect the two hemispheres and those fibres which pass from the reticular formation to the two hemispheres (Yakolev and Lecours, 1967; Davidson and Dobbing, 1966; van Gils, 1971; Dobbing, 1971; Conel, 1959, 1963; Bergstrom, 1969; Davidson and Peters, 1970; Holmes and Sharp, 1969).

The role of the commissures between the two hemispheres (as the "split-brain" research has illustrated) is that of a communication system for the incoming information and the subsequent processing of information between the hemispheres. The role of the fibres from the reticular formation is to inhibit and/or facilitate functioning of the hemispheres, or subparts of the hemispheres (Thompson, 1975; Holmes and Sharp, 1969; Schulte, 1969).

Yakolev and Lecours (1967) report that the maturation of these two fibre systems is barely apparent until two years of age. The commissures between the two hemispheres mylinize rapidly from two until seven, while those fibres passing to the hemispheres from the reticular formation mylinize rapidly from two until twelve and continue into senility.

Gazzaniga (1974) postulates that because the young child has extremely poor interhemispheric communication, he operates as a functional "split brain" until the age of two, processing experience in each hemisphere with little specialization. While Harris (1970), Knox and Kimurs (1970) suggest that the right hemisphere modality is dominated in the spatial orientation of young children's behavior. This pattern slowly changes to a left hemisphere orientation, as language is acquired and visuo-spatial concepts are compacted into a single symbol (word) which stands for the entire concept/process.

In summary, the functional asymmetry of the two cerebral hemispheres has been confirmed by research involving lesioned patients, split-brain patients and "normal" subjects. The left cerebral hemisphere has been shown to be a sequential processing system and the mediator of language, analytical and propositional thought, while the right cerebral hemisphere has been demonstrated to be a synthetical processing system and the spatial, Gestalt specialist.

The propensity of the sequential processing system toward verbal stimuli (and the synthetical processing system toward nonverbal stimuli) apparently is either present at birth or very shortly thereafter, but complete lateralization of language processes is postulated to develop with maturity and may not be present in some adults.

Buffery and Gray (1972) in summarizing current research in sex differences state that language lateralization tends to be diffused (processed in both hemispheres) in women with a greater degree of lateralization (processed mainly in the left, analytic hemisphere) in men. Greater right hemisphere (visuo-spatial) lateralization has also been reported for men. For instance, males consistently show superiority (Harris, 1976) in Witkin's (et al., 1962) rod and frame measures of cognitive style (field dependence-independence or FDI) which has been associated with proprioception and is believed to have visuo-spatial, right hemisphere process emphasis.

Another population which has been cited as having diffuse lateralization are left handers (Levy, 1969; Miller, 1971) who often have lower performance IQ's on the WAIS although verbal IQ's between dextrals and sinistrals are similar. Levy (1964) postulates that diffuse lateralization causes deficiencies in visuo-spatial abilities because language processing takes priority. However, Kirschner (1974) citing research on men and women with mixed hand-eye dominance postulates that diffuse spatial lateralization may interfere with verbal ability.

Galin (1976) states that difficulties arise not only from a failure to develop lateral specialization but also from individual or cultural differences in preferred cognitive style. Studies by Cohen (1969) and Marsh (1970) have indicated that subcultures may be characterized by emphasis on a predominant cognitive mode: the middle class employ a verbal-analytical mode and the urban poor are more likely to utilize a spatial-synthetic mode.

Application of the differential functioning of the two hemispheres and the preference of some individuals has been extended to definitions of learning disability. David Galin (1976) proposes a continuum with creativity on one end and learning disability on the other. This continuum is based on the ability to integrate verbal and analytic thought (left hemispheric modality) and intuition and understanding patterns (right hemispheric modality). Therefore, a smooth integration with complementary functioning of the two hemispheres would facilitate creative thinking while interference between the two processing systems facilitates learning disabilities.

Review of Related EEG Studies of Hemispheric Brain Functioning

This section is organized as follows: 1) brief historic discussion of EEG studies, 2) research measuring lateral alpha asymmetry, 3) evoke potential research, 4) brief summary of the results, and 5) discussion of the possible interaction between the two hemispheres in normal adults.

Until recently, the research involving the hemispheric activity measured by recording from leads placed on the scalp did not assess asymmetrical activity between the two hemispheres and often were based on unilateral measurements (reviewed in Vogel et al., 1968 and Lairy, 1975). Consequently the bilateral symmetry of the human brain waves were assumed. Furthermore, these investigations usually recorded hemispheric activity when subjects were passive, rather than actively involved in task solution or recorded averaged evoke potentials to subsequent task performance (Galin and Ornstein, 1975).

Researchers began assessing lateral EEG asymmetry in normal subjects. Following publication of the split brain findings, and facilitated by technological advances, such as the digital computer, which enabled quantification of EEG recordings.

In 1967, two studies were published which indicated that asymmetrical hemispheric activity was present in the alpha frequency band. Liske, Hughes and Stowe (1967) reported that they found evidence of asymmetrical alpha in the left and right hemispheres of forty-two subjects. That same year, Rossi and Rosadini (1967) reported that unilateral alpha was present in the hemisphere contralateral to hemisparesis following injections of intracarotid sodium amytal, which indicated that the active hemisphere had less alpha activity.

Postulating that this asymmetrical electrical activity measured asymmetrical hemispheric functioning, David Galin and Robert Ornstein at the Langley Porter Neuropsychiatric Institute in San Francisco conducted a pilot study in 1970 (reported in Galin and Ornstein, 1972; Ornstein and Galin, 1975, and Kiester and Cudhea, 1976) recording from homologous leads of the temporal and parietal areas (T3-T4, P3-P4) of normal subjects during performance of spatial and verbal tasks. The results supported their hypothesis: there were predictable lateral EEG asymmetries between the spatial and verbal tasks.

Encouraged by the pilot study, Galin and Ornstein (1972) administered motor and nonmotor verbal tasks--writing a letter and mental letter composition and motor and nonmotor spatial tasks, modified Kohs Block Design and modified Paper Form Board--to ten right handed adult males. Computing ratios of average power recorded from homologous leads (T3-T4, P3-P4), they confirmed the results of the pilot study.

Assessing the asymmetrical hemispheric activity in each of the frequency bands and adding serial arithmetic, verbal listening, Seashore Tonal Memory Test and Magic Etch-a-Sketch to the paradigm these researchers (Doyle, Ornstein and Galin, 1973) reconfirmed their previous findings and reported that although lateral EEG asymmetry is found in the alpha, beta and theta bands, the alpha band was the most sensitive. They concluded that motor output elicited greater lateral asymmetry than nonmotor tasks.

The next question the Langley Porter group addressed was whether they could find hemispheric patterns which would characterize the preferred cognitive mode of individuals (Ornstein and Galin. 1974). Using vocational choice as criteria, they administered to lawyers and artists two spatial tasks, modified Kohs Block Design and Mirror writing, and two verbal tasks, writing from memory and text copying. The alpha power ratios recorded between tasks from the same homologous lead placed over the parietal and temporal areas supported their hypothesis that lawyers, having a verbal analytic approach to problem solving, consistently showed greater change in left hemisphere alpha production than the artists, who tend to have a spatial holistic modality. However, there were little differences in right hemispheric alpha shifts between the two groups.

At Stanford University another group of researchers have shown that lateral alpha asymmetry is also present in the left and right occipital area. Morgan, McDonald and MacDonald (1971) reported that subjects had an increased percentage of left hemispheric functioning, during performance of analytic tasks (arithmetic and vocabulary questions) and greater right hemispheric functioning when instructed to image various scenes.

Adding a musical task to their paradigm, this group (Morgan, MacDonald and Hilgard, 1974) confirmed their previous findings, but reported that the musical task elicited greater left hemispheric functioning. This finding was contrary to other lateral asymmetry studies (Kimura, 1964; Doyle, Ornstein and Galin, 1973).

Citing a previous study by McKee, Humphrey and McAdam (1973) which assessed hemispheric differences in verbal and musical detection tasks of various complexity and found that the ratios became greater with increasing difficulty in both tasks, the Stanford group interpreted the unexpected results of the musical task in their study as a function of task difficulty. Judging the analytic and musical tasks to be considerably more difficult than the spatial tasks, they postulated that individuals rely on their dominant hemisphere rather than the specialized hemisphere when encountering very difficult tasks. Dumas & Morgan (1975) building this task difficulty hypothesis into their next investigation as well as the assessment of the preferred cognitive mode of the subjects (using occupational choice as criteria) administered spatial and analytical tasks to engineers and artists varying the degree of task difficulty. They found significant differences in the alpha ratios between the (1) spatial (facial recall and Nebes ring test) and (2) analytical (linguistic and mathematical) tasks in the predicted direction across subjects and task difficulty, but they found no statistical differences in the alpha ratios on the basis of occupation or task difficulty. However, they reported significantly greater alpha amplitudes in the artists across tasks.

The findings of the Langley Porter and Stanford groups have been confirmed by other researchers. Butler and Glass (1974) reported significant left hemispheric functioning of subjects while performing arithmetic tasks. Robins and McAdam (1974) found left hemispheric functioning during verbal tasks and right hemispheric functioning while subjects were imaging.

At Purdue University, Dilling (1975) classified subjects as formal, transitional or concrete operational using a set of three Piagetian tasks. The formal and concrete operational subjects were then administered a battery of spatial, verbal, logical and mathematical tasks while electroencephalograms were recorded from homologous leads attached to the scalp over the central (C3-C4) and parietal P3-P4) regions. Lateralized activity of all the frequency bands were computed.

Dilling's findings supported the use of alpha ratios as the most sensitive to lateral asymmetry. Using lateralized alpha ratios, he found that the formal operational subjects had significantly greater left hemispheric functioning during performance of a logic task and tended to have greater left hemispheric functioning across tasks. Based on these findings, he concluded that the concrete operational subjects relied on the spatial, pictoral modality of the right hemisphere, while the formal operational subjects used the more efficient analytic mode of the left hemisphere during performance of logical tasks.

Using an evoke potential paradigm other researchers have also reported evidence of asymmetrical hemispheric functioning in normal subjects. Buchbaum and Fedio (1969) found larger evoked responses to complicated visual spatial stimuli from the right temporoparietal area. They also reported (Buchbaum and Fedio, 1970) larger left hemispheric responses to verbal information presented in the right visual field and larger right hemispheric responses to nonverbal information presented in the left visual field.

McAdam and Whitaker (1970) recorded significantly larger DC potentials (evoke potential responses) over the left fronto-temporal areas prior to speech production than from homologous leads on the right, but did not find this shift preceding nonverbal vocal production such as coughing and spitting. Wood, Goff and Day (1971) also found significant auditory evoke responses of the left hemisphere during speech production.

Morrell and Salamy (1971) recording from homologous temporoparietal and frontal leads found greater average cortical potentials from the left hemisphere of subjects listening to nonsense words and larger evoked responses to presentations of visual stimuli recorded from the right parietal lead.

Using a paradigm which manipulated EEG alpha asymmetry while observing the effect of concomitant evoked potentials, Galin and Ellis (1975) reported that both the EEG and evoked potential asymmetry measures reflected the hemispheric specialization of verbal and spatial tasks. However, they concluded that the lateralized alpha ratios were more consistent across subjects and tasks.

Summarizing this research, Ornstein and Galin (1975) state that the two modes of consciousness, each with its own specialization, found in the split brain subjects can be isolated in normal subjects using EEG frequency analysis and evoke potential techniques. The findings of these EEG studies have shown that right handed adult males have a greater left hemispheric response during performance of verbal, mathematical, logical and analytic tasks and a greater right hemispheric response during performance of visuo-spatial, musical and imaginal tasks.

However, the study of how these two processing systems cooperate or interfere with each other has just begun (Dimond, 1972; Dimond and Beaumont, 1974; Galin, 1976). Based on the findings of their investigations Galin (1975) discusses the possible interaction between the two hemispheres in normal adults:

> One possibility is that they operate in alternation, i.e., taking turns, depending on situational demands. When one hemisphere is "on" it may inhibit the other. A variant of this relationship might be that the dominating hemisphere makes use of one or more of the subsystems of the other hemisphere (e.g., memory) inhibiting the rest (e.g., planning, motivation). The inhibition thus may be only partial, suppressing enough of the subordinate hemisphere so as to render it incapable of sustaining its own plan of action.
>
> Our EEG studies of normal people are consistent with this view; when subjects performed verbal tasks (left hemisphere) we observed an increase in alpha waves (an idling rhythm) over the right hemisphere; when they performed spatial tasks

> (right hemisphere) the idling rhythm shifted to the left hemisphere. Another variant is the one hypothesized . . . in relation to "repression"; one hemisphere dominates overt behavior, but can only disconnect rather than totally inhibit (disrupt) the other hemisphere, which remains independently conscious. The fourth possible condition, in which the two hemispheres are fully active and integrated with each other, is the condition which Bogan (Bogan and Bogan, 1969), associates with creativity (Galin, 1975, p. 43).

Norman Geschwind (cited in Galin, 1976) states that "practically all of us have a significant number of special learning disabilities." However, the definition of learning disability for Western cultures includes only those disabilities which interfere with left hemispheric processes, i.e., propositional and analytic thinking.

Bogan (1975) suggests an educational neglect of right hemisphere cognitive potential which is "as important (for high level problem solving) as language skills" and necessary, though not sufficient for creative thinking (Bogan and Bogan, 1969).

Furthermore, "if we want to cultivate creativity it appears that we must first develop each mode, both the rational-analytic and the intuitive-holistic; second, we must develop the ability to inhibit either one when it is inappropriate to the task at hand; and finally we must be able to operate in both modes in complementary fashion" (Galin, 1976).

The growing implications for educators to 1) join the research effort uncovering young children's development of processing and 2) reorganize curriculum and instructional techniques to include the right hemispheric modality is prevalent in the literature (Sperry, 1974; Bogan, 1975; Galin, 1975; Harris, 1973, 1976; Livingston, 1973; Samples, 1976; National Institute of Education, 1976; National Science Foundation, 1976).

EEG Research Involving Children

All of the preceding research investigations cited have included only right handed adult subjects who usually are male. This section which summarizes the EEG research involving children is organized into four parts: investigation of lateral asymmetry, investigations of developmental EEG, investigations relating EEG to intelligence and investigations relating EEG to developmental stages. Table 1 lists these studies, the number of subjects in each sample and the focus of each investigation.

In reviewing the related literature no studies were found which assessed lateral alpha asymmetry in normal children. However, there were two studies in which the auditory evoked response asymmetry in infants and children was reported.

Molfese (1972) presented meaningful and unmeaningful verbal and nonverbal stimuli to three groups of subjects, including ten infants (ranging in age from one week to ten months) and eleven children (from four to eleven years of age) while recording from homologous leads over the temporoparietal area. He found significant left hemispheric evoke responses to the verbal stimuli (two nonsense syllables and two words) and significant right hemispheric evoke responses across subjects to the nonverbal stimuli (C-major piano chord and a speech noise burst). Gardiner, Schuleman and Walter (1973) have supported Molfese's results.

Many of the investigations reported (Lindsley, 1936, 1938, 1939; Bernard and Skoglund, 1939a, 1939b; Henry, 1944; Gibbs and Knott, 1949; Corbin and Bickford, 1955; Garsche, 1956; Kalamutsu et al., 1964, and Scheffner, 1968) are concerned with the normative development of hemispheric electrical activity measured with an EEG. These studies report a gradual development of the alpha frequency band which increases with age throughout childhood. The adult level of 8 - 13 cycles/second is reached approximately by twelve years of age. Surveys of the EEG's of children and adolescents (0 - 21 years) are found in Eeg-Olofsson (1971) and Lairy (1975).

Another group of studies have attempted to relate EEG and intelligence (Netchine, 1969; Knot et al., 1942; Lindsey, 1938; Henry, 1944; Novikova, 1954, and Netchine and Lairy, 1960). Lairy (1975) reviews these investigations and concludes that although EEG maturation is one of the conditions <u>necessary</u> for intellectual development it is not <u>sufficient</u> and the two processes may not develop simultaneously.

The last group of studies in this summary are those which have attempted to relate developmental EEG processes to developmental behavior patterns. The first investigator cited proposes his own model of ontological development while the last two postulate a relationship with Piaget's model.

Walter (1953) proposed a model of ontogenetic development which was a synthesis of successive dominance of distinct brain wave rhythms associated with consecutively dominant aspects of personality and behavior profiles. In this model the first developmental stage, termed ductility (i.e., the ability to be moulded without cracking or taking a permanent shape), is accompanied by predominant delta activity. Starting around the age of three a second period begins in which the theta activity predominantes. This period is termed "a search for pleasure" or hedonism. The last stage, accompanied by a predominance of alpha activity, begins at nine and continues throughout adulthood. This stage is characterized by "a search for pattern" and an orientation toward exploration.

Another attempt to link ontogenetic evolution and EEG frequency activity was postulated by Stevens et al. (1968).

Drawing parallels among the increase in brain weight, acceleration of average EEG frequency and Piagetian stages of development, they proposed that the Sensorimotor stage correlated with slow brain waves and low brain weight. The average EEG frequency accelerates rapidly as the brain weight from birth until two years of age, which is the beginning of the preoperational period. At that time the frequency acceleration reaches a plateau but the brain weight continues rapidly. As the brain weight reaches a plateau, around six years of age, the concrete operational stage begins. The parallelism of this model holds best during the Sensorimotor and Preoperational stages, as throughout both the Concrete Operational and Formal stages both the brain weight and accelerating frequencies gradually increase.

A second attempt to relate Piagetian theory and EEG development was proposed by Dreyfus-Brisac and Blanc (1957). This model is built on the parallelism in early infancy between the principal stages of motor development at three and five months cited in Piagetian literature and the succession of the EEG organizational stages. At the age of three months, they postulate, the EEG spatio-temporal structure undergoes an important transformation which includes a slow occipital activity of relatively large amplitude blocked by the opening of the eyes. This transformation is postulated to be accompanied by behavioral changes in the infant which include the disappearance of archaic reflexes, the control of head tonus and oculomotor coordination permitting the scanning of space. At five months, occipital activity from 5 to 6 cycles/second acquires a rhythmic character and voluntary prehension appears permitting sitting, babbling and accurate macular vision. It must be noted that this model has been challenged by other investigators who differ with both the age in which occipital rhythmic activity first appears and with its possible interpretations (Pamplglione, 1965; Torres and Blaw, 1968; Ellingson, 1967, cited in Lairy, 1975).

Piagetian Theory

Jean Piaget's theory has become one of the most influential models underlying the understanding of children's cognitive abilities and processing. Although his methodology has been criticized (Hazlett and McCarthy, 1930; Braine, 1962; Flavell, 1963; Fleischmann et al., 1966; Wallace, 1972), his research and subsequent theory investigating how children come to know (reality) have been replicated around the world (Modgil, 197_; Flavell, 1970), becoming the theoretical foundation of many educational implementation programs (Elkind, 1961; Smedslund, 1961; Wholwill and Lowe, 1962; Karplus, 1974).

The model of developing cognitive abilities evolving from Piaget's explorations into children's thinking includes two parallel structures of knowledge. Defining the two, Piaget states ". . . these structures may be figurative, for example, perceptions and mental images, or operative, for example, the structures of actions or of operations . . . (The image) serves on the par with language as symbolic instrument to signify the content of cognitive significations; for spatial concepts the image is particularly evident" (Piaget, 1973 pp. 356, 357).

This model, however, gives high priority to operative structures. It is a logico-mathematical model, which traces children's increasing ability to explain perceptual, spatial observations and knowings into rational operations. Using this model as criteria for differentiating behavior and the inferred cognitive constructs and thinking processes underlying the behavior, Piaget has proposed a developmental and hierarchical system of cognitive periods. Although the cognitive processing of information within the periods is conceived as qualitatively different, each subsequent period grows out of and builds upon the knowledge of the preceding period, and the modes of processing often continue to function in parallel with each other (Phillips, 1969; Piaget, 1970).

There are three major periods in Piaget's model: the sensorimotor period which occurs from birth to approximately two years of age; the period of concrete logical operations which occurs from approximately two until twelve; and finally, the period of formal logical operations beginning at approximately twelve years of age and extending onward throughout life. Each of the two last periods is divided into subperiods (or stages): the first subperiod is a time of preparation and the second subperiod is a time of attainment. Thus the second period has two subperiods: the subperiod of preoperational thinking which extends from ages two until approximately seven, and the subperiod of concrete operational thinking which begins around the age of seven and continues until the formal operational period is attained. The differentiating cognitive constructs and behaviors of these periods and subperiods are described below.

1. During the sensorimotor period the child constructs a multi-modality space and then permanent objects in that space which he can act upon in an elementary cause-effect relationship. The behavior of this period is characterized by imitations of objects in the environment and a general motor response to the objects in the environment and a general motor response to the environment. In this period there is no reversibility or conservation, but the beginnings of directional functions and qualitative identities is initiated around one and one-half to two years of age with the formation of semiotic processes such as language and

mental imagery (Piaget, 1970).

2. During the preoperational subperiod of the concrete operations period the child constructs a) symbols which represent objects in space and can be manipulated and communicated to others, b) organization of his own behavior as it relates to a goal, and c) a personal sense of time, which includes past, present and future. The behavior of this period is characterized by a shift in interest from action to explanation, but his explanations are perceptually bound, irreversible, egocentric and tending to center on one detail of an event often seeing states rather than transformations (Piaget, 1970, 1973; Phillips, 1969). Piaget believes that the development of mental imagery during this subperiod plays an important role in enabling children to predict recurring events and to plan actions in advance (Modgil, 1974).

3. During the concrete operational subperiod the child constructs an operative ability, which is decentered and reversible. The behavior of this period is characterized by the ability to solve conservation tasks which means that he can think logically about perceived transitions. However, these operations are limited to concrete i.e., not abstract, thinking.

4. During the formal operational period the adolescent constructs combinatory thinking which is characterized

by the ability to perform operations on operations and abstract logical (propositional) thinking (Piaget, 1970).

For Piaget, the underpinnings of operative knowing for the concrete operation l child are the primitive actions of the sensorimotor period which evolved into the intuitive actions of the preoperational stage and finally are transformed into "true operations. . . these operations are interiorized actions (e.g., action which can be performed either physically or mentally) that are reversible (addition acquires an inverse in subtraction) and constitute set-theoretical structures (such as logical additive 'grouping' or algebrac groups)" (Piaget, 1970).

Although most of his research and subsequent theory involves operative knowing, Piaget (1970) has postulated developmental stages of perceptual (or figurative) knowing. The supportive research for this hypothesis is found in his volume concerning mental imagery (Piaget and Inhelder, 1971) and perceptual mechanisms (Piaget, 1969).

Furthermore, in his latest book, Piaget (1971) also postulates dual interacting memory systems: imaginal and cognitive. Piaget believes that the imaginal system in the young child is limited to reproductive images (e.g., to imagine an object or event that has happened, but is not actually perceived at the time). After seven or eight years of age, anticipatory images appear (e.g., ability to imagine the result of a new combination). Therefore, he concludes that there is an interdependency between the evolution of imaginal memory systems (as evidenced by his research on imagery, perception and memory) and cognitive memory systems (as evidenced by his earlier research on operative thinking) and the evolution of operations.

This recent developmental model of two interactive ways of knowing is ill-defined and tends to interpret knowing processes by the verbal explanations given about that knowing. However, this model appears to be the area of Piaget's current interest and research (Elkind, 1975).

Review of the Related Piagetian Literature

In his search to discover the ontogeny of rational thinking, Piaget has investigated many topics, such as language, space, time, geometry, number, conservation, perception, imagery and memory. This discussion will be limited to the investigations of time and conservation, because the present investigation was limited to temporal and conservation tasks. The ensuring paragraphs are organized in the following manner: 1) a general discussion of conservation, 2) a discussion of the conservation tasks used in this investigation: conservation of substance and conservation of area, 3) a summary of the related conservation research, 4) a discussion of the Piagetian temporal tasks and related research.

Conservation

Conservation involves the understanding that quantity remains constant, i.e., invariant following a transformation of its physical appearance. Piaget (1952) has characterized this understanding as "a necessary condition for all rational activity." In order to conserve, the formerly perceptually dominated intuitive thinker must understand 1) that an object can change in one respect without changing in other respects, 2) that it may be classified simultaneously on more than one attribute, 3) that it may be compared to another object on more than one dimension and 4) that every transformation is reversible (Phillips, 1969). There are many varieties of conservation and although the specific age which a given child attains these conserving abilities might differ, the sequence or pattern is the same across subjects and cultures (Piaget, 1950).

To understand the importance of conservation in Piaget's theory consider the following statements: 1) The elaboration of Piaget's theory into periods and stages was articulated in terms of his conservation tasks (Elkind, 1975); 2) These tasks are the subject of most of the Piagetian replication studies (Flavell, 1970); and 3) The term "conserver" has become synonymous with concrere operational thinking (Modgil, 1974).

Related Conservation Research

Piaget first reported his investigations of conservation of quantity in 1941 (Piaget and Inhelder, 1941 cited in Flavell, 1970). The concepts usually referred to as conservation of quantity are substance, weight and volume. These concepts are conserved in sequence. "The child discovers the conservation of substance at seven or eight, as is clear from his judgment of changes in a lump of clay. He discovers the conservation of weight at nine or ten, and the conservation of volume at eleven or twelve (Piaget and Inhelder, 1969).

The procedure followed during this Piagetian investigation is as follows: 1) Two quantities of a given material or substance having identical perceptual appearances are initially established as equivalent; 2) One of the two is then altered in some "quantity-irrelevant" way, e.g. changing the shape or dividing into parts; 3) The child is then asked if there is still the same amount (or some equivalent expression) in the one as the other; 4) The child is finally asked to explain his reasoning.

Piaget states that the physical transformation of the substance presents the subjects with the temptation to judge the relative amounts perceptually (by noting the greater length of the elongated clay ball, etc.) rather than conceptually (by evoking the knowledge that nothing has been added or taken away during the transformation). The younger nonconserving subjects succumb to the temptation, assess the quantities in terms of one striking perceptual feature and erroneously conclude that there is more substance in one than the other (cited in Flavell, 1970).

From his observations of performers on this task, Piaget concludes that "amount" for the nonconserver is not yet a multi-dimensional affair and that the young child "is quite content" to estimate quantity and many other physical variables by means of a single cue (centering) such as length.

However, the seven or eight year old who conserves substance also has two conceptual components which his quantity concept usually does not include: 1) there is no understanding that weight and volume of substances also remain constant _during_ transformations and 2) because this first concept of "amount" is not yet based on the more precise concepts of weight and volume, there appears to be a global, nonmeasurable understanding (Flavell, 1970).

The ability to understand that the amount of space on a two-dimensional surface remains invariate with changes in its physical shape is termed Conservation of Area and is attained around seven or eight years of age. Piaget, Inhelder and Szeminska (1960) have assessed this understanding in different ways following the same investigative procedures as the conservation of quantity tasks: 1) the child is presented with two cardboard geometric shapes (e.g., rectangles) and equivalence is established, 2) following the equivalence response, one of the shapes is transformed (by changing the shape, dividing it into parts) or both shapes have equivalent objects placed on them in different patterns and positions, and 3) the child is asked if there is still the "same amount of room" on the two shapes and why he thinks so. Again the preoperational child succumbs to the perceptual temptation that one of the shapes seems longer, while the concrete operational child overcomes this perceptive deception and understands that since nothing had been added or subtracted, the two still have the same.

Piaget's investigations of conservation have been widely replicated. A comprehensive review is found in Modgil (1974). The following paragraphs discuss some of these studies.

Lovell and Ogilvie (1960, 1961) investigated the development of conservation of substance, weight and volume with 322 British children from seven to ten years of age. They found 1) that the patterns of reasoning of the British children were identical to Piaget's Swiss subjects and 2) that the children conserved substance, weight and volume in that order. Modgil's (1965) investigation of twenty-six ten year old British children supported these results.

Uzgiris (1964) individually administered tests of conservation of substance, weight and volume to 120 first to sixth grade children. She used four different kinds of materials for each test. The results of this investigation confirmed that the conservation of substance, weight and volume were achieved in that order and at approximately the same time, but found differences between ability to conserve based on the material used, concluding that individual past experiences may well underlie situational differences and may account for the observed inconsistency of subjects across the various materials. However, she also suggested that many of the children might have been transitional thinkers. Za'rour (1971) found that the ability of seven to nine year old Lebanese children to conserve was dependent on the material used during the task.

Goldschmid and Bentler (1968) administered two parallel forms of ten conservation tasks to 142 children ranging from five to nine years of age. The tasks included the three conservation tasks and conservation of area. The results of this investigation were used to establish the reliability of the tasks and to construct a conservation scale which was then administered to 107 different children of the same age range for cross validation. The results of this investigation was supportive of the Geneva research and theory establishing a reliability of the conservation tasks.

Cross-cultural replication studies have been reported in 1) Algeria (Bovet, 1972), 2) Arabia (Hyde, 1959), 3) Australia (De Lemos, 1969; Dasen, 1972), 4) Canada (Dodwell, 1960, 1961; Laure eau and Pinare, 1962), 5) Central Africa (Heron and Simonsson, 1969), 6) China (Cheng and Lee, 1964), 7) England (Lovell and Ogilvie, 1961), 8) Hong Kong (Goodnow and Bethon, 1962), 9) Iran (Mohseni, 1966), 10) Italy (Peluffo, 1962), 11) Jamaica (Vernon, 1965), 12) Japan (Noro, 1961; Fujinage, Saiga and Hosoya, 1963), 13) Lebanon (Za'rour, 1971), 14) Mexico (Price-Williams, 1968), 15) New Guinea (Prince, 1968; Weddell, 1968), 16) Senegal (Greenfield, 1966) 17) USA (Mermelstein and Shulman, 1967), and 18) West Africa (Price-Williams, 1961; Lloyd, 1971; Piller, 1971).

Hyde (1959) was one of the earliest to attempt to replicate Piaget's findings. She repeated many of Piaget's tasks with a multi-racial group in Arden, Arabia. The results described by Piaget were generally confirmed.

Although one replication in Japan (Noro, 1961) reported results identical with Piaget's, another (Fujjinage, Saiga and Hosoya, 1963) suggest that not enough attention is given to learning in Piagetian theory. Cheng and Lee (1964) reported results which were contradictory to Piaget's following administration of conservation tasks to Chinese children, but did not publish the details of the investigation (cited in Modgil, 1974).

In a replication study of Ghanaian children ranging in age from eight to eleven years of age, Beard (1963) found that in comparing her sample with English children, the Ghanaian children conserved later. She further stated that English children were advanced in the Piagetian tests of spatial concepts. Vernon (1966) compared Eskimo, West Indian and Canadian Indian children, finding that the conservation concepts and tasks of perceptual-spatial operativity were attained first by Eskimo children. His explanation was that the training of Eskimo children for perceptual-spatial concepts was the factor distinguishing the two (Modgil, 1974).

Bruner, Oliver and Greenfield (1966) have gathered results from a wide variety of cultures (Boston, Senegal, Alaska and urban and rural Mexico) finding that the unschooled children showed an apparent arrest in performance of any conservation tasks after the age of eight or nine years. However, Goodnow and Bethon (1966) reported that the results of their investigation with schooled and unschooled children in China did not indicate any differences on the basis of education and in fact, were similar to the results of children tested in America.

Wasic and Wasic (1971) found that culturally deprived children (black and white) lag in their conservation abilities.

Graves (1972) reported that minimally educated adults also lag particularly in the conservation of volume task. Elkind (1961) found sex differences between adolescent and adult males and females. Wheatley and Towler (1971) replicated this study and suggested that some adults may not reach the formal operational stage.

De Lemos (1969) demonstrated that the conservation abilities of full-blooded Australian aboriginal children was significantly lower than the part-blooded aboriginals. Since she found no apparent difference in the environment of the two groups, she concluded that the significant differences may be due to linguistic and genetic factors. Tuddenham (1968, 1969) found that Negro children performed at lower levels of conservation operativity than whites and orientals. Bat-haee (1971) concluded that intelligence tests and Piagetian tasks appear to be sampling cognitive processes which are "highly correlated" and presumably rest on some fundamental construct following an investigation with Iranian children.

Price-Williams, Gordon and Ramirex (1969) postulated that children of pottery makers would conserve substance before children who did not belong in pottery making families. The results revealed significant early conservation of substance by potters' children and they approached significance on other conservation of quantity tasks.

Modgil (1973) summarizes the Piagetian replication studies and concludes that there are problems interpreting the results of many of the cross cultural investigations, partly due to experience, cultural values and language differences; however, in general, Piaget's results have been supported. Those inconsistencies that exist are rarely found in the invariance of the sequence of attainment of the conservation tasks, but rather in the age of attainment.

Investigating the development of objective time, Piaget (1946 cited in Flavell, 1970) elicited comparative temporal judgments of two simultaneously moving objects which proceeded at different velocities and therefore traveled different distances. During performance of this task, Objects Moving Through Time and Space, the young child denied the simultaneity of their starting and stopping, as well as the equality of the temporal durations. Piaget concluded that this child relied purely on spatial cues, judging that since the distance traveled (or spatial successions) were inequivalent, then he also judged that the two objects moved for different time periods.

In another temporal investigation, Piaget (1946 cited in Lovell and Slater, 1960) assessed the ability to determine conservation of liquid (quantity) flowing simultaneously into two different sized containers. Performing this task, Time-Ordered Liquid Flow, the young child judges that the containers are not equivalent, therefore he judges as inequivalent the liquid in the containers and the time intervals of the liquid flow.

Flavell (1970) reports that the Piagetian temporal tasks have not attracted much attention, therefore, they have not been widely replicated. However, Lowell and Slater (1960) reported that following individual administration of the two tasks to 100 British children ranging from five to eleven years of age, they found similar results. There was a steady increase in the perception of simultaneity (judging that the starting and stopping was equivalent) with age, but the concept of "equality of synchronous intervals" (the ability to coordinate time and spatial intervals) appeared to be a more difficult task. In every case, the inability to judge time duration was explained by the differential size of the containers or the differential distance traveled by the dolls which indicated that spatial perceptions were affecting their thinking. They concluded that their results confirmed Piaget's findings and interpretations concerning these temporal tasks.

CHAPTER III

PROCEDURES

This chapter is organized into three major divisions: Preliminary Procedures leading to the research, which includes a time line of events, pilot study, results of the pilot study, dependent variable decisions and electrode placement decisions; Research Procedures including sample, hand-eye dominance screening, experimental procedures and instruments; and Analysis of the Data which includes scoring of instruments, classification of preoperational and concrete operational thinkers, data analysis to obtain the dependent variable and statistical analysis.

Preliminary Procedures

Time-line of events:

In order to prepare and execute this study a number of critical procedures have had to be completed. An interdisciplinary team of experts in such fields as neuropsychology, neurology, biomedical engineering and developmental psychology was consulted for advice, training and assistance; the investigator and her adviser developed a general background in each of these areas in order to synthesize the expertise of each specialist. An adequately equipped lab including technicians and specialists also had to be located and scheduled for use. The timeline of these procedures is as follows:

1. Winter 1973-74. Seminar in biophysics was attended in which asymmetrical hemispheric functioning research was discussed. .

2. Spring 1974. Consultation with biophysist for help with library research and proposed course work to build a background in hemispheric functioning.

3. Spring 1974. Preparation of research position paper.

4. Summer 1974. Consultation with neuropsychologist at Wittenberg University on EEG techniques, hemispheric literature and exploration of collaborative research.

5. Autumn, Winter, Spring, 1974-75. Course work in Neuropsychology, Cognitive Psychology, and Developmental Psychology.

6. Winter, 1975. Completion of an interdisciplinary seminar of research trends and issues in asymmetrical hemispheric functioning at University of California, Davis.

7. Winter, 1975. Consultation with nationally recognized specialists in EEG asymmetrical hemispheric research at Langley Porter Neuropsyciatric Institute, San Francisco, California.

8. Spring, 1975. Initial contact with professors at Purdue University for use of their EEG laboratory and collaborative research.

9. Summer, 1975. Two on-site visits to Purdue University to inspect the EEG laboratory, participate in on-going research and negotiate collaborative research.

10. Autumn, 1975. Consultation with neurologist in charge of EEG laboratory at The Ohio State University Hospital on EEG techniques, neurology literature, and possible collaborative research.

11. Autumn, 1975. Training in electrode placement and EEG procedures at the EEG laboratory, Department of Neurology, The Ohio State University.

12. November, 1975. Consultation with researcher in charge of EEG asymmetrical hemispheric research at Langley Porter Neuropsyciatric Institute on electrode placement sites and possible tasks for study.

13. November, 1975. Submission of written outline of study to Purdue's research team and major advisor.

14. December, 1975. Final negotiation for study with Purdue's research team.

15. December, 1975. Pilot study conducted at the Biomedical Engineering EEG laboratory at Purdue University.

16. February, 1976. Consultation by phone with nationally recognized expert in EEG asymmetrical hemispheric research at Langley Porter Neuropsyciatric Institue, San Francisco, on final discussion about tasks and coding procedures.

Pilot study:

A pilot study was conducted in the biomedical engineering EEG laboratory during December, 1975. The following were the purposes of the pilot study:

1. To familiarize the investigator with procedures involved in the study.

2. To give the investigator practice in administering Piagetian tasks to 7- and 8-year-old-children.

3. To further establish within the research team working relationships and roles.

4. To analyze tasks based upon previous research and theory and validate those which would be the most feasible for EEG study. The tasks considered were: Piagetian conservation, spatial, temporal and perceptual tasks, silent reading, block design, rotated forms, syllogistic logic and mental arithmetic, and writing.

Results of the pilot study:

The results were used to modify procedures in the main study as discussed in later sections of this chapter and to select tasks for the main study. The major criteria for task selection were those tasks which facilitated few artifacts (muscle and jaw movement) in the EEG data, therefore having the most potential for inferring cognition.

Dependent variable decisions:

Cortical activity indicating asymmetrical hemispheric functioning during task performance can be measured in different ways. The most widely accepted instruments of measurement in the current literature are dichotic listening machines which measure lateralized auditory input; tachtistscopic presentations, which measure lateralized visual input; and electroencephlographic measurements, including averaged evoked potential and frequency analysis which assess electrical signals from the surface of the skull over points of the cortex.

Averaged evoked potential measurement requires a simple uncomplex task that can be repeated over and over to obtain the average of the recorded evoked potentials for a given site on the scalp.

Frequency analysis compares the hemispheric frequency waves present in each hemisphere over a task or subtask performance, and therefore, can be used to measure complex thinking without requiring an abundance of repetition. This method appeared to be the most viable for measuring critical activity during Piagetian tasks, which involve complex cognition and more than one sensory modality.

The specific procedure used to measure asymmetrical hemispheric frequency bands has been developed by Galin and Ornstein (1972, 1973, 1974, 1975) in their laboratory at Langley Porter Neuropsychiatric Institute in San Francisco, California. These researchers have calculated a ratio of the magnitude of the various frequency bands (delta 1-3Hz, theta 4-7 Hz, alpha, 8-13Hz, beta 14-20Hz) of the brain wave spectrum in each hemisphere during tasks which were expected to show asymmetrical hemisphere functioning based on the split-brain studies (Sperry, 1964; Bogan and Gazzaniga, 1965; Gazzaniga, 1973; Levy, Trevarthen and Sperry, 1972) and found that the alpha band (7-13 Hz) was the most sensitive. Based on their data, Galin and Ornstein (1972) postulate that more alpha is present in the inactive hemisphere. Hence a greater proportion of alpha in the right hemisphere would indicate that the left hemisphere was primarily involved in cognition and the right hemisphere was idling and vice versa. These results and procedures have been replicated by other researchers in other laboratories (Butler and Glass 1974; Dumas and Morgan, 1975; Dilling, 1975).

The results of these studies and those of the research measuring blood flow in the cerebral cortex (Risberg and Ingvar, 1973) strongly suggest EEG analysis of alpha brain wave activity as an indicator of asymmetric hemisphere functioning.

Following the procedure used by Galin and Ornstein, this study used the ratio of the alpha output of the left hemisphere to the output of the right hemisphere for the parietal regions of the cerebral cortex using the ratio of the average power over the entire task.

The magnitude of alpha present is thus used as an indicator of activity or inactivity in the hemispheres, therefore, the weaker the alpha power the greater the cognitive activity. The ratio of the alpha power from the left hemisphere to that of the right hemisphere, designated as alpha ratio (left/right) will be less than one if the left hemisphere is more cognitively active and greater than one of the right hemisphere is more active.

Electrode placement decisions:

Several different positions were considered for sites of recording on the scalp for this study. Galin and Ornstein have generally recorded from the temporal (T3/T4) and parietal (P3/P4) regions, each lead referenced to Cz using the 10-20 International system coordinates (Jasper, 1958) (see Appendix B).

Morrell and Salamy (1971) used Frontal, Rolandic and Temporo-parietal locations to record electrocortical responses to natural speech stimuli. They found a significantly greater response from the left hemisphere with the major component contributed from the temporo-parietal leads.

The temporal region seems to be potentially important because Broca's area and the Sylvian fissure (Gechwind, 1974) are located in this region. However, data from my pilot study indicated a high incidence of muscle artifacts (teeth grinding, jaw moving, etc.) for children.

At Stanford University, Morgan and associates have used the occipital region exclusively (Duman and Morgan, 1975). This area has the least potential for artifacts, but appears to show less functional asymmetry between hemispheres (Ornstein and Galin, 1976, p. 56).

Galin and Ornstein (op cit.) have indicated that the temporal (T3/T4) and parietal (P3/P4) yield very similar results. Therefore, P3/P4 were chosen as the sites of electrode placement for this study.

Research Procedures

Sample:

Nineteen right-handed children (9 boys and 10 girls) between the ages of 6 years 8 months and 9 years 2 months were selected from thirty volunteers in the study from two schools in the West Lafayette School District, West Lafayette, Indiana. The criterion of selection was to match sex and age levels in the sample. One girl was excluded from statistical analysis of the major hypotheses following screening for hand-eye dominance because she was the only girl with left eye dominance (this procedure will be discussed later), leaving 9 boys (ages 8 years 10 months to 7 years 3 months with a mean age of 97.22 months) and 9 girls (ages years 10 months to 6 years 8 months with a mean age of 97.11 months). The children were all Caucasian from middle- to upper-middle class backgrounds except one boy and girl who were the children of Purdue faculty members from India's upper caste.

Hand and eye dominance screening:

Hand dominance was determined by: 1) establishing a preliminary criteria of only accepting subjects who consistently eat, write and throw a ball with their right hand (verbal report from teacher, parent and child); 2) watching each subject pick up objects, manipulate objects and point at objects at close range (1-1/2 feet) and at a distance (6-10 feet).

Eye dominance was determined by having each subject sight through a cone at the investigator who sat 5 feet away. The subject was instructed to place the large end of the cone (a megaphone-like object) over both eyes and to look at the investigator. The subject was asked "Now are you looking at me with both eyes?" If the subject replied "yes," the investigator sighted through the small end of the cone at the subject's dominant sighting eye, which was the only eye visible. This procedure was repeated twice: once before presentation of the tasks and again following the second attention to breathing task, which was half way through the battery.

Experimental procedures:

The data collection took place in the Biomedical engineering EEG laboratory in the Electrical Engineering Building at Purdue University, between 4:00 and 5:30 p.m., during the period February 11 - 21, 1976. Two subjects were scheduled per day. Each was accompanied by at least one parent. The data collection procedure took approximately one hour per subject. Upon their arrival at the EEG laboratory, the experimental procedure was carefully outlined to both the parent and child and their written consent was obtained.

Electrodes were placed according to the ten-twenty system of the International Federation (Jasper, 1958) in order that two homologous channels of EEG data would be recorded, P3-P4, each referenced to Cz with a ground electrode on the forehead and the interelectrode impedence was verified to be below the accepted 10,000 ohms with an electrode impedance meter (Gras EZMID). The child was then escorted into the next room, seated in a low chair in a shielded, sound-dampened booth which reduced external visual and auditory stimuli and instructed to do relaxing exercises to reduce muscle tension. An informal game was played with the child while the EEG polygraph (Grass 79D) was calibrated and several seconds of EEG were recorded to insure a good signal was being produced. The EEG signal was simultaneously recorded on the polygraph paper and a 4-track FM' tape recorder (Hewlett-Packard 3960A) which also recorded the audio portion of the testing. At the beginning and end of each task or subtask a DC code was recorded to mark the beginning and end of each segment.

Each task was carefully described to the child before presenting it. Then, the task was displayed on a low table in front of the child in order to minimize head and eye movements.

Instruments:

Prior to presentation of the battery of tasks and halfway through the battery the child was given several relaxation exercises to help eliminate tight neck and facial muscles which tend to produce a higher incidence of artifacts. During this time period and periodically throughout the task presentation the investigator joked and talked with the child to help ease emotional tension.

The beginning and ending points of EEG segments were coded to tap certain kinds of thinking. Each segment included not more than 30 seconds of the child's thinking due to limitations of the computer capability. In several cases, an end-code was entered in less than 30 seconds to insure only the desired cognition was included in the segment.

The battery of tasks which were individually administered while the subjects EEG was recorded were the following: two attention to breathing tasks; two rotated forms tasks; three block design tasks; two silent reading tasks; one reading comprehension task; two mental arithmetic tasks; one syllogistic logic task; two Piagetian conservation tasks; two Piagetian temporal tasks which were presented to the subject twice with alteration in the presentation mode.

(See Table 1.) These tasks included parallel forms of Silent reading, mental arithmetic, rotated forms and block design to assess the reliability of the battery.

(1) Breathing tasks:

Two attention to breathing tasks were employed to record the child's EEG when no "thinking" was taking place (when the hemispheres are at rest). The subject was instructed to relax, try not to think of anything and concentrate on his breathing. This task was administered twice, once before the testing started and once in the middle of the testing. The mean L/R alpha ratio of this task (but not greater than ± .15) for each subject was subtracted from the other task ratios as a precaution against individual differences in more alpha band activity normally being present in either hemisphere. In several cases, the attention to breathing L/R alpha ratios were extremely high indicating that this task was probably not measuring the hemispheres "at rest" but in some form of thinking. After consultation with an EEG expert, the limit of ± was decided as the acceptable maximum.

(2) Block design tasks:

The block design tasks were taken from the Wechsler Intelligence Scale for children, 1949 (see Appendix A). Block designs 1 and 3 were presented to the child by showing him the design which he was to copy and having him copy it from memory; Block design 2 was presented to the child as described in the WISC manual by leaving the design in front of the child while he copied it.

The EEG segment recorded for these tasks began as the child started to solve the problem and ended when he finished it.

(3) Rotated forms tasks:

The rotated forms tasks were developed by Professor Ernest McDaniel, Educational Psychology and Measurements, Purdue University. (See Appendix A.) The child was shown a cutout of the form which would be either rotated in space and/or "flopped over." He was asked to pick the forms which would point the same way as the form in the box if it were rotated to the same position and to consider all forms which were flopped as "foolers" whether they were rotated or not. He was instructed to solve the problem by rotating each form in his head and by not turning his head, the paper, point or saying anything until the investigator told him to, and by looking up when he was finished. The sheet containing the rotated forms was then placed in front of him. The EEG segment for this task was recorded while the child tried to rotate each form in his head and ended when the child looked up.

(4) Silent reading tasks:

The silent reading tasks (SRD1, SRD2) were taken respectively. For SRD1 the child was given a sheet which contained the reading task (see Appendix A) and told that later he would be asked some questions about what he read. He was asked to read silently and to put the paper down when he was finished. The EEG segment recorded for this task started when he started to read and ended when he finished.

Silent reading 2 (SRD2) was administered the same as SRD1, except the child was not told that he would be asked questions about what he read.

The reading comprehension tasks (RDG) were questions asked about the first reading task. The EEG segment recorded for this task started as the investigator started to ask questions and ended as the child finished answering.

1. Who was sad?
2. Why were they sad?
3. How were they planning to solve their problem?
4. What do you think happened?

(5) Mental arithmetic tasks:

The child was told that he would be given an addition problem on a card and should add it in his head. He was told to put the card down when he had the answer. The EEG segment for these tasks began as the child took the card and ended when he put the card down.

MA1 9 + 8 + 6 = 3 =

MA2 7 + 4 + 8 + 1 =

(6) Syllogistic logic task:

The syllogistic logic task (LV) was read to the child after the investigator explained that verbal problem would be read aloud and the child would be asked to solve it. The EEG segment recorded for this task started when the investigator started to read the logic problem and ended when the child started to answer "Why do you think so?"

If Peg's bike is fixed she will go for a ride.
If she goes for a ride, she will be happy.
Peg is happy.
Is her bike fixed?
Why do you think so?

(7) Piagetian conservation tasks:

The Piagetian conservation tasks were conservation of substance and area (see Appendix A). Conservation of substance was taken from Elkind (1961) adapted without modification from Piaget's original task (Piaget, 1961). The child was given two balls of clay and asked if both balls had the same amount of clay He was instructed to make both balls the same if he felt one ball had more clay than the other. After the child agreed that both balls had the same amount. The investigator took both balls and rolled one ball into a sausage.

The EEG segment of the initial subtask for conservation of substance (Clay I) was coded while the child observed the clay ball and the clay sausage ending just before the investigator asked the following questions:

"And now? Are they both the same? Or does one have more? Why do you think so?"

The EEG segment of the subsequent subtask for the conservation of substance (Clay) was recorded while the child listened to the questions being asked, thought about the answer, and ended when the child started to answer the question "Why do you think so?"

Conservation of area was adapted from Piaget (1960). The child was shown two rectangles. One rectangle (A) was cut diagonally to make two triangles. When placed together these two triangles made a rectangle the same size and shape as the second rectangle (B). The child was asked if the two rectangles had the same amount of space on the surface. To help explain the definition of space the child was told "If grass was growing on both rectangles would there be the same amount of room or space for each to grow?" The child had to agree that both rectangles had the same amount of space before the next part of the task could begin. (Two children felt that the grass on the cut rectangle (A) had less space to grow due to the crack and agreed to the equivalence of the rectangles only after the investigator explained that grass could grow on the crack).

The EEG segment of the initial subtask for the conservation of area (Area I) was recorded while observing rectangle A being converted into parallelogram A and for a few seconds following while the child observed rectangle B and Parallelogram A ending just before the investigator asked the following questions.

"And now? Do they both have the same amount of space? Or does one have more? Why do you think so?"

The EEG segment of the subsequent subtask for the conservation of area (Area Q) was not coded in and is not currently available for data analysis.

(8) Piagetian temporal tasks:

The Piagetian temporal tasks, Time-ordered Liquid Flow and Objects Moving Through Time and Distance, were adapted from Lovell and Slater (1960) and were similar to Piaget's original tasks (Piaget, 1946). Each task was presented to the child twice with variation in the presentation mode, once exactly as described by Lovell and Slater and once presented behind a perceptual screen.

The apparatus for Time-ordered Liquid Flow (Waterflow) consisted of a container of blue liquid which had an upside-down Y tube with a tap which turned the liquid on and off. When the tap was opened the liquid flowed simultaneously into a tall thin test tube (container A) and a wide, but shorter beaker (container B), of about twice the volume of the test tube. (See Appendix A.)

The child was told that the openings of the Y tube were the same on both sides so that the same amount of liquid would flow from both sides and would be turned on and off at the same time.

The tap was then opened and the blue liquid flowed into container A and container B.

The EEG segment of the initial subtask for waterflow (WFII) was recorded while the child watched the liquid flowing simultaneously into containers A and B and ended when the investigator asked:

"Did the liquid stop flowing into both containers at the same time?

"How long (How many seconds or minutes) did it take for the liquid to go from the bottom of this container (A) to here? (Investigator pointed to the liquid level)

"How long did it take for the liquid to go from the bottom of this container (B) to here? (Investigator pointed to the liquid level in the beaker.)

The EEG segment of the subsequent subtask for waterflow (WF1Q) was recorded as the child was being asked the following questions and while he was thinking about the answer and ended when the child started to answer the question "Why do you think so?"

"Is there the same amount of liquid in this container (A) as in this container (B)?"

"If I poured this liquid (A) into a container the same size as this one (B) would there be the same amount of liquid in both containers?"

"Why do you think so?"

The child was then told that the task would be repeated again behind a screen while he listened to the investigator telling him what was happening.

A perceptual screen was then placed in front of the child (see Appendix A) and the task was then repeated in the following manner:

The valve was turned on and the investigator stated:

"Now the liquid is flowing into both containers at the same time."

"Now the liquid is flowing into both containers at the same time."

"Now the tap is turned off and the liquid has stopped flowing into both containers at the same time."

The EEG segment of the initial subtask (Waterflow 2) was recorded while the child listened to the investigator state what was happening.

The screen was then taken down and the child was asked the following questions:

"Did the liquid stop flowing into both containers at the same time?"

"How long (how many seconds or minutes) did it take for the water to go from the bottom of this container (A) to here?" (Investigator pointed to the liquid level.) "How long did it take for the liquid to go from the bottom of this container (B) to here?" (Investigator pointed to the liquid level in the beaker.)

The EEG segment of the subsequent subtask for Waterflow 2 (WF3Q) was recorded as the child was being asked the following questions, and while he was thinking about the answer.

"Is there the same amount of liquid in this container (A) as in this container (B)?"

"If I poured this liquid (A) into a container the same size as this one (B) would there be the same amount of liquid in both containers?"

The apparatus for Objects-moving-through-time and distance (Dollrace) consisted of a platform 3 feet long with two dolls (one yellow and one blue) which moved along a track when a crank was turned. The dolls both start and stop at the same time, but the blue doll goes faster and for a longer distance (see Appendix A).

The child was told that the crank moved both dolls, so the dolls would start when the investigator started turning the crank and stop when the investigator stopped turning the crank. The child then watched as the investigator turned the crank and the dolls travelled down the track with the blue doll moving faster and going a longer distance than the yellow doll.

The EEG segment recorded for the initial subtask of Dollrace 1 (DR1I) began as the investigator started to turn the crank and ended just before the following questions were asked:

"Did the dolls start walking at the same time?"

"Did the dolls stop walking at the same time?"

"Have both dolls walked the same distance?"

The EEG segment recorded for the subsequent subtask of Dollrace 1 (DR1Q) started as the investigator asked the following questions, while the child was thinking about the answer and ended when the child started to answer the question "Why do you think so?"

"Has one doll been walking for a longer (or more) time than the other?"

"Which doll?"

"Why do you think so?"

The child was then told that the task would be repeated behind a screen while he listened to the investigator report what was happening. A perceptual screen was placed in front of the child. The investigator started to turn the crank and said while turning the crank:

"Now the dolls have started to walk down the track both at the same time."

"Now the dolls are walking down the track."

"Now the dolls have stopped walking down the track."

The EEG segment of the initial subtask for Dollrace 2 (DR2I) was recorded as the investigator told the child what was happening behind the screen and ended as the screen was being taken away.

The screen was removed and the investigator asked the following questions:

"Did the dolls start walking at the same time?"

"Did the dolls stop walking at the same time?"

"Which doll?"

"Why do you think so?"

The EEG segment recorded for the subsequent subtask of Dollrace 2 (DR2Q) was recorded as the investigator asked the following questions:

"Has one doll been walking for a longer (or more) time than the other?"

"Which doll?"

"Why do you think so?"

Analysis of the Data

Scoring of Instruments:

The spatial and logic/verbal tasks have been reported in the literature or in other unpublished research reports as significantly either right or left hemisphere tasks. They were included primarily to further test the validity of the hypothesis that Piagetian initial and subsequent subtasks would elicit predominately right or left hemisphere functioning. Therefore, the scorings of these tasks were not crucial to the major hypotheses of this study and the validity and reliability of scoring will not be discussed. The investigator did score these tasks, however, and performed some statistical treatment correlating L/R alpha ratio and score on the task across subjects and between subjects. The scoring of the various tasks are indicated below.

a) Rotated forms scoring:

The rotation tasks were scored by subtracting the number wrong from the number right. Rotated forms 1 had a maximum score possibility of 4 with a range from 0 - 4. Rotated forms 2 had a maximum score possibility of 3 with a range from 0 - 3.

b) Block design scoring:

The block design tasks were scored similarly to the procedure suggested in the WISC manual, which included time and error rate. A score of 3 indicates a correct answer within 30 seconds, 2 indicates a correct answer with 60 seconds, 1 indicates a correct answer in a longer period of time, 0 indicates an incorrect answer.

c) Reading comprehension scoring:

The reading comprehension task was scored by adding the number of correct answers. There was a maximum of 4 points, with a range of 0 - 4. The score on this task has little variance as the investigator deliberately included easy to read material to insure that the L/R alpha ratio of the silent reading task measured silent reading.

d) Mental arithmetic scoring:

The mental arithmetic tasks were scored by time and error rate with a maximum score possibility of 2 if the child answered correctly in less that 30 seconds and a minimum of 0 if the child answered incorrectly.

e) Syllogistic logic scoring:

The syllogistic logic was scored on a scale of 0 - 2. A score of 0 was assigned when the child stated that the bike was fixed. A score of 1 was assigned when the child stated that the bike was not fixed, but could not give an explanation of his reasoning. A score of 2 was assigned when the child stated that the bike probably was not fixed or that he did not say whether the bike was fixed and gave an adequate explanation for his statement.

Piagetian tasks scoring:

The Piagetian tasks were scored from 0 to 2 points for a total possible range of 0 to 12 points. A criterion similar to Elkind (1961) and Lovel and Slater (196) was used.

1) 0 point - child indicated that one object had more (matter, space or liquid) or traveled for a longer period of time after the transformation.
2) 1 point - the child indicated that both objects had the same amount (of matter, space or liquid) or traveled for the same period after the transformation.
3) 2 points - child answered the above correctly and gave an adequate explanation.

Examples of adequate explanations are:

1) Substance and area - "You did not add anything or take anything away, so they are the same";

"you just changed the shape, they still have the same."

2) Time-ordered liquid flow - "If the liquid started and stopped at the same time then the same amount flowed into each side, they have to be the same." "One is shorter and fatter and one is taller and thinner, but the same amount of liquid flowed into each so they have to be the same."
3) Objects moving through time/distance - "If they both started and stopped at the same time, they have walked for the same amount of time." "The blue one went faster so he went a longer distance, but they both went for the same amount of time."

Examples of inadequate explanations: "Because"; "I don't know"; "My mother taught me this trick" (no response, or shrug).

Classification of preoperational and Concrete operational thinkers:

The tasks used to classify subjects into Preoperational and Concrete Operational Thinkers were Conservation of Substance and Area As discussed in the previous chapter a number of studies have demonstrated the validity and reliability of the conservation tasks to measure preoperational and concrete operational thinkers.

The criteria used was basically the same as suggested by Elkind (1961). The child had to be able to answer e explanation portion of both tasks to be classified as ncrete Operational. All other children are classified preoperational. Therefore, transitional thinking was not considered. There are 9 preoperational thinkers and 10 concrete operational thinkers in this study.

Data analysis to obtain the Dependent variable:

The data analysis proceeded through a sequence of three separate steps: transforming the taped data into digitized data and storing it on disks which were suitable input media for the Fast Fourier Analysis program; screening the digitized data for artifacts to insure the data reflected cognition and not "noise"; analyzing the remaining digitized data by Fast Fourier Analysis to obtain the L/R alpha power ratio, which was the dependent variable used in later statistical analysis.

The taped data was fed into a PDP-11/40 DECLAB computer and the data between the predetermined code levels was identified, transformed into digitized data by analyzing each channel of data 256 times per second and quantizing each sample using 12 bits (4096 levels) and stored on RK05 disks (2 subjects per disk).

The data was then edited for artifacts. A computer program was utilized which screened out segments having saturation caused by large artifacts. In addition, each one second segment of the EEG channels was then displayed on a screen (VR14L) and was compared with the polygraph paper record. Each portion which appeared to still have artifacts was deleted.

The remaining data was analyzed by a computer program which performed a Fast Fourier Transform and power spectral calculation on each channel of data in each 1/2 second segment. The spectral power values were then averaged together in five groups (1-3 H_z, 4-6 H_z, 7-12 H_z, 13-19 H_z, 20-20 H_z) corresponding to the normal bands of brain waves adjusted for the age level of the group.

The adjustment was based on a vast body of literature reporting a developmental sequence in the alpha frequency band (summarized in Lairy, 1975). This literature suggests a mean alpha frequency of 9.3 ± 0.8 c/sec. (range 7-12 c/sec.) for children 6-8 years of age. This adjusted range, the alpha band, was the band for further analysis as previously discussed.

Both time plots of the changes in lateralized alpha and an overall average of the lateralized alpha for each task or sub-task was obtained.

Validity of the data was obtained by the use of a real time data processing system designed by Professor Owen Robert Mitchell, Biomedical Engineering, Purdue University. This electronic hardware gives an instantaneous indication of alpha lateralization. A block design of the circuit is shown in Appendix B. The taped data will be fed into this system giving a real time estimate of the alpha lateralization, which was used to detect possible errors in the computer analysis of lateralized alpha.

Statistical analysis:

The main analysis concerned (1) differences in hemispheric functioning (a) within Piagetian tasks and (b) between Piagetian tasks when the presentation mode was altered and (2) the differences in performance scores on a Piagetian task when the presentation mode was altered.

A three by two analysis of variance for repeated measures followed by Fisher's correlated sample t-test was used to assess the differences between hemispheric functioning during the initial observation of task phenomena and the subsequent hemispheric functioning when the subject was asked to logically explain the task.

Stated in the null, the first major hypothesis that was tested (p .05) is:

> H_1: There is no significant difference in log L/R alpha ratios between the initial and subsequent responses during performance of Piagetian tasks of 6-8 year old children.

Two by two multivariate analysis of variance for repeated measures followed by Fisher's correlated sample - test was used to assess the differences between hemispheric functioning during the initial and subsequent subperiods of the visuo-spatial and audio-verbal presentation of tasks.

Stated in the null, the next major hypotheses that were tested (p .05) are:

H_2: There are no significant differences in log L/R alpha ratios between the visuo-spatial initial response and the audio-verbal initial response during performance of Piagetian temporal tasks of 6-8 year old children.

H_3: There are no significant differences in log L/R alpha ratios between the visuo-spatial subsequent response and the audio-verbal subsequent response during performance of Piagetian temporal tasks of 6-8 year old children.

H_4: There are no significant differences in performance scores between visuo-spatial and audio-verbal presentation of temporal tasks of 6-8 year old children.

If the initial observation of a Piagetian task tends to activate right hemisphere functioning and subsequent logical thinking about a Piagetian task tends to activate left hemispheric functioning as the investigator hypothesized, then initial responses will be positively correlated with each other and with tasks which have been reported in the literature as right hemisphere tasks and subsequent responses will be positively correlated with each other and with tasks which have been reported in the literature as left hemisphere tasks.

The Pearson product moment statistic was employed to assess the correlation of hemispheric functioning with 1) all initial responses on Piagetian tasks; 2) initial responses on Piagetian tasks and spatial tasks; 3) all subsequent responses on Piagetian tasks and 4) subsequent responses and verbal/logical tasks.

Stated in the null form, the following hypotheses were tested (p .05):

H_5: There is no significant positive correlation of log L/R alpha power ratios between
  a. initial responses on Piagetian tasks
  b. initial responses on Piagetian tasks and spatial tasks

H_6: There is no significant positive correlation of log L/R alpha power ratios between
  a. subsequent responses on Piagetian tasks
  b. subsequent responses on Piagetian tasks and verbal/logical tasks.

The literature suggests several independent variables, (e.g. sex and Piagetian Stage) which might be related to patterns of hemispheric functioning. Discriminant analysis and t-tests were used to assess group differences (sex and Piagetian state) on hemispheric functioning during performance of Piagetian tasks.

Stated in the null form, the following hypotheses were tested (p .05):

H_7: There is no significant differences on log L/R alpha power ratios between preoperational and concrete operational children during performance of Piagetian tasks.

H_8: There is not significant differences on log L/R alpha power ratios between girls and boys during performance of Piagetian tasks.

The Pearson product moment statistic was used to determine if the two forms of each task were significantly positively correlated.

Stated in the null form, the following hypothesis was tested (p .05):

H_9: There is no significant positive correlation between parallel forms of repeated tasks.

CHAPTER IV

ANALYSIS AND INTERPRETATION OF THE DATA

The findings of the study are analyzed, interpreted and discussed in this chapter. Nine hypotheses of this study are evaluated first and then attention is given to related questions.

Evaluation of Hypotheses

The first four hypotheses were concerned with differences in hemispheric functioning 1) within Piagetian tasks during subjects' responses; 2) between Piagetian tasks when the presentation mode of the tasks was altered and also differences in subjects' performance scores on Piagetian tasks when the presentation mode was altered.

Restated in the null form (for appropriateness in statistical analysis) the first hypothesis tested was

There are no statistically significant differences in log L/R alpha power ratios (subtracted from baseline) between the initial and subsequent responses of six to eight year old children during performance of Piagetian tasks.

The design and raw scores and the results of a three by two analysis of variance for repeated measures in log L/R alpha power ratios of the following Piagetian tasks;

Conservation of substance (Clay), Time-ordered Liquid Flow (WF/VS) and Objects moving through time/space (DR/VS) are reported in Tables 3 and 4 respectively.

Post hoc analysis of the significant effects is reported next, followed by Fisher correlated t-tests for each of the tasks.

Statistical analysis of Conservation of Area could not be performed because the data for the subsequent response of this task is not available due to coding difficulties during the data collection.

As indicated in Table 4, there are significant differences in the log L/R alpha power ratios between Piagetian tasks (F = 7.3308; df = 2/34; p .005), between the initial and subsequent responses within Piagetian tasks (F = 5.9096; df = 1/17; p .05) and a significant interaction effect (F = 4.173, df = 2/34; p .05) between Piagetian tasks and responses within those tasks. Therefore the null hypothesis (H_1) was rejected. There are statistical differences between the initial and subsequent responses of six to eight year old children during performance of Piagetian tasks.

In order to determine the nature of the differences, Newman Keuls procedure was applied at the .05 alpha risk level to assess differences in the interactive cell means. The observed differences between the 6 mean comparisons of interest are presented in Table 5.

The Newman Keul test of the differences between the interactive means found that the initial response of Time-

Ordered Liquid Flow ($\overline{x}$ = .1899) was significantly higher than the subsequent response of Conservation of Substance ($\overline{x}$ = -.0278; NK = 4.75; df = 4/34; p .01), the mean of the subsequent response of Objects Moving Through Time/Space ($\overline{x}$ = .0033; NK = 4.41; df = 3/34; p .01), and the initial response of Objects Moving Through Time/Space ($\overline{x}$ = -.0733; NK = 5.18; df = 6/34; p .01). The mean of the initial response of Conservation of Substance ($\overline{x}$ = .0922) was significantly higher than the mean of the subsequent response of Objects Moving Through Time/Space (NK = 4.07, df = 5/34; p .05) and the initial response of Objects Moving Through Time and Space (NK = 4.07; df = 5/34; p .05) and indicated a statistical trend when compared with the mean of the subsequent response of Conservation of Substance (NK = 2.88; df = 3/34; p .1).

To further assess the differences between the log L/R alpha power ratios on the initial and subsequent responses for each task, four correlated t-tests were administered. The results of these tests are found in Table 6 and reveal that the mean of the initial response of Conservation of Substance is significantly higher (t = 2.25; df = 17; p = .038) than the mean of the subsequent response of Conservation of Substance and the mean of the initial response of Time-Ordered Liquid Flow is significantly higher (t=2.91; df = 17; p = .01) than the mean of the subsequent response of Time-Ordered Liquid Flow, but there were no significant differences (t = -.49; df = 17; p =.633) between the initial and subsequent responses of Objects Moving Through Time/Space.

When these statistical analyses are juxtaposed (see Tables 4 and 5), the findings indicate that there are statistically significant differences (F = 5.9096; df = 1/17; p = .026) between the overall means of 6-8 year old childrens' initial response ($\bar{x}$ = .0709) and subsequent response ($\bar{x}$ = -.0235) during performance of Piagetian tasks. This pattern was reflected in the differences between the interactive means of two of the Piagetian tasks; Time-Ordered Liquid Flow (NK = 4.41; df = 3/34; p .01 and t = 2.91; df = 17; p = .01) and Conservation of Substance (NK = 3.88; df = 3/34; p = .1 and t = 2.25; df = 17; p = .05) which indicates that children did have greater right hemispheric functioning during the initial observation of the transition (phenomena) taking place than when subsequently asked to think logically about this transition during performance of Conservation of Substance and Time-Ordered Liquid Flow.

However, this shift from right to left was not found during the performance of Objects Moving Through Time/Space, which was reflected in the significant differences (F = 7.3308; df = 2/34; p = .0005) found between Piagetian tasks. Furthermore, the initial response of this task was significantly different from the initial responses of Time-Ordered Liquid Flow (NK = 5.18, df = 6/34; p = .01) and Conservation of Substance (NK = 4.07; df = 5/34; p = .05), although there were no significant statistical differences between the subsequent responses on these three tasks.

Furthermore, the shift pattern within performance of Objects moving through time/space is different from the other two Piagetian tasks. The mean of the subsequent response for this task ($\bar{x} = -.0461$) is slightly higher than the mean of the initial response ($\bar{x} = -.0733$) indicating that there was more left hemispheric activity during the initial observation of the transition than when asked to think logically about the transition.

Graphs 1 - 3 show the shift between the initial and subsequent responses of the raw scores (subtracted from base-line) and interactive cell means for each task.

As discussed in Chapter I, the investigator strongly suspects the log L/R alpha power ratios of the initial response during children's performance of Objects Moving Through Time/Space is contaminated due to vocal and subvocal applauding of one of the objects (dolls) which moved along the track.

Further discussion of this hypothesis is found in the related questions section of this chapter following statistical analysis of sex and hand-eye dominance differences between groups of subjects.

For ease and appropriateness of statistical evaluation, hypotheses two, three and four may be combined in the null form as follows:

There are no statistically significant differences during performance of six to eight year old children on Piagetian temperal tasks between;

1) (H_2) log L/R alpha power ratios of visuo-spatial and audio-verbal initial responses
2) (H_3) log L/R alpha power ratios of visuo-spatial and audio-verbal subsequent responses
3) (H_4) visuo-spatial and audio-verbal performance scores

To appropriately evaluate the proposed relationship the following sequence of statistical analyses were performed. First, using log L/R alpha power ratios of the initial and subsequent responses and the performance scores of each task as dependent variables, a one-way multivariate analysis of variance for repeated measures (MANOVA) was employed to assess the overall differences and significance level of the two Piagetian temporal tasks with alteration in the presentation mode: Visuo-spatial presentation of Time-ordered Liquid Flow (WF/VS); Audio-verbal presentation of Time-ordered Liquid Flow (WF/AV); Visuo-spatial presentation of Objects moving through Time/space (DR/VS) and Audio-verbal presentation of Objects Moving through Time/space (DR/AV).

To search for sources of the statistically significant differences found, a sequence of four statistical procedures were undertaken for each of the two Piagetian task First, a one-way multivariate analysis of variance for repeated measures was performed which computed the over-all significances level for the hypothesis and the relationship of the log L/R alpha power ratios of the initial and subsequent responses to the performance score between the visuo-spatial and audio-verbal presentations. Based upon statistically significant findings, a univariate one-way analysis of variance was computed for the performance score differences between the visuo-spatial and audio-verbal presentation of the task and a two by two analysis of variance was used to evaluate interaction differences in log L/R alpha power ratios between the initial and subsequent responses of the visuo-spatial and audio-verbal presentation of the task. Finally, when appropriate, a post hoc test was employed.

The design and raw scores (subtracted from baseline) for the one-way multivariate analysis of variance for repeated measures of the initial and subsequent responses, measured by the log L/R alpha power ratios, and the performance scores of the subjects during performance of two Piagetian temporal tasks: Time-Ordered Liquid Flow and Objects Moving Through Time/Space, which were each presented visuo-spatially and audio-verbally are found in Table 7.

The summary table of this statistical analysis is reported in Table 8. The multivariate statistical program (Clyde Manova) also computed univariate one-way analyses for each of these variables, which is also reported in Table 8.

The results of the multivariate statistical test using Wilks' lambda criterion indicate significant centroid differences (F = 3.340; df = 9/199.404; $p > .001$) between the visuo-spatial and audio-verbal presentations of Time-Ordered Liquid Flow and Objects Moving Through Time/Space.

The standardized discriminant function coefficients and the univariate one-way analysis of variance for each of the variables both indicate that the differences between the log L/R alpha power ratios of the initial response (SDFC 1 = .965; F = 7.627; df = 3/51; p = .001) and the differences between the audio-verbal and visuo-spatial presentations of the two Piagetian temporal tasks, but do not indicate specifically where the differences are or the direction of the differences.

To further evaluate the centroid differences between visuo-spatial and audio-verbal presentation modes, one-way multivariate analysis of variance for repeated measures were computed for each of the Piagetian temporal tasks. The design for the multivariate analysis of Time-ordered liquid flow is found in Table 9 and the summary table in Table 10.

Although the multivariate F did not reach the previously stated acceptable significance level (F = 2.891; df = 3/15; p = .07), the univariate F assessing differences between the means of the initial responses during the visuo-spatial and audio-verbal presentations were significant (F = 8.130; df = 1/17; p .01) and the standardized discriminant function coefficient revealed an inverse relationship of the log L/R alpha power ratio of the initial responses (SDFC = .846) and the performance scores (SDFC = -.425) between the two presentation modes.

The univariate one-way analysis of variance for repeated measures of the mean differences between performance scores on the visuo-spatial ($\bar{x}$ = .7778) and audio-verbal ($\bar{x}$ = 1.2222) presentation of Time-Ordered Liquid Flow was not significant (F = 2.956; df = 1/17; p = .104), but was in the expected direction.

To determine if there were interaction effects between response mode and presentation mode a two by two analysis of variance assessing differences in the initial and subsequent responses between visuo-spatial and audio-verbal Time-Ordered Liquid Flow was compute. The design and summary table for this test are found in Tables 11 and 12, respectively.

As the summary table indicates, there are no statistically significant main effects for tasks or responses, but there is a significant interaction effect (F = 5.62; df = 1/17; p .05) between presentation mode and responses.

The nature of this interactive difference in cell means was explored using the Newman-Keuls procedure at the .05 alpha risk level. The observed differences between the four mean comparisons are found in Table 13.

The results of the Newman Keul statistic revealed that the mean of the initial response, measured by log L/R alpha power ratios, during the visuo-spatial presentation of Time-ordered Liquid Flow is significantly higher (NK = 2.985, 4.025; df = 2/17, 4/17; p .05) than both of the subsequent responses and also significantly higher (NK = 3.63; df = 3/17; p .05) than the initial response during the audio-verbal presentation of the same task.

However, there is no significant difference between the log L/R alpha power ratios of the initial ($\bar{x}$ = .0044) and subsequent ($\bar{x}$ = .0250) responses during the audio-verbal presentation of the task. This relationship of the mean differences and raw scores are illustrated in Graph 4. The log L/R alpha power ratios of the visuo-spatial subsequent response ($\bar{x}$ = .0033) and the audio verbal subsequent response ($\bar{x}$ = .0250) are also statistically similar, which is the direction stated in experimental hypothesis 3. This relationship is illustrated in Graph 5.

These findings indicate that for the Piagetian temporal task, Time-Ordered Liquid Flow, there was a significant shift (NK = 3.63; df = 3/17; p .05) from right hemispheric functioning, measured by the log L/R alpha power ratios, during the visuo-spatial initial response ($\bar{x}$ = .1889) when the task was presented so that the subject could visually observe the transition taking place toward a left hemispheric functioning, measured by the log L/R alpha power ratios, during the audio-verbal initial response ($\bar{x}$ = .0044) when the task was presented behind a perceptual screen and the time order of transition was verbally described to the subjects. This shift in both the raw scores and the means is illustrated in Graph 6.

The raw scores, which depict the shift for each individual subject between the visuo-spatial initial response and the audio-verbal initial response, indicate that all but five subjects exhibit the positive (right-hemisphere functioning) to negative (greater left hemisphere functioning) shift.

As Graphs 1 and 2 illustrate, two of these five subjects (17 & 18) consistantly exhibit a different shift pattern and one subject (10) often has a different shift pattern from the other 15 subjects. Further discussion and interpretation of these interesting individual patterns is found in the related questions section of this chapter, following analysis of the shift pattern between silent reading and the reading comprehension question.

However, as Graph 5 illustrates, there is no consistant pattern between the visuo-spatial subsequent responses and the audio-verbal subsequent responses, nor are there any consistant patterns during the initial and subsequent responses of Objects moving through time and space/visuo-spatial (see Graph 3) and Time-Ordered Liquid Flow/Audio-Verbal (see Graph 4). Further discussion and interpretation of these relationships will be found in the related questions section of this chapter.

The multivatiate inverse relationship (SDFC = .846; -.425) between the significant (F = 8.130; df = 1/17; p .01) negative shift in the initial responses (indicating greater left hemispheric functioning) and the positive shift (F = 2.956; df = 1/17; p = .10) in performance scores (indicating that more children could now logically explain the transition) between the visuo-spatial and audio-verbal presentation of the task approached but did not reach significance (F = 2.891; df - 3/15; p = .07). Moreover, it is in the expected direction as stated in the experimental form of hypotheses 2 and 4.

To continue the evaluation of centroid differences between visuo-spatial and audio-verbal presentation modes, a one-way multivariate analysis of variance for repeated measures was computed for the Piagetian temporal task, Objects Moving through Time and Space with three dependent variables; subjects' log L/R alpha power ratios of the initial and subsequent response during performance of the task and their performance score on task. The design and raw scores (subtracted from baseline) is found in Table 14 and the summary table is presented in Table 15.

The results using Wilks lambda criterion indicate that there is a significant (F = 6.905; df = 3/15; p = .004) multivariate difference between the centroids of Objects Moving Through Time and Space presented visuo-spatially and Objects Moving Through Time and Space presented audio-verbally. The three one-way univariate analysis of variance for repeated measures assessing differences in each of the variables between the two presentations of the task also reveal significant differences.

The mean of the performance score ($\bar{x}$ = .89) during the audio-verbal presentation was significantly higher (F = 4.857; df = 1/17; p = .04) than the mean of the performance score ($\bar{x}$ = .44) during the visuo-spatial presentation.

The mean of the initial responses ($\bar{x}$ = .0827) during the audio-verbal presentation was significantly higher (F= 9.575; df = 1/17; p = .007) than the mean of the initial response ($\bar{x}$ = 1.0733) during the visuo-spatial presentation. These differences are shown in Graph 7.

Results of the univariate one-way analysis of variance did not reveal significant differences (F = .839; df = 1/17; p = .37) between the mean of the subsequent responses ($\overline{x}$ = .01) during the audio-verbal presentation and the mean of the subsequent responses ($\overline{x}$ = -.0461) during the visuo-spatial presentation. These differences are shown in Graph 8.

To further evaluate the observed centroid differences, a two by two analysis of variance for repeated measures was computed to assess possible interaction of the initial and subsequent responses as measured by subjects log L/R alpha power ratios between visuo-spatial and audio-verbal presentation modes.

The design and raw scores of the two by two analysis of variance is found in Table 16 and the summary table of the computation is reported in Table 17.

The results of the two by two analysis of variance show that the significant (F = 12.5572; df = 1/17, p = .0025) differences found are in the over-all means between the visuo-spatial presentation of the task and the audio-verbal presentation of the task.

Since there were no significant interactive cell means, interpretation of these data is more meaningful when the multivariate and univariate one-way analyses of variance are discussed first. These findings reveal significant (F = 6.905; df = 3/15; p = .004) multivariate differences between the centroids which was interpreted by the univariate follow-up to the initial responses and performance scores. Thus there were significant differences ($F = 9.575$; df = 1/17; $p = .007$) between the initial responses of the visuo-spatial and audio-verbal presentations of Objects Moving Through Time and Space, which is interpreted to mean that children had a greater left hemispheric functioning during the initial response ($\bar{x} = -.0733$) when observing the transition taking place than when the transition was presented behind a verbal screen accompanied by the investigator's verbal description of the event ($\bar{X} = .0827$).

The results of the two by two analysis of variance indicate significant ($F = 12.5572$; df = 1/17; $p = .0025$) overall task differences between the visuo-spatial presentation of the task ($\bar{x} = -.0597$) and the audio-verbal presentation of the task ($\bar{x} = .0464$). This indicates that, by summing over the initial and subsequent responses, the visuo-spatial presentation had greater left hemispheric functioning than the audio-verbal presentation. Since there were no significant differences found between the subsequent responses of the two presentation modes ($F = .832$; df = 1/17; $p = .373$), the highly significant ($F = 9.575$; df = 1/17; p .007) differences found between the initial responses of the two presentation modes account for most of the differences found.

As previously discussed in the limitations section of Chapter I and in the previous discussion of hypothesis 1 of this chapter, the investigator strongly suspects that the initial response during the visuo-spatial presentation of Objects Moving Through Time and Space was contaminated because many of the subjects either vocalized (or reported sub-vocalizing) while "rooting" for the doll of their choice. The initial response of the audio-verbal presentation of Objects Moving Through Time and Space was also possibly contaminated when the subjects were instructed to listen as the transition was described to them from behind a screen as there was a constant rhythmic clicking in the experimental apparatus, which may have elicited right hemispheric functioning during the periods when the investigator was not describing the event.

When the results are summed together, they indicate that there are significant ($F = 3.340$; $df = 9/119.404$; $p = .001$) multivariate centroid differences between the visuo-spatial and audio-verbal presentations of the two Piagetian temporal tasks: Time-Ordered Liquid Flow and Objects Moving Through Time/Space. The dependent variables which account for the most of this multivariate centroid differences are the log L/R alpha power ratios of the initial responses (SDFC 1 = .965) and the performance scores (SDFC 2 = -.959). See Table 8.

The mean of the initial responses measured by the log L/R alpha power ratios between the two presentation modes was significant ($F = 7.627$; $df = 3/51$; $p = .001$) and had a significant ($F = 3.130$; $df = 1/17$; $p = .011$) shift from positive ($\bar{x} = .1889$) during the visuo-spatial presentation toward negative ($\bar{x} = .0044$) during the Time-Ordered Liquid Flow tasks (see Table 10), but had a significant ($F = 9.575$; $df = 1/17$; $p = .007$) shift from negative ($\bar{x} = -.0733$) during the visuo-spatial presentation toward positive ($\bar{x} = .0827$) during the audio-verbal presentation of Objects Moving Through Time/Space (see Table 15).

Therefore, the null hypothesis (H_2) that there are no significant differences during performance of six to eight year old children on Piagetian temporal tasks between the log L/R alpha power ratios of the visuo-spatial and audio-verbal initial responses was rejected. However, the experimental form of H_2 as stated in Chapter I predicts a shift from positive (right hemispheric functioning) during the visuo-spatial presentation to negative (left hemispheric functioning) during the audio-verbal presentation. The statistical results for Time-Ordered Liquid Flow tasks did match the predicted direction, but the results for the Objects Moving Through Time/Space did not. Therefore, the experimental form of H_2 was rejected for the Objects Moving Through Time/Space.

The subsequent response variable did not have significant mean differences (F = .487; df = 3/51; p = .288) and did not account for much of the multivariate variance (SDFC = .288, -.259). Therefore, the null hypothesis (H_3) that there would be no statistically significant differences during performance of six to eight year old children on Piagetian temporal tasks between the log L/R alpha power ratios of visuo-spatial and audio-verbal subsequent responses was not rejected. Because the null form relationship was the predicted direction stated in the hypothesis in Chapter I, the experimental hypothesis (H_3) was not rejected.

The mean of the performance score variable was larger during the audio-verbal presentation than the visuo-spatial presentation for both tasks. This may indicate that visual screening accompanied by verbal description facilitates logical thinking about the event. Since the pattern of initial responses between the two modes are very different for each of the tasks, it is impossible to state what kind of thinking was taking place during the initial response period, and since the sequential responses over all Piagetian tasks are not significantly different, it is impossible to state what differences in hemispheric functioning accounted for the shift toward logical thinking during the sequential period. Moreover, since the audio-verbal presentation always followed the visuo-spatial presentation, there may be other factors such as tasks learning which account for the increased logical ability.

The overall differences between the subjects' performance scores on the visuo-spatial presentation of Piagetian temporal tasks and subjects' performance on the audio-verbal presentation of Piagetian temporal tasks did not reach the previously stated acceptable significance level (p .05), but did approach significance (F = 2.445; df = 3/51; p = .065). The mean of subjects' performance scores on Time-Ordered Liquid Flow/Audio Verbal ($\overline{x}$ = .778) was larger than the mean of subjects performance score ($\overline{x}$ = 1.122) on Time-Ordered Liquid Flow/visuo-spatial. This difference approached significance (F = 2.956; df = 1/17; p = .104). The same pattern was observed on the Objects Moving Through Time/Space task. The mean of the subjects performance score on Objects Moving Through Time/Space presented audio-verbally ($\overline{x}$ = .89) was significantly larger (F = 4.857; df = 1/17; p = .042) than the mean of the subjects' performance score of Objects Moving Through Time/Space presented visuo-spatially ($\bar{x} = .44$).

Therefore, the null hypothesis (H_4) that there are no statistically significant differences during performance of six to eight year old children on Piagetian temporal tasks between visuo-spatial and audio-verbal performance scores was not rejected. However, the overall findings did approach significance ($F = 2.556$; $df = 3/51$; $p = .065$) and were in the direction predicted by the experimental form of the hypothesis (H_4) as stated in Chapter I.

The next two hypotheses are also combined for appropriate statistical analysis. Stated in the null form:

There is no statistically significant intercorrelations between the log L/R alpha power ratios of:

(H_5) 1) initial responses during subjects performance of Piagetian tasks

(H_6) 2) subsequent responses during subjects' performance of Piagetian tasks

There is no statistically significant correlations between the log L/R alpha power ratios of:

(H_5) 3) initial responses during subjects' performance of Piagetian tasks and subjects' performance of spatial tasks

(H_6) 4) subsequent responses during subjects' performance of Piagetian tasks and subjects' performance of verbal/logical/mathematical tasks.

The Pearson product moment statistic was computed to determine the intercorrelations and their significance level of initial and subsequent responses on Piagetian tasks. The same statistic was also computed to determine the correlation and its significance level between the initial and subsequent responses of Piagetian tasks and spatial, verbal, logical and mathematical tasks.

The correlation matrix of the intercorrelations between responses, measured by the log L/R alpha power ratios, during performance of Piagetian tasks (Table 18) reveals that there is a cluster of nine intercorrelations between initial responses to Piagetian tasks that approach or reach statistical significance (p .05). Moreover, all of these intercorrelations are moderate to moderately high positive values. This indicates that in nine of the fifteen possible intercorrelations comparisons between subjects' initial responses there was a moderate or high positive relationship. Of the remaining six correlations, none show even a moderate negative relationship. Thus it was concluded that subjects in this study were generally engaging their brain hemispheres in a consistent manner to their initial encounters with the transition phenomena of Piagetian tasks.

Examination of the intercorrelations (Table 18) of subjects' subsequent responses to Piagetian tasks reveals that there is a cluster of five of the ten possible intercorrelations in which the correlations are of such magnitude as to achieve or approach statistical significance. Again, all of these are moderate to high positive values. None of the subsequent responses of the remaining five possible correlations approached even a moderate negative relationship. Therefore, it was concluded that in subjects' subsequent encounters with the battery of Piagetian tasks in this study, there was a clearly defined and consistent pattern of hemispheric brain functioning.

Finally, examination of the cells for the intercorrelations between subjects initial and subsequent responses to Piagetian tasks reveals only three correlations (out of the thirty possible) approach statistical significance and one is a negative value. In addition, there are ten other negative correlations. This indicates that while initial responses correlate well together and subsequent responses correlate well together, the comparisons between initial and subsequent responses do not correlate highly.

Therefore part 1 and 2 of the null hypothesis that there is 1) (H_5) no statistically significant intercorrelations between the log L/R alpha power ratios of the initial responses during subjects performance of Piagetian tasks and 2) (H_6) no statistically significant intercorrelations between the log L/R alpha power ratios of the subsequent responses was rejected.

However, the correlation matrix of the log L/R alpha power ratios during Piagetian tasks and the log L/R alpha power ratios during spatial, verbal, logical and mathematical tasks (Table 19) indicates there was not a cluster of significant positive correlations between initial responses and spatial tasks, instead generally, low negative and positive or near zero correlations were observed.

Of the thirty possible correlations, only six approach or reach statistical significance ($p > .05$). Three of the five positive significant (or nearly significant) relationships involve Objects Moving Through Time and Space/Visuo-Spatial. The sixth is a negative value. There are sixteen other nonsignificant negative correlations, and eight nonsignificant low positive correlations, many of these are approaching a zero value.

Further examination of the correlation matrix, (Table 19) for the log L/R alpha power ratio relationships between the initial responses during performance of verbal, logical and mathematical tasks revealed that out of the thirty-six cells, there were seven moderate or moderately high positive correlations which approached or reached statistical significance (p .05). Six of these seven correlations involved silent reading. Except for one moderate negative correlation which approached significance, the rest were low positive or negative values, including eight which were close to a zero relationship.

Clearly, the subjects' patterns of hemispheric functioning during the initial response of the transition of phenomena is not related to their brain wave patterns during performance of spatial tasks. Furthermore, except for the silent reading tasks, the hemispheric functioning patterns measured while the subjects were initially responding to Piagetian task phenomena are not related to their hemispheric patterns measured during verbal, logical and mathematical tasks. Therefore, part 3 of the null hypothesis (H_5) that the log L/R alpha power ratios of subjects' initial responses during Piagetian tasks are not significantly correlated with the log L/R alpha power ratios measured during performance of spatial tasks was not rejected.

As the correlation matrix (Table 19) illustrates there are significant correlations between subsequent responses and verbal, logical and mathematical tasks. Fourteen of the thirty possible correlations approach or reach significance ($p > .05$) and these are all moderate or high positive values. The four observed negative correlations all approach a zero relationship. The rest are positive values.

The remaining twenty-five cells in the correlation matrix of Table 19 involve relationships of the log L/R alpha power ratios between the subsequent responses during performance of Piagetian tasks and performance of spatial tasks. Evaluation of these cells reveal that there are ten moderately high positive correlations that approach or reach statistical significance ($p > .05$). There are five nonsignificant negative correlations and four of these had low values. The rest were moderate or low positive nonsignificant correlations.

Overall, the subjects' hemispheric patterns measured during the sequential response to observed phenomena of Piagetian tasks, do tend to have positive moderate or moderately high correlations with verbal, logical and mathematical tasks which are significant or approach significance ($p > .05$).

Therefore, part 4 of the null hypothesis (H_6) that there is no statistically significant correlations of the log L/R alpha power ratios between subsequent responses during subjects' performance of Piagetian tasks and subjects' performance of verbal/logical/mathematical tasks was rejected.

Hypotheses seven and eight evaluate possible group differences in patterns of asymmetrical hemispheric functioning between subjects who were classified as Preoperational and Concrete Operational on the basis of their scores on the Piagetian Conservation tasks and between males and females in the study. Stated in the null form, the hypotheses are:

(H_7) There is no significant differences in log L/R alpha power ratios between preoperational and concrete operational subjects during performance of Piagetian tasks.

(H_8) There is no significant differences in log L/R alpha power ratios between girls and boys during performance of Piagetian tasks.

Both of these hypothesis were evaluated first by a dichotomous discriminant function analysis to determine if there were statistically significant patterns in the battery of log L/R alpha power ratios measured during performance of Piagetian tasks, which would discriminate between the groups.

The differences between concrete operational and preoperational subjects (H_7) is evaluated and interpreted first.

Then attention is given to the differences between boys and girls (H_8).

The raw scores for concrete operational pre-operational subjects are found in Table 20. The summary table for the discriminant analysis assessing statistically significant patterns of log L/R alpha power ratios measured during performance of Piagetian tasks between the two groups is reported in Table 21.

The results of the discriminant analysis indicate that there is not a statistically significant ($x^2 = 2.333$; df = 11; p = .997) discriminant function of the log L/R alpha power ratios measured during performance of Piagetian tasks, which can predict concrete operational and pre-operational membership.

The patterns of hemispheric functioning between the concrete operational subjects, who successfully performed on Piagetian conservation tasks and preoperational subjects, who did not, are statistically equivalent. Therefore, the null hypothesis (H_7) that there is no significant differences in log L/R alpha power ratios between Preoperational and Concrete Operational children during performance of Piagetian tasks was not rejected.

Further discussion and interpretation of this hypothesis is found in the related questions section of this chapter, following analysis of high and low performers for each task.

The raw scores for male and female subjects are found in Table 22. The summary table for the discriminant analysis assessing statistically significant patterns between these two groups is reported in Table 23.

The results of the discriminant analysis indicate that there is not a statistically significant ($x^2 = 11.209$; df = 11; $p = .429$) discriminant function of the log L/R alpha power ratios measured during performance of Piagetian tasks, which can predict males from females.

The brainwave patterns of both genders while performing Piagetian tasks are statistically similar. Therefore, the null hypothesis (H_8) that there is no significant differences in log L/R alpha power ratios during performance of Piagetian tasks between boys and girls was not rejected.

The final hypothesis concerns parallel forms of four tasks; silent reading, mental artithmetic, block design and rotated forms, which were included to assess the reliability of the battery. Stated in the null form this hypothesis is:

(H_9) There is no significant positive correlation between parallel forms of repeated tasks.

To evaluate this hypothesis the Pearson product moment statistic was computed between each of the repeated tasks. The summary table of the results of this statistic is reported in Table 24. As Table 24 indicates, parallel forms of silent reading, block design and mental arithmetic are significantly (p .05) positively correlated. The two rotated forms tasks are also positively correlated approaching significance ($p = .074$).

It can be concluded that the hemispheric brain functioning of the subjects in this study during performance of parallel forms of the same task are significantly related. Therefore, the null hypothesis (H_9) that there is no significant positive correlation between parallel forms of repeated tasks was rejected.

Related Findings

During the initial statistical analysis of the data, it became increasingly apparent that examination of several additional potential relationships in the study data was critical for comprehensive analysis and interpretation of the findings. These proposed relationships deal with 1) the asymmetrical hemispheric brain waves between a) the stimulus and response during performance of the reading task and b) high and low performers on all tasks and 2) other possible independent variables, such as, the combination of sex and hand-eye dominance, which might be related to patterns of hemispheric brain waves, and which are expressed as null statistical relationships and are discussed in the following paragraphs.

In the original design of the study, the stimulus and response of the reading task were included as tasks which would elicit left hemisphere functioning. However, the stimulus period of the reading task, silent reading of a passage, was not highly correlated with other tasks which had higher proportions of left hemispheric activity, but rather with right hemispheric related tasks. Therefore, statistical analysis of the differences between the ratios measured while subjects were reading a passage silently and the ratios measured while the subjects were thinking about and answering comprehension questions concerning the passage was computed.

Stated in the null form, this hypothesis is:

H_{10} There are no statistically significant differences in the log L/R alpha power ratios measured during subjects performance of the reading task between the stimulus (reading a passage silently) and the response (thinking about and answering questions concerning the passage).

This hypothesis was evaluated with Fisher's correlated t-test which is reported in Table 25. The raw scores for this analysis are found in Table 26.

As Table 25 indicates there are significant differences ($t = 2.95$; $df = 17$; $p = .009$) between the means of the ratios measured during the stimulus and those measured during the response of the reading task. Therefore, the null hypothesis (H_{10}) was rejected.

The ratios measured during the silent reading of a passage ($\overline{x} = .0694$) are significantly higher than the ratios measured while thinking about and answering questions concerning elicited greater proportions of right hemispheric activity than the subsequent response to questions about the passage.

As graph 10 illustrates, this shift pattern from right hemispheric activity during the stimulus to left hemispheric functioning during the response is consistent across subjects (with the exception of three subjects) and is similar to the pattern observed between the stimulus (initial response) and response (subsequent response) of the Piagetian tasks, Conservation of Substance (see Graph 1) and Time-Ordered Liquid Flow/Visuo-Spatial (see Graph 2).

Because this investigation did not employ random selection of subjects, these results cannot be generalized beyond the population from which the sample was selected, but for these subjects there appears to be an emerging pattern suggesting that complex tasks having visuo-spatial components in the stimuli and verbal components in the response elicits a shift from greater right hemispheric functioning during the stimuli to greater left hemispheric functioning during the response.

The fact that this interesting finding has not been reported in other EEG frequency studies may be a function of differences in sampling techniques and/or differences in statistical analysis. However, most of the EEG frequency studies reported in the literature mainly involved adult subjects. Therefore, this finding may support the hypothesis of an increasing development of left hemispheric modality (Harris, 1973; Knox and Kimura, 1970; Galin, 1975; Bogan, 1975).

Concommitant with the EEG measurement of the hemispheric brain waves during the subjects' performance of each of the tasks, performance scores for each task was obtained. Statistical analysis assessing the differences of the asymmetrical hemispheric ratios between high and low performers on each task was computed. Stated in the null form, the hypothesis tested was:

> H_{11} There is no statistically significant differences in the log L/R alpha power ratios between high and low performers on each task.

To evaluate this hypothesis, multivariate discriminant analyses were computed for each of the tasks having two EEG measurements (stimulus period and response period) with the log L/R alpha power ratios as the predictor variables and the performance score on that task as the criteria variable. This was followed by a one way analysis of variance of the ratios measured during each of these periods between the high and low performers.

To statistically evaluate those tasks having one EEG measurement, the subjects were placed in groups based on their performance score and a one way analysis of variance was computed between these groups.

The tasks requiring multivariate analysis followed by univariate analysis are evaluated and discussed first, then attention is given to those tasks requiring only univariate analysis for evaluation.

For appropriateness and ease in computing a discriminant analysis, subjects were separated into two groups (high performer group and low performer group). The high performers on the Reading task were those subjects who scored three points or higher on the comprehension questions, those subjects scoring less than three points were placed in the low performer group. The

The results of the discriminant analysis of the log L/R alpha power ratios measured during the Silent Reading and the Reading Comprehension Questions between the high and low performers is reported in Table 27. The one way analysis of variance of the log L/R alpha power ratios measured during the Silent Reading and the Reading Comprehension Questions between high and low performers is reported in Table 28. The means and standard deviations of these groups are found in Table 29 and the raw scores in Table 26.

As Table 27 indicates the discriminant analysis did not reach the acceptable level of significance, but approached significance ($x^2 \doteq 4.032$; df = 2; p = .133). The univariate one way analysis (Table 28) of the log L/R alpha power ratios of the Reading Comprehension response between the high and low performers did reach statistical significance (F = 4.6789; df = 1/16; p = .04), which is reflected in the standardized discriminant function coefficient for this response (SDFC = .91437). The Silent Reading response had a low negative (SDFC = -.18273) relationship with the reading comprehension response. As the group centroids indicate this pattern reflects an inverse relationship with the poor performers (Centroid = -.68311) more accurately than it does the relationship with the high performers (Centroid = .26273). In other words, the main differences between the log L/R alpha power ratios measured during these two periods was not the low positive ratios of both groups during the Silent Reading which were statistically equivalent (F = .0001; df = 1/16; p = .99) but the extreme negative ratios ($\bar{x}$ = -.21) of the low performers during the Reading Comprehension Questions in relation to the high performers ($\bar{x}$ = -.07).

As previously discussed (see Table 25 and Graph 10), the ratios measured during the Silent Reading response had significantly greater right hemispheric activity (t = 2.94; df = 17; p = .009) than the ratios measured during the Reading Comprehension response and this pattern was consistent across subjects. However, using the subjects ability to answer questions concerning the reading passage as criteria, the poor readers had significantly more left hemispheric activity (F = 4.680; df = 1/16; p = .04) than the good readers.

If, as Piavo postulates, words, particularly high imagery words, have a dual memory trace with constructs for these words found in both the right and left hemisphere (Piavo, 1966, 1969, 1971; Bower, 1970, 1973, 1975), then the difference between the good and poor readers in this study appears to be the difference between subjects who did and those who did not tap the constructs of both hemispheres concerning the passage they read.

The next five statistical analyses reported and discussed are the differences in the log L/R alpha power ratios measured during the initial and subsequent response between high and low performers on the following Piagetian tasks: Conservation of Substance, Objects Moving Through Time and Space/Visuo-Spatial, Objects Moving Through Time and Space/Audio-Verbal, Time-Ordered Liquid Flow/Visuo-Spatial and Time-Ordered Liquid Flow/Audio-Verbal.

The high performers on each of the Piagetian tasks are those subjects who scored two pointson the questions concerning the task (indicated both objects were the same following the transition and adequately explained their judgment) and the low performers are those who scored less than two. The log L/R alpha power ratios measured during the initial and subsequent response and the performance score for each of these tasks is found in Table 26.

Each of the tasks are analyzed and discussed separately in the following paragraphs which is followed by an overall summary and discussion.

Analysis of Objects Moving Through Time and Space/Visuo-Spatial

The summary table for the results of the discriminant analysis of the log L/R alpha power ratios of the initial and subsequent responses measured during the Piagetian task, Objects Moving Through Time and Space/Visuo-Spatial as predictor variables for membership in the high and low performer groups is reported in Table 30.

The results of the one way analysis of the log L/R alpha power ratios between the high and low performers measured during the initial and subsequent response periods is reported in Table 31 and the means and standard deviations are found in Table 32.

As Tables 30 and 31 indicate there are no significant differences in the patterns of hemispheric activity ($x^2 = .261$; df = 2; p = .878) nor in the ratios measured during the initial (F = .193; df = 1/16; p = .649) of subsequent (F = .011; df = 1/16; p = .776) response period between the high and low performers on this task.

The failure to find differences is not unexpected as only four subjects qualified as members of the high performer group and, as previously discussed, the initial response period is suspected to be contaminated due to subjects applauding the doll of his/her choice either vocally or subvocally.

Analysis of Objects Moving Through Time and Space/Audio-Verbal

The summary table of the results of the discriminant analysis of the log L/R alpha power ratios measured during performance of the Piagetian task, Objects Moving Through Time and Space/Audio-Verbal as predictor variables for membership in the high and low performer groups is reported in Table 33.

The one way analysis of variance of the log L/R alpha power ratios measured during the initial and subsequent response periods between the high and low performers is reported in Table 34 and the means and standard deviations of these two groups are found in Table 35.

The results of the discriminant analysis (see Table 33) did not reach the acceptable level of significance ($p > .05$), but did approach significance ($x^2 = 4.918$; df = 2; $p = .086$) and the one way analysis of variance (see Table 34) of the ratios measured during the subsequent response period between the two groups was significant ($F = 4.636$; df = 1/16; $p = .045$).

The discriminant analysis revealed that differences in the patterns of hemispheric activity between the high and low performers on this task was the greater negative ratios (SDFC = -.54705) during the initial response and greater positive ratios (SDFC = .99747) during the subsequent response of the high performers (Centroid = .78364) relative to the low performers (Centroid = -.49868).

During the initial response period, the high performers had greater proportions of left hemispheric activity ($\bar{x} = -.04$) than the low performers ($\bar{x} = .10$), but these differences were not significant ($F = 1.721$; df = 1/16; $p = .206$). However, the greater proportions of right hemispheric activity of the high performers ($\bar{x} = .10$) in relation to the low performers ($\bar{x} = -.04$) during the subsequent response period was significant ($F = 4.636$; df = 1/16; $p \simeq .045$).

These results are interpreted as indicating that the ability to conserve (in Piagetian terms) for these subjects was reflected in the ability to utilize left hemispheric constructs during the stimulus period (audio-verbal presentation of the transition) as originally hypothesized in Chapter 1 (see the experimental form of hypotheses 2 and 4), but the critical factor was the ability to utilize right hemispheric constructs during the verbal response to questioning concerning their judgement of the transition.

Analysis of Conservation of Substance

The summary table of the discriminant analysis of the log L/R alpha power ratios of the initial and subsequent response during performance of Conservation of Substance as predictor variables for membership in the high and low performer groups is reported in Table 36.

The results of the one way analysis of variance of the log L/R alpha power ratios between high and low performers during the initial and subsequent response period is reported in Table 37 and the means and standard deviations of the two groups is found in Table 38.

As Table 36 indicates the results of the discriminant analysis was not significant ($x^2 = 3.184$; df = 2; p = .204), nor were the univariate one way analyses of variance of the log L/R alpha power ratios during the initial response period (F = .895; df = 1/16; p = .361) and the subsequent response period (F = 2.180; df = 1/16; p = .156) between the high and low performers.(see Table 37).

However, since the patterns observed in these analyses are similar to those observed in the Reading task and the Piagetian task, Objects Moving Through Time and Space/Audio-Verbal, the results will be interpreted and discussed.

The overall pattern indicated by the results of the discriminant analysis is one of greater negative ratios during the initial response period (SDFC = -.55475) and greater positive ratios during the subsequent response period (SDFC = .77245) of the high performers (Centroid = .30636) relative to the low performers (Centroid = -.48142).

In other words, during the initial observation of the transition the high performers had greater proportions of left hemispheric activity ($\bar{x} = .06$) than the low performers ($\bar{x} =.15$)

and had greater proportions of right hemispheric activity ($\bar{x} = .02$) than the low performers ($\bar{x} = -.10$) when thinking about an explanation for their judgement concerning the transition.

A previous analysis of the Conservation of Substance task (see Table 6 and Graph 1) revealed that across subjects the ratios measured during the initial response period had significantly ($t = 2.91$, $df = 17$; $p = .038$) more right hemispheric activity than the subsequent response. However, though not significant, the differences between those subjects who could logically explain their judgement and those who could not appears to be the utilization of left hemispheric constructs during the visuo-spatial observations of the stimuli and the utilization of right hemispheric constructs during the verbal response to questions concerning the observation.

Analysis of Time-Ordered Liquid Flow/Visuo-Spatial

The summary table of the results of the discriminant analysis of the log L/R alpha power ratios measured during the initial and subsequent responses during performance of Piagetian task, Time-Ordered Liquid Flow/Audio-Verbal as predictor variables for membership in the high and low performer groups is reported in Table 39.

The results of the one way analysis of variance of the log L/R alpha power ratios measured during the initial and subsequent responses between the high and low performers is reported in Table 40 and the means and standard deviations of these two groups are found in Table 41.

As Tables 39 and 40 indicate there were no significant differences in the patterns of hemispheric activity ($x^2 = .133$; df = 2; p = .945) nor in the ratios measured during the initial (F = .008; df = 1/16; p = .945) or subsequent(F = .142; df = 1/16; p = .674) response periods between the high and low performers on this task.

The nonsignificant results of these analyses was not expected and hard to explain. However, the high standard deviations (see Table 41) of the high performers on both the initial response period (SD =.3076) and the subsequent period (SD = .2027) in relation to the low performers (SD = .1974; .1779) reveals that the patterns of the high performers were quite different from each other.

One possible explanation accounting for both the insignificant results and the high standard deviations, which should be viewed as speculative, is that at least two of the high performers (1/3 of the sample) confounded the results.

Listening to the audio tapes of the data collection revealed that one subject (#12), following performance of the battery reported that his teacher "taught me the trick of the two glasses of water". This might indicate that his "correct" response was not the result of cognitive reasoning, but the result of another "learning" which elicited different hemispheric patterns.

A second subject in the high performer group had consistent patterns of "reversed hemispheric activity" from most of the other subjects. For her, a greater proportion of right hemispheric activity appeared to indicate verbal, analytical cognition rather than spatial, synthetical cognition and vice versa. This suspicion will be explored and discussed later following a discriminant analysis of possible group differences in patterns of hemispheric functioning across Piagetian tasks.

Analysis of Time-Ordered Liquid Flow/Audio-Verbal

The results of the discriminant analysis of the log L/R alpha power ratios measured during the initial an subsequent responses of the Piagetian task, Time-Ordered Liquid Flow/Audio-Verbal as prefictor variables for membership in the high and low performer groups is reported in Table 42.

The results of the one way analysis of the log L/R alpha power ratios of the high and low performers measured during the initial and subsequent responses is reported in Table 43 and the means and standard deviations of the two groups are found in Table 44.

As Table 42 and 43 indicate there are no significant differences in the observed patterns of hemispheric activity ($x^2 = 1.303$; df = 2; $p = .521$) nor in the initial ($F = .709$; df = 1/16; $p = .417$) or subsequent ($F = .450$; df = 1/16; $p = .518$) responses between the high and low performers on this task.

This finding was also not expected and hard to explain. A previous analysis (see Table 10) revealed that the audio-verbal persentation of this task facilitated significantly (F = 3.130; df = 1/17; p = .01) greater proportions of left hemispheric activity during the initial response period across subjects accompanied by greater (F = 2.956; df = 1/17; p = .104) numbers of subjects who conserved (high performers) than the visuo-spatial presentation of the task. This was interpreted as indicating that greater left hemispheric activity during the stimulus period (initial response) resulted in greater ability to logically explain the transition.

Examination of Table 25 reveals that all of the subjects who conserved during this presentation of the task and did not conserve during the visuo-spatial presentation did have greater proportions of left hemispheric activity measured during the initial response period during this performance than during the initial response period of the visuo-spatial presentation. Furthermore, five of these six subjects had greater right hemispheric ratios measured during the subsequent response period of this presentation, than measured during their subsequent response of the visuo-spatial presentation.

This pattern is similar to the patterns observed between the high and low performers of the Reading task and the Piagetian tasks, Conservation of Substance and Objects Moving Through Time and Space/Audio-Verbal.

However, similar patterns are also observed in three of the nonconservers (low performers). One of these subjects having this pattern (#5) conserved during the visuo-spatial presentation and did not during this presentation stating that he changed his mind regarding the amount of liquid in the two containers because one of the container was larger than the other.

Consequently, the interpretation of the patterns of hemispheric ratios which distinquish high performers from low performers and the explanation for the insignificant results is not clear. Perhaps among the high performers there are subjects who "learned this trick" in school, transition thinkers having different patterns of hemispheric functioning than the "true conserver" or subjects with"reversed hemispheres" which are confounding the analysis.

Whatever the explanation or explanations regarding the nonsignificant results might be, this study data is not adequate for further exploration. Another study is implied which screens for reversed subjects and for subjects who have previously "learned the trick" and blocks transition thinkers into the study design.

To summarize the preceding evaluations of possible differences of the hemispheric ratios between high and low performers on Reading and Piagetian tasks, a pattern appears to be emerging which suggests that high performers are those subjects who have greater proportions of left hemispheric functioning during the stimuli period and greater proportions of right hemispheric functioning during the response period relative to the low performers.

These differences approached significance for the overall pattern on the Reading and Objects Moving Through Time and Space/Audio-Verbal. However, further evaluation of both tasks revealed that the significant factor which differentiated the high and low performers was the greater right hemispheric ratios of the high performers when thinking about and answering questions concerning the stimuli. This pattern, although not significant, was also observed beween the high and low performers on the Conservation of Substance task.

Therefore, although the results were not conclusive, the null hypothesis (H_{11}) was rejected for the Reading and Piagetian tasks. There are significant differences between high and low performers measured by their hemispheric ratios, and these differences appear to be the same for Reading and Piagetian tasks.

Analysis of Conservation of Area

The summary table of the one way analysis of variance of the log L/R alpha power ratios measured during the initial response period between high and low performers on Conservation of Area is reported in Table 45. The means and standard deviations of the three groups are found in Table 46 and the raw scores in Table 47.

There were no significant differences (F = 1.892; df = 2/15; p = .184) between the three groups (see Table 45). This finding is not unexpected as the ratios measured during this task were those measured during the initial response period, and previous analysis of Piagetian tasks have indicated that the critical factor differentiating between conservers and nonconservers are the ratios measured during the subsequent response period.

However, the means of the three groups are interesting (see Table 46). The mean of the subjects who indicated that the two forms were now not equivalent because one was bigger than the other following the transition (the nonconservers) was the greatest negative value ($\overline{x}$ = -.06), the mean of the subjects who indicated that the two geometric forms were equivalent, but could not logically explain their judgment was the greatest positive value ($\overline{x}$ = .14), while the mean of the subjects who judged the two forms equivalent and logically explained their judgment (the conservers) was a positive value, but closer to zero ($\overline{x}$ = .04) than the other two groups.

This finding indicates that the conservers in this task were those subjects having more equivalent alpha blocking in both hemispheres during the stimulus period, which suggests that they were processing the incoming information in both hemispheres and possibly processing the incoming information interactively between the two hemispheres.

Analysis of Syllogistic Logic

The summary table of the one way analysis of variance of the log L/R alpha power ratios between performers with different performance scores on the Syllogistic Logic task is reported in Table 45. The means and standard deviations of the three groups are found in Table 46 and the raw scores in Table 47.

As Table 45 indicates there were no significant differences (F = .463; df = 2/15; p = .63) between the groups. This finding is not surprising as the cell sizes of the groups were small. One cell had only two subjects.

However, the EEG sampling of this task could also account for the insignificant results. The EEG measurement of ratios summed over the first 30 seconds (or less) of the task, therefore summing over the stimulus period and part of the response and the measurement would differ from subject to subject.

Analysis of Mental Arithmetic Tasks

The summary tables of the one way analyses of variance of the log L/R alpha power ratios between subjects with different performance scores on the Mental Arithmetic 1 task and the Mental Arthmetic 2 task are reported in Table 45. The means and standard deviations of the groups on each of these tasks are found in Table 46 and the raw scores in Table 47.

As Table 45 indicates there were no significant differences between the three groups measured during the Mental Arithmetic 1 task (F = 1.887; df = 1/16; p = .186) or the Mental Arithmetic 2 task (F = .828; df = 2/15; p = .459).

The failure to find significance on the Mental Arithmetic 2 task is probably due to the small number of subjects in the cells. There were only three subjects in the zero performance score cell.

The failure to find significance on the Mental Arithmetic 1 task might be a function of the method of selecting appropriate EEG segments. The segments recorded started as the subject was handed the card containing the addition problem (visuo-spatial stimulus period) and continued for 30 seconds (or less) as the subject solved the problem (sequential-symbolic response), but did not record the verbal response to the problem.

Based on the results of the Reading and Piagetian tasks, which also had visuo-spatial and sequential-symbolic components, the chance of detecting significantly different patterns of hemispheric ratios between high and low performers would have increased had the study design included separate EEG measurements of the stimulus period and response (or problem solving) period.

Although the differences between the high and low performers were not significant, the means of these two groups are interesting and correspond with the means of the conservers and nonconservers on the Conservation of Area task (see Table 46).

The mean of the low performers was a low negative value ($\overline{x} = -.06$), while the mean of the high performers was a low positive value ($\overline{x} = .04$) and closer to zero. This finding indicates that the low performers had greater proportions of left hemispheric functioning than the high performers.

Examination of Table 47 reveals that both of the Mental Arithmetic tasks had successful performers with high positive ratios (indicating large proportions of right hemispheric activity), successful performers with high negative ratios (indicating large proportions of left hemispheric activity), and successful performers with ratios close to zero (indicating activity in both hemispheres). This may indicate that the assumed necessity for sequential-symbolic processing in computation is faulty. Some subjects may have solved these tasks in a synthetical-symbolic processing modality or a combination of the two.

It would be interesting to find that mathematical symbols and processing, as well as verbal symbols and processing, have a dual memory trace (Paivio , 1966, 1969, 1971; Bower, 1970, 1973, 1975) with constructs in both hemispheres. Further research is implied in this area.

Analysis of the Block Design Tasks

The summary tables for the one way analyses of variance of the log L/R alpha power ratios measured during performance of the Block Design 1 task, the Block Design 2 task and the Block Design 3 task between subjects with different performance scores on each of the tasks are reported in Table 45.

The means and standard deviations of each of the groups on each of the tasks are reported in Table 46 and the raw scores in Table 47.

There were no significant differences (see Table 45) in the alpha power ratios measured during the Block Design 1 task (F = .758; df = 3/14; p = .487), the Block Design 2 task (F = .605; df = 1/16; p = .605) or the Block Design 3 task (F = .846; df = 3/14; p = .494).

The failure to find significance, particularly in the Block Design 1 and Block Design 3 tasks) might be a function of small cell sizes. However, as previously discussed this task was probably confounded as the ratios measured summed over the thinking involved and sequential motor functioning as the subjects manipulated their blocks to match the design. However, Vandenberg (1975) presents an argument that this task can be solved with either spatial-synthetical modality or sequential-analytical modality.

The ratios of the three successful performers on the first Block Design task may support his argument (see Table 47). Two of the three subjects (#3 and #8) had extremely high positive ratios (.25 and .34) indicating large proportions of right hemispheric activity, while the third high performer (#16) had an extremely high negative ratio (-.44) indicating large proportions of left hemispheric activity.

Vandenberg (1975) also states a convincing argument that little is known about children's spatial development which contributes to the difficulty in selecting appropriate tasks for them. As Table 46 illustrates, the spatial tasks selected for this study appeared to be extremely difficult for the subjects and supports Vandenberg's plea (1975) for an extensive search for appropriate tasks before research in this area can begin.

Analysis of Rotated Forms Tasks

The summary table of the one way analysis of variance of the log L/R alpha power ratios between subjects with different performance scores on the Rotated Forms 1 task and the Rotated Forms 2 task are reported in Table 45. The means and standard deviations of the groups on both of the tasks are found in Table 46 and the raw scores in Table 47.

As Table 45 indicates there are no significant differences in the alpha power ratios measured during performance of Rotated Forms 1 task (F = .435; df = 3/14; p = .685) or the Rotated Forms 2 task (F = .859; df = 3/14; p = .490).

Again the failure to find significance on these tasks could be a function of small cell sizes and inefficient EEG sampling techniques.

Some of the latest literture concerning asymmetrical hemispheric functioning postulates differences in subjects grouped on the basis of sex and hand-eye dominance (Kirshner, 1975; Keirster and Cudhea, 1976). Eye dominance was determined during the data collection, but has not been interpreted to this point.

Moreover, Robert Ornstein (cited in Keirster and Cudhea, 1976) reports that in a recent investigation of subjects with different sex/hand-eye dominance characteristics, which he and David Galin have just completed, they found some subjects who appeared to have reversed hemispheres. This pattern has also been observed by three of the subjects in this study (see Graphs 1, 2 and 10).

Consequently, the last hypothesis, stated in the null form is:

H_{12}: There are no statistically significant differences in the patterns of the log L/R alpha power ratios measured during performance of Piagetian tasks between right-dominant males, mixed-dominant males, right-dominant females and reversed subjects.

This hypothesis was evaluated by a multivariate discriminant analysis assessing patterns of hemispheric functioning which predicts group membership of right-dominant males, mixed-dominant males, right-dominant females and reversed subjects.

The summary table of this analysis is reported in Table 48. The means and standard deviations of the four groups are found in Table 50 and the raw scores in Table 26.

Since significance was reached, further evaluation of the differences between these groups was obtained by computing one way analyses of variance between the groups for each response measured. The summary table of these analyses are reported in Table 49. These analyses indicated which variables significantly contributed to the group differences. The Scheffe statistic was then computed between the group means of the appropriate variables.

The discriminant analysis revealed that there are two significant discriminant functions and a third which approached significance. The formulas of the two significant functions accurately predicted 100% of the subjects in the study (see Table 51 and Graph 11).

The first significant function ($x^2 = 59.824$; df = 33; p = .003), which accounted for 52.06% of the variance, describes the differences in the patterns of ratios between the reversed group (centroid = .92912) and the mixed dominant boys (centroid = -.63494). The largest weights describing this difference were observed in the ratios of the subsequent responses of Time-Ordered Liquid Flow/Audio-Verbal (SDFC = .31482), Objects Moving Through Time and Space/Visuo-Spatial (SDFC = -.25288) and the ratios of the initial responses of Time-Ordered Liquid Flow/Visuo-Spatial (SDFC = -.25290) and Objects Moving Through Time and Space/Visuo-Spatial (SDFC = -.30572).

Using the Scheffe statistic, post hoc analysis of the observed significant differences were computed. As the discriminant analysis indicated, the results of this statistic revealed the majority of these differences involved the reversed group, the mixed-dominant males and the right-dominant males.

During the initial response of Time-Ordered Liquid Flow/ Visuo-Spatial, the mixed-dominant males had significantly (F = 3.34; df = 3/14; p = .05) larger ratios ($\overline{x}$ = .43) than the rest of the groups ($\overline{x}$ = .15; .10; .03) (see Table 50). This indicates that although all the groups had positive means, the mixed dominant males had significantly greater proportion or right hemispheric functioning during the initial observation of the water flowing into containers.

The mixed-dominant males also had significantly (F = 3.34; df = 3/4; p = .05) larger ratios ($\overline{x}$ = .31) than the rest of the groups ($\overline{x}$ = .02; -.06; -.14) during the initial response of Objects Moving Through Time and Space/Audio-Verbal, indicating that they had a larger proportion of right hemispheric functioning while the dolls moved down the track behind a screen accompanied by a verbal time ordering of the event. These results may indicate that these five boys were the ones which listened to the click in the apparatus, ignoring the verbal component of the task.

During the initial response of Objects Moving Through Time and Space/Visuo-Spatial, the reversed group ($\overline{x}$ = -.26) and the right-dominant males ($\overline{x}$ = -.22) had significantly (F = 3.34; df = 3/14; p = .05) lower ratios than the other two groups ($\overline{x}$ - .05; - .02). These results indicate that they had significantly greater proportion of left hemispheric functioning during the observation while dolls moving down the track than the mixed dominant males and right dominant females. The investigator interprets these results to indicate that these subjects are those which were vocally or subvocally applauding the doll of their choice (which matches the verbal report of the boys). If the reversed group do have their hemispheres reversed, this result may indicate a strong proportion of "right" hemispheric functioning for this group.

The evaluation of the observed differences of the subsequent response during performance of the Conservation of Substance task reveals that the reversed group had significantly ($F = 3.34$; $df = 3/14$; $p = .05$) higher positive ratios ($\overline{x} = .16$) than the other three groups $\overline{x} = -.21, -.03, -.03$) and the right dominant boys had significantly ($F = 3.34$; $df = 3/14$; $p = .05$) higher negative ratios ($\overline{x} = -.21$) than the mixed dominant boys ($\overline{x} = -.03$) and the right dominant girls ($\overline{x} = -.03$). This indicates that the reversed group had a larger proportion of right hemispheric functioning and the right-dominant males had a larger proportion of left hemispheric functioning while thinking about whether either piece of clay had more substance following the transition and why they thought so than the other two groups.

If the cell sizes of these groups were large enough to compute an analysis of the high and low performers for each of these groups on this task, the results may have been different. Although the two significantly different groups probably "canceled each other" as each group had two conservers and one nonconserver. However, this finding suggests that future research should carefully control the independent variables sex, dominance and reversed hemispheric patterns.

Quite clearly, apart from individual differences, there are four kind of thinkers in terms of patterns of asymmetrical hemispheric functioning, in this study. Except for the reversed group, which contained the two children of Indian heritage and one right dominant girl (the mixed dominant girl which was dropped out of this study also fits the reversed pattern), the groups can be accurately classified on the basis of sex and hand-eye dominance.

Assessing the overall patterns of these groups (see Tables 48, 50 and 52 and Graph 11), the pattern of the mixed dominant males was that of a larger proportion of right hemispheric functioning; the pattern of the right-dominant males was that of a larger proportion of left hemispheric functioning; the pattern of the reversed group was observed to be a swing in the opposite direction than the other three groups, while the right dominant females appeared to be one of low to moderate ratios across tasks.

These patterns support the hypothesis that women are not as lateralized as men (Buffery and Gray, 1972; Harris, in press) and also supports Galin and Ornstein's findings (cited in Kierster and Cudhea, 1976) that among the general population there are individuals with reversed patterns from most right handed people.

Therefore, the null hypothesis (H_{12}) that there are no statistically significant patterns of log L/R alpha power ratios which will differentiate right-dominant males, right-dominant females, mixed-dominant males and reversed subjects was rejected.

CHAPTER V

SUMMARY AND IMPLICATIONS

Overview

This study focused upon investigation of asymmetry in children's hemispheric brain functioning during performance on Piagetian tasks.

Eight subproblems were investigated:

1. Differences in brain functioning within Piagetian tasks, between the initial response period (when subjects were observing phenomena) and the subsequent response period (when subjects were thinking about explanations for their observations);
2. Differences in brain functioning and "conservation" performance between administrations of Piagetian tasks when the presentation mode of the tasks were altered;
3. Intercorrelations of subjects' brain functioning between the initial and subsequent responses on Piagetian tasks;
4. Correlations of subjects' brain functioning between responses on Piagetian tasks and spatial, reading, syllogistic logic and mathematical tasks;
5. Correlations of subjects' brain functioning between parallel forms of the same task;

6. Differences in patterns of Brain functioning between male and female subjects and between Preoperational and Concrete Operational subjects.

Four related questions were studied:

1. Differences in subjects' brain functioning within a reading task, between the initial response period (when reading a passage silently) and the subsequent response period (when thinking about and answering comprehension questions concerning the passage;
2. Differences in brain functioning between high and low performers on all tasks;
3. To identify groups of children with similar patterns of brain functioning;
4. To identify consistent patterns of brain functioning within individual subjects.

Eighteen volunteer right-handed children between the ages of six to eight years were identified and electroencephlagrams were recorded from homologous parietal leads while the subjects performed a battery of tasks. This data was computer analyzed to provide a log L/R alpha power ratio for each task or subtask.

The following battery of tasks was administered to each child: Piagetian Conservation tasks (Conservation of Area and Substance), Piagetian Temporal tasks (Time-ordered Liquid Flow and Objects Moving Through Time and Space), spatial tasks (WISC Block Design and Rotated Forms), and curriculum related tasks (reading, syllogistic logic and mental arithmetic).

Summary of the Results

The results of this study are limited by the design of the study, the procedures employed and the sampling technique which limits the generalizability. Acknowledging these limitations, the results of the study are summarized below:

I. There were significant differences in asymmetrical hemispheric functioning between the initial and subsequent responses of children during performance on Piagetian tasks.

   A. There was a significantly greater proportion of right hemispheric functioning during the initial response of Time-Ordered Liquid Flow/Visuo-Spatial than the subsequent response at the .01 alpha level.

   B. There was a significantly greater proportion of right hemispheric functioning of the initial response of Conservation of Substance than the subsequent response at the .05 alpha level.

   C. There were not significant differences in asymmetrical hemispheric functioning between the initial and subsequent responses of

Objects Moving Through Time and Space/ Visuo-Spatial.

II. There were significant differences in the asymmetrical hemispheric functioning and in the "conservation" performance scores between the visuo-spatial and audio-verbal presentations of Piagetian Temporal tasks.

   A. There were significantly greater proportions of left hemispheric activity of the initial response measured during subjects' performance of Time-Ordered Liquid Flow/Audio-Verbal than the initial response measured during subjects' performance of Time-Ordered Liquid Flow/Visuo-Spatial at the .007 alpha level.

   B. There were significantly greater proportions of right hemispheric activity of the initial response measured during subjects' performance on Objects Moving Through Time and Space/Audio-Verbal than the initial response measured during subjects' performance of Objects Moving Through Time and Space/Visuo-Spatial at the .05 alpha level.

   C. There were significantly more "conservation" performance scores during the audio-verbal presentation of Objects Moving Through Time and Space than during the visuo-spatial presentation at the .05 alpha level.

D. There were more "conservation" performance scores during the audio-verbal presentation of Time-Ordered Liquid Flow than during the visuo-spatial presentation which approached significance at the .07 alpha level.

E. There were no significant differences in hemispheric functioning between the subsequent responses during performance of Piagetian Temporal tasks.

III. There were significant positive intercorrelations of the asymmetrical hemispheric functioning between responses measured during subjects' performance of Piagetian tasks.

A. There were significant positive intercorrelations between initial responses at the .05 alpha level.

B. There were significant positive intercorrelations between subsequent responses at the .05 alpha level.

C. There were not significant positive intercorrelations between initial and subsequent responses.

IV. There were significant positive correlations between the hemispheric brain waves measured during subjects' performance of Piagetian tasks and spatial, verbal, logical and mathematical tasks.

A. There were significant positive correlations between initial responses and the silent reading tasks at the .05 alpha level.

B. There were not significant positive correlations between initial responses and spatial tasks.

C. There were significant positive correlations between subsequent responses and verbal, logical and mathematical tasks.

V. There were significant positive correlations of subjects' hemispheric brain waves measured during performance of parallel forms of the same tasks.

A. There were significant positive correlations between parallel forms of silent reading tasks at the .03 alpha level.

B. There were significant positive correlations between parallel forms of WISC Block Design at the .04 alpha level.

C. There were significant positive correlations between parallel forms of mental arithmetic at the .04 alpha level.

D. There were positive correlations between parallel forms of the Rotated Forms task which approached significance at the .07 alpha level.

VI. There were significantly greater proportions of right hemispheric activity measured during the initial response (when reading a passage silently) than during the subsequent response (when answering comprehension question) on subjects' performance of the reading task at the .009 alpha level.

VII. There were no significant differences in patterns of asymmetrical hemispheric activity between Preoperational and Concrete Operational subjects.

VIII. There were no significant differences in patterns of asymmetrical hemispheric activity between male and female subjects.

IX. There were significant differences in the asymmetrical hemispheric activity between high and low performers on tasks.

A. High performers on the reading task had a pattern of slightly greater proportion of left hemispheric activity measured during the initial response (when reading a passage silently) and greater right hemispheric activity during the subsequent response (when thinking about and answering reading comprehension questions about the passage) than the low performers which indicated a statistical trend at the .1 alpha level.

B. High performers on the reading task had significantly greater right hemispheric activity during the subsequent response than the low performers at the .05 alpha level.

C. High performers on the Objects Moving Through Time and Space/Audio-Verbal task had a pattern of greater proportions of left hemispheric activity during the initial response (when listening to the time ordering of an event presented behind a perceptual screen) and a greater proportion of right hemispheric activity during the subsequent response (when thinking about and answering "conservation" questions about the event) than the low performers which approached significance at the .09 alpha level.

D. High performers on the Objects Moving Through Time and Space/Audio-Verbal task had a significantly greater proportion of right hemispheric activity measured during the subsequent response than the low performers at the .05 alpha level.

E. There were no significant differences in the asymmetrical hemispheric functioning between high and low performers measured during performance of Conservation of Area, Conservation of Substance, Time-Ordered Liquid Flow/Visuo-Spatial, Objects Moving Through Time and Space/ Visuo-Spatial, the Block Design tasks, the Rotated Forms tasks, the Syllogistic Logic task or the Mental Arithmetic tasks.

X. There were significantly greater proportions of right hemispheric activity measured during the initial response (when reading a passage silently) than the subsequent response (when thinking about and answering comprehension questions concerning the passage) during subjects' performance of the reading task.

XI. There were significant differences in patterns of asymmetrical hemispheric functioning measured during Piagetian tasks between subjects in the four groups, three of which were characterized by same sex/hand-eye dominance and a fourth which consistently had reversed shift patterns.

A. There were significant differences between the reversed group and the other three groups at the .003 alpha level.

B. There were significant differences between the male/mixed-dominant group and the other three groups at the .05 alpha level.

C. There were significant differences between the male/right-dominant group and the other three groups at the .05 alpha level.

D. Differences between the female/right-dominant group and the other three groups suggested a statistical trend at the .1 alpha level.

XII. There were consistent patterns of asymmetrical hemispheric functioning across tasks within individuals.

Discussion and Conclusions

In reflecting on the results of this investigation several conclusions became apparent. There are differences in the asymmetrical hemispheric functioning within the stimulus and response periods which are involved in solving Piagetian tasks. Based on the findings of this study, these differences appear to be a greater proportion of right hemispheric cognition during the initial observation of the transition of phenemona and greater proportions of left hemispheric cognition during the subsequent thinking about explanations of the transition. This shift from right to left was observed in most subjects whether the answer was "acceptable" or "not acceptable" by Piaget's definition.

That this shift was not found during the performance of Objects Moving Through Time and Space/Visuo-Spatial task is not surprising. Subjects were either observed to vocalize or reported subvocalizing during the initial response period. Galin and Ornstein (1975) have found that motor output (e.g., speaking and writing) elicits a large proportion of left hemispheric functioning in right handed subjects. However, this large proportion of left hemispheric alpha blocking does not necessarily indicate internal attention or mental cognition. Rehearsing a phrase over and over (such as repeating a telephone number over and over until you have dialed the number) may not evoke long term memory substrates (Hilgard and Bower, 1975), but be a function of short term memory. Because the present psysiological data does not allow prediction of internal or external attention, this cannot be investigated. However, the extremely low performance scores on this task (four conservation responses) may support the suspicition that the observed applauding of a favorite doll was a function of "verbal rehearsal" and external attention.

The presentation of Piagetian tasks behind a perceptual screen accompanied by a description of the time ordering of the event does facilitate an increase in the number of conserving responses, as Bruner (1966) has suggested.

This increase in the number of conservers was accompanied by a shift from greater right hemispheric ratios measured during the initial response of the visuo-spatial presentation to greater left hemispheric ratios measured during the initial response of the audio-verbal presentation of the Time-Ordered Liquid Flow tasks. But was accompanied by a left to right shift between the visuo-spatial and audio-verbal initial responses measured during the performance of the Objects Moving Through Time and Space tasks.

The hypothesis in chapter one postulated that a shift from right to left during the initial responses would facilitate an increase in successful performance. This hypothesis is based on the assumption that conservation performance requires a left hemispheric solution. The results of the shift during the initial responses of the Time-Ordered Liquid flow tasks support this hypothesis. However, the results of the Objects Moving Through Time and Space presentations do not.

One probable explanation for these conflicting findings is that the initial responses during the Objects Moving Through Time and Space/Visua-Spatial task were the product of the observed vocalizing or subvocalizing. If this is the case, then the initial ratios during this presentation would be expected to be lower (indicating greater left hemispheric alpha blocking) than verbal listening (Galin and Ornstein, 1975) during the audio-verbal presentation.

Furthermore, there is reason to believe that the constant click in the apparatus would elicit right hemispheric alpha blocking (Curry, 1967) during the audio-verbal presentation when the subjects were instructed to listen.

Although it is possible to suggest a rationale for the differences observed in the hemispheric functioning between the initial responses, this rationale does not explain the increase in performance scores during the audio-verbal presentations. However, the results of the analysis between high and low performers on this task suggests an explanation. These findings revealed that the differences between the high performers (those that conserved) and the low performers (those that did not conserve) was that the conservers had a pattern of slightly greater left hemispheric ratios measured during the initial response and greater right hemispheric ratios during the subsequent response than the low performers. This overall pattern approached significance and the differences between the subsequent responses for the two groups was significant.

This pattern was also observed between the high and low performers on the reading and Conservation of Substance tasks, with the differences between the good and poor readers reaching significance.

Analysis of the patterns between the high and low performers on the Time-Ordered Liquid Flow/audio verbal task did not reveal the same consistent pattern; evaluation of the six subjects who conserved during the audio-verbal presentation of this task and did not conserve during the visuo-spatial presentation indicates that five of the six subjects had a pattern of greater left hemispheric ratios during the subsequent responses when they conserved than when they did not.

Analysis of the high and low performers on the Conservation of Area task reveals: 1) that the high performers (the conservers) had ratios close to zero measured during the initial response period, 2) that the subjects who indicated that the two geometric forms were equivalent, but could not logically explain their answers, had high right hemispheric ratios, and 3) that the nonconserving subjects, who indicated that one of the geometric forms had more space following the transition, had slightly higher left hemispheric ratios during the initial response period.

This emerging pattern indicates that children who "successfully" performed these tasks are those who have 1) greater access to left hemispheric substrates during the initial observation, when across subjects the right hemispheric modality tended to be evoked and 2) greater access to right hemispheric substrates during the subsequent response, when across subjects the left hemispheric modality tended to be evoked.

In other words, solution of tasks such as Piagetian and reading, for these subjects, appeared to have required complementary or integrative functioning between the two hemispheres; and this combination of functioning was more crucial during the subsequent response period than during the initial stimuli period.

These results are certainly not conclusive, but the pattern does seem to indicate that the ability to logically or comprehensively answer questions about events which have visuo-spatial components requires a combination of cognitive processes which include both the right and left hemispheric functioning. Therefore, the assumption underlying the second, third, and fourth hypotheses is assumed to be only partially accurate: left hemispheric processing would be required since successful solution requires verbal and propositional thinking which (as summarized in Chapter II) has been associated strongly with left hemispheric processes. Further, the results of this investigation seem to indicate that subjects with a greater proportion of right hemispheric functioning, while thinking about and answering questions concerning observed visuo-spatial phenemona, have the most conserving responses.

Based on these findings, it is postulated that the perceptual screen accompanied by a verbal time ordering of the transition facilitated in the nonconservers complementary hemispheric functioning of an event, which was either previously witnessed by one hemisphere and discussed by the other, or witnessed and discussed by one hemisphere alone.

A previously discussed (see Table 25 and Graph 10) the ratios measured during the Silent Reading response had significantly greater right hemispheric activity (t = 2.94; df = 17; p = .009) than the ratios measured during the Reading Comprehension response and this pattern was consistent across subjects. However, using the subjects' ability to answer questions concerning the reading passage as criteria, the poor readers had significantly more left hemispheric activity (F = 4.680; df = 1/16; p = .04) than the good readers.

If, as Paivio postulates, words, particularly high imagery words, have a dual memory trace with constructs for these words found in both the right and left hemisphere (Paivio, 1966, 1969, 1971; Bower, 1970, 1973, 1975), then the difference between the good and poor readers in this study may be the difference between subjects who did and did not tap the constructs of both hemispheres concerning the passage they read.

Results of research based on Paivio's theory indicate that instructing subjects to construct a mental picture (image) of a relationship between words in a word association paradigm significantly increases the ability to remember the association between words (Seamon, 1972; Gibson, Dimond and Gazzaniga, 1972; Seamon and Gazzaniga, 1972). Summarizing this literature, Bower (1974) suggests that the significant results are a function of interhemispheric communication, since imagery appears to be a right hemispheric function and words a left hemispheric function. This research suggests that the poor readers in this study might improve their ability to tap the constructs of both hemispheres with instruction facilitating interhemispheric communication. Further research is indicated in this area.

Summarizing the findings of the statistical analyses a pattern is emerging suggesting that complex tasks having visuo-spatial components in the stimuli and verbal-analytical components in the response elicit greater proportions of right hemispheric activity during the stimuli period and greater proportions of left hemispheric activity during the response. However, using the ability to logically or comprehensively answer questions concerning the stimuli as criteria, high performers are those which utilize greater proportions of left hemispheric activity during the stimuli period and greater proportions of right hemispheric activity during the verbal response. Moreover, the ability to tap right hemispheric constructs during the verbal response appears to be the most crucial factor across reading and Piagetian tasks. This pattern was interpreted as indicating that successful verbal discussion of tasks having visuo-spatial components requires interhemispheric communication.

Perhaps the most conclusive results of this investigation are the significant positive intercorrelations of the hemispheric brain waves between the initial responses and the subsequent response of Piagetian and reading tasks. The most significant intercorrelations involved the ratios measured during the subsequent responses on tasks on which the most subjects had conserving responses: Conservation of Substance, Time-Ordered Liquid Flow/Audio-Verbal and Objects Moving Through Time and Space/Audio-Verbal. The Piagetian subsequent responses were also significantly positively correlated with other curriculum tasks, such as syllogistic logic and mental arithmetic.

Based on these results, it was concluded that within subjects there is an internal consistency of the hemispheric brain waves when performing tasks which involve related cognitive processes. The significant positive correlations of the hemispheric ratios measured while subjects were performing parallel forms of the same task supports this conclusion.

Although the Rotated Forms tasks did have positive correlations with the initial responses of the two Temporal tasks which were presented visuo-spatially, a surprising finding was that the hemispheric brain waves measured during performance of the spatial tasks were not correlated positively with those measured during the initial responses, but instead, were ofter significantly positively correlated with those measured during the subsequent responses.

The Block Design Tasks were chosen specifically because other researchers (Galin and Ornstein, 1972, 1973, 1974, 1975) found them to elicit right hemispheric functioning in right-handed adults.

One possible explanation for the divergent findings of this investigation and those of other researchers is that children may solve spatial tasks differently from adults. However, the fact that these tasks were significantly correlated with the subsequent responses, which were significantly more left hemispheric than initial responses, indicates that these also had greater proportions of left hemispheric activity than the initial responses. The limited literature involving children postulates that children tend to solve problems in a greater right hemispheric modality than adults (Knox and Kimura, 1970; Harris, 1973).

Another explanation is that the sample of children in this investigation might be skewed toward a propensity to solve problems in a left hemispheric mode. This is possible as the population from which this sample was selected included a high percentage of children of university professors and graduate students in areas such as electrical engineering, mathematics, and psychology. It is conceivable that persons with a tendency to solve problems in a sequential and analytic style would choose these kinds of professions.

A third explanation is that the Block Design tasks did require motor output which might have confounded any right hemispheric processing involved for these right-handed subjects.

A combination of these last two explanations probably more accurately explains the low positive or negative correlations found between these tasks and the initial responses on the Piagetian tasks. This last explanation also suggests a rationale for the significant positive correlations between the hemispheric brain waves measured during performance of the Block Design tasks and those measured during the subsequent responses on Piagetian tasks.

If, as previously [illegible] the subsequent responses, particularly those of the high performers, involved a combination of spatial and sequential-logical processing, and the Block Design tasks also required spatial processing and motor sequencing, then the hemispheric functioning of the two would be expected to be highly positively correlated since they involve similar hemispheric processing.

The explanation for the nonsignificant sex difference analysis was answered during the analysis of groups of children classified by sex and hand-eye dominance with one group of "reversed" thinkers. The most significant group differences in patterns of hemispheric functioning are not between the boys and girls as a group who consistently had similar shift patterns, but rather between the "reversed" thinkers and the rest of the subjects. The hemispheric functioning patterns of the "reversed" group was, in fact, consistent reversal from the other subjects--this involved shifts to the right when the rest shifted left during initial and subsequent responses and vice versa.

The male/mixed dominant and the male/right dominant were also significantly different from each other and from the girls during some subtasks. These differences were not in the kind of shift pattern observed, but rather in the degree of shift observed for some subtasks.

The mixed dominant boys had patterns of high positive ratios which indicated greater proportions of right hemispheric functioning. This finding may be partially explained by the fact that they are left eye dominant which could indicate a right hemisphere dominance for visual stimuli. However, except for peripheral vision, both hemispheres have access to the visual input of either eye.

This group had significantly higher ratios during the initial response of Objects Moving Through Time and Space/Audio-Verbal than the rest of the subjects. This may indicate that this group listened to the click in the apparatus more intently than the other subjects.

The right dominant boys had patterns of high negative ratios which indicates greater proportions of left hemispheric functioning. The task in which they had significantly greater left hemispheric ratios was the initial response of Objects Moving Through Time and Space/Visuo-Spatial. Although both boys and girls were observed to applaud the doll of their choice this group may have "rooted" for their choice more fervently than the others.

The right dominant females as a group did not have high negative or positive ratios. Other researchers, (Buffery and Gray, 1972; Harris, in press) have postulated that women are not as lateralized as men. This study supports that hypothesis since the males as a group had larger deviation scores (plus or minus) from zero than the females whose ratios tended to hover close to zero across tasks.

The failure to find statistically significant differences between Concrete Operational and Preoperational subjects was not expected. One explanation for these results is that the rationale for classifying these subjects was based on the assumption that Preoperational and Concrete Operational thinking was a cognitive state from which patterns of thinking processes could be predicted. However, from the results of this investigation, it is concluded that conserving or not conserving for these subjects was a process that could be manipulated. This conclusion, however, does not exclude the possibility that a cognitive state is also involved.

The fact that the Preoperational subjects had almost as many conserving responses during the Temporal tasks presented audio-verbally as the Concrete Operational subjects and that the successful performers on these tasks had similar patterns of hemispheric functioning as other tasks which were not manipulated (e.g. reading and

Conservation of Substance) suggests that conserving is a process which can be deduced by manipulation.

However, the fact that Preoperational subjects were not as successful as the Concrete Operational subjects on the Temporal tasks presented visuo-spatially suggests that conserving may also be a cognitive state.

The analysis between these two classes of thinkers did not confirm the cognitive state assumption, but did reveal that the ratios measured during the subsequent responses of Conservation of Substance and the Temporal tasks presented visuo-spatially were the most discriminating. Although this analysis was not close to significance, these discriminating responses between the two groups were the results of the non-manipulated tasks. This suggests that there may be some differences in the states of cognitive processing which were too subtle for the data base of this investigation. Another study with a larger sample which carefully controls sex and hand-eye dominance might prove fruitful.

Finally, that there were no significant differences between the high and low performers on the spatial and curriculum tasks may be a function of inaccurate measurement. The ratios obtained during performance of these tasks were summed over the first thirty seconds of the task. If different proportions of hemispheric functioning was involved within the task, then the ratios which were used for statistical analysis averaged them together. Another study in which thoughtful consideration is given to possible within task cognitive processes is suggested.

Hypothesis of Ontological Parallelism between Piagetian Theory and Asymmetrical Brain Functioning Theory

In this discussion the author is suggesting that a parallel ontogeny exists between Piagetian theory and brain functioning theory and that the brain functioning findings may explain Piaget's observations of developmental cognitive stages. The discussion of the parallelism between the two theories is organized as follows: 1) Piaget's two structures of knowing and the right/left hemispheric functional specialization; 2) experimental methodology used by Piaget as related to brain functioning theory; 3) ontogeny of Piagetian developmental periods and the maturation of neural fibres; and 4) the hypothesis of ontological parallelism between Piagetian theory and asymmetrical brain functioning theory.

In his recent writings, Piaget is postulating that two interacting systems of knowing, each with its own "kind" of memory, are present in children's thinking processes (Piaget, 1969, 1970, 1973; Piaget and Inhelder, 1971). The figurative system, which is particularly evident in children's spatial concepts, involves imaginal thinking. The cognitive system, which evolves into propositional cognition, is a function of the operative system.

These two systems of knowing are similar to the functional lateral asymmetry reported in the brain functioning research. The right cerebral hemisphere has been found to be the spatial, imaginal specialist while the left crebral hemisphere is the verbal, analytical and propositional specialist. (Bogan, 1971, 1975; Galin, 1974, 1976; Sperry, 1969; Wittrock, 1975; Languis and Kraft, 1976).

Piaget's experimental paradigm usually involves 1) presenting the child with a visuo-spatial experience (stimuli) and 2) requiring a verbal logical explanation (response) of the experience, As the results of the present investigation indicate the visuo-spatial stimuli period tends to elicit right hemispheric functioning and the verbal-logical response tends to elicit left hemispheric functioning. This indicates that Piaget's paradigm is measuring the ability of the verbal-logical left hemisphere to respond to visuo-spatial experiences to which the right cerebral hemisphere was attending. Restated in Piagetian terminology: Conservation appears to be the ability of the operative knowing system (or left hemispheric knowing) to respond to experiences to which the figurative knowing system (or right hemispheric knowing) attended.

Furthermore, there is evidence that the communication system which transmits messages between the two hemispheres (or systems of knowing) does not start to mature until two years of age and completes its cycle at seven years of age, whereas, the fibres from the attention center which acts as a control switch (Bower, 1974; Thompson, 1975) to inhibit and/or facilitate (turn off and on) areas in the brain has its rapid cycle of maturation from two until twelve years of age, but then continues into senility. (Yakolev and Lecours, 1967)

The maturation of these fibres closely parallels Piaget's developmental stages:

1. The sensorimotor stage which occurs from birth until two years is the period of little or no maturation between the hemispheres or from the attention center to the hemispheres. Gazzaniga (1974) postulates that this inability to communicate between hemispheres results in infants being functional "split-brains" up to two years of age.

2. The concrete operational period which occurs from two until twelve years of age is the period of rapid maturation of both fibre systems. This period is divided into two subperiods: a) the preoperational subperiod (or stage) which occurs from two until seven and is a period of organization for operations (rational logical thinking)--this subperiod matches the rapid myelination period of both fibre systems and ends as the communication fibre system between the hemispheres reaches maturation at seven years of age; b) the concrete operational subperiod which is the period of attainment of operations begins at seven years and lasts until twelve years which matches the period

of time when the fibres from the attention system are completing their cycle.

3. The formal operational period begins at twelve when the "control switch" fibres have completed their rapid cycle and extends into senility as does the continuing maturation of the fibres.

This observed parallel ontogeny suggests that Piaget's cognitive stages may be behavioral indices of the maturation of these two fibre systems. In other words, Piaget may have ingeneously developed a behavioral indication of the degree of interhemispheric communication and selective attention possible in children at a given developmental stage.

If this is so, the implications for parents, educators and psychologists could be significant. Before discussing these possible implications, however, several qualifiers should be discussed.

First, Piaget's logico-mathematical model is biased toward left hemispheric knowing as the criteria for success on most of his tasks is verbal-logical ability. Consequently, his tasks measure the increasing access of the logical-verbal system to visuo-spatial knowings. However, his recent investigations and writings appear to also be directed toward right hemispheric knowings (Piaget, 1969; 1970; Piaget and Inhelder, 1971). His suggestion that perceptual-imaginal knowing also has developmental stages which parallel the verbal-logical stages supports the hypothesis that these stages are behavioral indices of increasing interhemispheric communication and selective attention.

Second, the attention center (reticular activating system) previously discussed is just one of two (and possibly more) attention and arousal systems. Routtenberg (1968) postulates that cortical and autonomic arousal are two different systems. The cortical reticular activating system is suggested to be an attention-response activation system measured by EEG alpha inhibition, whereas, the autonomic-limbic system may be an affect or reinforcement related system measured by such physiological measurements as galvanic skin potential and heart rate. These measurements are further postulated as being indicators of internal and external attention (Kaiser and Sandman, in press).

Warren and Harris (1975) postulate that the relationship between these two systems may determine arousal, memory and motivation. Galin (1975) suggests that motivation as well as hemispheric specialization determines which functioning system attends to a given task. Consequently, the attention and cognition which can be inferred from indicators of reticular activating systems function as well as asymmetrical hemispheric functioning is limited.

Implications for Additional Research and Educational Application

1. Future investigations of asymmetrical hemispheric brain functioning should incorporate in the design blocking for hand-eye dominance and a larger sample randomly selected from a cross-section of the population.

2. Attention in this study was focused on right handed subjects. Future investigations of asymmetrical hemispheric brain functioning should assess differences between right handed and left handed subjects with various combinations of sex and hand-eye dominance.

3. Investigation of hypotheses generated from current research based on samples of subjects in which language and sequential processing was predominantly a left hemisphere function and spatial and synthetical processing was predominantly a right hemisphere functioning requires subjects which also have the same neurological organization. Therefore, careful screening of subjects to detect such possible neurological anomalies as reversed hemispheres, two synthetical processing hemispheres, or two sequential processing hemispheres is suggested for sample selection in future research. A reliable real time analyzer could be used for such purposes (Wheatley and Mitchell, 1975).

4. In addition to EEG measurement future research should include additional concommitant psyciological measurements associated with cognitive processing and

attention, such as heart rate, galvanic skin response (GSR), skin conductance and galvanic skin potentials (GSP) (Kaiser and Sandman, in press).

5. Future research should include considerations of designs which would provide better measurement of intra- and inter-hemispheric communication. The coupling concept might be considered (Calloway, 1975).

6. Future research should include other independent variables that may eventually be useful as predictors of task performance and efficient instruction techniques (e.g., cognitive style variables, school achievement variables).

7. Data from this study and other investigations (Dimond and Beaumont, 1974) suggests the possibility that spatial tasks having dynamic components which are hard to analyze or verbalize evoke greater right hemispheric functioning (e.g., flowing water or sand, moving complex patterns). To obtain baseline data concerning the degree of lateralization of right hemispheric processes such tasks should be considered in future research.

8. Data from this study clearly suggest that there may be different hemispheric demands within components of tasks. Therefore, careful consideration should be made in terms of these components when sampling EEG segments. The same analysis would be useful in designing research which would elucidate desired change in curriculum and instruction.

9. Data from this study suggests that a right hemisphere component was involved in successful performance of questions asked concerning visual and verbal stimuli. Interpretation of this data suggests discrete patterns of integrative or complementary hemispheric functioning during stimulus and response which are predictors of successful performance. Future investigations are implied assessing various stimuli (e.g., verbal vs spatial, visual vs auditory, concrete vs abstract, simple vs complex, static vs dynamic, two dimensional vs three dimensional) and the elicited response (e.g., question asking strategies) in relation to subjects' patterns of asymmetrical hemispheric functioning and performance measures.

10. Data from the reading task suggests a right hemispheric component to silent reading. Future investigations of reading are implied assessing possible hemispheric differences between reading modes (e.g., silent reading, oral reading, speed reading) and reading materials (e.g., passages with large percentages of concrete words or abstract words, picture books) (Paivio, 1969, 1971, 1974).

11. Interpretation of the data from this study suggests that differing integrative or complementary patterns of hemispheric functioning in components of the reading act and Piagetian tasks are predictors of successful readers and conservers. The data also suggest that subjects

with differing neurological organization had differing patterns of hemispheric functioning. However, the sample was too small to assess these patterns in relation to reading and Piagetian task performance. Future invdstigations are implied assessing hemispheric patterns in components of reading and Piagetian tasks and performance of these tasks between subjects with differing neurological organization.

12. Implications based on data from the reading task which implied that silent reading includes right hemispheric functioning and that successful readers are those who have greater right hemispheric functioning when being asked questions concerning the passage they read, would include assessing and planning instructional techniques with synthetical processes in mind and the possibility of including high imagery words in the beginning reading vocabulary lists (Bower, 1974; Paivio, 1972).

13. The interpretation of this study data suggests that successful solution to complex cognitive tasks requires complementary or integrative functioning of both hemispheres. Therefore attention might well be given to instructional techniques that engage both hemispheres (e.g., "hands on" approach to science and math instruction, audio-visual aids, mnemotic devices).

14. The developmental parallelism just discussed and supported by the findings of this study suggests further research in which the design would focus on investigation

of possible developmental "stages" or patterns of right hemispheric knowing (Bogan, 1975; Galin, 1975).

15. Data from high and low performers in this study suggest that improved hemispheric communication facilitates efficient task performance. Piaget (1970, p. 712) suggests that deviations in cognitive functioning may be influenced by pedagogical intervention. Therefore, research designed to employ biofeedback of physiological indices in such areas as selective attention and hemispheric brain functioning might assist children in more effective learning or in resolution of learning problems. This suggests a powerful application to education from groundwork laid in the present study (Nowlis and Kamiya, 1970; Ornstein and Galin, 1974). This further suggests the possibility that education of the future may be regarded as facilitating individual children's control of developing cognitive structures as well as the imparting of knowledge.

APPENDIX A

TASKS

READING TASK 1 & 2

There was a prince and there was a princess.

There was a king and there was a queen.

The king was the father, of course. The queen was the mother, of course. And the prince and princess were a little boy and girl. And there was a cat. He was a secret cat. The king and the queen did not know about the cat. He was the secret cat of the prince and princess. He could do magic tricks and they loved him.

The prince and princess are sad. Today is the queen's birthday. And they do not have a birthday present to give her.

"It is a shame," the princess says. "I am the princess and you are the prince, and we cannot get a birthday present to give to Mom."

"We can sell our crowns," says the prince.

"Sell our crowns?" the princess says. "NO! You are a prince and I am a princess. A prince and princess cannot sell their crowns."

"I know what we can do," says the prince. "That is a smart cat. Maybe we can trade him for something. Then we will have a present for Mom, the queen."

One morning the rain came down, down, down. Down on the houses! Down on the gardens! Everything looked pretty and green and new.

Peter looked out of the window. He saw puddles all up and down the street. Big puddles! Little puddles! Shining brown puddles!

"They are just the puddles to sail my boat on," said Peter. "I will go out and sail my boat now."

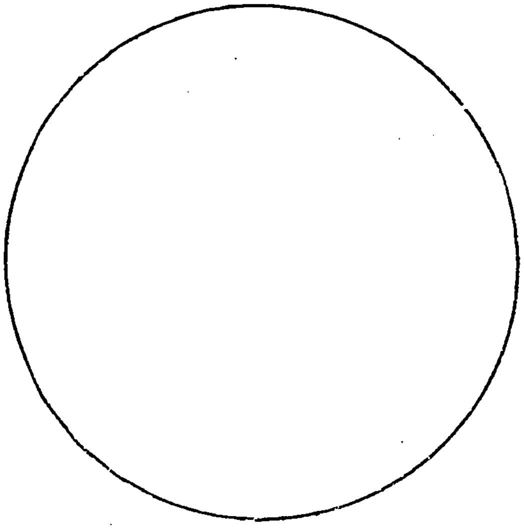
Peter's mother came to the window. She looked out at the rain. "You can not go out in the rain," she said. "The sun will come out again. Then you may go out to play. But you can not go go out in the rain."

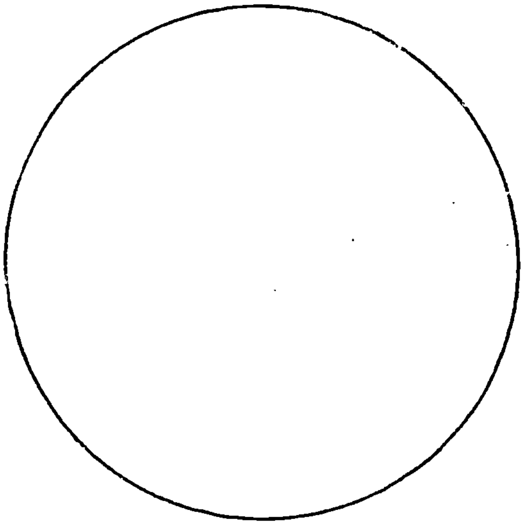
Peter's mother had work to do. She could not stay at the window with Peter. But Peter could stay at the window. And he did. Peter looked and looked at the rain. He looked and looked at the shining brown puddles.

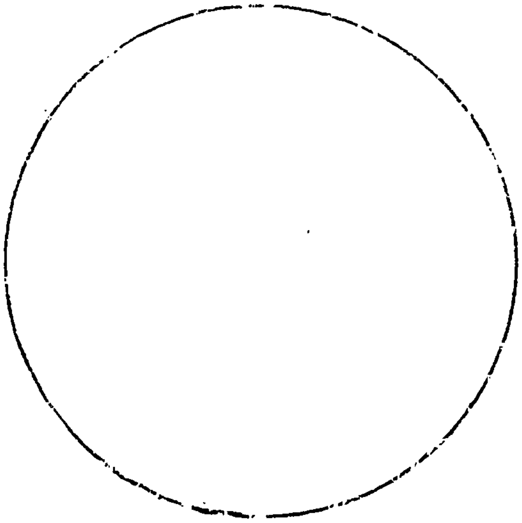
By and by Peter said, "This rain will go on and on. The sun will not come out." Then he looked at his boat. He looked at the puddles in the street. He looked at Mother. Mother was at work. She did not see Peter. So Peter put on his coat and cap. Then out of doors he ran.

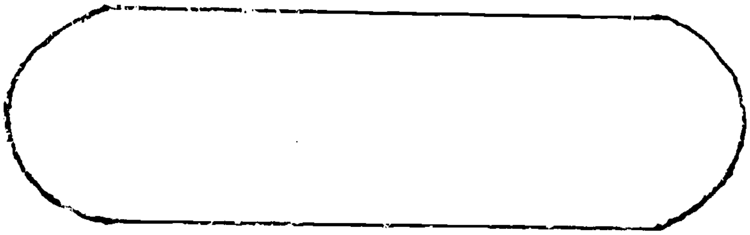
He ran up and down the street. He walked by all the big puddles. He jumped all the little puddles. He stopped to sail his boat on all the shining brown puddles.

CONSERVATION OF SUBSTANCE

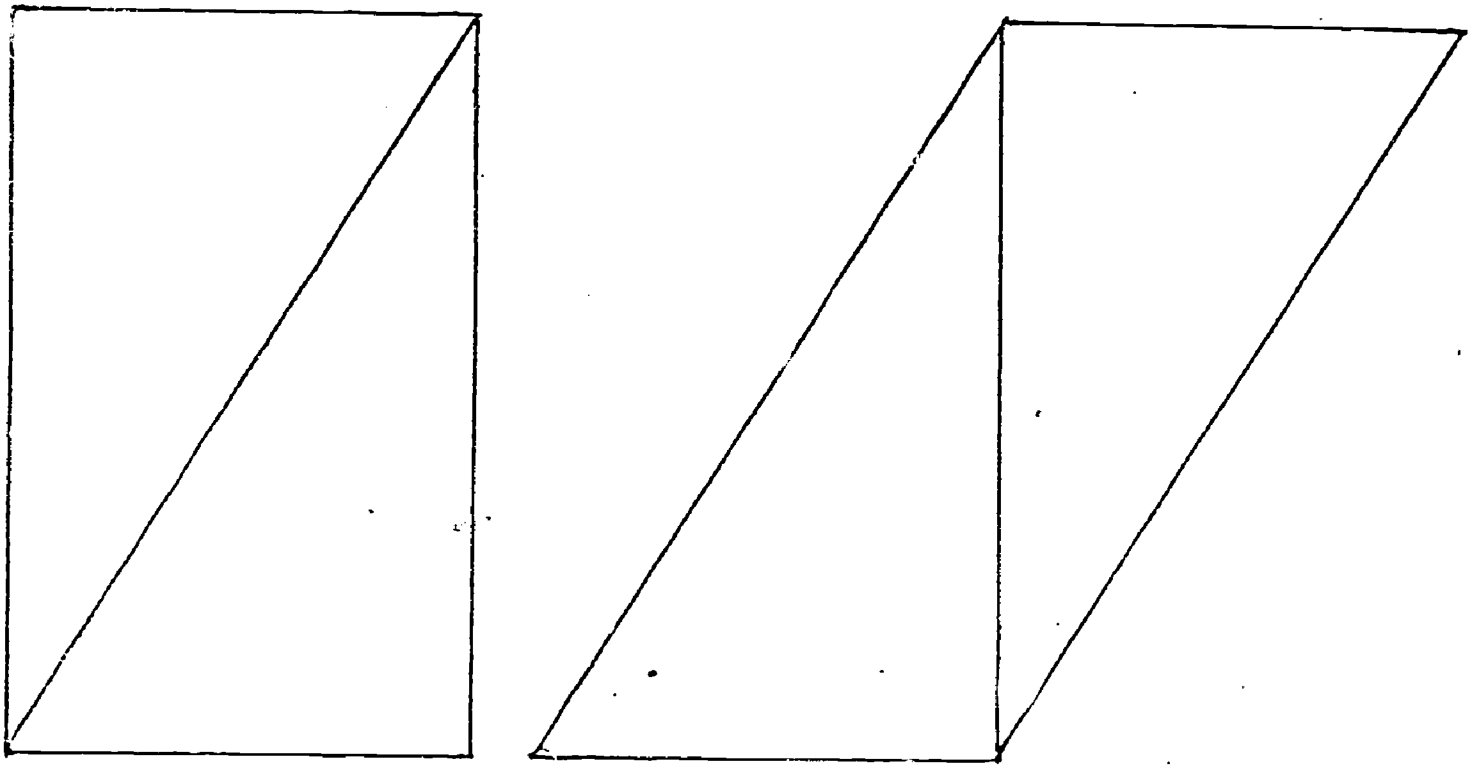




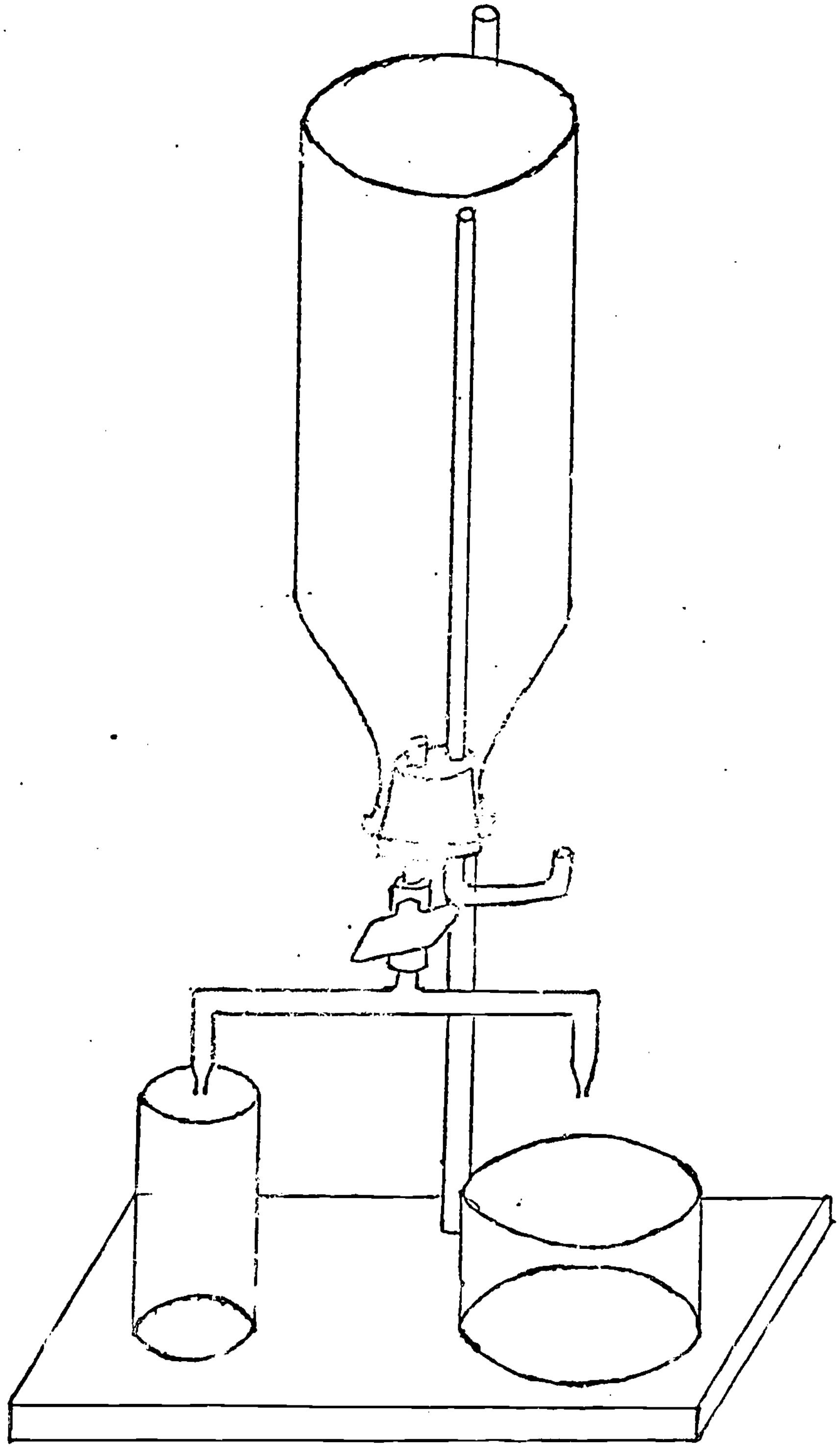




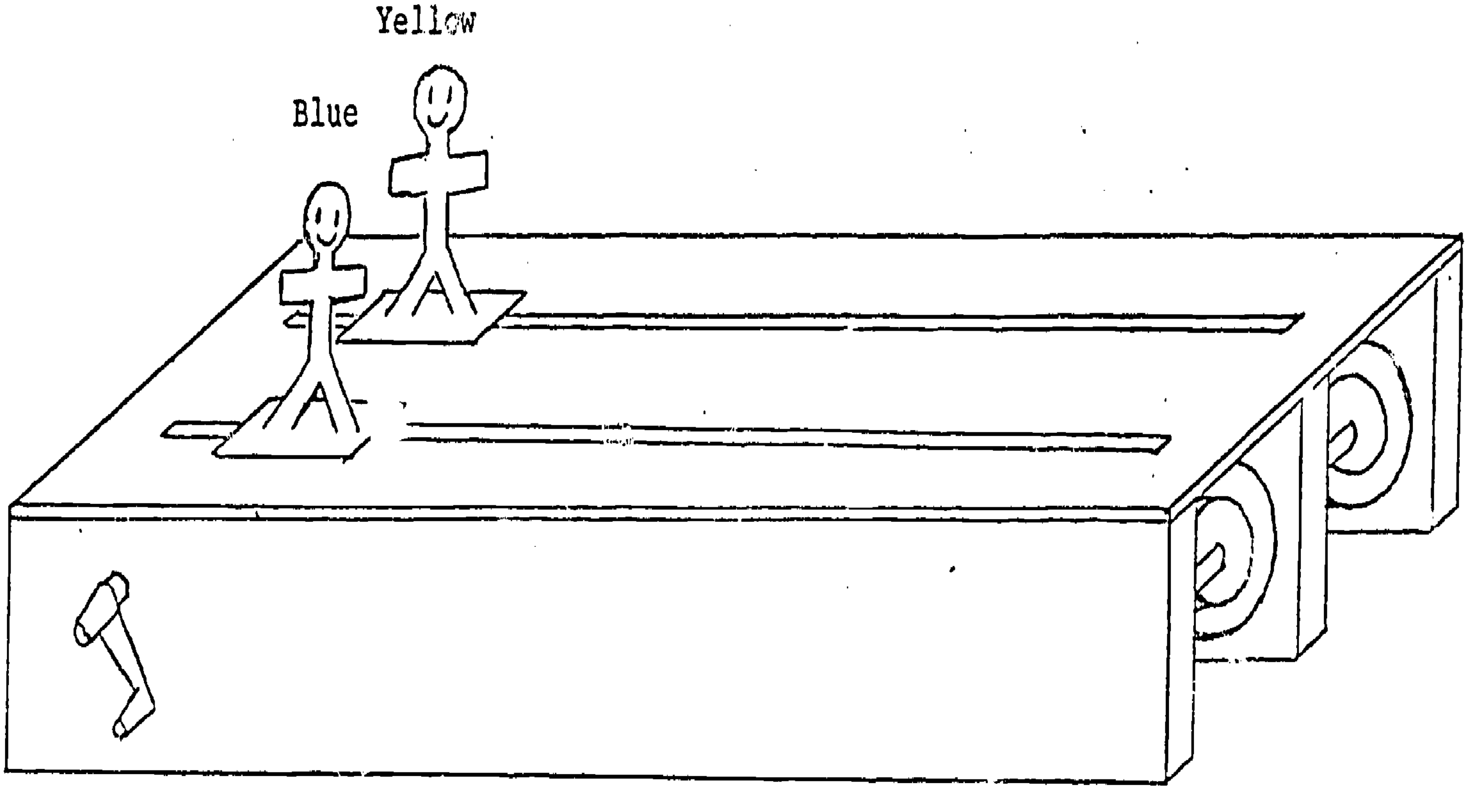
CONSERVATION OF AREA



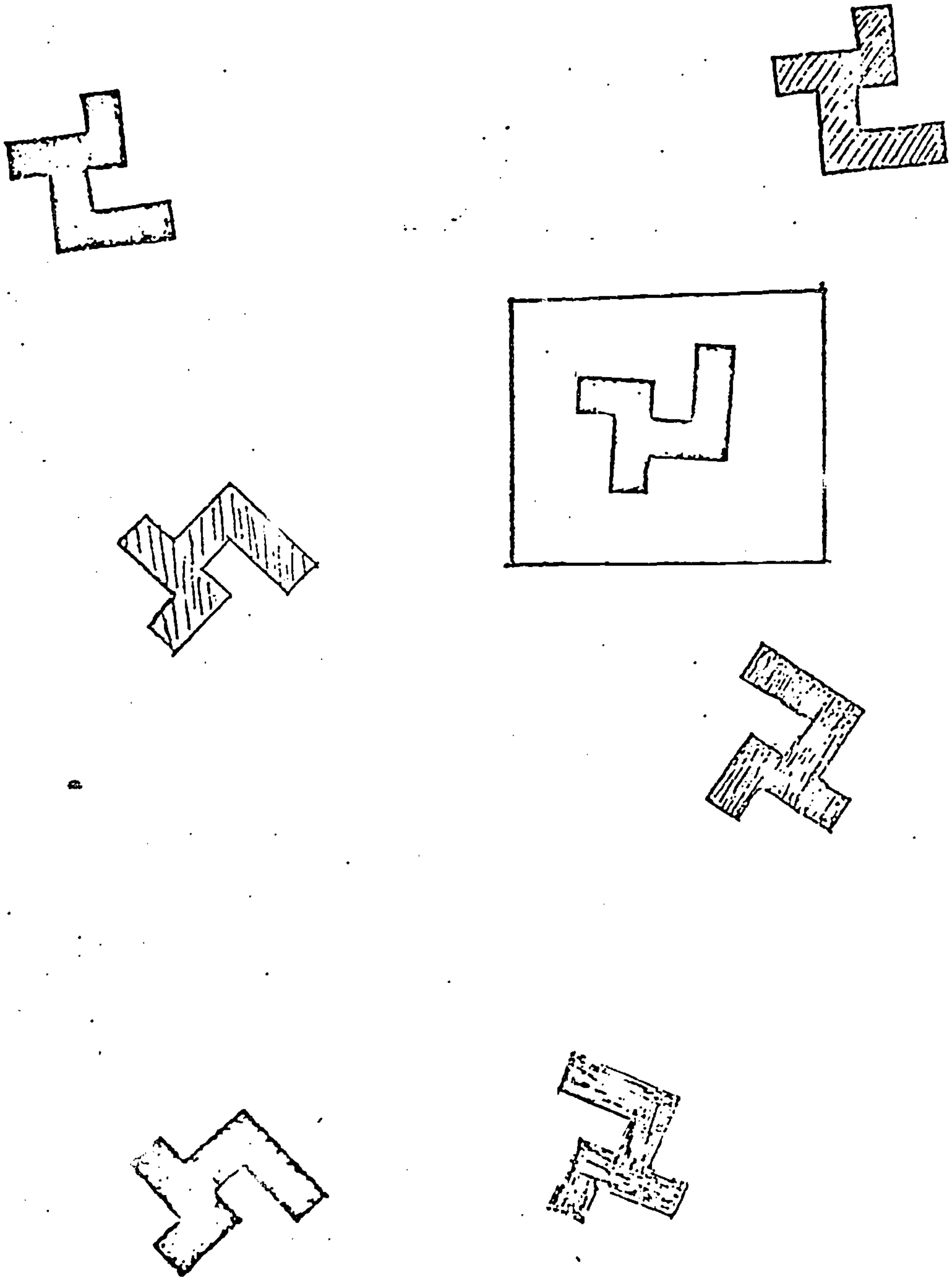
TIME-ORDERED LIQUID FLOW (WATERFLOW)



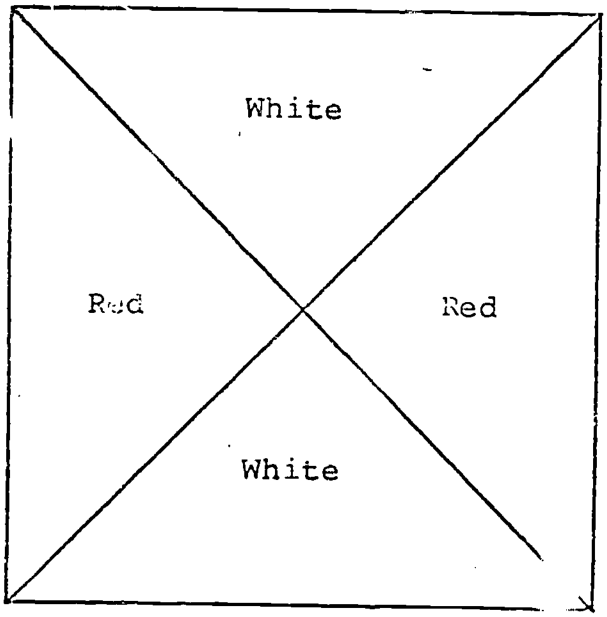
OBJECTS MOVING THROUGH TIME AND SPACE (DOLLRACE)



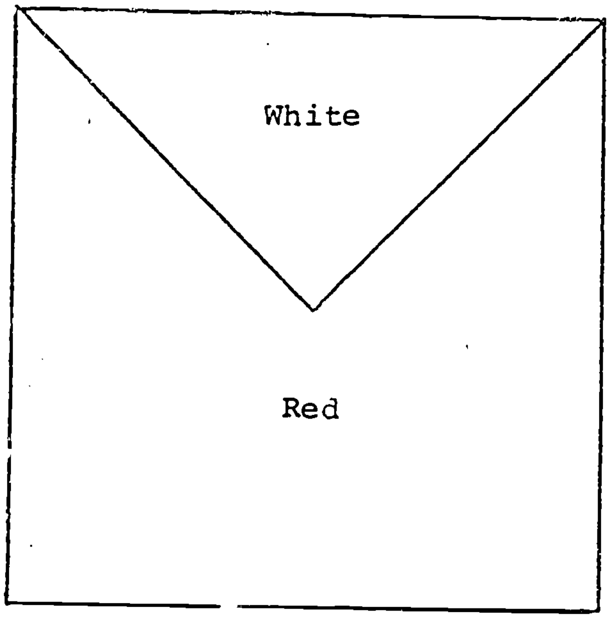
ROTATED FORMS



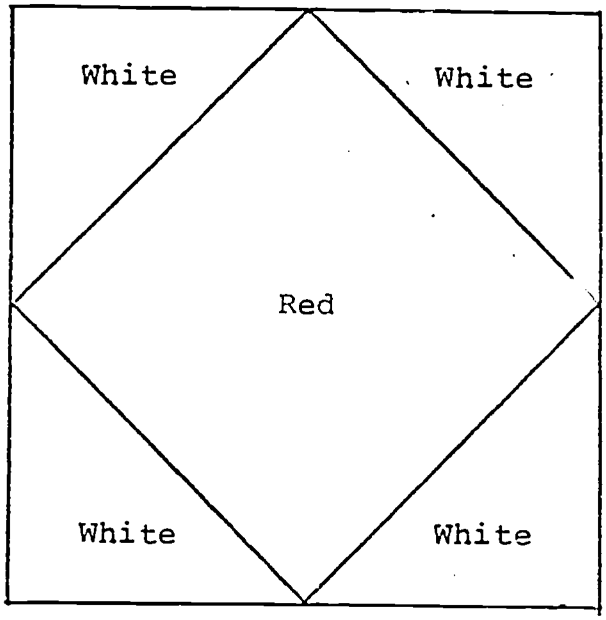
BLOCK DESIGN 1



BLOCK DESIGN 2

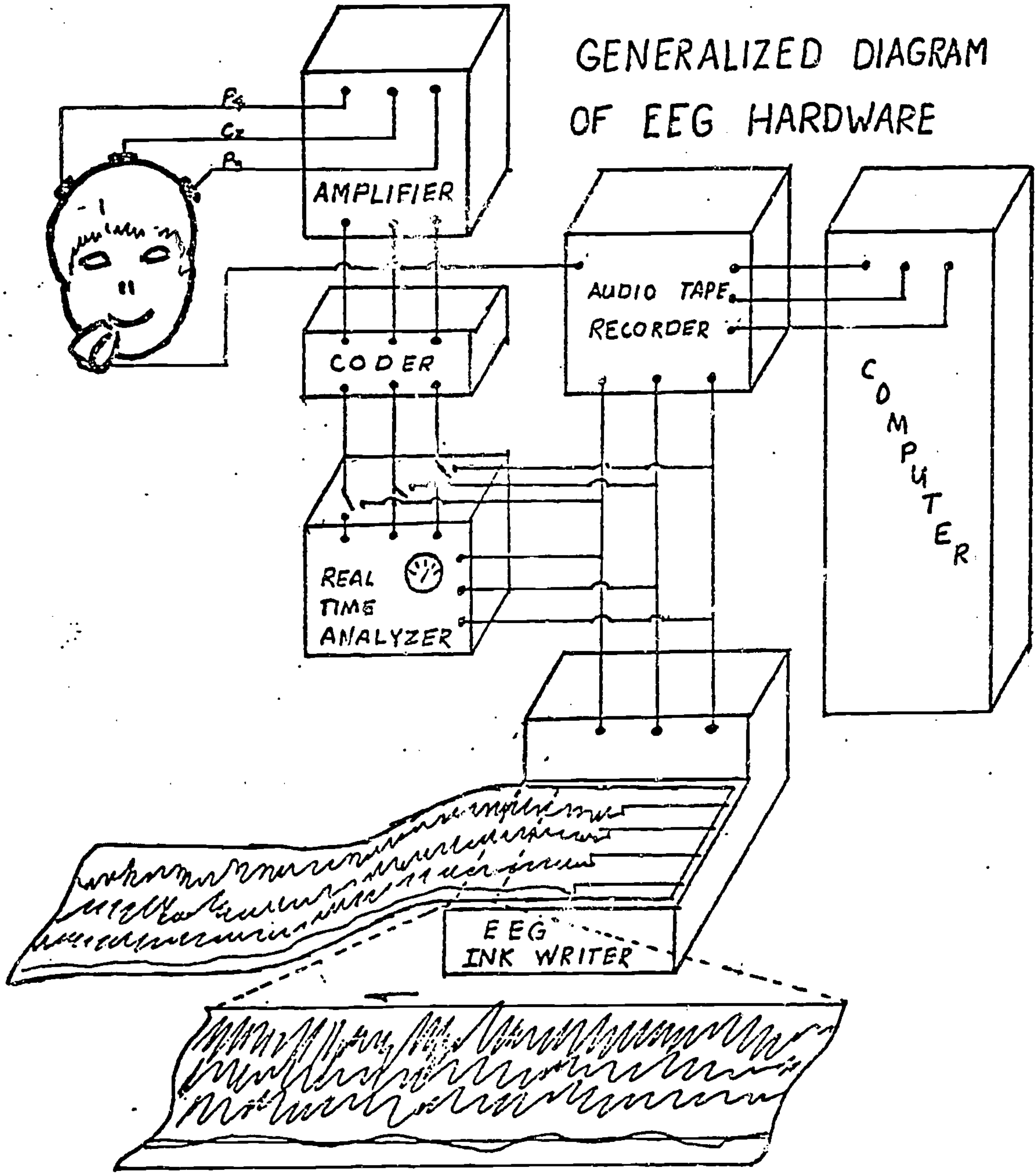


BLOCK DESIGN 3

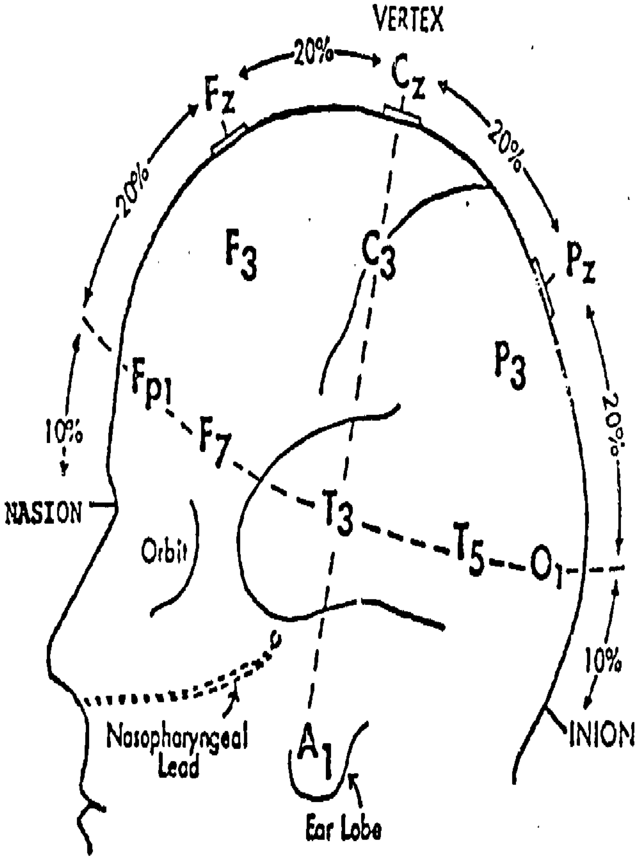


APPENDIX B

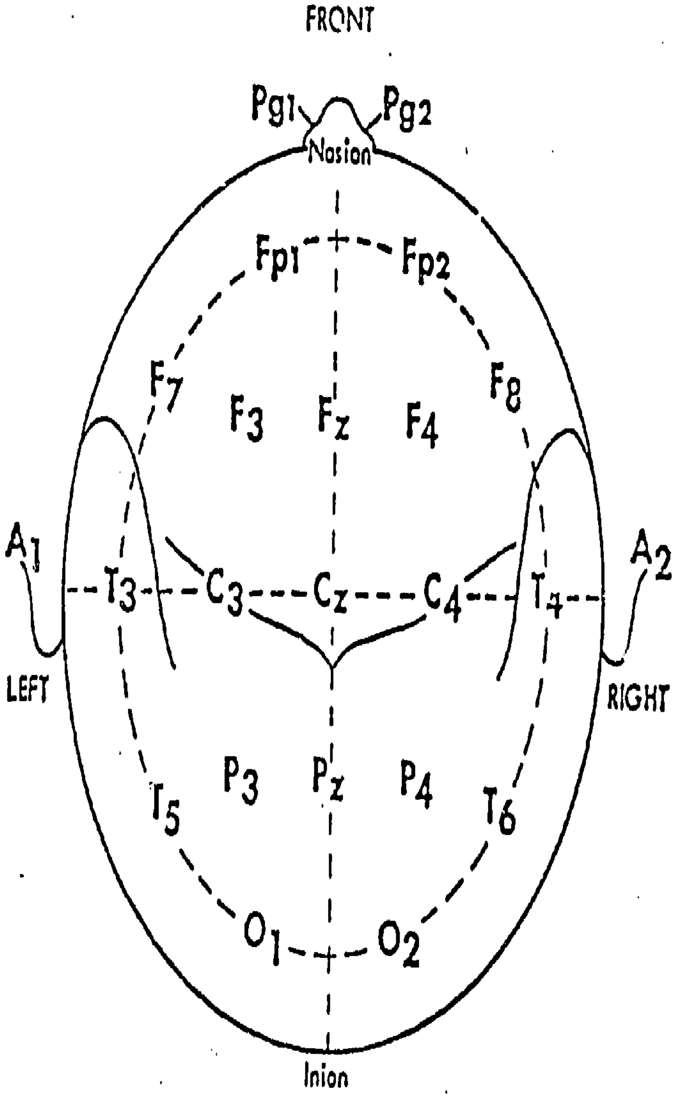
DESIGN AND LAYOUT


GENERALIZED DIAGRAM
OF EEG HARDWARE
P4
Cz
P3
AMPLIFIER
CODER
AUDIO TAPE
RECORDER
COMPUTER
REAL
TIME
ANALYZER
EEG
INK WRITER

INTERNATIONAL (10-20) ELECTRODE PLACEMENT

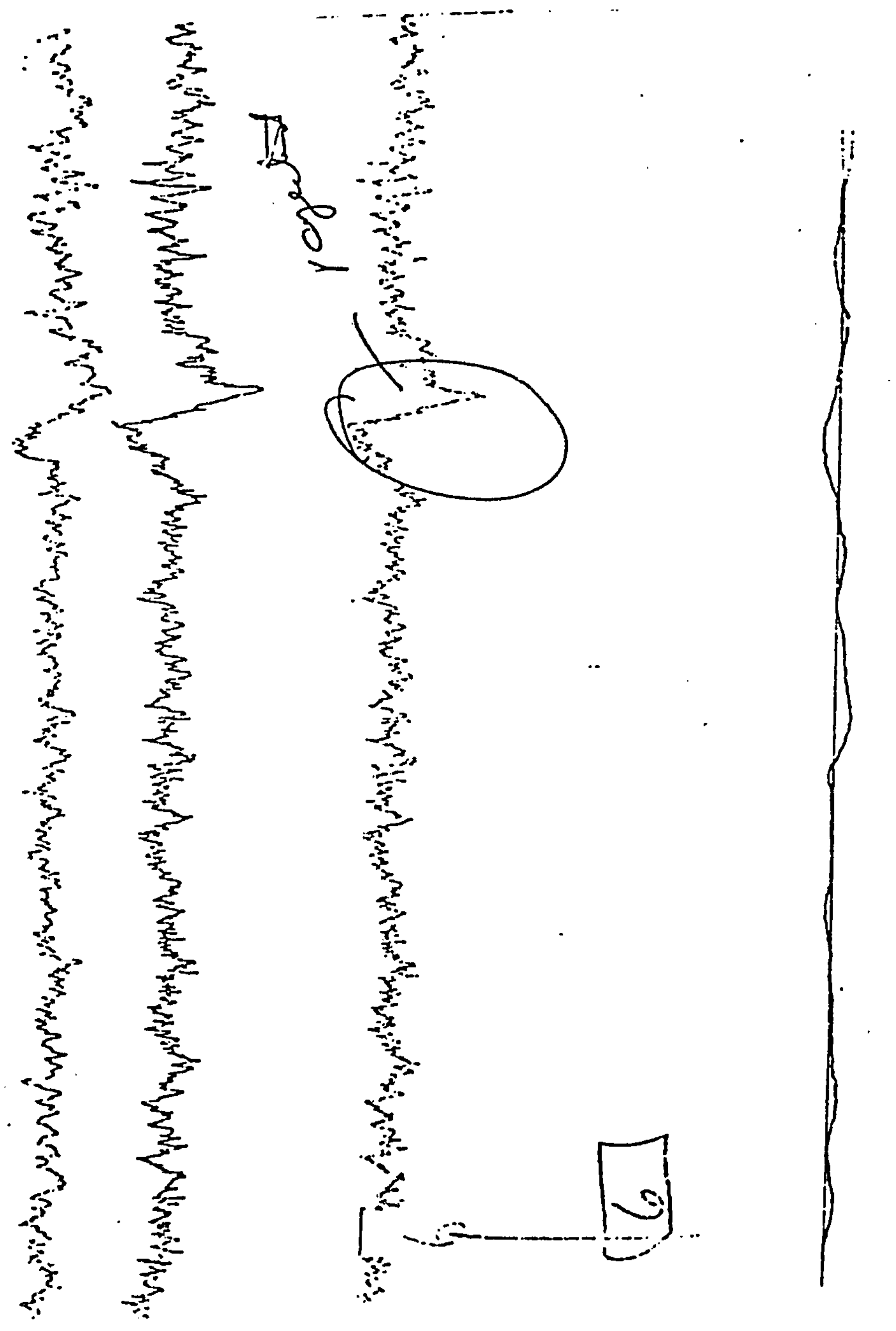


LEFT SIDE OF HEAD



TOP OF HEAD

EEG STRIP CHART



APPENDIX C

TABLES

Table 1: Survey of the Literature on EEG in Children and Adolescents.

Authors		n of cases	Age (years)	Focus of EEG Investigation
Bernard and Skoglund	1939a	200	0-30	Normative alpha activity
Bernard and Skoglund	1939b	130	0-45	Normative alpha activity
Corbin and Bickford	1955	71	1-10	Normative spectral analysis
Dreyfus-Brisac & Blanc	1957		0-5 mo.	EEG patterns/Piagetian theory
Gardiner et al	1973	2	0-5 mo.	AER/lateral asymmetry
Garsche	1956		0-15	Normative beta activity
Gibbs and Knott	1949	930	0-29	Normative spectral analysis
Henry	1944	890	3-19	Normative alpha activity
Kasamutsu et al	1964	233	1-10	Normative resting EEG
Knot et al	1942		8	Frequency analysis/IQ
Lindsley	1936	154	0-64	Normative alpha activity
Lindlsey	1938	326	1-64	Normative alpha activity/IQ
Lindlsey	1939	132	0-16	Normative alpha activity
Molfese	1972	31	0-25	AER/lateral asymmetry
Netchine and Lairy	1960	209	5-12	EEG rhythms and IQ
Netchine	1969	500	6-10	Resting EEG and intelligence
Novikova	1961	100	9-12	Resting EEG and intelligence
Stevens et al	1968		0-14	Frequency acceleration/Piaget
Walter	1953	200	0-20	Developmental frequency analysis

Table 2: Battery of Tasks Administered: Classification, Approximate Length of Time to Complete and Length of EEG Measurement

Classification of Tasks	Approximate Time of Task	EEG Segment Coded
Baseline (at rest)		
task 1a	30 seconds	30 seconds
task 1b	30 seconds	30 seconds
Baseline (spatial)		
task 2a Rotated Forms 1	1-2 minutes	30 seconds
task 2b Rotated Forms 2	1-2 minutes	30 seconds
task 3a Block Design 1	1-2 minutes	30 seconds
task 3b Block Design 2	1-2 minutes	30 seconds
task 3c Block Design 3	1-2 minutes	30 seconds
Baseline (curriculum related)		
task 4a Silent Reading 1	2-3 minutes	30 seconds
task 4b Silent Reading 2	1 minute	30 seconds
task 4c Comprehension	4 minutes	30 seconds
task 5a Mental Arithmetic	1/2-1 minute	30 seconds
task 5b Mental Arithmetic	1/2-1 minute	30 seconds
task 6 Syllogistic Logic	1-2 minutes	20 seconds
Piagetian Conservation Tasks		
Conservation of Substance		
task 7a Clay Initial	1/2-1 minute	30 seconds
task 7b Clay Subsequent	1 minute	20 seconds
Conservation of Area		
task 8a Initial	1/2-1 minute	30 seconds
task 8b Area Subsequent	1 minute	---
Piagetian Temporal Tasks		
Time-Ordered Liquid Flow (Waterflow)		
task 9a WF/VS Initial	1 minute	30 seconds
task 9b WF/VS Subsequent	3 minutes	20 seconds
task 9c WF/AV Initial	1 minute	30 seconds
task 9d WF/AV Subsequent	3 minutes	20 seconds
Objects Moving Through Time and Space (Dollrace)		
task 10a DR/VS Initial	1 minute	30 seconds
task 10b DR/VS Subsequent	3 minutes	20 seconds
task 10c DR/AV Initial	1 minute	30 seconds
task 10d DR/AV Subsequent	3 minutes	20 seconds

Table 3: Design and Raw Scores for a Three by Two Analysis of Variance for Repeated Measures of the following Piagetian Tasks: Conservation of Substance, Time-Ordered Liquid Flow/Visuo-Spatial and Objects Moving Through Time and Space/Visuo-Spatial

	A1		A2		A3	
Subjects	B1	B2	B1	B2	B1	B2
01	.43	.12	.11	.08	-.01	-.10
02	-.14	.11	.16	.07	-.06	.06
03	.17	.08	.26	-.19	-.05	.14
04	.14	-.19	.01	-.08	-.18	.06
05	.11	.08	.56	.11	.28	-.15
06	.39	.07	.55	-.12	-.06	.39
07	-.13	-.16	.02	-.28	.01	-.13
08	.08	-.13	.60	-.07	.22	-.03
09	.04	-.04	.24	.39	-.01	.31
10	.07	.29	.44	.08	-.24	-.16
11	-.05	-.23	-.02	-.05	.01	-.11
12	.14	-.17	.05	.26	-.04	.03
13	.05	.07	.16	.02	.16	-.04
14	.51	-.12	.20	.05	-.19	-.08
15	-.05	-.10	.16	.28	-.21	.00
16	.05	-.37	.24	-.21	-.41	-.76
17	.00	.19	-.14	-.11	-.24	-.10
18	-.06	.00	-.20	-.17	-.30	-.16

A = tasks: A1 = Clay, A2 = Waterflow, A3 = Dollrace
B = within task response: B1 = initial, B2 = subsequent

Table 4: Three by Two Analysis of Variance of the Differences Between Initial and Subsequent Responses on Three Piagetian Tasks: Conservation of Substance (Clay) Time-ordered Liquid Flow (WF/VSand Objects Moving Through Time Space (DR/VS)

Source of Variance	df	SS	MS	F	Significance Level
Tasks (A)	2/34	.443668	.221834	7.3308	.000225
Response (B)	1/17	.240833	.240833	5.9096	.02642
A x B	2/34	.216339	.108169	4.1730	.02395
Subjects/A	34	.010289	.030261		
Subjects/B	17	.692799	.040753		
Subjects/AB	34	.881328	.025921		
Subjects	17	.014065	.082734		

Table 5: Interactive Cell Mean Comparison Matrix of the Log L/R Alpha Power Ratios of Initial and Subsequent Responses of 6-8 Year Old Children During Performance of Piagetian Tasks for the Newman Keuls Test

$\bar{x}_3$	$\bar{x}_1$	$\bar{x}_4$	$\bar{x}_2$	$\bar{x}_6$	$\bar{x}_5$
.1889	.0972	.0033	-.0278	-.0461	-.0733
			2.88'	3.82*	4.07*
		4.41**	4.75**	4.99**	5.18**

	Mean	SD
$\bar{x}_1$	.0922	.183
$\bar{x}_2$	-.0278	.168
$\bar{x}_3$	.1889	.230
$\bar{x}_4$	.0033	.181
$\bar{x}_5$	-.0733	.180
$\bar{x}_6$	-.0461	.236

* significant at .05 level
' approaching significance

$\bar{x}_1$ = Mean initial response of Conservation of Substance

$\bar{x}_2$ = Mean subsequent response of conservation of Substance

$\bar{x}_3$ = Mean initial response of Time-ordered liquid flow

$\bar{x}_4$ = Mean subsequent response of Tume-ordered liquid flow

$\bar{x}_5$ = Mean initial response of Objects moving through time/space

$\bar{x}_6$ = Mean subsequent response of Objects moving through time/space

Table 6: Summary Table of Correlated t-tests of the Differences in the Alpha Power Ratios Between the Initial and Subsequent Responses of the Following Piagetian Tasks: Conservation of Substance, Time-Ordered Liquid Flow/Visuo-Spatial and Objects Moving Through Time and Space/Visuo-Spatial

task	mean of initial	SD	mean of subsequent	SD	df	t	level of significance
Clay	.0972	.183	-.0278	.168	17	2.25	.038
WF/VS	.1889	.206	.0033	.190	17	2.91	.01
DR/VS	-.0733	.180	-.0461	.236	17	-.49	.633

Clay = Conservation of Substance
WF/VS = Time-Ordered Liquid Flow/Visuo-Spatial
DR/VS = Objects Moving Through Time and Space/Visuo-Spatial

Table 7: Design and Raw Scores for the Multivariate Analysis for the Multivariate One Way Analysis of Variance for Repeated Measures Assessing Differences in log L/R Alpha Power Ratios of the Initial and Subsequent Responses and Performance Scores on Visuo-Spatial and Audio-Verbal Presentations of Time-Ordered Liquid Flow and Objects Moving Through Time and Space.

	A1			A2			A3			A4		
Subjects	I	S	P	I	S	P	I	S	P	I	S	P
01	.11	.08	2	.24	.02	2	-.01	-.10	2	-.12	.23	2
02	.16	.07	0	-.35	.17	2	-.06	.06	2	.35	.04	2
03	.26	-.19	0	.32	.23	0	-.05	.14	0	.05	.02	0
04	.01	-.08	0	-.06	-.11	2	-.18	.06	0	.11	-.12	0
05	.56	.11	2	-.14	.14	0	.28	-.15	0	.14	.02	0
06	.55	-.12	2	.13	-.10	2	-.06	-.13	0	.58	-.16	0
07	.02	-.28	2	-.02	-.03	2	.01	-.13	0	-.19	-.10	2
08	.60	-.07	0	-.07	.33	2	.22	-.03	2	.40	.18	2
09	.24	.39	0	.00	-.11	0	-.01	.31	0	.29	.19	2
10	.44	.08	0	-.05	.28	2	-.24	-.16	0	-.20	.22	0
11	-.02	-.05	0	.01	-.12	0	.01	-.11	0	.08	-.13	0
12	.05	.26	2	-.09	.08	2	-.04	.03	0	.18	.00	2
13	.16	.02	0	.04	-.01	0	.16	-.04	0	.03	-.11	0
14	.20	.05	0	.10	-.45	2	-.19	-.08	0	.12	-.19	0
15	.16	.28	0	.14	-.05	0	-.21	.00	0	.01	-.04	0
16	.24	-.21	0	-.08	-.14	0	-.41	-.76	0	-.12	-.19	0
17	-.14	-.11	0	.01	.29	0	-.24	-.10	0	-.08	.17	2
18	-.20	-.17	2	-.05	.03	2	-.30	-.16	2	-.14	.15	2

I = Initial Response
S = Subsequent Response
P = Performance Score

A1 = Time-Ordered Liquid Flow/Visuo-Spatial
A2 = Time-Ordered Liquid Flow/Audio-Verbal
A3 = Objects Through Time and Space/Visuo-Spatial
A4 = Objects Through Time and Space/Audio-Verbal

Table 8: Summary Table of the One-Way Multivariate Analysis of Variance for Repeated Measures (MANOVA) Assessing Differences in log L/R Alpha Power Ratios of the Initial and Subsequent Responses and Performance Scores on Visuo-Spatial and Audio-Verbal Presentations of Time-Ordered Liquid Flow and Objects Moving Through Time/Space: WF/VS, WF/AV, DR/VS and DR/AV.

Source of Variance Multivariate (Wilks Lambda Criterion)	F	df	level of significance	r
Roots: 1 - 3	3.340	9/119.404	.001	.574
2 - 3	1.883	4/99	.119	.369
3 - 3	.005	1/50	.942	.010

Univariate tests	F	df	ms	level of significance	SDFC	
					1	2
Initial	7.627	3/51	.226	.001	.965	.211
Subsequent	.487	3/51	.014	.693	.288	-.259
Performance Score	2.556	3/51	1.481	.065	.163	-.959

SDFC = Standardized discriminant function coefficients

Table 9: Design and Raw Scores for the One Way Multivariant Analysis of Variance Assessing Differences in the Initial Responses, Subsequent Responses and Performance Scores Between the Visuo-Spatial and Audio-Verbal Presentations of Time-Ordered Liquid Flow.

	A1			A2		
subjects	I	S	P	I	S	P
01	.11	.08	2	.24	.02	2
02	.16	.07	0	-.35	.17	2
03	.26	-.19	0	.32	.23	0
04	.01	-.08	0	-.06	-.11	2
05	.56	.11	2	-.14	.14	0
06	.55	-.12	2	.13	-.10	2
07	.02	-.28	2	-.02	-.03	2
08	.60	-.07	0	-.07	.33	2
09	.24	.39	0	.00	-.11	0
10	.44	.08	0	-.05	.28	2
11	-.02	-.05	0	.01	-.12	0
12	.05	.26	2	-.09	.08	2
13	.16	.02	0	.04	-.01	0
14	.20	.05	0	.10	-.45	2
15	.16	.28	0	.14	-.05	0
16	.24	-.21	0	-.08	-.14	0
17	-.14	-.11	0	.01	.29	0
18	-.20	-.17	2	-.05	.03	2

A = Tasks presentation: A1 = visuo/spatial, A2 = audio/verbal
I = Initial response ratios
S = Subsequent response ratios
P = Performance scores

Table 10: One-Way Multivariate Analysis of Variance for Repeated Measures (MANOVA) Assessing Differences in Log L/R Alpha Power Ratios of the Initial and Subsequent Responses and Performance Scores on Visuo-Spatial and Audio-Verbal Presentations of Time-Ordered Liquid Flow: WF/VS and WF/AV

Source of Variance Multivariate (Wilks Lambda Criterion)	F	df	level of significance	r
Roots: 1 - 1	2.891	3/15	.07	.605

Univariate tests	F	df	ms	level of significance	SDFC
Initial	3.130	1/17	.306	.011	.846
Subsequent	0.013	1/17	.000	.909	-.067
Performance Score	2.956	1/17	.104	.104	-.425

SDFC = Standardized discriminant function coefficients

Table 11: Design and Raw Scores (Subtracted from Baseline) for the Two by Two Analysis of Variance for Repeated Measures Assessing Differences in Log L/R Alpha Power Ratios Of the Initial and Subsequent Responses on Visuo-Spatial and Audio-Verbal Presentations of Time-Ordered Liquid Flow

	A1		A2	
	B1	B2	B1	B2
subjects				
01	.11	.08	.24	.02
02	.16	.07	-.35	.17
03	.26	-.19	.32	.23
04	.01	-.08	-.06	-.11
05	.56	.11	-.14	.14
06	.55	-.12	.13	-.10
07	.02	-.28	-.02	-.03
08	.60	-.07	-.07	.33
09	.24	.39	.00	-.11
10	.44	.08	-.05	.28
11	-.02	-.05	.01	-.12
12	.05	.26	-.09	.08
13	.16	.02	.04	-.01
14	.20	.05	.10	-.45
15	.16	.28	.14	-.05
16	.24	-.21	-.08	-.14
17	-.14	-.11	.01	.29
18	-.20	-.17	-.05	.03

A = Performance Mode A_1 = visuo-spatial A_2 = audio-verbal
B = Response B_1 = initial B_2 = subsequent

Table 12: Two by Two Analysis of Variance for Repeated Measures (ANOVA) Assessing Differences in the Initial and Subsequent Responses Between Visuo-Spatial and Audio-Verbal Presentations of Time-Ordered Liquid Flow: WF/VS, WF/AV

Sources of Variance	df	ss	ms	F	level of significance
Tasks (A)	1/17	.1136	.1136	2.7154	.11774
Responses (B)	1/17	.1168	.1168	3.1254	.09502
A x B	1/17	.1984	.1984	5.620	.02980
subjects/A	17	.7112	.0418		
subjects/B	17	.6353	.0374		
subjects/AB	17	.5413	.0318		
subjects	17	.6109	.0349		

Table 13: Interactive Cell Mean Comparison Matrix of the Log L/R Alpha Power Ratios of Initial and Subsequent Responses of Six to Eight Year Old Children During Performance of the Piagetian Temporal Task, Time-Ordered Liquid Flow, Presented Visuo-Spatially and Audio-Verbally

$\bar{x}_1$	$\bar{x}_4$	$\bar{x}_3$	$\bar{x}_2$
....	2.985*	3.63*	4.025*

	Mean	SD
$\bar{x}_1$	.1889	.230
$\bar{x}_2$	.0033	.181
$\bar{x}_3$	.0044	.149
$\bar{x}_4$	.0250	.195

* significant at the .05 alpha risk level

$\bar{x}_1$ = WF/VS initial response
$\bar{x}_2$ = WF/VS subsequent response
$\bar{x}_3$ = WF/AV initial response
$\bar{x}_4$ = WF/AV subsequent response

Table 14: Design and Raw Scores for the One Way Multivariate Analysis of Variance for Repeated Measures Assessing Differences in log L/R Alpha Power Ratios of the Initial and Subsequent Responses and Performance Scores on Visuo/Spatial and Audio/Verbal Presentations of Objects Moving Through Time and Space

	A1			A2		
Subjects	I	S	P	I	S	P
01	-.01	-.10	2	-.12	.23	2
02	-.06	.06	2	.35	.04	2
03	-.05	.14	0	.05	.02	0
04	-.18	.06	0	.11	-.12	0
05	.28	-.15	0	.14	.02	0
06	-.06	-.13	0	.58	-.16	0
07	.01	-.13	0	-.19	-.10	2
08	.22	-.03	2	.40	.18	2
09	-.01	.31	0	.29	.19	2
10	-.24	-.16	0	-.20	.22	0
11	.01	-.11	0	.08	-.13	0
12	-.04	.03	0	.18	.00	2
13	.16	-.04	0	.03	-.11	0
14	-.19	-.08	0	.12	-.19	0
15	-.21	.00	0	.01	-.04	0
16	-.41	-.76	0	-.12	-.19	0
17	-.24	-.10	0	-.08	.17	2
18	-.30	-.16	2	-.14	.15	2

I = Initial Response
S = Subsequent Response
P = Performance Score
A1 = Objects Through Time and Space/Visuo-Spatial
A2 = Objects Through Time and Space/Audio-Verbal

Table 15: Summary Table of the One-Way Multivariate Analysis of Variance for Repeated Measures (MANOVA) Assessing Differences in Log L/R Alpha Power Ratios of Subjects Initial and Subsequent Responses and Performance Scores On Visuo-Spatial and Audio-Verbal Presentations of Objects Moving Through Time/Space

Source of Variance

Multivariate (Wilks lambda criterion)	F	df		level of significance	r
Roots: 1 - 1	6.905	3/15		.004	.762
Univariate tests	F	df	ms	level of significance	SDFC
Initial	9.575	1/17	.219	.007	.971
Subsequent	.839	1/17	.028	.373	.638
Performance	4.857	1/17	1.778	.042	.570

SDRC = Standardized discriminant function coefficients

Table 16: Design and Raw Scores (Subtracted from Baseline) for the Two by Two Analysis of Variance for Repeated Measures Assessing Differences in Log L/R Alpha Power Ratios of the Initial and Subsequent Responses on Visuo-Spatial and Audio-Verbal Presentations of Objects Moving Through Time and Space

	A1		A2	
subjects	B1	B2	B1	B2
01	-.01	-.10	-.12	-.23
02	-.06	.06	.35	.04
03	-.05	.14	.05	.02
04	-.18	.06	.11	-.12
05	.28	-.15	.14	.02
06	-.06	-.13	.58	-.16
07	.01	-.13	-.19	-.10
08	.22	-.03	.40	.18
09	-.01	.31	.29	.19
10	-.24	-.16	-.20	.22
11	.01	-.11	.08	-.13
12	-.04	.03	.18	.00
13	.16	-.04	.03	-.11
14	-.19	-.08	.12	-.19
15	-.21	.00	.01	-.04
16	-.41	-.76	-.12	-.19
17	-.24	-.10	-.08	.17
18	-.30	-.16	-.14	.15

A = Performance Mode A_1 = visuo-spatial A_2 = audio-verbal
B = Response B_1 = initial B_2 = subsequent

Table 17: Summary Table for a Two by Two Analysis of Variance for Repeated Measures (ANOVA) Assessing Differences in Six to Eight Year Old Children's Initial and Subsequent Responses (Measured by Log L/R Alpha Power Ratios) Between Visuo-Spatial and Audio-Verbal Presentations of the Piagetian Temporal Task: Objects Moving Through Time/Space

Sources of Variance	df	ss	ms	F	level of significance
Task (A)	1/17	.20267	.20267	12.5572	.00250
Response (B)	1/17	.00934	.00934	.3497	.56207
A x B	1/17	.04500	.04500	1.1099	.30685
subjects/A	17	.27438	.01614		
subjects/B	17	.45401	.02671		
subjects/AB	17	.68924	.04054		
subjects	17	.01256	.07388		

Table 18: Correlation Matrix of the Intercorrelations Between the log L/R Alpha Power Ratios of Subjects' Initial and Subsequent Responses During Performance of Piagetian Tasks

	Clay I	AreaI I	WF/VS I	DR/VS I	WF/AV I	DR/AV I	Clay S	WF/VS S	DR/VS S	WF/AV S	DR/AV S
ClayI	1.00	.51	.33'	.03	.54**	.46*	.10	.08	.21	-.41*	-.13
AreaI		1.00	.29	.04	.36'	.37'	-.11	.04	.07	-.09	-.07
WF/VSI			1.00	.45*	.01	.51*	.17	.14	.16	.07	.02
DR/VSI				1.00	-.04	.40*	.14	.19	.37'	.15	.10
WF/AVI					1.00	.28	.10	-.09	.23	-.16	-.02
DR/AVI						1.00	-.18	.17	.53**	-.30	-.17
ClayS							1.00	.14	.36'	.64***	.60***
WF/VSS								1.00	.35'	-.06	.29
DR/VSS									1.00	.04	.15
WF/AVS										1.00	.64***
DR/AVS											1.00

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance
WF/VS = Time Ordered Liquid Flow/ visuo-spatial
WF/AV = Time Ordered Liquid Flow/ audio-verbal
DR/VS = Objects Moving Through Time and Space/ visuo-spatial
DR/AV = bjects Moving hrough Time and Space/ visuo-spatial

' = approaching significance
* = significant (p .05)
** = significant (p .01)
*** = significant (p .005)

Table 19: Correlation Matrix of the log L/R Alpha Power Ratios of Subjects' Initial and Subsequent Responses During Performance of Piagetian Tasks and the log L/R Alpha Power Ratios of Subjects' Performance During Spatial, Verbal, Logical and Mathematical Tasks

	R1	R2	BD1	BD2	BD3	SRD1	RDQ	SRD2	LV	MA1	MA2
Clay I	-.17	.19	.13	-.10	.38'	.52**	.03	.18	.21	-.23	-.37'
Area I	-.15	-.11	-.04	-.11	-.11	.31	.13	.20	.30	.09	.21
WF/VS I	.21	.37'	.09	-.08	-.30	.58**	-.01	.15	.18	.04	.04
DR/VS I	.66***	.41*	.33'	.02	-.15	.42*	.18	.34'	-.03	.04	.07
WF/AV I	-.16	.03	.21	-.09	-.09	.29	.14	.02	.52**	-.15	-.05
DR/AV I	-.12	.28	.33'	-.30	-.24	.34'	.29	.57**	.19	.003	.21
Clay S	.30	-.03	.37'	.27	.44*	.41*	.08	.001	.04	.13	-.01
WF/VS S	.32'	.04	.16	-.01	-.36	.47*	.02	.63***	.16	.54**	-.01
DR/VS S	.004	.06	.53**	-.09	.08	.33'	.31	.42*	.44*	.15	.01
WF/AV S	.43*	-.15	.34'	.51*	.60***	.14	.32'	-.07	.07	.47*	.52*
DR/AV S	.35'	-.09	.57**	.57**	.44*	.43*	.44*	.36'	-.02	.51*	.22

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance
Area = Conservation of Area
WF = Time-Ordered Liquid Flow
DR = Objects Through Time and Space
VS = isuo-Spatial Presentation
AV = Audio-Verbal Presentation

R = Rotated Forms
BD = Block Design
SRD = Silent Reading
RDQ = Reading Comprehension Questions
LV = Syllogistic Logic
MA = Mental Arithmetic
' = Approaching Significance
* = Significant(p = .05)
** = Significant(p = .01)
*** = Significant(p =.005)

Table 20: Raw scores (subtracted from baseline) of the log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks of Concrete and Preoperational Subjects

	Area	Clay	Clay.	WF/VS	WF/VS	WF/AV	WF/AV	DR/VS	DR/VS	DR/AV	DR/AV
	I	I	S	I	S	I	S	I	S	I	S
Concrete Operational subjects											
01	.14	.43	.12	.11	.08	.24	.02	-.01	-.10	-.12	.23
02	-.14	-.14	.11	.12	.07	-.35	.17	-.06	.06	-.35	.04
05	.11	.11	.08	.56	.11	-.14	.14	.28	-.15	.14	.02
06	.18	.39	.07	.55	-.12	.13	-.10	-.06	.39	.58	-.16
07	-.02	-.13	-.16	.02	-.28	-.02	-.03	.01	-.13	-.19	-.10
15	-.17	-.05	-.10	.16	.28	-.09	-.05	-.21	.00	.01	-.04
16	.16	.05	-.37	.24	-.21	.04	-.14	-.41	-.76	-.12	-.19
17	-.06	.00	.19	-.14	-.11	.10	.29	-.24	-.10	-.08	.17
18	-.12	-.06	.00	-.20	-.17	.14	.03	-.30	-.16	-.14	.15
Pre-operational subjects											
03	.25	.17	.08	.26	-.19	.32	.23	-.05	.14	.05	.02
04	-.05	.14	-.19	.01	-.08	-.06	-.11	-.18	.06	.11	-.17
08	-.07	.08	-.13	.60	-.07	-.05	.10	.22	-.03	.40	.18
09	.16	.04	-.04	.24	.39	.00	-.11	-.01	.31	.29	.19
10	.04	.07	.29	.44	.08	-.05	.28	-.24	-.16	-.20	.22
11	.10	-.05	-.23	-.02	-.05	.01	-.12	.01	-.11	.08	-.13
12	.21	.14	-.17	.05	.26	-.08	.08	-.04	.03	.18	.00
13	-.16	.05	.07	.16	.02	.01	-.01	.16	.04	.03	-.11
14	.06	.51	-.12	.20	.05	-.05	-.45	-.19	-.08	.12	-.19

I = Initial Response

S = Subsequent Response

Clay = Conservation of Substance

Area = Conservation of Area

WF/VS = Time-ordered Liquid Flow/Visuo-spatial

WF/AV = Time-ordered Liquid Flow/Audio-verbal

DR/VS = Objects Moving Through Time and Space/Visuo-spatial

DR/AV = Objects Moving Through Time and Space/Audio-verbal

Table 21: Summary Table of the Results of a Discriminant Analysis Assessing Patterns of log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks which would Best Predict Concrete and Preoperational Subjects

Discriminant Function	Eigenvalue	r	Wilks Lambda	Chi Square	df	significance level
1	.24881	.446	.8008	2.333	11	.997

Tasks	mean	SD	SDFC
AreaI	.0344	.1363	-.04185
ClayI	.0972	.1831	-.16561
ClayS		.1678	.41316
WF/VSI	.1889	.2304	.02625
WF/VSS	.0033	.1812	-.20788
WF/AVI	.0056	.1487	-.07284
WF/AVS	.0122	.1804	-.15055
DR/VSI	-.0733	.1804	-.13882
DR/VSS	-.0461	.2360	-.23376
DR/AVI	.0439	.2285	-.04964
DR/AVS	.0100	.1484	-.04900

SDFC = Standardized Discriminant Function Coefficient

Table 22: Raw Scores (Subtracted from Baseline) of the Log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks of Males and Females

	Area	Clay	Clay	WF/VS	WF/VS	WF/AV	WF/AV	DR/VS	DR/VS	DR/AV	DR/AV
	I	I	S	I	S	I	S	I	S	I	S
Female Subjects											
01	.14	.43	.12	.11	.08	.24	.02	-.01	-.10	-.12	.23
02	-.14	-.14	.11	.12	.07	-.35	.17	-.06	.06	-.35	.04
03	.25	.17	.08	.26	-.19	.32	.23	-.05	.14	.05	.02
04	-.05	.14	-.19	.01	-.08	-.06	-.11	-.18	.06	.11	-.12
07	-.02	-.13	-.16	.02	-.28	-.02	-.03	.01	-.13	-.19	-.10
10	.04	.07	.29	.44	.08	-.05	.28	-.24	-.16	-.20	.22
11	.10	-.05	-.23	-.02	-.05	.01	-.12	.01	-.11	.08	-.13
13	-.16	.05	.07	.16	.02	.01	-.01	.16	.04	.03	-.11
18	-.12	-.06	.00	-.20	-.17	.14	.03	-.30	-.16	-.14	.15
Male Subjects											
05	.11	.11	.08	.56	.11	-.14	.14	.28	-.15	.14	.02
06	.18	.39	.07	.55	-.12	.13	-.10	-.06	.39	.58	-.16
08	-.07	.08	-.13	.60	-.07	-.05	.10	.22	-.03	.40	.18
09	.16	.04	-.04	.24	.39	.00	-.11	-.01	.31	.29	.19
12	.21	.14	-.17	.05	.26	-.08	.08	-.04	.03	.18	.00
14	.06	.51	-.12	.20	.05	-.05	-.45	-.19	-.08	.12	-.19
15	-.17	-.05	-.10	.16	.28	-.09	-.05	-.21	.00	.01	-.04
16	.16	.05	-.37	.24	-.21	.04	-.14	-.41	-.76	-.12	-.19
17	-.06	.00	.19	-.14	-.11	.10	.29	-.24	-.10	-.08	.17

I = Initial Response

S = Subsequent Response

Area = Conservation of Area

Clay = Conservation of Substance

WF/VS = Time-ordered Liquid Flow/Visuo-spatial

WF/AV = Time-ordered Liquid Flow/Audio-verbal

DR/VS = Objects Moving Through Time and Space/Visuo-spatial

DR/AV = Objects Moving Through Time and Space/Audio-verbal

Table 23: Summary Table of the Results of a Discriminant Analysis Assessing Patterns of Log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks Which Would Best Predict Male and Female Gender

Discriminant Function	Eigenvalue	r	Wilks Lambda	Chi Square	df	significance level
1	1.90814	.810	.3439	11.209	11	.429

Tasks	Mean	SD	SDFC
AreaI	.0344	.1363	-.02590
ClayI	.0972	.1831	.00485
ClayS	-.0278	.1678	.03938
WF/VSI	.1889	.2304	.01211
WF/VSS	.0033	.1812	.20741
WF/AVI	.0056	.1487	-.05488
WF/AVS	.0122	.1804	.07354
DR/VSI	-.0733	.1804	-.14540
DR/VSS	-.0461	.2360	-.25951
DR/AVI	.0439	.2285	.46375
DR/AVS	.0100	.1484	-.04287

SDFC = Standardized Discriminant Function Coefficient

Table 24: Correlations Between Parallel Forms of the Same Task

Task	r	significanc
Silent Reading 1 Silent Reading 2	.45	.031
Rotated Forms 1 Rotated Forms 2	.35	.074
Block Design 1 Block Design 2	.44	.035
Mental Arithmetic 1 Mental Arithmetic 2	.43	.04

Table 25: T-Test of the Differences Between the log L/R Alpha Power Ratios Measured During the Silent Reading 1 Task and the Reading Comprehension Questions

Source of Variance	mean	SD	df	t	Level of Significance
SRD1	.0694	.135	17		
RDQ	-.0733	.183	17	2.94	.009

SRD1 = Silent Reading 1 Task
RDQ = Reading Comprehension Questions

Table 26: Table of Raw Scores of the log L/R Alpha Power Ratios (subtracted from baseline) of the Responses and Performance Scores for the Following Tasks: Reading, Conservation of Substance, Objects Moving Through Time and Space/Visuo-Spatial, Objects Moving Through Time and Space/Audio-Verbal, Time-Ordered Liquid Flow/Visuo-Spatial and Time-Ordered Liquid Flow/Audio-Verbal. The sex and hand-eye Dominance of each Subject is also Listed.

				Clay			WF/VS			DR/VS			WF/AV			DR/AV			Reading.		
Group	Subject	SEX	ED	I	S	P	I	S	P	I	S	P	I	S	P	I	S	P	I	S	P
RDF	01	F	R	43	12	2	11	08	2	-01	-10	2	24	02	2	-12	23	2	32	19	2
RDF	02	F	R	-14	11	2	16	07	0	-06	06	2	-35	17	2	-35	04	2	-01	-12	2
RDF	03	F	R	17	08	0	26	-19	0	-05	14	0	32	23	0	05	02	0	15	-01	2
RDF	04	F	R	-14	-19	0	01	-08	0	-18	06	0	-06	-11	2	11	-12	0	13	04	2
MXM	05	M	L	11	08	2	56	11	2	28	-15	0	-14	14	0	14	02	0	19	00	2
MXM	06	M	L	39	-07	2	55	-12	2	-06	39	0	13	-10	2	58	-16	0	09	08	2
RDF	07	F	R	-13	-16	2	02	-28	2	01	-13	0	-02	-03	2	-19	-10	2	-17	-09	0
MXM	08	M	L	08	-13	0	60	-07	0	22	-03	2	-05	10	2	40	18	2	18	11	2
MXM	09	M	L	04	-04	0	24	39	0	-01	31	0	00	-11	0	29	19	2	24	05	0
RDF	10	F	R	07	29	2	44	08	0	-24	-16	0	-05	28	2	-20	22	0	21	-40	0
RV	11	F	R	-05	-23	0	-02	-05	0	01	-11	0	01	-12	0	08	-13	0	-07	-30	0
RDM	12	M	R	14	-17	0	05	26	2	-04	03	0	-09	08	2	13	00	2	03	02	2
RDF	13	F	R	05	07	0	16	02	0	16	-04	0	04	-01	0	03	-11	0	14	-31	0
MXM	14	M	L	51	-12	0	20	05	0	-19	-08	0	10	-45	2	12	-19	0	04	-45	2
RDM	15	M	R	-05	-10	2	16	28	0	-21	00	0	14	-05	0	01	-04	0	01	-04	2
RDM	16	M	R	05	-37	2	24	-21	0	-41	-76	0	-08	-14	2	-12	-19	0	-05	-17	2
RV	17	M	R	00	19	2	-14	-11	0	-24	-10	0	01	29	0	-08	17	2	-06	09	2
RV	18	F	R	-06	00	2	-20	-17	2	-30	-16	2	-05	03	2	-14	15	2	-12	03	2

ED = Eye Dominance
I = Initial Response (Stimulus Period)
S = Subsequent Response(Response period)
P = Performance Score
Clay = Conservation of Substance
WF/VS = Time-Ordered Liquid Flow/Visuo-Spatial
WF/AV = Time-Ordered Liquid Flow/Audio-Verbal
DR/VS = Objects Moving Through Time and Space/Visuo-Spatial
DR/AV = Objects Moving Through Time and Space/Audio-Verbal

RDF Right Dominant Female
RDM = Right Dominant Male
MXM = Mixed Dominant Male
RV = Reversed Group

Table 27: Table of the Results of a Discriminant Analysis of the log L/R Alpha Power Ratios of Subjects Responses During Performance of Silent Reading 1 and Reading Comprehension Questions on the Silent Reading with the Performance Score on the Comprehension Questions as the Criteria Variable

Discriminant Function	Eigenvalue	r	Wilks' Lambda	Chi Square	df	level of significance
1	.30837	.485	.7643	4.032	2	.133

Response Period	SDFC
SRD1	-.18273
RDQ	.91537

Centroids of Groups	
Low Performers	-.68311
High Performers	.26273

SDFC = Standardized Discriminant Function Coefficient
SRD1 = Silent Reading Response
RDQ = Reading Comprehension Questions Response

Table 28 : Table of the Results of One Way Analysis of Variance of the log L/R Alpha Power Ratios of the Reading Comprehension Questions Response Between High and Low Performers on the Reading Comprehension Questions.

Source of Variance	SS	MS	df	F	level of significance
SRD1	.0000	.0000	1	.0001	.99
Error	.3099	.0194	16		
RDQ	.1293	.1293	1	4.680	.044
Error	.4421	.0276	16		

SRD1 = Silent Reading Response
RDQ = Reading Comprehension Questions Response

Table 29: Table of the Means and Standard Deviations of the log L/R Alpha Power Ratios of the High and Low Performers Measured During the Silent Reading Response and Reading Comprehension Response During Performance of the Reading Task

Response	Group	N of Subjects	Mean	Standard Deviation
SRD1	LP	5	.0700	.1807
	HP	13	.0692	.1222
RDQ	LP	5	-.2100	.1845
	HP	13	-.0280	.1597

LP = Low Performers
HP = High Performers
SRD1 = Silent Reading Response
RDQ = Reading Comprehension Questions Response

Table 30: Table of the Results of a Discriminant Analysis of the log L/R Alpha Power Ratios of Subjects Initial and Subsequent Responses on Objects Moving Through Time and Space/Visuo-Spatial with the Performance Score as the Criteria Variable

Discriminant Function	Eigenvalue	r	Wilks' Lambda	Chi Square	df	level of signficance
1	.01753	.131	.9828	.261	2	.878

Response Period	SDFC
DR/VS I	.72525
DR/VS S	-.41029

Group Centroids	
Low Performers	-.04682
High Performers	.16387

DR/VS = Objects moving Through Time and Space/Visuo-Spatial
I = Initial Response
S = Subsequent Response
SDFC = Standardized Discriminant Function Coefficients

Table 31: Table of the Results of a One Way Analysis of Variance of the log L/R Alpha Power Ratios Between the High and Low Performers on the Piagetian task Objects Moving Through time and Space/Visuo-Spatial

Source of Variance	SS	MS	df	F	level of significance
DR/VS I	.0066	.0066	1	.193	.649
Error	.5466	.0342	16		
DR/VS S	.0007	.0007	1	.011	.776
Error	.9462	.0591	16		

DR/VS = Objects Moving Through time and Space/Visuo-Spatial
I = Initial Response
S = Subsequent Response

Table 32: Table of the Means and Standard Deviations of the log L/R Alpha Power Ratios of the High and Low Performers Measured During the Initial and Subsequent Responses During Performance of the Piagetian Task, Objects Moving Through Time and Space/Visuo-Spatial

Response	Group	N of Subjects	Mean	Standard Deviation
DR/VS I	LP	14	-.0836	.1776
	HP	4	-.0375	.2133
DR/VS S	LP	14	-.0429	.2659
	HP	4	-.0575	.0946

DR/VS = Objects Moving Through Time and Space/Visuo-Spatial
I = Initial Response
S = Subsequent Response

Table 33: Table of the Results of a Discriminant Analysis of the log L/R Alpha Power Ratios of Subjects Initial and Subsequent Responses on Objects Moving Through Time and Space/Audio-Verbal with the Performance Score as the Criteria Variable

Discriminant Function	Eigenvalue	r	Wilks' Lambda	Chi Square	df	level of significance
1	.38798	.529	.7205	4.918	2	.086

Response Period	SDFC	Group Centroids	
DR/AV I	-.54706	Low Performers	-.49868
DR/AV S	.99747	High Performers	.78364

DR/AV I = Initial Response on Objects Moving Through Time and Space
DR/AV S = Subsequent Response on Objects Moving Through Time and Space
SDFC = Standardized Discriminant Function Coefficient

Table 34: Table of the Results of a One Way Analysis of Variance of the log L/R Alpha Power Ratios Between the High and Low Performers on the Objects Moving Through Time and Space/Audio-Verbal

Source of Variance	SS	MS	df	F	Level of significance
DR/AV I	.0862	.0862	1	1.721	.206
Error	.8014	.0501	16		
DR/AV S	.0842	.0842	1	4.636	.045
Error	.2904	.0182	16		

DR/AV I = Initial Response on Objects Moving Through Time and Space
DR/AV S = Subsequent Respone on Objects Moving Through Time and Space

Table 35: Table of the Means and Standard Deviations of the log L/R Alpha Power Ratios of the High and Low Performers Measured During the Initial and Subsequent Responses During Performance of Objects Moving Through Time and Space/Audio-Verbal

Response	Group	N of Subjects	Mean	Standard Deviation
DR/AV I	LP	11	.0991	.2056
	HP	7	-.0429	.2512
DR/AV S	LP	11	-.0445	.1436
	HP	7	.0957	.1184

I = Initial Response
S = Subsequent Response
DR/AV = Objects moving Through Time and Space/Audio-Verbal
LP = Low Performers
HP = High Performers

Table 36: Table of the Results of a Discriminant Analysis of the log L/R Alpha Power Ratios of Subjects Initial and Subsequent Responses During Performance of the Piagetian task, Conservation of Substance with the Performance Scores on the Task as the Criteria Variable

Discriminant Function	Eigenvalue	r	Wilks' Lambda	Chi Square	df	level of significance
1	.23644	.437	.8088	3.184	2	.204

Response Period	SDFC	Group Centroids	
Clay I	-.55475	Low Performers	-.48142
Clay S	.77245	High Performers	.30636

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance
SDFC = Standardized Discriminant Function Coefficients

Table 37: Table of the Results of a One Way Analysis of Variance of the log L/R Alpha Power Ratios Between the High and Low Performers on the Piagetian Task, Conservation of Substance

Source of Variance	SS	MS	df	F	level of significance
Clay I	.0302	.0302	1	.895	.361
Error	.5400	.0337	16		
Clay S	.0574	.0574	1	2.180	.156
Error	.4213	.0263	16		

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance

Table 38: Table of the Means and Standard Deviations of the log L/R Alpha Power Ratios of the High and Low Performers Measured During the Initial and Subsequent Responses During Performance of the Piagetian Task, Conservation of Substance.

Response	Group	N of Subjects	Mean	Standard Deviation
Clay I	LP	7	.1486	.1756
	HP	11	.0645	.1884
Clay S	LP	7	-.0986	.1242
	HP	11	.0173	.1813

Clay = Conservation of Substance
I = Initial Response
S = Subsequent Response
LP = Low Performers
HP = High Performers

Table 39: Table of the Results of a Discriminant Analysis of the log L/R Alpha Power Ratios of Subjects Initial and Subsequent Responses During Performance of the Piagetian Task, Time-Ordered Liquid Flow/Visuo-Spatial with the Performance Scores on the Task as the Criteria Variable

Discriminant Function	Eigenvalue	r	Wilks' Lambda	Chi Square	df	level of significance
1	.00893	.094	.9911	.133	2	.935

Response Period	SDFC	Group Centroids	
WF/VS I	.08885	Low Performers	.06013
WF/VS S	.91253	High Performers	-.12027

WF/VS = Time-Ordered Liquid Flow/Visuo-Spatial
I = Initial Response
S = Subsequent Response
SDFC = Standardized Discriminant Function Coefficients

Table 40: Table of the Results of a One Way Analysis of Variance of the log L/R Alpha Power Ratios Between the High and Low Performers on the Piagetian Task Time-Ordered Liquid Flow/Visuo-Spatial

Source of Variance	SS	MS	df	F	level of significance
WF/VS I	.0005	.0005	1	.008	.854
Error	.9017	.0564	16		
WF/VS S	.0049	.0049	1	.142	.674
Error	.5535	.0346	16		

I = Initial Response
S = Subsequent Response
WF/VS = Time-Ordered Liquid Flow

Table 41: Table of the Means and Standard Deviations of the log L/R Alpha Power Ratios of the High and Low Performers Measured During the Initial and Subsequent Responses During Performance of the Piagetian task, Time-Ordered Liquid Flow/Visuo-Spatial

Response	Group	N of Subjects	Mean	Standard Deviation
WF/VS I	LP	12	.1925	.1974
	HP	6	.1817	.3076
WF/VS S	LP	12	.0150	.1779
	HP	6	-.0200	.2027

I = Initial Response
S = Subsequent Response
WF/VS = Time-Ordered Liquid Flow/Visuo-spatial
LP = Low Performers
HP = HIgh Performers

Table 42: Table of the Results of a Discriminant Analysis of the log L/R Alpha Power Ratios of Subjects Initial and Subsequent Responses on Time-Ordered Liquid Flow/ Audio-Verbal with the Performance Score as the Criteria Variable

Discriminant Function	Eigenvalue	r	Wilks' Lambda	Chi Square	df	level of significance
1	.09076	.288	.9168	1.303	2	.521

Response Period	SDFC
WF/AV I	.83556
WF/AV S	.71422

Group Centroids	
Low Performers	.35355
High Performers	-.22498

I = Initial Response
S = Subsequent Response
WF/AV = Time-Ordered Liquid Flow/Audio-Verbal
SDFC = Standardized Discriminant Function Coefficient

Table 43: Table of the results of a One way Analysis of Variance of the log L/R Alpha Power Ratios Between the High and Low Performers on the Piagetian task Time-Ordered Liquid Flow/Audio-Verbal

Source of Variance	SS	MS	df	F	level of significance
WF/AV I	.0159	.0159	1	.709	.417
Error	.3599	.0225	16		
WF/AV S	.0151	.0151	1	.450	.518
	.5380	.0336	16		

WF/AV = Time-Ordered Liquid Flow/Audio-Verbal
I = Initial Response
S = Subsequent Response

Table 44: Table of the Means and Standard Deviations of the log L/R Alpha Power Ratios of the High and Low Performers Measured During the Initial and Subsequent Responses During Performance of the Piagetian Task, Time-Ordered Liquid Flow/Audio-Verbal

Response	Group	N of Subjects	Mean	Standard Deviation
WF/AV I	LP	7	.0429	.1511
	HP	11	-.0182	.1493
WF/AV S	LP	7	.0486	.1716
	HP	11	-.0109	.1901

I = Initial Response
S = Subsequent Response
WF/AV = Time-Ordered Liquid Flow/Audio-Verbal
LP = Low Performers
HP = High Performers

Table 45: Summary Table of the Results of One Way Analyses of Variance Assessing Differences in the log L/R Alpha Power Ratios Between Subjects with Different Performance Scores on the Following Tasks: Conservation of Area, Syllogistic Logic, Mental Arithmetic, Rotated Forms, and Block Design

Source of Variance	SS	MS	df	F	level of significance
Area	.0636	.0318	2	1.892	.184
Error	.2521	.0168	15		
SL	.0318	.0159	2	.463	.630
Error	.5152	.0343	15		
MA1	.0434	.0434	1	1.887	.186
Error	.3680	.0230	16		
MA2	.0411	.0205	2	.829	.459
Error	.3718	.0248	15		
R1	.0223	.0074	3	.435	.683
Error	.2225	.0171	14		
R2	.0685	.0228	3	.859	.487
Error	.3723	.0266	14		
BD1	.0602	.0228	3	.758	.490
Error	.5956	.0397	14		
BD2	.0002	.0002	1	.016	.605
Error	.2121	.0133	16		
BD3	.0521	.0174	3	.846	.494
Error	.2875	.0205	15		

Area = Conservation of Are
SL = Syllogistic Logic
MA = Mental Arithmetic
R = Rotated Forms
BD = Block Design

Table 46: Means and Standard Deviations of the log L/R Alpha Power Ratios Between High and Low Performers on the Following Tasks: Conservation of Area, Syllogistic Logic, Mental Arithmetic, Rotated Forms, and Block Design.

Task	Score	N of Subjects		Standard Deviation
Area	0	4	-.0550	.0904
	1	3	.1367	.0874
	2	11	.0391	.1457
SL	0	12	.0133	.1713
	1	2	.0600	.3536
	2	4	.1150	.1500
MA1	0	6	-.0133	.1279
	2	12	[illegible]108	.1613
MA2	0	3	[illegible]267	.140[illegible]
	1	6	.0483	.0537
	2	9	-.0056	.1899
R1	0	4	.0900	.1393
	1	8	.0050	.1451
	2	1	.0500	
	3	4	.0650	.0751
R2	0	9	.0411	.1186
	1	6	.1533	.2113
	2	1	-.0200	
	3	2	-.0050	.1909
BD1	0	15	.0420	.144[illegible]
	1	1	.3500	
	2	2	-.0500	.551[illegible]
BD2	0	11	.0300	.0913
	1	7	.0371	.1465
BD3	0	5	.1160	.2291
	1	7	.0529	.0736
	2	5	.0020	.1062
	3	1	.2000	

Area = Conservation of Area task
SL = Syllogistic Logic task
MA = Mental Arithmetic tasks
R = Rotated Forms tasks
BD = Block Design tasks

Table 47: Table of Raw Scores for the Following Tasks: Conservation of Substance, Rotated Forms, Block Design, Syllogistic Logic, and Mental Arithmetic.

Subject	Area		R1		R2		BD1		BD2		BD3		SL		MA1		MA2	
	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P
01	.14	2	.09	3	-.14	0	.14	0	.07	2	-.02	2	.21	0	.00	2	-.27	2
02	-.14	2	.01	3	-.03	1	.01	0	.06	2	.10	1	-.01	2	.00	2	-.15	2
03	.25	2	.00	3	.10	0	.25	1	.17	2	.18	1	.31	1	.06	0	.27	0
04	-.05	0	-.03	1	-.02	2	-.03	0	.12	0	-.02	1	.04	0	.15	2	-.03	2
05	.11	2	.22	1	.13	3	.20	0	.15	2	.13	2	-.14	0	-.04	2	.22	2
06	.18	2	-.22	4	-.06	0	.09	0	-.23	2	.08	2	.29	2	-.22	0	-.04	2
07	-.02	2	.05	2	.16	1	-.12	0	.00	0	.20	3	.16	0	-.17	0	-.01	0
08	-.07	0	.16	3	.39	1	.34	2	.15	2	-.09	2	-.01	2	.07	0	.12	0
09	.16	1	-.03	1	.07	1	.12	0	-.02	2	.08	2	.01	2	.26	2	.10	1
10	.04	1	.22	1	.09	0	-.14	0	.10	0	.05	1	.07	0	.20	2	.02	1
11	.10	2	.09	0	-.03	1	-.15	0	-.08	2	-.07	2	-.06	0	-.14	0	-.01	1
12	.21	1	.14	0	.06	0	.09	0	.03	0	.00	1	.19	2	.28	2	.26	2
13	-.16	0	.23	0	.23	0	-.17	0	-.15	0	-.08	0	-.19	1	.02	0	-.07	1
14	.06	0	-.08	1	.43	1	.00	0	.04	2	.13	2	-.09	0	-.28	2	-.23	2
15	-.17	2	-.01	1	.00	1	.10	0	.01	0	-.03	0	.39	0	.04	2	.05	1
16	.16	2	-.20	1	-.06	0	-.44	2	-.08	0	-.03	0	-.11	0	-.03	2	.05	2
17	-.06	2	-.05	1	.11	0	.17	0	.16	0	.13	0	-.13	0	-.03	2	.20	1
18	-.12	2	-.10	0	-.17	0	.32	0	.09	0	.29	0	-.19	0	-.12	2	.14	2

Area = Conservation of Area
R = Rotated Forms
BD = Block Design
SL = Syllogistic Logic
MA = Mental Arithmetic
R = log L/R Alpha Power Ratios
P = Performance Score

Table 48: Discriminant Analysis of the log L/R Alpha Power Ratios of Initial and Subsequent Responses Measured During Piagetian Task Performance as Predictors for Group Membership of Right-Dominant Boys Mixed-Dominant Boys, Right-Dominant Girls and Reversed Subjects

Discriminant Function	Eigenvalue	% of Variance	r	Wilks' Lambda	Chi Square	df	Level of Significance
1	12.40358	56.06	.962	.0018	59.824	33	.003
2	7.83300	32.88	.942	.0247	35.167	20	.019
3	3.58732	15.06	.884	.2180	14.471	9	.107

Standardized Discriminant Function Coefficients

	Function 1	Function 2	Function 3
Clay I	-.06509	.11463	.07031
Clay S	.15127	-.38804	-.11806
WF/VS I	-.25290	.04859	-.06221
WF/VS S	.08303	.20276	-.16164
WF/AV I	.04998	.10861	.06403
WF/AV S	.31482	.32187	.02503
DR/VS I	-.30572	-.02018	.22491
DR/VS S	-.25288	.04811	.26289
DR/AV I	.16339	-.18130	-.41659
DR/AV S	-.04793	-.20266	-.05006
Area I	-.06957	-.04483	.01098

Group Centroids

	Function 1	Function 2	Function 3
Boys	.30843	.51019	-.32023
Mx Boys	-.63494	-.17020	-.26125
Girls	-.07685	.05411	.37481
Reversed	.92912	-.35278	-.11893

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance
WF/VS = Time-ordered Liquid Flow/Visuo-spatial
WF/AV = Time-ordered Liquid Flow/Audio-verbal
DR/VS = Objects Moving Through Time and Space/Visuo-spatial
DR/AV = Objects Moving Through Time and Space/Audio-verbal

Table 49: One Way Analysis of Variance of the Differences in the log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks Between Right-Dominant Males, Mixed-Dominant Males, Right-Dominant Females and Reversed Subjects

Source of Variance	df	SS	MS	F	Level of Significance
Area I	3	.0393	.0197	.663	.587
S/A	14	.2764	.0197		
Clay I	3	.1234	.0411	1.289	.317
S/A	14	.4468	.0319		
WF/VS I	3	.4231	.1410	4.122	.027
S/A	14	.4791	.0342		
WF/VS S	3	.1018	.0339	1.040	.406
S/A	14	.4566	.0326		
WF/AV I	3	.0074	.0025	.094	[illegible]4
S/A	14	.3685	.0263		
DR/VS I	3	.2648	.0883	4.284	.024
S/A	14	.2884	.0206		
DR/VS S	3	.2389	.0796	1.575	.239
S/A	14	.7079	.0506		
DR/AV I	3	.5157	.1719	6.470	.006
S/A	14	.3720	.0266		
Clay S	3	.2091	.0697	3.619	.040
	14	.2696	.0193		
WF/AV S	3	.1598	.0533	1.897	.176
S/A	14	.3933	.0281		
DR/AV S	3	.1175	.0392	2.132	.141
S/A	14	.2571	.0184		

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance
Area = Conservation of Area
WF/VS = Time-ordered Liquid Flow/Visuo-spatial
WF/AV = Time-ordered Liquid Flow/Audio-verbal
DR/VS = Objects Moving Through Time and Space/Visuo-spatial
DR/AV = Objects Moving Through Time and Space/Audio-verbal

Table 50: Means and Standard Deviations of the log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks of Right-dominant Boys, Mixed-dominant Boys, Right-dominant Girls and Reversed Subjects

	Boys		Mx Boys		Girls		Reversed	
	mean	SD	mean	SD	mean	SD	mean	SD
Clay I	.0467	.0950	.2260	.2103	.0671	.2014	.0033	.0651
Clay S	-.2133	.1401	-.0280	.1003	-.0286	.1564	.1600	.1473
WF/VS I	.1500	.0931	.4300	.1931	.1000	.1015	.0333	.3535
WF/VS S	.1100	.2773	.0700	.2000	-.0614	.1346	-.0667	.1305
WF/AV I	-.0100	.1300	.0080	.1103	.0257	.2174	-.0300	.0346
WF/AV S	-.0367	.1106	-.0840	.2339	.0214	.1332	.2000	.1473
DR/VS I	-.2200	.1852	.0480	.1969	-.0171	.1019	-.2600	.0346
DR/VS S	-.2433	.4477	.0880	.2446	-.0171	.1044	-.1400	.0346
DR/AV I	.0233	.1504	.3060	.1913	-.0557	.1699	-.1400	.0600
DR/AV S	-.0767	.1002	.0080	.1805	-.0243	.1318	.1800	.0361
Area I	.0667	.2065	.0880	.0998	.0171	.1517	-.0467	.0808

I = Initial Response
S = Subsequent Response
Clay = Conservation of Substance
Area = Conservation of Area
WF/VS = Time-ordered Liquid Flow/Visuo-spatial
WF/AV = Time-ordered Liquid Flow/Audio-verbal
DR/VS = Objects Moving Through Time and Space/Visuo-spatial
DR/AV = Objects Moving Through Time and Space/Audio-verbal
Boys = Right-dominant Boys
Mx Boys = Mixed Dominant Boys
Girls = Right Dominant Girls
Reversed = Reversed Subjects

Table 51: Table of Prediction Results Based on the Formulas Computed by the Discriminant Analysis of the log L/R Alpha Power Ratios Measured During Performance of Piagetian Tasks as Predictor Variables for Membership into Groups with Similar Hemispheric Functioning Patterns

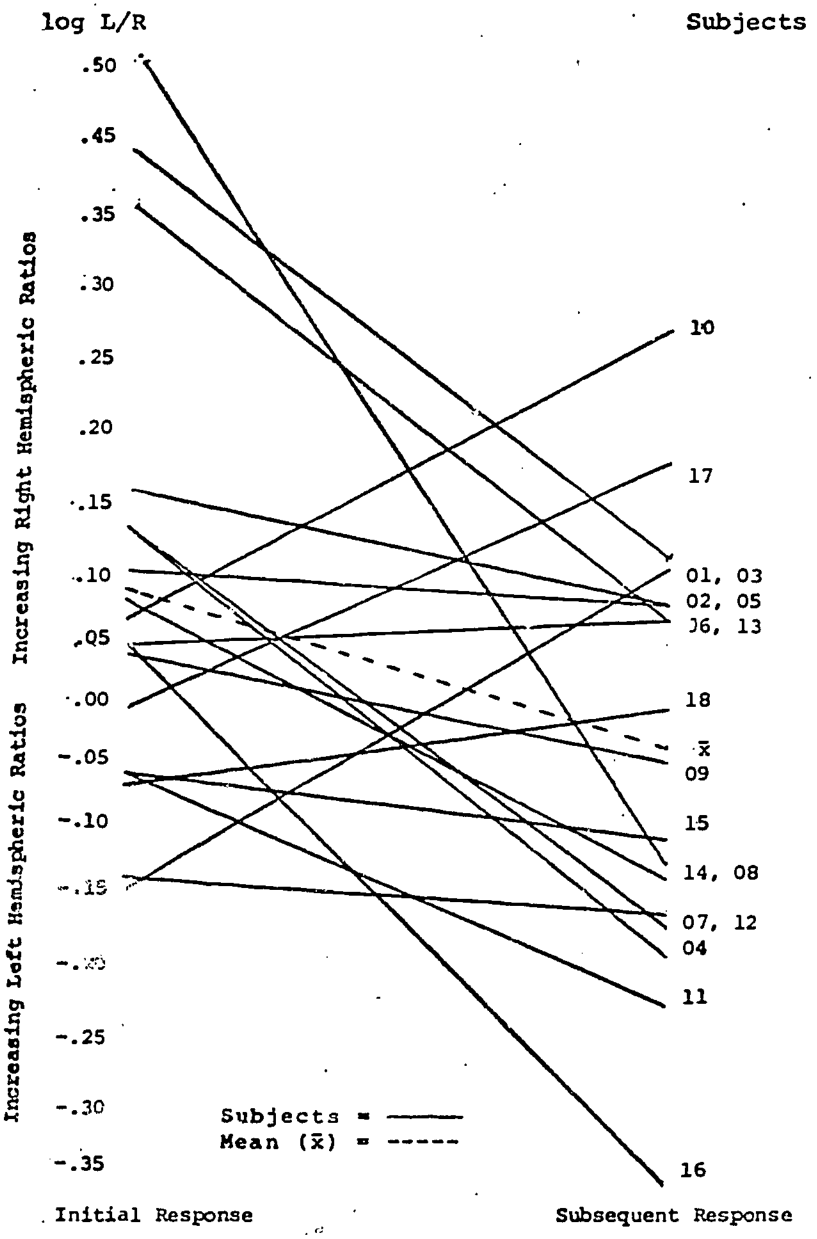
Actual Group	N of Cases	Predicted Group Membership Group 1	 Group 2	 Group 3	 Group 4
1	3	3 100%	0 0%	0 0%	0 0%
2	5	0 0%	5 100%	0 0%	0 0
3	7	0 0%	0 0%	7 100%	0 0%
4	3	0 0%	0 0%	0 0%	3 100%

Percent of "Grouped" Cases Correctly Classified: 100%

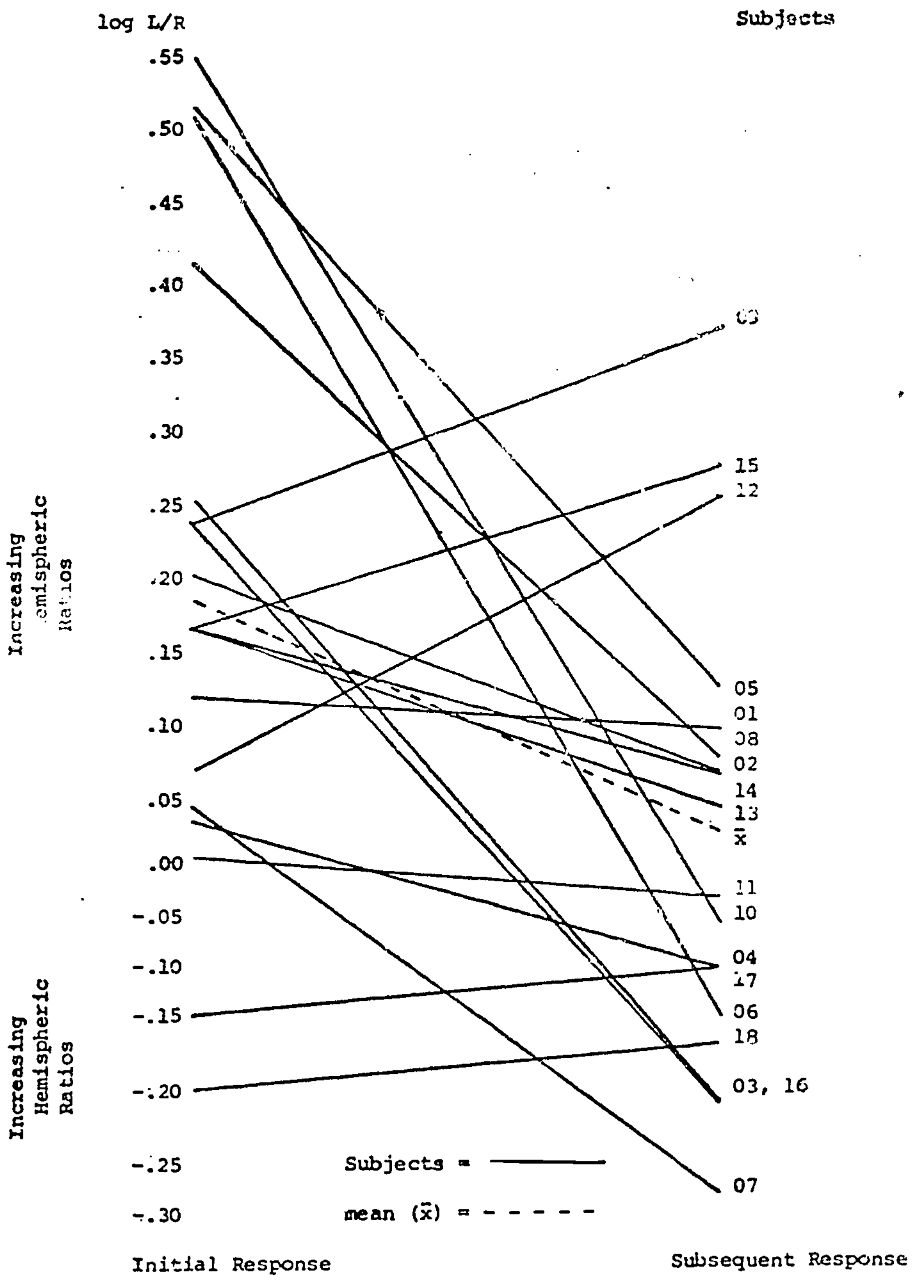
Group 1 = Male/Right-Dominant Subjects
Group 2 = Male/Mixed-Dominant Subjects
Group 3 = Female/Right-Dominant Subjects
Group 4 = Reversed Subjects

APPENDIX D

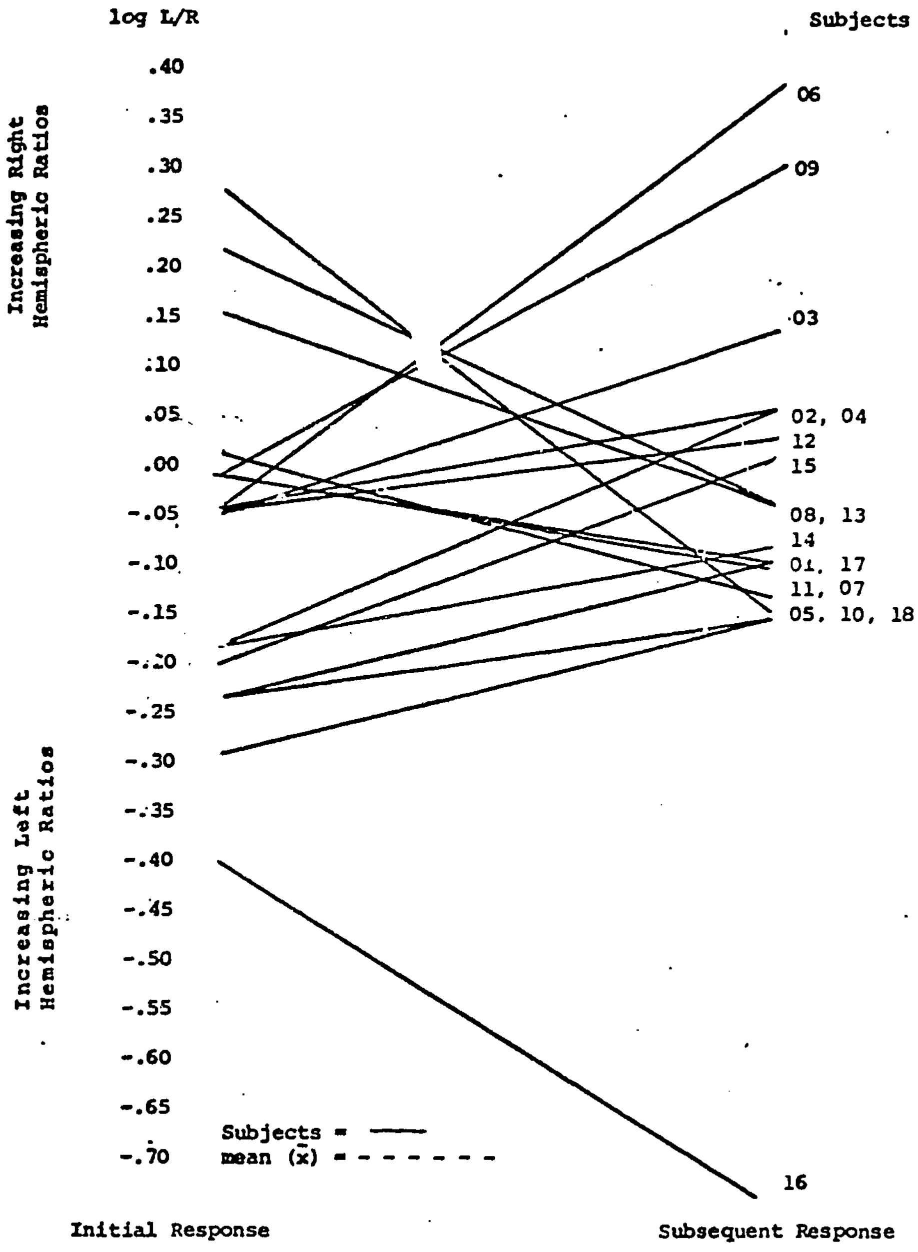
GRAPHS



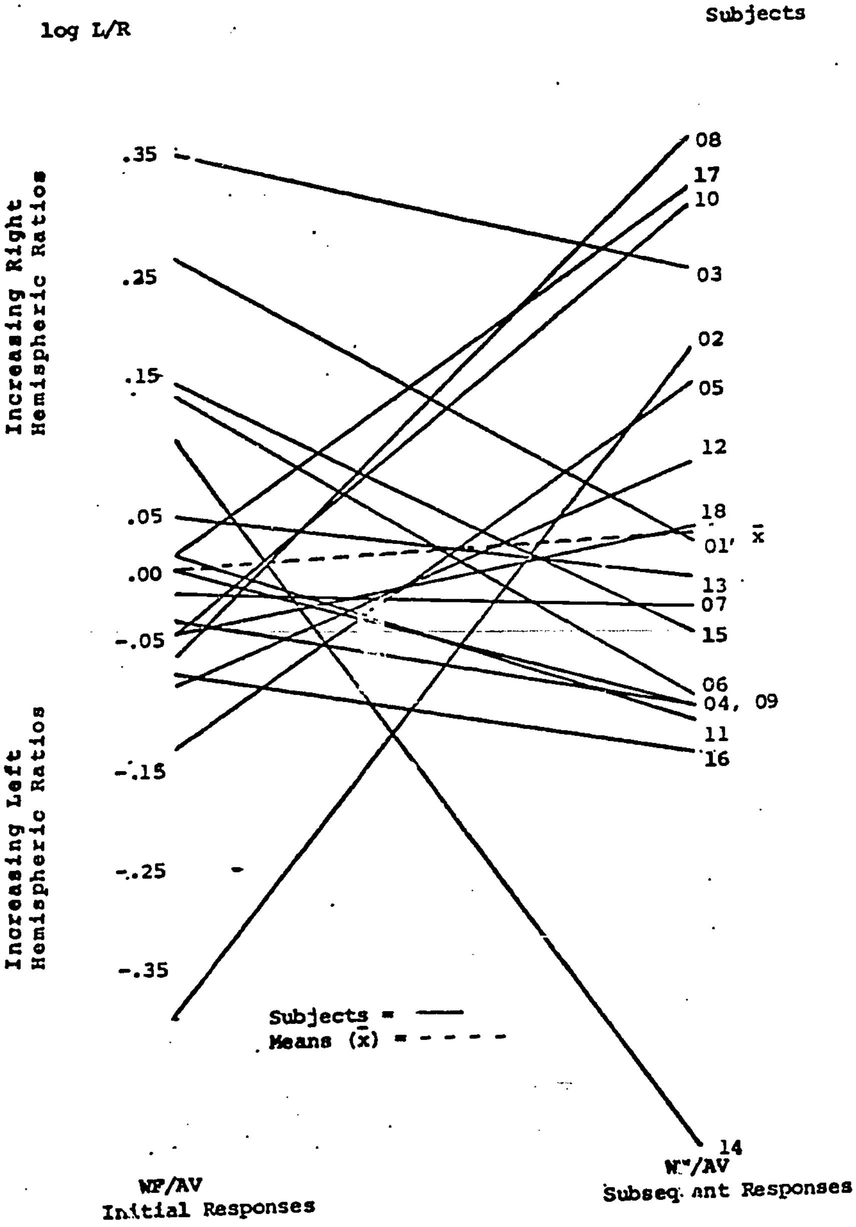
Graph 1: Graph of the raw Scores (log L/R alpha power ratios subtracted from baseline) and means ($\bar{x}$) illustrating the Relationship Between the Initial and Subsequent Responses During Performance of the Conservation of Substance



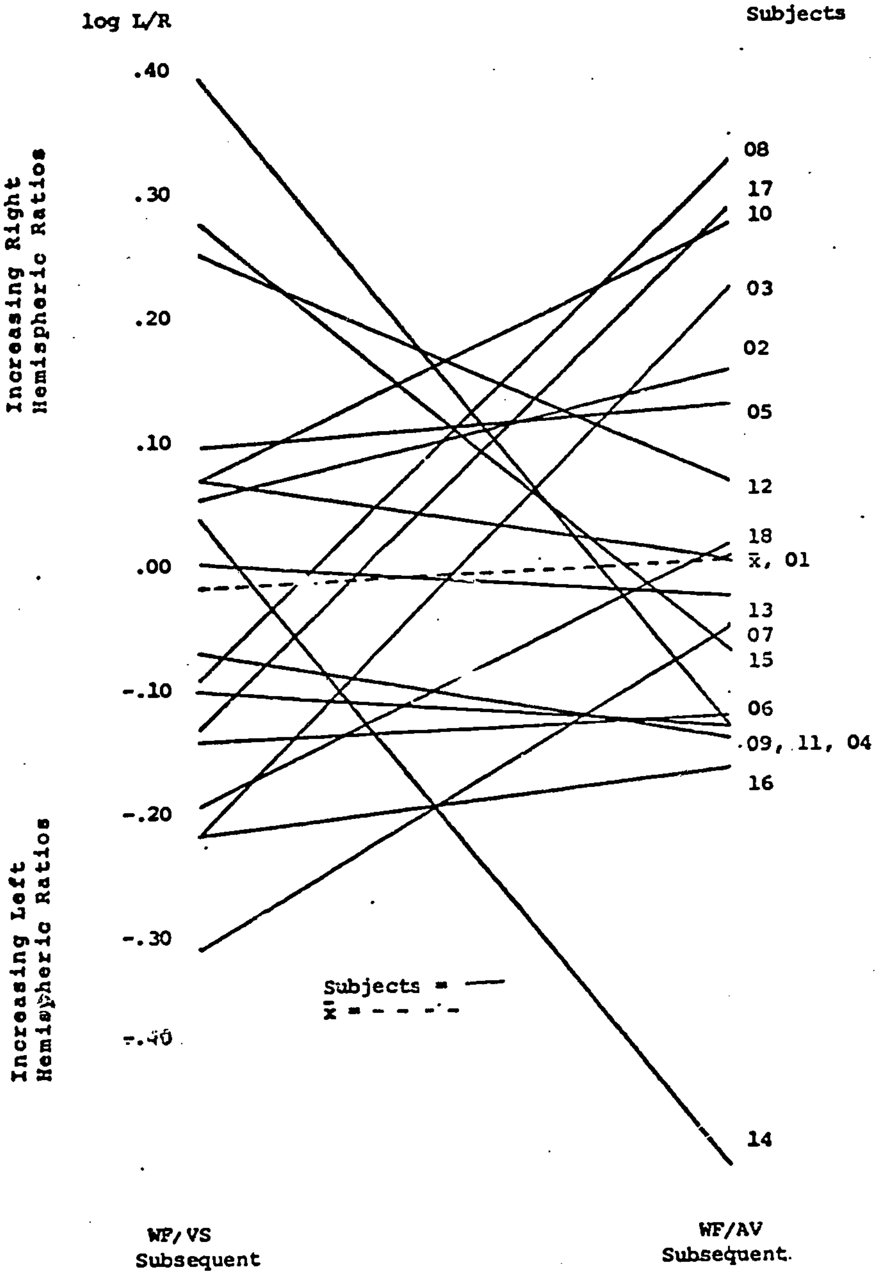
Graph 2: Graph of the raw scores (log L/R alpha Power Ratios subtracted from baseline) and means (x̄) illustrating the Relationship Between the Initial and Subsequent Responses During Performance of Time-ordered Liquid Flow/Visuo-spatial



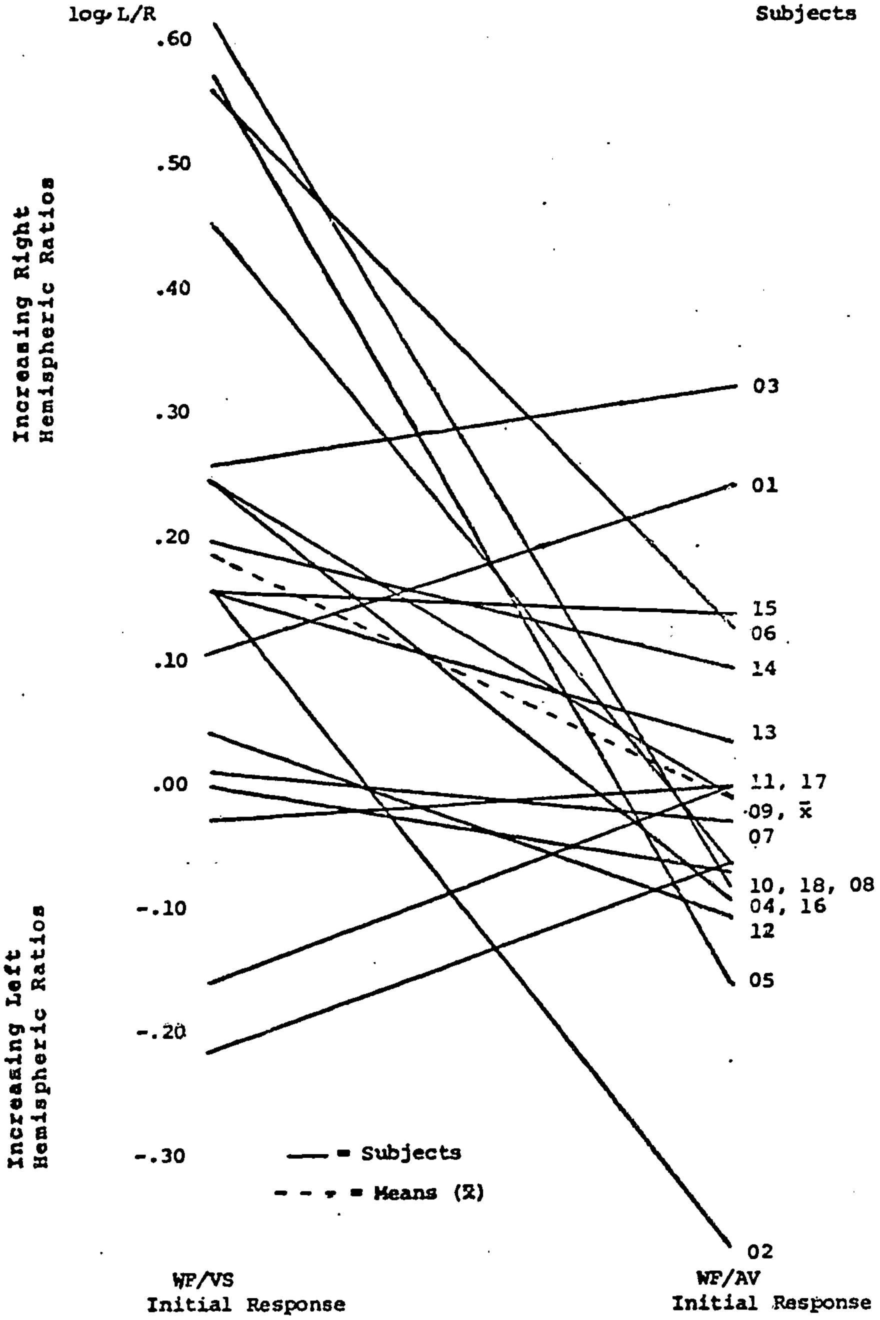
Graph 3: Graph of the Raw Scores (log L/R alpha power ratios subtracted from baseline) and means ($\bar{x}$) illustrating the Relationship Between the Initial and Subsequent Responses During Performance of Objects Moving Through Time and Space/Visuo-spatial



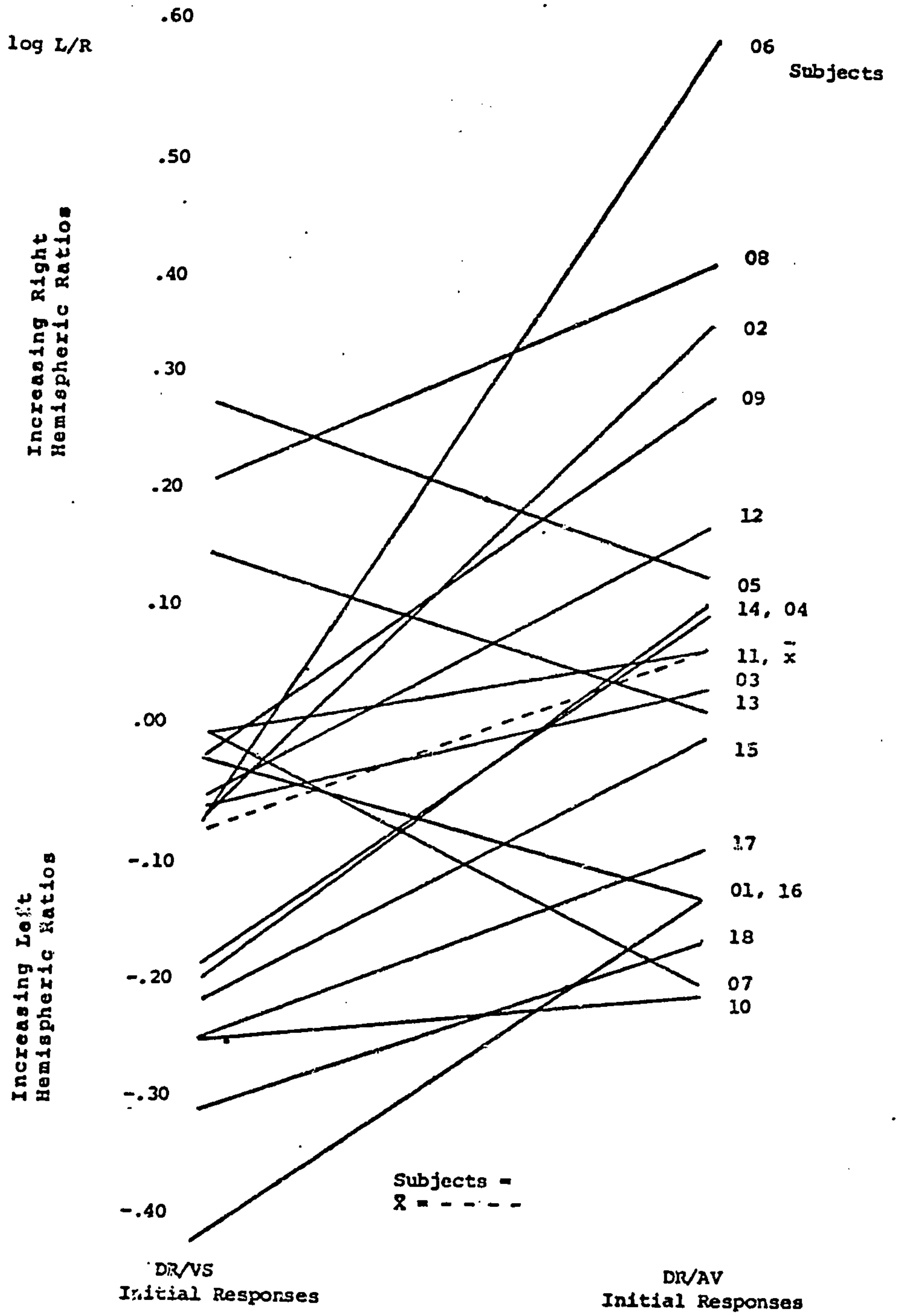
Graph 4: Graph of the Raw Scores (log L/R Alpha Power Ratios Subtracted from Baseline) and Means Illustrating the Relationship Between the Initial and Subsequent Responses of Time-Ordered Liquid Flow/Audio-Verbal



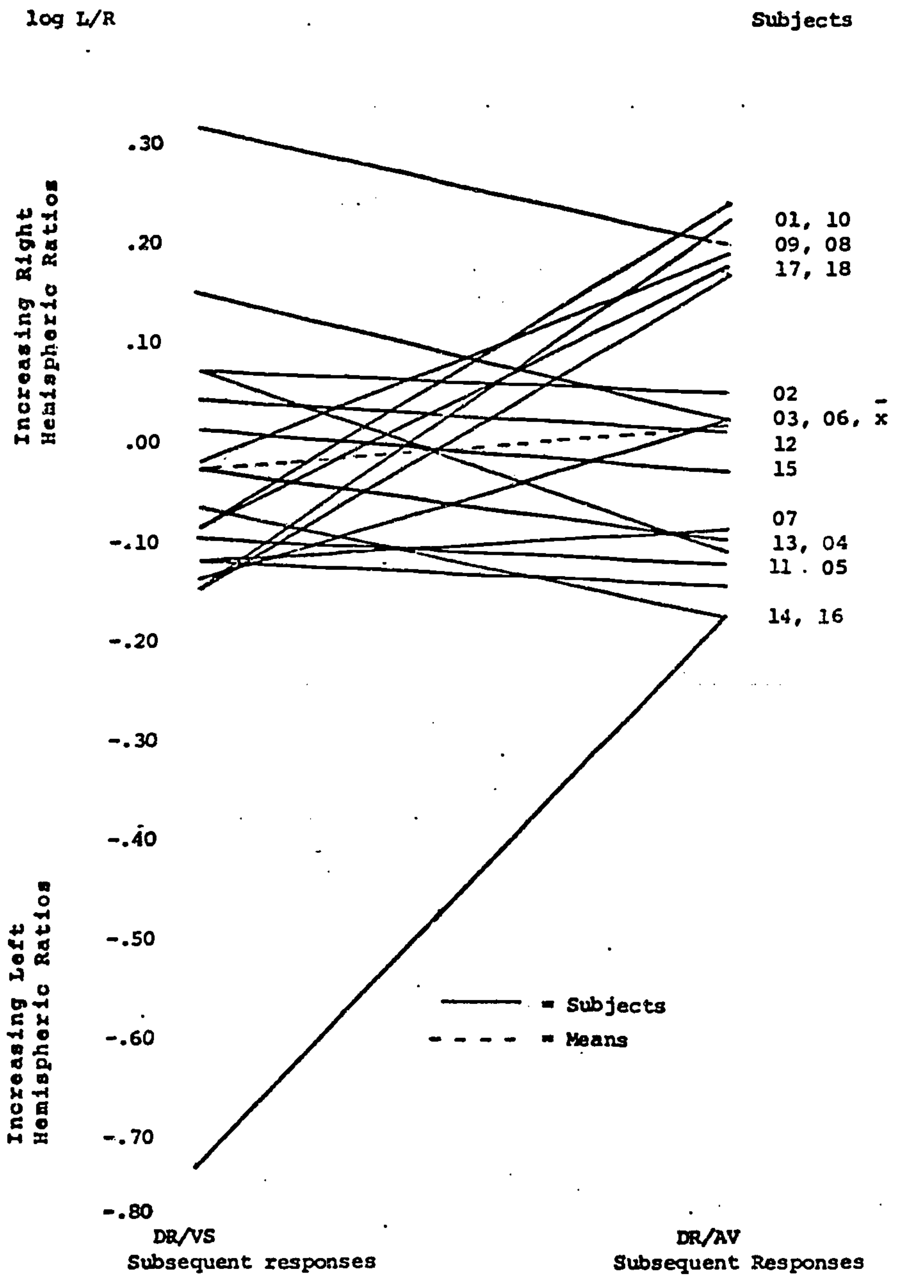
Graph 5: Graph of the raw scores (log L/R alpha power ratios subtracted from baseline) and the means (x) illustrating the relationship between the subsequent response of Time-Ordered Liquid Flow/Visuo-spatial and the subsequent Responses of Time-Ordered Liquid Flow/Audio-verbal



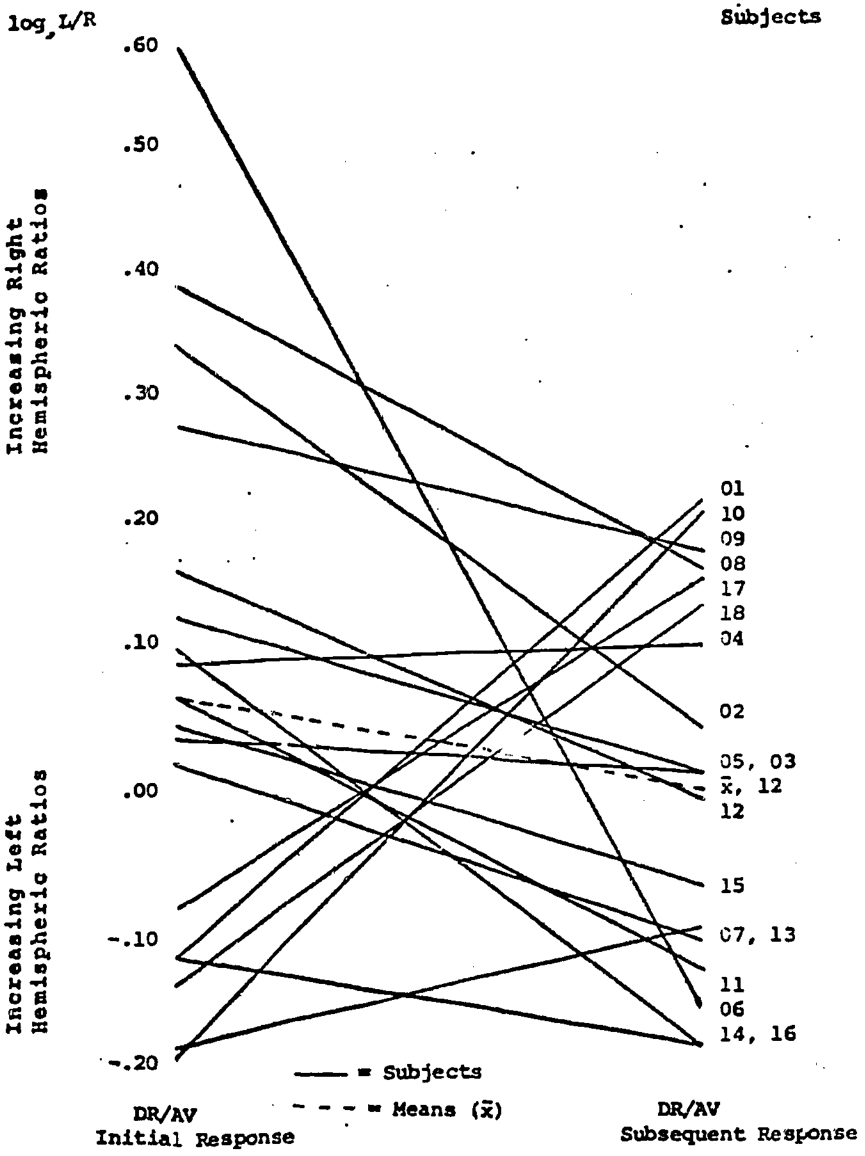
Graph 6: Graph of the raw scores and the means (x̄) illustrating the relationship between the initial response of Time-ordered Liquid Flow/Visuo-spatial and the initial response of Time-ordered Liquid Flow/Audio-verbal



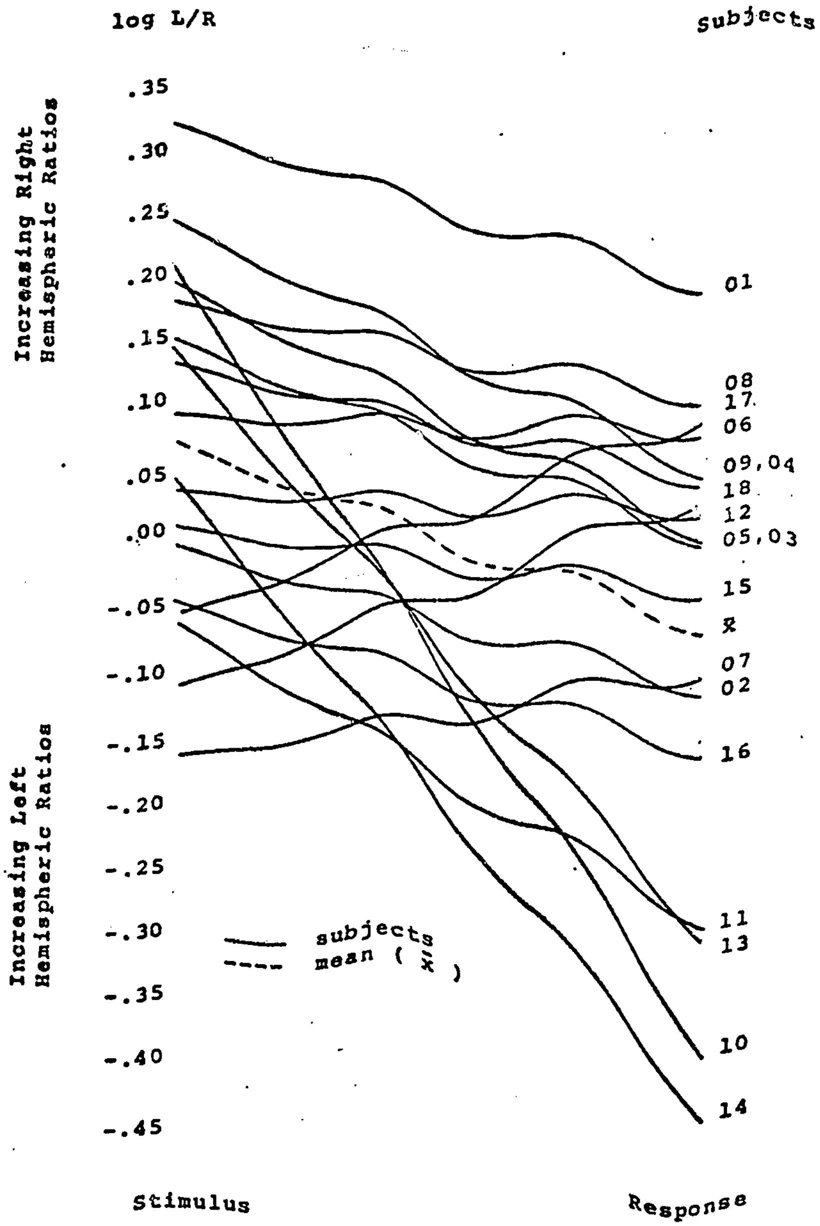
Graph 7: Graph of the raw scores and means ($\bar{x}$) illustrating the relationship between the initial response of Objects Moving Through Time and Space/Visuo-spatial and the initial response of Objects moving through Time and Space/Audio-verbal



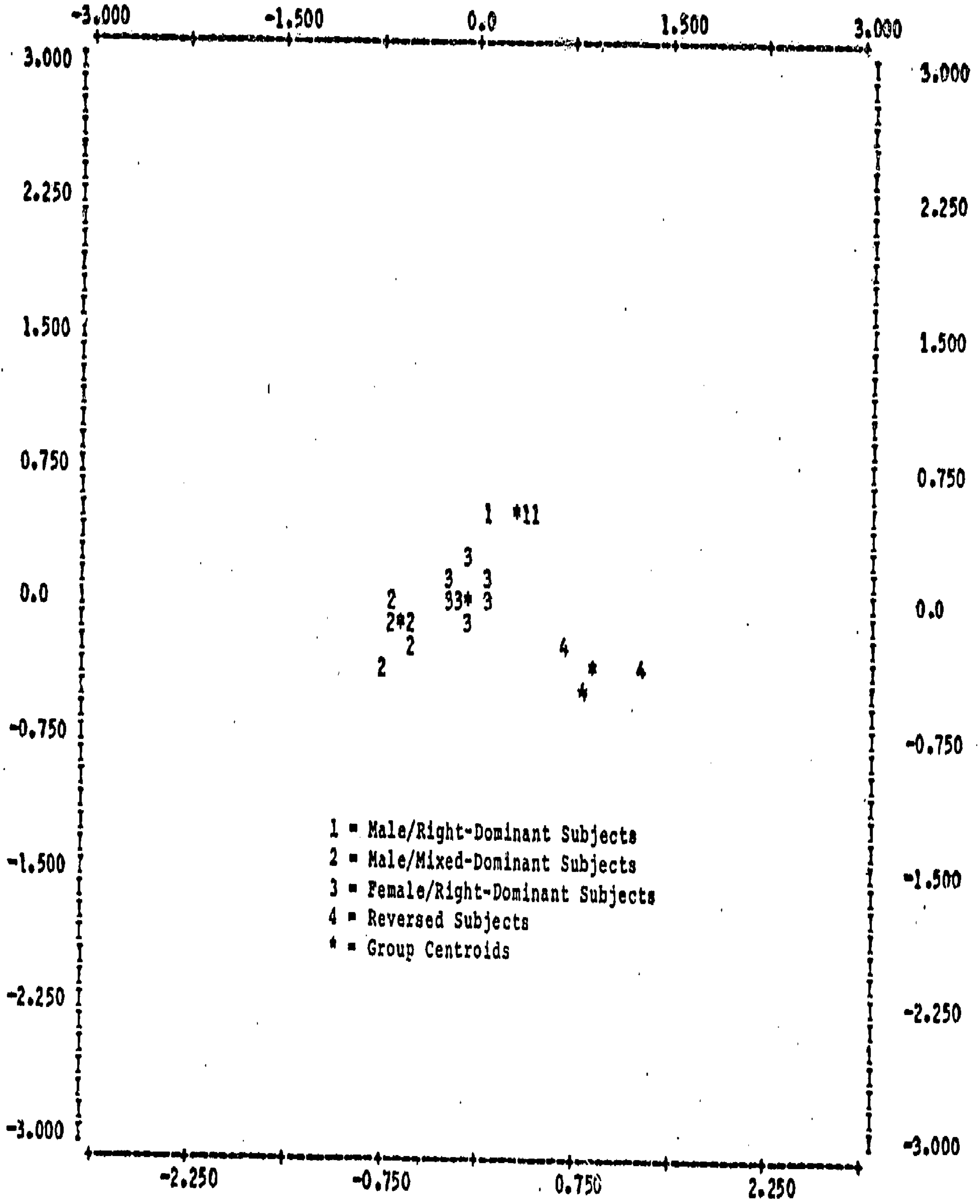
Graph 8: Graph of the Raw Scores and Means Illustrating the Relationship Between the Subsequent Responses of Objects Moving Through Time and Space/Visuo-Spatial and the Subsequent Responses of Objects Moving Through Time and Space/Audio-Verbal



Graph 9: Graph of the Raw Scores and Means Illustrating the Relationship Between the Initial and Subsequent Responses of Objects Moving Through Time and Space/ Audio-Verbal



Graph 10: Graph of the Raw Scores and Means Illustrating the Relationship Between the Stimulus (Silent Reading) and Response (Answering Reading Comprehension Questions) During Performance of the Reading Task



Graph 11: Plot of Discriminant Score 1 (Horzontal) vs Discriminant Score 2 (Vertical) illustrating Group Centroids and Subjects in Two dimentional Space

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