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THE EFFECT OF THE HAUSDORFF--BESICOVITCH DIMENSION
OF FIGURE BOUNDARY COMPLEXITY
ON HEMISPHERIC FUNCTIONING

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THE EFFECT OF THE HAUSDORFF-BESICOVITCH DIMENSION OF FIGURE BOUNDARY COMPLEXITY ON HEMISPHERIC FUNCTIONING

By

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ABSTRACT

THE EFFECT OF THE HAUSDORFF-BESICOVITCH DIMENSION
OF FIGURE BOUNDARY COMPLEXITY
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Researchers in the field of educational technology continue to investigate methods of applying psychological principle to the design of instructional materials. This study attempted to isolate a characteristic of pictures that could be used to predict which of the hemispheres would process the pictorial information being presented. Figure boundary complexity (the Hausdorff-Besicovitch dimension) was chosen as a possible predicting characteristic. Two specific questions were posed by the experimenter. First, if a subject is presented with a series of pictures with varying boundary complexity, will the amount of right/left hemisphere activation change as the boundary complexity increases? Secondly, will the amount of right/left hemispheric activation evoked by the pictures depend in some way on the imaging ability of the subject?

Each subject was asked to complete an imagery questionnaire to be used in investigating the relationship between hemispheric activity and imaging ability. Subjects were then shown a series of eleven figures in random order via a tachistoscope. These figures varied in their degree of boundary complexity. Figures were presented in the subject's central visual field for twenty seconds. This was followed by a thirty-second eyes closed rest period to lessen the effect of afterimages. Subjects were not required to make verbal or manual responses. EEG

recordings were gathered and referenced for each of the eleven trials. Baseline recordings were also sampled for each subject. Alpha brain wave activity was used as an indicator that the hemisphere was in a "resting" mode.

Due to time constraints data from six subjects were selected for analysis. Two-second epochs from each stimulus trial were converted to digital form and a computer was used to perform a Fast Fourier Transform to resolve the frequency makeup of the EEG waveforms.

Two primary and six post hoc hypotheses were tested. They are:

1. There is no significant difference between left- and right-hemisphere alpha activity for each of the stimulus figures.

2. There is no correlation between the ability to image and the amount of right hemisphere alpha activity.

3. There is no correlation between the ability to image and the subject's typical baseline state.

4. The pattern of differences between the left- and right-hemisphere alpha activity for each individual is random across all eleven figures.

5. The pattern of differences between the right-hemisphere alpha activity and the subject's baselines can be accounted for by chance for each of the stimulus figures.

6. The pattern of differences between the right- and left-hemisphere alpha activity of each subject can be accounted for by chance for each figure.

7. The pattern of differences between the right-hemisphere alpha and the subject's baseline can be accounted for by chance for each subject.

8. The pattern of differences between the left-hemisphere alpha and the subject's baseline can be accounted for by chance for each subject.

Statistical tests of these hypotheses showed no significant differences at the .05 level for hypotheses one through six. Tests of hypotheses seven and eight did produce significant differences.

for Jon...
and for the trees that gave their lives for these pages

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Background

Researchers in the field of educational technology continue to investigate methods of applying psychological principles to the design of instructional materials. Historically, the field emerged from a background of audiovisual education, based on a visual stimulus orientation. Much of its early theoretical foundations were grounded in stimulus-oriented cognitive learning theories. The popularity of the behavioral psychology movement of the 1950's caused many in the field to shift to response-oriented learning principles. Currently, a resurgence of interest in cognitive processing is again bringing about a theoretical shift in instructional psychology. The impact of this shift on educational technology is a renewal of emphasis on the stimulus and its relationship to cognitive processess.

Identification of the Problem

One aspect of cognitive processing that is of current interest to both psychologists and educators is the phenomenon of lateral hemispheric specialization. The human brain contains two cortical hemispheres connected by a large fiber bundle called the corpus callosum. Research has indicated that each of the brain's hemispheres is specialized for processing certain types of stimuli (Krashen, 1977; Bogen, 1977; Levy, 1969; Semmes, 1968; Gazzaniga, 1967; and Kimura, 1966). The left hemisphere is predominantly associated with linear processing functions such as language. It is adept at naming, classifying, analyzing, describing, and explaining. The right hemisphere is holistic. It has been associated with visual/spatial functions. It can juxtapose dissimilar stimuli and develop analogs of spatial topography. It also displays special musical abilities. Thus, the left hemisphere is somewhat like a digital computer that processes information sequentially, whereas the right hemisphere is like an analog computer that processes information simultaneously from several inputs. This differentiation of functions according to hemisphere is called lateral hemispheric specialization.

However, as author Carl Sagan points out:

> "To solve complex problems in changing circumstances requires the activity of both cerebal hemispheres;... the path to the future lies through the corpus callosum" (Sagan, 1977, pp.191,193).

Each hemisphere is proficient at various tasks. Yet, to focus narrowly on the dichotomy of the hemispheres is simplistic, for it is their interaction which is believed to give rise to creative thought and action. The fostering of growth in right-hemisphere functions has largely been ignored in American education, and the emphasis has been placed on the verbal processing functions of the left hemisphere (Nebes, 1977; Bogen, 1977; Crinella, 1971). To help achieve a balanced approach educators need to focus on providing input and stimulation to the right, as well as, to the left hemisphere. Since the right hemisphere is specialized for visual/spatial functions, visual education seems to offer one alternative. However, little is known about how the characteristics of pictures affect the right hemisphere.

Purpose

This study examined one characteristic of pictures and its relationship to hemispheric activity. It addresses the general question: "Is the complexity of the visual message itself critical to determining which hemisphere processes the visual information?" Since there are physiological connections between the two hemispheres of the brain, visual information can cross over. Thus, it is difficult to detect differences in information processing between the two hemispheres of normal humans in most instructional settings. One measure of information processing activity which is accurate enough to discriminate possible differences between the hemispheres is the electroencephalogram (EEG). It has been useful in clinical study of the brain's electrical activity and was chosen as a measure in this study.

The specific purpose of the study was to determine the effect of the Hausdorff-Besicovitch dimension of figure boundary complexity on the amount of right- and left-hemisphere alpha brain wave activity elicited while viewing a picture. It is an attempt to isolate a characteristic of a picture (boundary complexity) which could be used as an objective measure to predict the extent of right- and/or left-hemisphere involvement. It sought to answer these specific questions:

1. Given a series of pictures, will the amount of right/left hemisphere alpha activation evoked by each picture change as the figure boundary becomes more complex?
2. Given a series of pictures of varying figure boundary complexity, will the amount of right/left hemisphere activation depend in some way on the imaging ability of the subject?

Need

The nature of instruction depends to a great degree on the assumptions the teacher makes about the nature of man and the nature of mind. Such assumptions are often implicit and seldom questioned, but they form the basis for most decisions made about both what to teach and how to teach it. Professions, such as education, attempt to base their approach to practical problems on evidence from the scientific disciplines whenever possible. Thus, while attempting to eliminate intuitive decisions, these professions are still as much effected by the paradigms and views of the scientific disciplines that they borrow from as the scientific disciplines are themselves.

Educational technologists appear to have recently accepted the paradigmatic shift which took place within the scientific discipline of psychology during the late 1940's and early 1950's. However, another paradigmatic shift is taking place within the fields of psychology and neurology. This shift appears to negate or neutralize the earlier shift. This new shift is described by Wittrock and Lumsdaine in the 1977 Annual Review of Psychology:

> "Instructional psychology is now involved in a notable shift in emphasis in psychological research and theory... The current shift emphasizes the study of central cognitive processes.... The shift to greater emphasis on the study of cognitive processes has important implications for changing teaching and instruction. If learning is conceived primarily as change in behavior due to reinforced practice, instruction would often be designed to provide differential reinforcement of the correct behavior in the presence of the appropriate environmental stimulus.... By contrast a cognitive approach emphasizes that one can learn by observing others, by watching a model, by viewing a demonstration. In brief, cognitive approaches emphasize that one can learn without practice or reinforcement of overt behavior, and that one may learn by actively changing perceptions of experiences, by constructing new meanings and interpretations of events." (pp.417-418.)

Therefore, it seems important for members of the educational technology field to conduct their own scientific research to help resolve which basic paradigm the profession should be following and to further substantiate the field's basic assumptions. For example, in its earliest days, the educational technology movement was supported by a basic belief in the power of visualizationin education. This belief was more an article of faith than an established scientific fact. More direct experimentation by the profession might help to further or dispel this basic belief. Schramm (1977) cites the need for such research and the lack of guidelines for selecting a medium of instruction based on solid evidence and scientific theory. He writes:

> "We have no taxonomy that matches media experiences to cognitive results or to learning tasks. We have only begun to understand what goes on cognitively when a learner is given instructional experience in one symbolic code rather than another; and it is a great advance even to hear it said that "the learner needs this kind of experience," rather than "the lesson needs a picture." (p.92)

Importance

In addition to testing the usefulness of a stimulus-oriented paradigm for educational technology, this specific research addresses another educational situation.

The current American educational system places heavy emphasis on the traditional, 'left-brained' mode of verbal processing of information (Crinella, 1971). This emphasis may well be at the expense of the development of the right-hemisphere processing modes. Researchers warn that we may be tragically short changing ourselves by using such a one-sided approach (Bogen, 1977; Nebes, 1977). Dr. Timothy Teyler, a neurobiologist, points out that "...brain processes present at birth will degenerate if the environmental simulation necessary to activate them is witheld" (Teyler, 1977, p.31). Such research suggests the need for educators to "...become concerned with developing equal qualities of cerebral functioning in children" (Rennels, 1976, p.47).

In view of this situation this study is important for the following reasons: First, there is a gap in the existing research. Little work has been done on the scaling of pictorial characteristics. There is also a lack of systematic studies aimed at exploring the effects that such characteristics have on behavior, (Paivio, 1971, p.78). Second, although many types of pictures are currently being used in educational settings, little is known about the functional properties of such media in regard to their ability to stimulate right-hemisphere processes. Third, the existence of an objective measure to predict right hemisphere involvement would facilitate a balanced selection of media. The production of more effective media would also be facilitated through the application of the proper Hausdorff-Besicovitch dimension. Fourth, the study is an attempt to go beyond a "black box" approach to human cognition and to examine the relationship of stimuli to hemispheric functioning within an information processing model, thereby facilitating more accurate media prescription.

Definition of Important Terms

The following terms are used throughout the study and require precise definition. Some are technical and not common among educators. Others, such as 'picture', are widely used but require specific definition.

Alpha Wave: Alpha waves represent a type of fluctuation in electrical potential occurring in the brain which can be recorded using an electroencephalograph (EEG). Alpha waves arise in posterior portions of the brain and are greatest in the parietal and occipital regions. The mean center frequency of alpha ranges from 8-13 cps for most individuals. The presences of alpha activity is believed to indicate a resting or 'idling' state of the hemisphere.

Cerebral Cortex: The cerebral cortex is that part of the brain that is specialized for higher cognitive functions in humans. Structurally, it is divided into two nearly symmetrical hemispheres which are connected by a bundle of nerve cells called the corpus callosum.

Corpus Callosum: The corpus callosum connects the two hemispheres of the cerebral cortex. It is associated with the cross-over of information from one hemisphere to the other.

Fourier Transform: Fourier transform is a method of frequency analysis in which a complex waveform is separated into its components.

Fractal: A set or curve for which the Hausdorff-Besicovitch dimension exceeds the topological dimension (A thorough discussion of fractals and the Hausdorff dimension is found in Appendix D)

Hausdorff-Besicovitch Dimension: "for every set S, there exists a real value D such that the d-measure is infinite for d<D and

vanishes for $d>D$. This D is called Hausdorff-Besicovitch dimension"[1] (See Appendix D)

Hemisphericity: A term used by Bogen, DeZure, TenHouten, and Marsh (Krashen, 1977). It is the tendency of individuals to appeal to one hemisphere and its mode of thought more than the other.

High, Medium, and Low Imagers: Individual ratings of the ability to image as scored on the Sheehan Questionnaire.

Picture: A black-and-white photograph of a computer-drawn figure.

Assumptions

The basic assumption underlying this research is that human cognition is a process which is "knowable." As such, this process of cognition is considered to be a legitimate area for research and scientific study. This assertion does not deny a spiritual component of the human being, but rather distinguishes a researchable set of mental events from those of metaphysical concern. Thus, the cognitive process is considered to be a physical reality that can be measured by either direct or indirect means.

It is further assumed that the electrical activity recorded from the scalp of a human being represents such a measure and that it is directly or indirectly related to the physical events of information processing.

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[1]Mandelbrot, Benoit B., Fractals: Form, Chance, and Dimension San Francisco: W.H. Freeman and Company; 1977, p.302.

Hypotheses

Based on these assumptions, the following hypotheses were tested:

1. There will be no significant difference between left-and right-hemisphere alpha activity for each of the stimulus figures.

2. There will be no correlation between the ability to image (measured by Sheehan's Questionnaire) and the amount of right-hemisphere alpha activity.

The findings and empirical evidence gathered from the testing of these hypotheses appear to indicate that further investigation of the relationship between hemispheric functioning and instructional design is feasible and warranted.

CHAPTER II

REVIEW OF THE LITERATURE

CHAPTER II

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Overview

In reviewing the literature for the study, three topical areas related most meaningfully with the research variables of interest. Therefore, in discussing the literature, this review will be organized into three sections: 1) the use of visualization in instruction, 2) functions of the human brain, and 3) complexity and the Hausdorff-Besicovith dimension.

Section 1 reviews the history of the visual stimulus in instruction and its relationship to learning. It gives both theory and application. Section 2 describes the physiology, hemispheric functions, hemisphericity and other cerebral functions that relate to the processing of visual information. Section 3 reviews the theoretical and empirical literature regarding a specific stimulus variable.

1. Visual Stimulus in Instruction

History:

With the advent of studies on lateral specialization it has become apparent that the right hemisphere is specialized for visual-spatial information and that the left hemisphere is specialized in processing sequential, verbal information. In problem solving these two information processing systems appear to combine to produce an integrated solution.

However, the fostering of growth in the right-hemisphere functions has largely been ignored in American education and emphasis has been placed

on the linear processing functions of the left-hemisphere (Nebes, 1977; Bogen, 1977; Crinella, 1971). Many researchers believe that a more balanced development of the hemispheres is an important aspect of human education (Bogen, 1977; Nebes, 1977; Rennels, 1976). However, the phenomenon of lateral specialization as a learner variables has been relatively unresearched in terms of learning experiments. As Wittrock and Lumsdaine (1977) conclude:

> "Since Roger Sperry's early papers on the lateralization processes of the human brain, only a few studies have elaborated or explored some of the implications of the research for the improvement of instruction." (p.435, American Review of Psychology, 1977)

To insure a balanced instructional program American educators must provide equal emphasis to the exercise of right-hemisphere functions. Because visual information appears to be processed in the right-hemisphere, it offers one possibility for enhancing right-hemisphere involvement in the educational process.

Visual education has long fallen within the domain of educational technology beginning with Orbus Pictus, the first 'visual aid' textbook, published by Johann Comenius in 1658. The first use of films in instruction began about 1907 and the first film catalog was published by Kleine in 1910. As Saetler states, "Although the term visual instruction was used since the beginning of this century to refer to a variety of visual instructional media, it is not surprising that the instructional film intensified its use and provided a great impetus to the audiovisual instruction movement in American education." (Saettler, 1968, p.118)

The first visual instruction organizations were established beginning in 1919. They included: the National Academy for Visual Instruction (1919), the National Academy of Visual Instruction (1920), the Visual Instruction Association of America (1922), and the National Education Association Department of Visual Instruction (1922). The first teacher course offered in visual instruction was given at the University of Minnesota in 1918. The application of visualization to instruction was advanced dramatically by its use during World War II in industrial and military training.

After the war research on the educational effectiveness of pictorial techniques became more sophisticated as described in May (1958). The Yale Motion Picture Research Project produced a significant number of studies on the effects of visual instruction. In 1955, a transition period began in visual education. Television, multimedia presentations, and computers made their appearance. This period contrasts sharply with visual education's earlier history not only in terms of media hardware innovations but in the philosophy of the educational technologist. This period marked the beginning of a greater dependence on psychological theory and research. No longer were visualizations seen as mere novelties which were used anytime at the descretion of the teacher. Assumptions were born that an increased knowledge of the effectiveness of visual instructional strategies and the psychological principles underlying them could enable educational technologists to improve the design of instructional systems, and to use visualizations as an integrated part of a total instructional system to achieve predetermined objectives.

Thus, with its long history in visual education and its commitment to the use of visualization based on firm psychological and educational principles, it is logical for the field of educational technology to pursue a further understanding of how visual information is processed by the learner and to apply this knowledge for the improvement of instruction. As Levie and Dickie conclude:

> "If improved theory is to be a goal of research, independent variables must relate to the constructs which are central to the theory--in this case, the implicit human processes which mediate instructional stimuli and learning outcomes.
>
> Understanding media may be furthered by 1) specifying media in terms of attributes, 2) defining these attributes in terms which relate to the ways in which information is processed internally, and 3) discovering relationships between these attributes and other important instructional variables." (p.877)

Relationship of Visualization to Learning

As stated in the Introduction, the response-oriented paradigm became popular in psychology during the 1950's and 1960's. It had subsequent impact on education. Learning became something that was evidenced by a change in behavior. Unfortunately, this concept was often interpreted to mean that no learning took place without a response. Active responding became a necessary condition for learning. Gropper describes how this view differs from a stimulus-oriented approach to learning:

> "Discussions of instructional strategies have in recent years made clear that the differences between instructional approaches that are stimulus-oriented and approaches that are response-oriented rest on a fundamental distinction. The stimulus approach stresses the over-riding importance of the design of the stimulus materials to be presented. It is the clarity and organization of these materials that make for effective learning. Those supporting the response approach in contrast, insist that it is the character of response practice which is crucial. The student learns the response he practices. No matter how well organized the instructional presentation is, to be optimally effective, instruction must provide for response practice." (Gropper, 1970, p.130)

During the 1950's and early 1960's, the programmed instruction movement, based largely on the response-oriented, operant conditioning paradigm, exerted great influence on the audio-visual field. The response paradigm became accepted by many members of the field and research was based on it. For example, in a 1951 project sponsored by the U.S. Army, Kendler, Kendler, and Cook attempted to develop testable hypotheses relating stimulus-response reinforcement theory to audio-visual training. Other early examples of audio-visual research placing heavy emphasis on responding include Black's study of pictorial methods for increasing desired responses (Black, 1962), and Fleming's study of the control of verbal responses to pictorial stimuli (Fleming, 1960). Gropper stated in 1970:

> "Evidence from a decade of research on programmed instruction and evidence from earlier decades of research on film mediated instruction provide ample support for the behavioral view that active responding is a necessary condition for learning." (Gropper, AVCR, 1970)

Nevertheless, educational technology had its roots in the design and use of audio-visual messages. Thus, the response paradigm was not a comfortable one for many. As Nord states:

> "...the shift was reluctant and not fully accepted. There was a basic discomfort in having one foot in the response-oriented camp of psychology and the other foot in the stimulus-oriented tool conscious profession of educational technology." (Nord, 1977)

Charles Hoban emphasized the point at the 1973 convention of the Association for Educational Communications and Technology:

> "....B.O. (Behavioral Objectives) derive directly from B.S. (Behavioral Science), and share with it the virtue of parsimony and the lack of sufficiency." (Hoban, AVI, 1974)

William Winn adds:

> "....the limits of behaviorism have now been stated by psychologists and unless some of the alternative models of human endeavour are taken seriously, media folk will find themselves receding so fast from the center of things that, like stars on the edge of the universe, they will become lost from view." (Winn, AVI, 1977)

As a resurgence of interest in cognitive processing occurred in instructional psychology (Brunner, 1966; Gagne, 1968; Arbib, 1972), a return to the stimulus-oriented paradigm also began to take place in educational technology. New emphasis was placed on the study of the stimulus and its role in information processing. Learning, according to this paradigm, was associated with a change in cognitive structure. Therefore, it may or may not result in a change in behavior. The need for active responding became suspect, especially in visual education, and much research in educational technology became based on how humans process information. Investigations such as those based on the Travers (1967) model of information processing were conducted to study the relationship between memory and single versus two-channel presentation modes. Standing, Conezio, and Haber (1970) investigated memory capacity for pictorial information. They presented subjects with 2560 photographs of real objects and scenes. After several sessions, they found that subjects could recognize between 85 and 95 percent of the stimulus pictures. This led them to consider a dual, information-processing system as a model for human memory.

Levie and Dickie (1973) in their literature review, speculated that if the channels of an audio-visual presentation provide stimuli, the subject may be required to shift attention back and forth between stimulus channels. They suggest that interference may be a problem when both presentation rate and content are high.

Further investigation of the role of visualization in cognitive processing was undertaken by Winn (1976). He used free association as an indicator of cognitive structure to measure the effects of presenting items as words, black-and-white pictures, or color pictures. Orwig (1979) researched recognition using pictures that were difficult to discriminate between because of inter-stimulus similarity. He found that added verbal input created no significant interference with the visual information processing even in trials where the recognition task for the pictures was rendered more difficult due to the similarity of distractors.

While educational technologists were busy investigating the relationship of visualization to information processing, a related line of research was taking place in neurophysiology (See section 2 below). This research produced evidence that the right hemisphere is specialized for processing visual information and that the left hemisphere is specialized for verbal tasks. This evidence brings into question the validity of much previous research on visual media.

Many investigations, whether based on the response-oriented paradigm or on the stimulus-oriented paradigm, have required subjects to communicate verbally during treatment procedures or in response to treatment. Researchers now believe that, because such verbalization engages the left hemisphere, it could have an interfering effect on the right hemisphere visualization process. The information produced by these subjects may be distorted during verbalizing. Therefore, new techniques such as the use of physiological measures like the electroencephalogram are now being employed to study cognitive processing.

2. Functioning of the Human Brain

Background Physiology:

Examination of the human brain shows it to be an almost symmetrical organ weighing three or more pounds. Its outer surface, called the cortex, is convoluted and contains billions of neurons or brain cells. The young adult starts with approximately twelve billion neurons in the cerebral cortex and does not grow any new neurons during his lifetime. Indeed, he loses about 100,000 cortical neurons per day (Guilford, 1967). In regard to Burns (1958) contention that unexcited neurons undergo degenerative changes, Guilford states: "It would seem that one way of stemming such a loss would be to ensure the exercise of those cells." (Guilford, 1967, p.362)

The cortex, itself is divided into two hemispheres that are joined by a fibrous bundle called the corpus callosum (Figure 1.). Each hemisphere is divided into four lobes: frontal, parietal, temporal, and occipital. Additionally these lobes are divided into sensory-motor zones, concerned with musculature, and associational zones which are thought to possess a role in cognitive abilities. The cortex is part of what is termed the forebrain, as is the thalmus. Changes across phylogeny have been mainly limited to the forebrain. It acts to process and relay visual information to the cortex. The forebrain also contains a set of structures known as the limbic system which includes: amygdala, hippocampus, and septum. Specific functions of the limbic system are unknown. However, these structures have been linked to memory, the inhibition of behavior, and the ability to keep track of objects in space.

Corpus Callosum

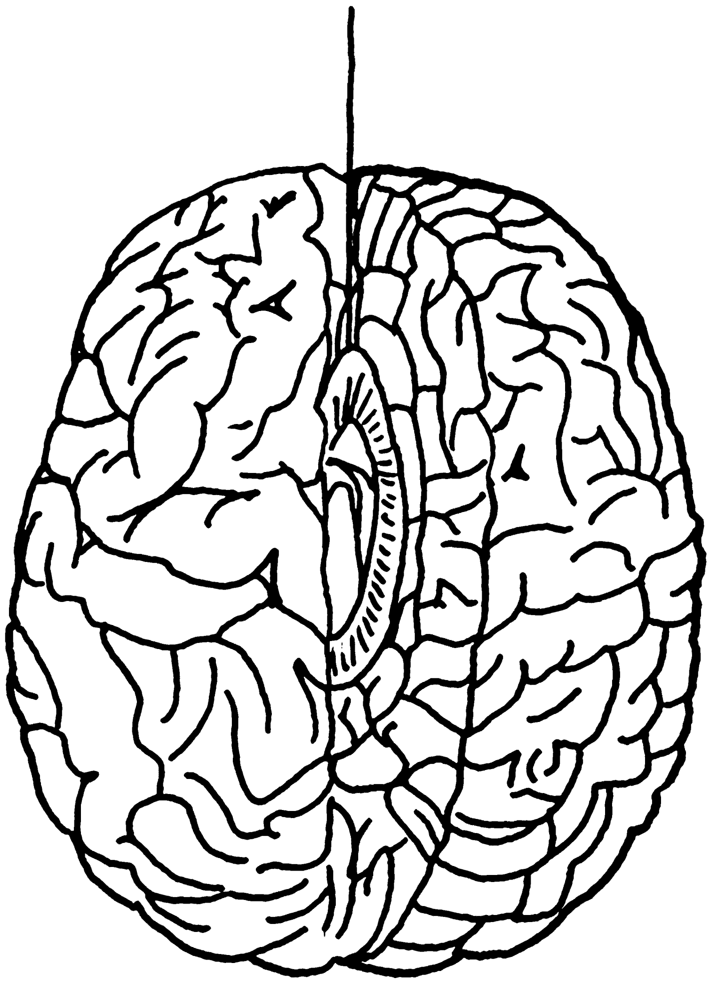


Figure 1. Cerebral Hemispheres

Adopted from "The Split Brain in Man" by Michael S. Gazzaniga, Scientific American August 1967.

Hemispheric Functioning:

Although appearing nearly anatomically symmetrical, the cerebral hemispheres seem to be highly specialized in their functions. Psychologists have long been aware that a dichotomy exists in mental organization. Many terms such as rational versus intuitive, realistic versus impulsive, analytic versus gestalt, successive versus simultaneous, and objective versus subjective have been used to describe this distinction. Nevertheless, a common thread runs throughout each pair of terms.

In the nineteenth century exploration of the physiology of the brain opened speculation that this dichotomy might originate in the brain's two hemispheres. Hughlings Jackson in 1864 noted the possibility that 'expression' resides in one hemisphere and 'perception' in the other. However, at about this same time a theory arose in which the left (or language) hemisphere was considered dominant in the brain's information processing. This led most neurologists of Jackson's time to concentrate primarily on the localization of left hemisphere functions and on the rational, analytic half of the dichotomy. The right hemisphere was considered the "minor" or "subordinate" hemisphere, while the left was considered the "major", "dominant" or "leading" hemisphere. Even with the advent of the holistic school of psychology, little consideration was given to right-hemisphere capacities. This dominant-subordinate brain theory was prominent until about 1940 when multifactor theories of intelligence were proposed with "the subsequent replacement of the concept of hemispheric dominance by one of hemispheric specialization" (Nebes, 1977, p.98). According to this new concept each hemisphere was thought to be specialized for different functions.

Investigations involving patients suffering various psychological and physiological deficits resulting from disease or trauma have supported this specialization hypotheses. Reitan (1959) reported a loss in spatial orientation in patients with right-hemisphere damage. Shure and Halstead (1958) reported verbal-logical deficiencies in left-hemisphere damaged patients. K.B. Fitzhugh, L.C. Fitzhugh, and R.M. Reitan (1962) found lowered verbal ability in persons with left-hemisphere lesions. Zangwill (1964) also attributed defects in abstractions regarding visual objects to right-hemisphere damage and verbal defects to left-hemisphere (temporal lobe) damage.

Research into the extent of hemispheric specialization (or lateralization) was furthered still by the 'split-brain' experiments of R.W. Sperry and M.S. Gazzaniga (Gazzaniga, Bogen, Sperry, 1965). In 1960 Dr. Joseph Borgen proposed the sectioning of the corpus callosum (major commissure joining the brain's hemispheres) for the purposes of controlling the inter-hemispheric spread of epilepsy. Sperry and Gazzaniga devised and administered a host of psychological tests to Bogen's first and subsequent patients (Gazzaniga, 1977). No noticeable changes were produced in the patients' temperments, personalities, or general intelligence. What was found, however, was that the right hemisphere was "completely divorced in perception and knowledge from the left after the operation" (Gazzaniga, 1973). Each hemisphere was functioning as if it were a separate brain. In follow-up tests Gazzaniga found that the main difference between hemispheres appeared to be that the left hemisphere in most individuals is specialized in verbal abilities, and the right in visual-spatial abilities.

Gazzaniga describes one visual experiment in which the patient is shown moving lights in the right visual field only. When asked to verbally report what he saw, the patient could not. However, when asked to respond to the lights in a psychomotor mode (i.e., press a button with the left hand), the patient had no difficulty. Gazzaniga concludes that the verbal report, requiring information to be processed in speech centers of the left hemisphere, was difficult because the information about the lights remained exclusively on the right side. The motor response, controlled by the same hemisphere which received the visual information, however, presented no difficulty for the patient.

Research involving 'normal' persons (i.e., those persons not suffering brain damage or corpus callosum sectioning) has also supported the lateral specialization concept. Kinsbourne and Cook (1971) performed an experiment in which subjects were asked to balance a wooden dowel on their left and right index fingers alternately. After establishing a baseline, the subjects were asked to simultaneously balance the dowel and perform a verbal task. The addition of the verbal task yeilded shorter balancing times for the right hand but longer ones for the left. Because the right hemisphere controls the left hand and the left hemisphere the right hand, (Figure 2.) the balancing descrepancy could be explained as an interference function. The processing of verbal information, predominantly a left-hemisphere function, might interfere with the balancing performance of the right hand.

In an earlier study Doreen Kimura (1966) used a tachistoscope to control the visual fields of 'normal' persons and investigated the relationships between hemispheric processing of visual information in the two fields. She found that letters of the alphabet were more accurately identified when flashed to the right visual field than the left. Nonverbal forms and dots were more effectively identified when flashed to the left visual field.

Because of the physiological connections between the two hemispheres of the brain, and the cross-over of visual information via the

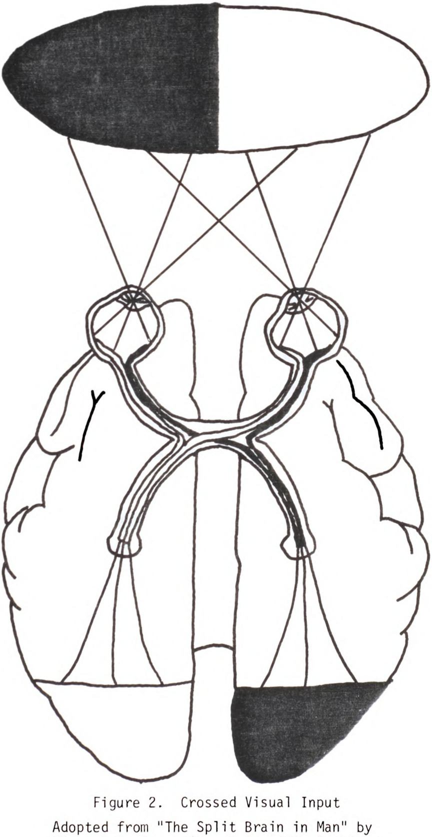


Figure 2. Crossed Visual Input

Adopted from "The Split Brain in Man" by Michael S. Gazzaniga, Scientific American August 1967.

optic system (see Figure 2.) it is difficult to detect differences in the information processing activities between the two sides of the brain in normal humans in most instructional settings. One method of isolating hemispheric differences in processing iconic, or visual information is to attempt to use the physical limits of perceptual performance (i.e. speed and angle of presentation of visual stimulus within the visual field) as a control for presenting the stimulus to each hemisphere selectively. This is done mechanically by means of a tachistoscope (t-scope) which can present the stimulus for only a fraction of a second to that part of the retina of the eye which is directly connected to a specific hemisphere. For example, when a picture is flashed approximately 4 degrees to the right of the center (the right visual field), by means of a t-scope, only the left half of each eye will receive this information. Because of the bilateral crossover system in the human optic system, the information received by the left half of the retina of each eye is sent to the left hemisphere. Therefore, when a visual image is flashed to the right side of the screen (the right visual field), the left hemisphere of the cerebral cortex will receive it first and directly from the optic nerve. Similarly, a visual image flashed to the left of center (left visual field) will be received first and directly by the right hemisphere.

Galin and Ornstein (1972) used electroencephalograms to measure the differential of information processing between the two hemispheres of normal people. The subjects engaged in a number of verbal and non-verbal tasks requiring only manual or thinking responses. The tasks included composing a letter, writing a letter, mentally constructing shapes from paper forms, and manually constructing patterns with colored blocks. Electroencephalograms were recorded and alpha waves are indicative of the resting mode and, thus, the hemisphere with a higher alpha output is less likely to be engaged in the task. Accordingly, the non-verbal, visual-spatial tasks were found to engage primarily the right hemisphere. The verbal and constructive tasks generally engaged the left hemisphere. These findings, again, lend support to the lateral specialization concept.

Many researchers have not only found evidence that the hemispheres are specialized for handling different types of information, but have also found evidence that the hemispheres process information in different ways. Trevarthen, Colwyn, and Sperry (1972) tested the ability of two hemispheres to separately perceive and respond to stimulus patterns and exercise control of motor functions. Their results indicated that "a distinct deficiency in basic pattern apprehension" exists in the language hemisphere. More notably, they found that when the task could be performed by either hemisphere distinctively different strategies were used by each to carry out the task. Levy (1969), in an earlier study, refers to research by Levy-Agresti and Sperry (1968) in which each hemisphere was tested for its ability to visualize in three dimensions. Levy states that this research indicated that "While the left hemisphere seemed to analyse the stimulus properties, the right hemisphere seemed immediately to abstract the stimulus Gestalt...". Thus, each hemisphere "used a different strategy in solving the problems."

Josephine Semmes (1968) has also found two contrasting modes of neural organization which provide a clue to the duality of hemispheric specialization of elementary functions. The left hemisphere favors specialization for fine sensorimotor control such as that needed in speech. Her study indicates a diffuse representation of elementary functions in the right hemisphere. Therefore, specialization requiring multimodal coordination, such as in spatial ability, is favored.

Research evidence is, thus, accumulating to reinforce the concept of hemispheric specialization with the right-hemisphere appearing to be specialized in handling visual-spatial information and the left-hemisphere specialized for verbal, sequential information. Additionally, evidence also seems to support a difference in the hemispheres in regard to the modes used to process information. This indicates support for Paivio's (1971) contention that information processing in humans is comprised of two separate but integrated systems.

However, not all researchers have been so positive about the concept of hemispheric specialization and the use of EEG data. Tepas, et.al. warn: "We recommend that extreme caution be exercised when interpreting the results of studies down-grading or ignoring the sensitivity of EBR (evoked response) measures to changes in stimulus parameters" (Tepas, et. al., 1973, p.536). Schwartz also notes the need for more stringent research methods and warns that average evoked response recordings may be altered by the subject's expectancies, attention, and affect. Morrow outlines the need for "proponents of the right hemisphere" to become aware of the need for synthesis of the left and right and not carry the bimodal model to an extreme (Morrow, 1979). Rose cautions researchers about the inferences made from EEG data (Rose, 1973).

EEG Studies:

Despite criticism the use of the electroencephalograph continues to dominate brain research. Donchin states one reason this is so: "Lateralization of sensory inputs . . . is not an easy procedure and imposes numerous restrictions on the range of paradigms in which hemispheric specialization can be studied. It is in this context that the use of electrophysiological techniques is of potential value" (Donchin et. al. 1977, p.340).

A great amount of research has been accumulated on EEG electrode placement and stimulus tasks. Investigators usually employ a subject-task thought to engage one hemisphere. Left-hemisphere tasks have included letter composition (Galin and Ornstein, 1972; Doyle et. al., 1974), word searches (McKee et. al., 1973), and listening to words (Morgan et. al., 1971, Butler and Glass, 1974). Right hemisphere tasks include Seashore tonal memory, Kohs Blocks, and drawing (Galin and Ornstein, 1972; Doyle et. al., 1974), as well as, imagery (Morgan et. al., 1971; Dumas and Morgan, 1975), and music listening (McKee et. al., 1973; Morgan et. al., 1971).

These EEG recordings have been taken from the occipital (Cumas and Morgan, 1975; Morgan, Macdonald, and Hilgard, 1974; Morgan, McDonald, and Macdonald, 1971), temporal and parietal positions (Doyle, Ornstein, and Galin, 1974; Galin and Ornstein, 1972; McKee, et. al., 1973).

Hemisphericity:

The duality of mental organization is believed by some researchers to lead to hemisphericity. Hemisphericity is a term used by Bogen, DeZure, TenHouten, and Marsh (Krashen, 1977) to describe the tendency of individuals to appeal to one hemisphere and its mode of information processing more than the other.

Researchers have sought an indicator of such hemisphericity. Handedness has been studied in this regard. Harris (1975) has described the general American population as 90-98 percent right-handed. Of this group, approximately 99 percent have language functions represented in the left hemisphere. Only 53 to 65 percent of left-handed people, according to Harris, have left-hemisphere laterality. Harris concludes that left-handed persons are less well lateralized for language functions.

Calder likewise believes that right-handedness may be connected with the occurrence of the speech area in the left hemisphere; but he describes this connection as highly complex.

The direction of a person's gaze while contemplating a problem has also been explored as a possible indicator of hemisphericity. The human visual field has crossed connection to the hemispheres. However, the left eye is not simply connected to the right hemisphere. The left half of the visual field from both eyes is connected to the right hemisphere. The right half of the visual fields is connected to the left. (See Figure 2.)

Kinsborne (1974) has found that while engaged in verbal thought subjects look to the right, whereas during spatial thought they look up and to the left. However, this effect can be disrupted by central fixation. He concludes that, "If proper precautions are taken in these respects, the phenomena is a useful index of cerebral lateralization of cognitive function."

Gur, Gur and Harris (1975) found that when facing the questioner subjects moved their eyes in predominantly one direction regardless of the type of question. When not facing the questioner right-handed subjects moved their eyes left when solving spatial problems and right for verbal problems.

The electroencephalograph has also been employed in an attempt to find an indicator of task specific hemispheric functioning. Using evoked potentials on the electroencephalograph, Buchasbaum and Fedio found that verbal and nonsense stimuli produced differences in evoked response waveforms for both hemispheres with greater differences evident in left-hemisphere tracings.

Doyle, Ornstein, and Galin (1974) conducted experiments in which subjects performed verbal, arithmetic, and spatial tasks. They again found that the hemisphere engaged in the cognitive activity develops proportionately less alpha power.

Imagery:

One ability that has been used as an indicator of 'hemisphericity' is the production of imagery. Imagery has been associated with right-hemisphere processes.

The concept of mental imagery has experienced both high and low periods of interest in educational and psychological study (Holt, 1964; Paivio, 1971). There is currently a resurgence of interest in the concept as Paivio notes: "...It is not surprising that we find the concept of imagery reappearing essentially in its pristine form but with its respectability enhanced by a behavioristic cloak. On the basis of results from experimental investigation involving a classical conditioning paradigm, Leuba (1940) felt justified in referring to images as conditioned sensations."

D.O. Hebb has distinguished various types of imagery based on locus of arousal. Memory imagery, he posits, is aroused centrally. Hebb believes this accounts for its lack of detail. However, eidetic images involve the first order cell assemblies that are characteristic of perception. Thus, according to Hebb, eidetic images would appear in detail. (Hebb, 1968)

Other researchers have similarly suggested that the activation of cell assemblies or neural patterns are the basis of imagery (Bruner, 1957; Pribram, 1960; Taylor, 1962, Tomkins, 1962 in Paivio).

Some researchers have attempted to link the concept of imagery to forms of creativity (Barron, 1958; Rugg, 1963; Walkup, 1965).

Schmeidler (1965) correlated scores on visual imagery and creativity questionnaires. The results showed a low but significant positive correlation.

Paivio relates Sheehan's (1967) findings that the accuracy of visual memory is related to individual differences in imaging ability. Sheehan reports that low imagers are more dependent on (verbal) symbolic coding and use coding devices to organize their perceptions while vivid imagers perceive directly and literally.

DiVesta (1971) studied the interaction of imagery-ability and instructional procedures. He conducted a series of seven studies attempting to link imagery-ability to stimulus aspects and learner information processes. Some of his findings include: imaginal processing is more effective for the processing of concrete words while the verbal mode is more effective for processing abstract words; self reports of imaging are strongly related to social desirability; and Paivio's model of associative learning is also supported.

3. Complexity and the Hausdorff-Besicovitch Dimension

Attneave and Arnoult (1956) noted that there "is virtually no psychophysics of shape or pattern." They further commented that, unless meaningful units of variation are specified, functional relationships cannot be obtained. The most precise knowledge of perception is in areas which have yielded to psychophysical analysis. These include such elements as size, color and pitch.

Battig (1962) reiterated the need for more precise measurement of shape in his study of the association value of perceptual shapes. He stated "the finding of complex interactions involving the complexity (N) and curvature (C) variables points strongly to the inadequacy of measurement procedures sensitive only to the detection of simple linear relationships...".

Clear definitions of pictorial attributes and reliable measures of these attributes are a necessary condition in the research of how such attributes interact with psychological variables. Complexity is one attribute which has eluded clear definition. One type of complexity which has recently yielded to mathematical definition and measurement is figure-boundary complexity. Dr. Mandelbrot of IBM's Watson Research Center has found that when figures are self-similar, that is, when each portion can be considered a reduced-scale image of the whole, the degree of boundary complication can be described by a mathematical quantity D, called the Hausdorff-Besicovitch dimension. He calls such self-similar figures fractals. Many figures to which free association and imaging are common, for example cloud and island outlines, also appear to be fractals. Hence, the speculation arises that boundary complexity may be related to the imagery process and hence to right-hemisphere functioning. The use of the Hausdorff-Besicovitch dimension has made many otherwise impossible figures yield to measurement. (A more complete description of the Hausdorff-Besicovitch dimension is found in Appendix D).

Summary

This literature review has presented the history of visual education. It has shown the relationship of visualization to two learning paradigms and the impact these paradigms have had on research in the field of educational technology. Studies related to the lateral specialization of the human brain and to the hemispheric processing of visual information were also reviewed. Finally, literature was presented that pertains to the identification and measurement of a specific characteristic (complexity) of visual stimuli.

CHAPTER III

DESIGN OF THE STUDY

CHAPTER III

DESIGN OF THE STUDY

This chapter describes the research design and procedures used in the study. Information is presented in the following sequence: 1) a statement of the research questions and hypotheses, 2) a description of the research procedures, and 3) a description of the research design over time.

1. Research Questions and Hypotheses

In attempting to investigate whether the complexity of figure boundary is a significant factor in determining which hemisphere processes a visual figure, two specific questions were posed by the experimenter. First, if a subject is presented with a series of pictures which vary in boundary complexity, will the amount of right/left hemisphere activation change as the boundary complexity increases? Secondly, will the amount of right/left hemisphere activation evoked by the pictures depend in some way on the imaging ability of the subject?

These questions generated two hypotheses. They are stated below in the null form.

1. There will be no significant difference between left- and right-hemisphere alpha activity for each of the stimulus figures.
2. There will be no correlation between the ability to image (measured by Sheehan's Questionnaire) and the amount of right-hemisphere alpha activity.

2. Research Procedures

A. Design:

A research study was designed to test these hypotheses. The design incorporated two independent variables and one dependent variable. The main independent variable was the Hausdorff-Besicovitch dimension of the picture boundaries. This dimension is a measure of boundary complexity. It is further described in section 2 C. of this chapter and in Appendix D. The second independent variable was the subject's ability to image as measured by the Sheehan Questionnaire. This questionnaire is discussed in section 2 D. below. The dependent variable in the design was the amount of activation in the right and/or left hemispheres while viewing the fitures. The amount of alpha wave activity as measured by an electroencephalograph was used as an indicator of hemispheric engagement. It is believed that the presence of alpha waves indicates a resting state in the hemisphere. A discussion of the electroencephalograph is offered in section 2 D.

The research design over variables can be diagrammed as:

Picture Treatment

	1	2	3	4	5	6	7	8	9	10	11
High Imagers											
Medium Imagers											

Note: There were no low imagers in the study sample.

Figure 3: Design Over Variables

Aside from the independent and dependent variables, attempts were made to control extraneous variables. Picture characteristics (e.g., color, detail) other than the Hausdorff-Besicovitch dimension were controlled by being held constant. The variable of subject age was confined to adults 18 to 45 years.

Both the internal and external validity of the design were considered. In regard to internal validity the effects of history and maturation were minimized to the extent that the imaging ability test and the treatments occurred close together in time. The effects of pretesting were minimized because the nature of the instrument for testing imaging ability made it unlikely that 'learning' occurred that would affect the experimental outcome. However, statistical regression may have occurred due to the use of extreme scores in assigning subjects to the categories of high and medium imagers.

External validity was threatened because the sample was not random. It consisted of volunteers. Therefore, there was the possibility of selection bias. The Hawthorne effect may also have threatened external validity because subjects were aware of their participation in an experiment. Additionally, it is possible that the experimental results may have occurred due to enthusiasm generated by the novelty of the treatment. The imaging ability tests may also have increased the subject's sensitivity to the treatment in some undetermined manner.

B. Population and Sampling:

The population for the study included 18 to 45 year old persons affiliated with Michigan State University during Spring Term 1979. This included both students and staff members. Sampling was done according to the following criteria: 1) willingness to be a subject for each of three experimental treatments, 2) absence of psychological or physical disorders, 3) right-handedness, 4) no report of use of drugs or medication, and 5) being of the age of legal consent.

All subjects were unpaid volunteers who self-selected involvement in the experiment. According to self-reports, these subjects have no known history of epilepsy, brain damage, or psychopathology. Subjects had normal or corrected-to-normal vision. Only right-handed persons were selected for the study. Harris (1975) has described the American population as 90 to 98 percent right-handed. Of this segment, approximately 99 percent have language functions in the left hemisphere. Left-handed persons are considered to be less well lateralized for language functions with only 53 to 65 percent having left hemisphere language specialization according to Harris. Because they are less well lateralized, left-handed persons were excluded from the study.

Additional demographic data (e.g., sex, race, native language) were also collected on each subject for possible post hoc analysis.

C. Description of the Stimuli:

A series of pictures were selected to test the subjects' hemispheric activation while viewing figures of differing boundary complexity. These black-and-white pictures were of figures originally constructed by a computer according to the specific mathematical formulae developed by Dr. Benoit Mandelbrot of I.B.M.

Figures were selected according to their Hausdorff-Besicovitch dimension which ranged from 1.0 to 1.9. Figures of low Hausdorff-Besicovitch dimension (e.g., 1.0) have low boundary complexity. Those of high dimension (e.g., 1.9) have very complex boundaries. Eleven figures were selected from those appearing in Dr. Mandelbrot's book, <u>Fractals: Form, Chance, and Dimension</u>. The figures were photographed and made into black-and-white prints. These prints were presented to the subjects via a tachistoscope.

D. Instrumentation:

Two instruments were used in the study. The first instrument was Sheehan's Shortened Bett's Questionnaire. It was chosen as an indicator of the subject's ability to image. The second instrument was the electroencephalograph. It was chosen as an indicator of hemispheric involvement.

Sheehan's Shortform Bett's Questionnaire:

In 1909 Bett developed a questionnaire of 150 items to measure mental imagery. It is still, perhaps, the most comprehensive imagery measure available.

Sheehan selected thirty-five of the original 150 items for use in a short form of the test. Sheehan's instrument predicts a subject's capacity to image in a variety of sensory modes. It has the advantage of taking only ten minutes to administer. Five questions are asked for each of seven imagery modalities: visual, auditory, cutaneous, kinaesthetic, gustatory, olfactory, and organic. The subject marks a seven point scale from "no image at all" (7) to "perfectly clear and vidid" (1). A mean score and overall mean can then be computed. The subject's overall means can be used to differentiate high imagers from medium and low imagers.

Sheehan found a correlation of .92 between the total scores on the original and shortened forms showing that the short form predicted overall imagery scores almost as well as the original Bett's Questionnaire (Paivio, 1971, p.487). The finding was replicated by further analysis of the data for a sample of teacher college students (r=.98).

Although the shortened form was developed in Australia, Sheehan reports a study which established the reliability and suitability for American college students. In a test-retest procedure over a seven month period it was found that the test-retest of both the total and visual scales as measured by the Pearson correlation was 0.78.

Electroencephalograph (EEG):

The electroencephalograph is a well known clinical instrument. It is a machine used to record fluctuations in electrical potentials occurring in the brain. The electroencephalogram is a record commonly produced by recording from electrodes attached to the scalp. Scalp recordings attenuate the potential differences of the cortex so that not all of the electrical activity of the brain is recorded by the EEG. This reduction is on the order of 3:1 from cortex to scalp. The small potential differences between points on the scalp are amplified by the EEG. A tracing is produced from them in the form of lines (channels) drawn on moving paper by the deflection of inkwriting pens.

Clinically, these tracings are used by physicians to determine abnormalities in brain function due to causes such as epilepsy, brain damage, and tumors. However, the EEG has also been used as a research instrument. One such use has been the determination of lateral, hemispheric differences. While in a resting mode, the parietal and occipital regions of the brain produce characteristic alpha waves which range in frequency from 7-14 Hz. The assumption has been made (Galin and Ornstein, 1972) that the presence of alpha waves conotes a resting mode of the hemisphere in which they occur. Thus, any information being presented is not being processed in that hemisphere.

Because of the nature of the instrument and the relative newness of its application to hemispheric information-processing research, no data on its reliability or validity were reported.

E. Data Analysis

Three major steps were involved in the analysis of data for this research. These included: 1) selecting and sampling specific epochs from the EEG records for analysis, 2) digitizing the selected EEG waveforms, and 3) frequency analysis of the digitized waveforms. A brief description follows of these techniques, their rationale, and application. A more detailed account of the statistical analysis of the data is presented in Chapter 4.

Selection and Sampling of Epochs:

The selection of EEG channels for comparison was based on a study by Galin and Ornstein (1972) in which parietal and temporal recording sites demonstrated the most laterality. In this study parietal and temporal sites P3-T5 and P4-T6 were analyzed for differences between the hemispheres.

The output from the electroencephalograph consisted of pen tracings on paper. The beginning and end of each stimulus epoch was marked on the EEG record. Stimuli were presented for twenty seconds each. Two-second epochs from each stimulus event were digitized. Epochs were chosen at random with the aid of a number table. Visual over-ride was used to discard epochs which displayed artifacts.

Digital Conversion of the Data:

Due to time constraints it was decided to reduce the subject number to six. This was done by random selection. In order to conduct statistical analysis of the EEG data for these six subjects, it was necessary to convert the data to numerical (digital) form. This was accomplished via a device known as a DATATIZER. This device determines x and y coordinates for specific points. It consists of a cursor with cross-hairs and a 5X magnifying glass for tracing the curve to be digitized. The DATATIZER at Michigan State University is interactively connected to the CDC 6500 computer system.

The channel tracings from the EEG were followed with the DATATIZER cursor and the curves were converted to digital form. A full account of this process is presented in Chapter 4. (Further description of the DATATIZER can be found in Appendix B).

Frequency Analysis:

A specifically modified computer program was used to analyze the digitized waveforms. The program broke the waveforms into their component frequencies. The electrical activity measured at the scalp contains frequencies between 1 and 60Hz. The frequencies of particular interest in this study were the alpha wave frequencies ranging between 7 and 14 Hz. The presence of alpha waves has been used as an indicator of a resting mode in the hemisphere being monitored.

A Fast Fourier Transformation was utilized to resolve the frequency makeup of the EEG waveforms. It provided a mathematical estimate of the percentage of the waveform that was contributed by the alpha frequencies. The percentage of the alpha in the left-hemisphere EEG output was then divided by the percentage of the alpha present in the right-hemisphere for the same channel during the same time period. This ratio (left/right) was then used to indicate which hemisphere was active and the extent of activation during the viewing of each stimulus.

3. Research Design Over Time

An appointment was made for the subject to receive the experimental treatment procedure at the M.S.U. Clinical Center. In many cases the treatment could immediately follow the administration of the Sheehan Questionnaire. When this was not possible, an attempt was made to make the intervening time interval as short as possible.

When the subject arrived for the treatment procedure, he was greeted and a brief verbal explanation of the treatment sequence and an introduction to the electroencephalogram was offered to lessen his/her anxiety. (See Appendix G for a copy of this verbal explanation). The subject was then asked to read and sign a final consent form and to fill out a self-report of other demographic data for possible post hoc analysis. (See Appendix G for copies of these forms)

Before electrode placement was made, the subject was questioned about personal comfort (chair height, restroom needs, and so on). Electrodes from a Beckman electroencephalograph were then attached to the subject's scalp by a trained technician from the Clinical Center staff. Gold-plated electrode discs were used and attached to the temporal left and right (T_5, T_6), parietal left and right (P_3,P_4), and occipital left and right (0_1,0_2) locations on the scalp. In addition, two central electrodes (C_3,C_4), and two earlobe electrodes (A_1,A_2) were used. Finally, an electrode was placed on the left forearm to monitor EKG.

Sensitivity was adjusted for .5 with high linear filters adjusted to 7 and low linear filters set at 0.3. The strip chart speed was standardized at 30 mm/sec. Following attachment, a short run was made to obtain a baseline and to eliminate conductance problems while screening for 60 cycle "noise" and muscle artefact.

Three separate experimental treatments were given to each subject. In addition to the treatment described in this study two others (a facial recognition test, and museum display test) were also administered. To control for possible serial effects of these treatments and possible subject fatigue as a contaminating variable, treatments were rotated.

The experimental treatment for this study consisted of exposing the subject to eleven pictures of figures whose Hausdorff-Besicovitch dimensions ranged from approximately 1.0 to 1.9. After the subject was attached to the EEG, these pictures were shown to him in random order. The pictures were presented via a tachistoscope. Each picture was presented in a center view for a period of twenty seconds. A thirty second eyes-closed rest period followed the viewing of each picture to help eliminate afterimages. During the viewing, the subject's electroencephalogram was recorded for both the left and right hemispheres. Special attention was given to ascertaining the alpha wave pattern. Presentation events were marked on the EEG paper tracing to provide reference points for subsequent data analysis.

Summary

This chapter has presented a statement of the research questions and hypotheses. The research procedures used to test these hypotheses were described, and an account of the research design over time was given.

CHAPTER IV

ANALYSIS OF RESULTS

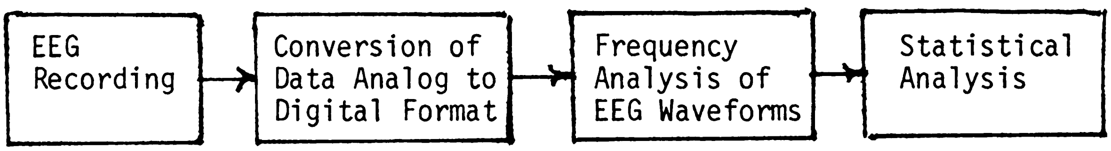
CHAPTER IV

ANALYSIS OF RESULTS

This chapter contains: 1) a description of the data collection, and 2) the analysis of the results of the study. Each testable hypothesis is presented individually with findings obtained from the results. A summary follows the presentation of results.

Data Collection

Nineteen adults from Michigan State University were shown a series of figures with differing boundary complexities. During the viewing of these figures electroencephalographic recordings were made of each subject's brain activity. Because of a variety of technical reasons, some of which will be explained later, only 6 recordings were used in the final data analysis. The sequence of data collection and analysis can be diagrammed as follows:



EEG Recordings were gathered and referenced for each subject during the eleven stimulus trails. A standard, Interantional 10/20 system was used during data recordings. Data collection was made by a clinical EEG technician. All recordings were manually referenced to the presentation of each of the stimuli. These reference marks and trial numbers were later used to identify the EEG waveforms which succeeded the presentation of the stimulus to the subject. The EEG recordings were obtained from scalp sites P3,P4, T5, and T6. These correspond to the left and right parietal and the left and right temporal lobes of the cortex. Two-second epochs from each stimulus trial were chosen for analysis.

Epoch Selection and Marking

The EEG record could not be directly read by the computer. It first had to be turned into numerical data. This was done through the use of a digitizer. However, before the data could be digitized, the paper record needed to be prepared and epochs selected.

Leads T_5, T_6 and P_3, P_4 were selected for analysis since previous studies indicated the possibility of the greatest differential at these sites. Because of limited time, it was decided that a two-second epoch from each stimulus event would be digitized. Epochs were chosen at random with the aid of a number table. However, visual over-ride was used to discard epochs which displayed artifacts.

Because the paper record changed position slightly from subject to subject, a base was needed for each epoch. To find one, a measurement was made at the beginning of each record. Baselines were then drawn above and below the lead line for each stimulus epoch selected. The assumption was made that the paper position remained constant during the recording of the subject but varied between subjects.

Digitizing

Once a base had been drawn the epoch could be digitized. Epochs from all eleven stimuli and a stimulus-free baseline epoch were digitized for each of the subjects.

The digitizer is a device which determines x and y coordinates of a specific point. The M.S.U. device is a DATATIZER model from G.T.C.O.

Corporation. (Further description of the DATATIZER can be found in Appendix B). It consists of a cursor with cross-hairs and a 5X magnifying glass for tracing the curve to be digitized. It also employs a 42 inch by 60 inch grid table. The digitizer is connected to a microprocessor with an interactive 53 character keyboard and display, and to the interactive CDC 6500 computer system.

Data was digitized according to an incremental mode. Everytime a predetermined increment was passed on the X-axis (time) a value was sent to the computer for the Y-axis (amplitude). It was decided that each two-second epoch would be broken down into 256 increments on the X-axis. This number was selected to correspond with the needs of later Fourier analysis. Thus, the far left point on the X-axis was called zero and the far right point on the X-axis was labeled 256. Variance did occur in the number of points recorded on the X-axis per epoch due to the speed at which points can be sent to the computer. At times the manual tracing was fater than the digitizer's ability to send points.

The EEG curve was manually traced for each epoch with the cross-hairs following the line. As points were sent, they registered in a local file and were displayed on a cathode ray tube. An identifier was given to each data point which listed the experimentor, subject, trial, and lead numbers. Later, the local files were cataloged into permanent files on the CDC 6500 computer. Difficulty was encountered with this system when the CDC 6500 'crashed' periodically due to hardware problems and local files were lost. Due to time constraints, data from a total of six subjects, who displayed the least amount of artifact, were digitized.

In order to check the digitizing procedure, some of the data which resulted from the digitizing process was then used to generate a wave form pattern. This artificially produced wave for pattern was then checked by eye to see how closely it conformed to the original wave form pattern from which it was derived. Figure X shows a wave form generated from the digitized data and Figure Y shows the original wave form. This check indicates that there does not seem to be much loss of information due to the digitizing process.

Frequency Analysis

Several types of analysis have been employed in the study of the EEG. Superimposition was first used by Dawson in 1951 (Redmond, 1976, p.4B-10). This method is done photographically using a cathode ray oscilloscope. A second method uses averaging in which the mean value of the record is taken following a number of presentations. Another technique is period analysis in which the time between zero-line crossings is measured. Correlational analysis has also been employed by Brazier and Casby (Redmond, 1976, p.4B26). One popular form of study employs the use of frequency analysis. The most common type of frequency analysis is the Fourier which separates the waveform into a number of harmonically related components. (Details of the Fourier Transform and of how it relates to power spectra can be found in Appendix E.) Cooley and Tukey (Redmond, 1976) developed a quick method for approximating the Fourier known as the Fast Fourier Transform. The Fast Fourier Transform and subsequent power spectra calculation were selected for analysis of the data in this study.

A computer program was written by a staff member of the M.S.U. Computer Center's Applications Programming section to prepare the data for the Fourier analysis (for a copy of this program see Appendix A). The data was then run through an IMSL Fast Fourier subroutine. Power spectra were calculated for the following frequency bands: delta 1-4 cps, theta 5-7 cps, alpha 8-13 cps, and beta 14-35 cps.

The table on the following page displays the alpha values for the left and right hemispheres by subject and figure. It also gives the right/left ratio and Sheehan Questionnaire scores for each subject.

The amount of information processing is assumed to be inversely proportional to the amount of alpha wave activity in the hemisphere. Thus, if there is high alpha wave activity there is considered to be a low level of information processing taking place in that hemisphere. Using a ratio of alpha activities provides an inverse, but direct measure of the ratio of information processing taking place within the two hemispheres. For example, if the alpha ratio (right/left) is say 30 to 20 or 1.5, then, this implies that there is more alpha activity in the right hemisphere, and hence less information processing in the right hemisphere. Hence a ratio over 1 indicates left hemispheric information processing dominating, while a ratio of less than one (i.e. a fraction) would indicate right hemisphere was dominating the information processing. Thus from an analysis of the alpha activity, and the ratio of alpha activities, one can infer which hemisphere was dominant for a particular visual stimulus.

TABLE 1. Display of Data

Figure	Hem.	Subject 1	Ratio	Subject 2	Ratio	Subject 3	Ratio	Subject 4	Ratio	Subject 5	Ratio	Subject 6	Ratio
1	left right	.0137 .0143	1.04	.0068 .0057	.84	.0038 .0034	.89	.0077 .0147	1.91	.0078 .0068	.87	.0038 .0044	1.16
2	left right	.0140 .0360	2.57	.00912 .0068	.75	.0032 .0039	1.22	.0077 .0168	2.18	.0051 .0073	1.43	.0002 .0029	14. 5
3	left right	.0186 .0102	.55	.0115 .0120	1.04	.0018 .0033	1.83	.0006 .0280	46. 7	.0073 .0085	1.16	.0068 .0063	.93
4	left right	.0070 .0123	1.76	.0081 .0075	.93	.0025 .0036	1.44	.0153 .0097	.63	.0076 .0098	1.29	.0042 .0069	1.64
5	left right	.0094 .0079	.84	.0101 .0065	.64	.0021 .0024	1.14	.0129 .0241	1.87	.0087 .0074	.85	.0063 .0099	1.57
6	left right	.0212 .0127	.60	.0051 .0122	2.39	.0025 .0027	1.08	.0092 .0177	1.92	.0100 .0081	.81	.0056 .0076	.74
7	left right	.0091 .0320	3.52	.0077 .0050	.65	.0018 .0041	2.28	.0073 .0127	1.74	.0082 .0064	.78	.0056 .0074	1.32
8	left right	.0120 .0123	1.03	.0162 .0087	.54	.0021 .0024	1.14	.0248 .0496	2.00	.0118 .0122	1.03	.0077 .0063	.82
9	left right	.0233 .0134	.58	.0072 .0032	.44	.0036 .0034	.94	.0057 .0440	7.72	.0186 .0202	1.09	.0049 .0021	.43
10	left right	.0119 .0101	.84	.0082 .0055	.67	.0020 .0043	2.15	.0104 .0493	4.74	.0102 .0085	.83	.0047 .0052	1.11

"TABLE 1 (continued)"

Figure	Hem.	Subject 1	Ratio	Subject 2	Ratio	Subject 3	Ratio	Subject 4	Ratio	Subject 5	Ratio	Subject 6	Ratio
11	left	.0135	1.21	.0095	.51	.0031	.84	.0072	3.50	.0113	.57	.0054	.63
	right	.0164		.0049		.0026		.0252		.0064		.0034	
Base-line	left	.0394	.41	.0076	.63	.0046	.93	.0105	3.14	.0062	1.63	.0030	.93
	right	.0163		.0048		.0043		.0330		.0101		.0028	
Sheehan Question-naire	Total	1.89		1.51		2.05		2.2		2.8		2.14	
	Visual	3.4		1.2		2.25		2.2		2.8		1.6	

Statistical Methods

The following statistical tests were applied to the data: 1) Eleven dependent t-tests were used to test for significant differences in hemispheric alpha activity for each of the stimulus figures; 2) a Runs test was used to determine if the pattern of alpha activity for each subject was random across all the stimulus figures; 3) Sign tests were used to determine A) if the difference between the right-hemisphere alpha activity while viewing a figure and the baseline right-hemisphere activity was random for each figure, B) if the difference between the right-hemisphere alpha activity while viewing a figure and the baseline right-hemisphere alpha activity was random for each subject, C) if the difference between the left-hemisphere alpha activity while viewing a figure and the baseline left-hemisphere alpha was random for each subject, D) if the difference between right- and left-hemisphere alpha activity was random for each figure; 4) four Spearman Rank Correlation tests were performed to determine the correlations between: A) the subject's visual score on the Sheehan imagability test and the subject's baseline, B) the subject's total score on the Sheehan and the subject's baseline, C) the subject's visual score on the Sheehan and the subject's right-hemisphere alpha activity, D) the subject's total score on the Sheehan and the subject's right-hemisphere alpha activity.

Hypotheses Testing

Results of testing each hypothesis are presented in this section. Each hypothesis is stated in the testable, null form and findings are presented for each.

Differences in Hemispheric Alpha Activity by Stimulus Figure

H_0: There is no significant difference between left- and right-hemisphere alpha activity for each of the stimulus figures.

H_1: The null hypothesis is false.

The following table presents the t-tests results for each of the eleven stimulus figures.

TABLE 2. Results of T-Test

Figure	No. of Cases	T-value	Complexity Dimension	Reject/Not Reject Null Hypothesis
1	6	- .76	1. 0	Not Rejected
2	6	-1.59	1. 0	Not Rejected
3	6	- .73	1. 1	Not Rejected
4	6	- .56	1. 3	Not Rejected
5	6	- .66	1. 4	Not Rejected
6	6	- .48	1. 5	Not Rejected
7	6	-1.21	1. 5	Not Rejected
8	6	- .62	1. 6	Not Rejected
9	6	- .54	1.67	Not Rejected
10	6	- .89	1. 7	Not Rejected
11	6	- .42	1. 9	Not Rejected

For an $\alpha = .05$ level, a a t-value of $\pm$ 2.571 is necessary for statistical significance. Accordingly, none of the t-values for the eleven stimulus figures achieved this level. Therefore, the null hypothesis was not rejected for any of the figures.

Correlation of Ability to Image and Right-Hemisphere Alpha Activity

H_0: There is no correlation between the ability to image (measured by Sheehan's Questionnaire) and the amount of right hemisphere alpha activity.

H_1: The null hypothesis is false.

A Spearman Rank Correlation coefficient was computed for the variables of visual Sheehan imagability score and mean right alpha. The resulting coefficient was equal to .31. This correlation coefficient would not allow prediction from one variable to the other.

A Spearman Rank Correlation coefficient was computed for the variables of total Sheehan imagability score and mean right alpha. The resulting coefficient was equal to .26. This correlation would not allow prediction from one variable to the other.

Because of these relatively low correlations, the null hypothesis was not rejected.

Further Post Hoc Analysis

Correlation of Ability to Image and Baseline State

H_0: There is no correlation between the ability to image and the subject's typical baseline state.

H_1: The null hypothesis is false.

A Spearman Rank Correlation coefficient was computed for the variables of visual Sheehan imagability score and subject baseline. The resulting coefficient was equal to .43. This correlation would not allow prediction from one variable to the other.

A Spearman Rank Correlation coefficient was computed for the variables of total Sheehan imagability score and subject baseline. The resulting coefficient was equal to .20.

Because of these relatively low correlations, the null hypothesis was not rejected.

Pattern of Differences between Left and Right Alpha Activity

H_0: The pattern of differences between the left- and right-hemisphere alpha activity for each individual is random across all eleven figures.

H_1: The null hypothesis is false.

A Runs Test was performed on the data. The number of runs for all six subjects fell within the random range. The null hypothesis is not rejected.

TABLE 3. Runs Test

Subject	n_1	n_2	r
1	5	5	7
2	5	5	6
3	5	4	8
4	5	5	5
5	6	5	5
6	5	4	3

Randomness of Differences between Right-Hemisphere Alpha and Subject Baseline State for Each Figure

H_0: The pattern of differences between the right-hemisphere alpha activity and the subject's baseline can be accounted for by chance for each of the stimulus figures.

H_1: The null hypothesis is false.

A one-tailed sign test was applied to test this hypothesis. All eleven differences can be accounted for by chance. Therefore, the null hypothesis is not rejected.

Randomness of Difference between Right-Hemisphere Alpha and Left-Hemisphere Alpha for Each Figure

H_0: The pattern of differences between the right- and left-hemisphere alpha activity of each subject can be accounted for by chance for each figure.

H_1: The null hypothesis is false.

A one-tailed sign test was applied to test this hypothesis. All differences can be accounted for by chance. Therefore, the null hypothesis was not rejected.

Differences between Right-Hemisphere Alpha and Subject Baseline for Each Subject

H_0: The pattern of differences between the right hemisphere alpha and the subject's baseline can be accounted for by chance for each subject.

H_1: The null hypothesis is false.

A two-tailed sign test was applied to the data to test the above hypothesis. Probabilities for three of the six subjects were not accounted for by chance at $\alpha = .05$. Results are shown below, P = .5 is chance.

TABLE 4. Sign Test #3

Subject	No. Positive Differences (Right Alpha minus Baseline)	No. Negative Differences (Right Alpha minus Baseline	P
1	3	8	.226
2	10	1	.012
3	0	10	.000
4	3	8	.226
5	2	9	.066
6	10	10	.012

The null hypothesis was rejected.

Differences between Left Hemisphere Alpha and Subject Baseline for Each Subject

H_0: The pattern of differences between the left-hemisphere alpha and the subject's baseline can be accounted for by chance for each subject.

H_1: The null hypothesis is false.

A two-tailed sign test was applied to the data to test the above hypothesis. Probabilities for four of the six subjects were not accounted for by chance at $\alpha = .05$. Results are shown below. P = .5 is chance.

TABLE 5. Sign Test #4

Subject	No. Positive Differences (Left Alpha minus Baseline)	No. Negative Differences (Left Alpha minus Baseline)	P
1	0	11	.000
2	8	3	.226
3	0	11	.000
4	3	8	.226
5	10	1	.012
6	10	1	.012

The null hypothesis was rejected.

Summary

The following table summarizes the results of the study.

TABLE 6. Summary of Results

Null Hypothesis	Statement of Rejection/Non-Rejection
There is no significant difference between left- and right-hemisphere alpha activity for each of the stimulus figures.	Not Rejected
There is no correlation between the ability to image (measured by Sheehan's questionnaire) and the amount of right-hemisphere alpha activity.	Not Rejected
There is no correlation between the ability to image and the subject's typical baseline state.	Not Rejected
The pattern of differences between the left- and right-hemisphere alpha activity for each individual is random across all eleven figures.	Not Rejected
The pattern of differences between the right-hemisphere alpha activity and the subject's baseline can be accounted for by chance for each of the stimulus figures.	Not Rejected
The pattern of differences between the right and left-hemisphere alpha activity of each subject can be accounted for by chance for each figure.	Not Rejected

CHAPTER V

SUMMARY AND CONCLUSIONS

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This chapter presents a review of the study and a summary of the conclusions and recommendations. In the first section the experiment's purpose, need, and procedures are summarized. In the second section a rationale of the findings is presented and conclusions are drawn based on the data analysis. Finally, implications and recommendations for future research are discussed.

Review of the Study

This research was based on a stimulus-oriented paradigm. It emphasized the relationship of visual stimuli to cognitive processing. The study experimentally investigated the effect of figure boundary complexity on hemispheric activation.

Literature describing the phenomenon of lateral hemispheric specialization was presented. Research has shown that the left hemisphere of most adults controls verbal information while the right hemisphere controls visual and spatial information. Currently, only the left, or verbal, hemisphere functions are emphasized in American education. Therefore, the need for a more hemispherically balanced approach to education was presented. Since the right hemisphere is specialized for visual material, visual instruction would seem to present one method of enhancing right-hemisphere involvement in the educational process. As was related in the review of literature, few research studies have been conducted that relate visual instruction to information processing in human learners.

Such research is needed to further the understanding of the psychological principles that underlie the design of visual instructional materials.

This study attempted to isolate a characteristic of pictures that could be used to predict which of the hemispheres would process the pictorial information. Figure boundary complexity was chosen as a possible predicting characteristic. The subjects were shown a series of eleven figures via a tachistoscope. These figures varied in their degree of boundary complexity. The figures were presented to the subjects in their central visual field for twenty seconds. This was followed by a thirty second eyes-closed rest period to lessen the effect of after images. Subjects were not required to make verbal or manual responses.

EEG recordings were gathered and referenced for each of the eleven trials. Baseline recordings with eyes open and closed were also sampled for each subject. Subsequent to the EEG data collection and experimental treatment, each subject was asked to complete Sheehan's short-form version of the "Betts QMI Vividness of Imagery Scale." This test was selected for its construct validity and test-retest reliability. It was used to investigate the relationships between imaging ability and hemispheric activation.

Two primary and six post hoc hypotheses were tested. They are stated below:

1. There is no significant difference between left-and right-hemisphere alpha activity for each of the stimulus figures.

2. There is no correlation between the ability to image (measured by Sheehan's Questionnaire) and the amount of right-hemisphere alpha activity.

3. There is no correlation between the ability to image and the subject's typical baseline state.

4. The pattern of differences between the left- and right-hemisphere alpha activity for each individual is random across all eleven figures.

5. The pattern of differences between the right-hemisphere alpha activity and the subjects' baselines can be accounted for by chance for each of the stimulus figures.

6. The pattern of differences between the right- and left-hemisphere alpha activity of each subject can be accounted for by chance for each figure.

7. The pattern of differences between the right-hemisphere alpha and the subject's baseline can be accounted for by chance for each subject.

8. The pattern of differences between the left-hemisphere alpha and the subject's baseline can be accounted for by chance for each subject.

Statistical tests of these hypotheses showed no significant differences at the .05 level for hypotheses one through six. Tests of hypotheses seven and eight did produce significant differences.

Conclusions

The following conclusions are tentatively proposed:

1. Since no significant differences were found in the right- and left-hemisphere alpha activity for the stimulus figures, it is tentatively concluded that the degree of figure boundary complexity does not determine which hemipshere the figure will be processed in.

2. The Sheehan short-form of the Bett's imagery questionnaire showed that the subjects for this investigation were all medium to high imagers. The Spearman Rank Correlation coefficients between the Sheehan scores and the right-hemisphere alpha activity did not achieve significance at the .05 level. Therefore, it is tentatively concluded that right-hemisphere information processing as measured by alpha activity does not correlate very highly with the ability to generate clear visual images as measured by the Sheehan questionnaire.

3. Since the ability to image as measured by the Sheehan questionnaire and the subject baselines had very low Spearman Rank Correlation coefficients, it is tentatively concluded that the subject's baseline states are not predictive of their ability to image.

4. The pattern of differences between the left- and right-hemisphere alpha activity was random across all the stimulus figures for each subject. Therefore, it is tentatively concluded that there is no consistent pattern of hemispheric activation associated with the complexity of the figure boundaries.

5. Because the pattern of differences between the right-hemisphere alpha activity and the subjects' baselines can be accounted for by chance for each stimulus figure, it can be tentatively concluded that none of the stimulus figures produced a consistent pattern of high or low right-hemisphere alpha activity in the subjects.

6. Because the pattern of differences between the right- and left-hemisphere alpha activity of each subject can be accounted for by chance for each figure, it can be tentatively concluded that none of the figures consistently produced relatively more right- or left-hemisphere alpha activity.

7. Since the pattern of differences between the right-hemisphere alpha and the subject's baseline was not accounted for by chance for three of the six subjects, it is tentatively concluded that the subjects possess a pattern of consistently more or less right-hemisphere alpha across all stimulus figures.

8. Since the pattern of differences between the left-hemisphere alpha and the subject's baseline was not accounted for by chance for four of the six subjects, it is tentatively concluded that the subjects possess a pattern of consistently more or less left-hemisphere

across all stimulus figures.

Discussion

Conclusions one, four, five, and six appear to cast doubt on the theory that the complexity of the figure is associated with the determination of which hemisphere processes the figure. However, the number of subjects was not sufficiently large to add certainty to this analysis. Also, the subjects were all right-handed adults. Results may differ for left-handed persons or for children prior to lateralization.

Conclusions two and three appear not to support the theory that imaging ability is associated with right-hemisphere activity or with the person's typical baseline brain activity state. Again, the subject number is not large enough to add certainty.

Conclusions six and seven appear to add credibility to the theory that persons possess a preferred mode of processing information regardless of its complexity. This appears to be person-specific with some subjects having consistently more right-hemisphere activity across all figures and some consistently more left-hemisphere alpha activity. The subject number is not large, however, and only adults were tested.

There are several potential sources of error in the study. One important limitation is the number of subjects and their range of imagability and age. The most likely source of error is the selection and sampling of the EEG epochs since the actual timing of the visual processing operation is unknown. Error may also have occurred during the digitizing and frequency analysis process. The visuals themselves may also have introduced error since most are linear variations, but one involves curvilinear variations.

Recommendations

1. It is recommended that this study be replicated using improved methodology. The use of a DC, FM tape recorder to collect the EEG signals would allow more rapid, less expensive, and more accurate data analysis. Manual digitizing is both costly and time consuming. It is also subject to many more sources of possible error.

2. It is recommended that this study be replicated using a larger number of subjects to help substantiate or disconfirm its results.

3. It is recommended that further studies be conducted to explore the possibility of preferred modes of information processing, and that these studies be expanded to include children prior to the age of lateralization.

Implications for Future Research

This study and the literature surrounding it generate the following questions for possible research:

1. Does a person-specific preferred mode for processing visual information exist?
2. If a preferred mode does exist, is it acquired through learning, through maturation, or is it genetically determined?
3. Does use of a response-oriented learning paradigm lead primarily to the acquisition of left hemisphere knowledge?
4. Do EEG readings indicate that learning is taking place or merely that processing is occurring?
5. Can a person learn without an overt change in behavior?
6. Can visual presentations alone create learning? If so, does this learning occur only in the right hemisphere?
7. Can the findings of verbal learning studies be legitimately generalized to visual learning?

Summarization of the Relationship of the Results of the Study to Educational Technology

Applied fields, such as educational technology, attempt to base their practical approaches to problems on scientific evidence whenever possible. Instructional designers are concerned with assessing the scientific information that impacts on psychological principles involved in learning, cognition, and information processing. Because basic research in these areas has often come from other disciplines, the educational technologist has been subject to accepting the response-oriented paradigm under which such research has been carried out. However, experimental investigations of cognitive functions and information processing can be conducted by educational technologists with the aid of appropriate research personnel and content experts. These first-hand studies allow the educational technologist to accelerate the development of theoretical guidelines for instructional application of psychological principles without necessitating the acceptance of a paradigm that is antithetical to their field. This study is an attempt at such basic research.

Results of this study point out the possibility of preferred processing modes or hemisphericity in adult learners. The existence of such a phenomenon would have major implications for the design and selection of instructional materials since their success would be learner dependent. The question of whether such a preferred mode exists prior to lateralization is also of great import to the design of instructional media for young children.

This study was part of a systematic team effort to investigate the hemispheric processing of visual information. Advantages of this team approach include the networking of resources, literature, and professional contacts, as well as, the sharing of individual talents and time. Such a collaborative problem-solving method is seen as a useful system for researchers in the field of educational technology.

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APPENDICES

APPENDIX A

INTERFACING PROGRAM FOR THE FOURIER ANALYSIS SUBROUTINE

APPENDIX A

INTERFACING PROGRAM FOR THE FOURIER ANALYSIS SUBROUTINE

Program for Interfacing with MISL Subroutine FTFREQ-1

```
      -PROGRAM-F1019(OUTPUT,TAFE1),TAPE2)
       DIMENSION IND (6),XLNO(2),XYMV(6),X(256),ACV(60),FREQ(61),PS(61)
       DIMENSION DATA (270,2),NAME(3),POWER(5),FRQ(5)
       COMMON XCOV (122)
       DIMENSION XSPECT(1) ,AMPHAS(L),XFER(1),3OHER(1)
       INTEGER EXPR,SUBJ,TRIAL,LEAD,COUNTER
       EQUIVALENCE (XSPECT(1),XCOV(1)),(AMPHAS(1),XCOV(1)),(XFE (1),XCOV(
      +)),(COHER(1),XCOV(1))
       DATA INO/0,256,0,60,0,0/
       DATA XIND/.390625E-2,0.C/
       DATA ENDO/0/0
       DATA NAME/3HSUE,4HJOHN,SHTERRY/
10     DO 15 I=1,540
15     DATA(I)=0.0
       I=1
20     READ(1,25)ID,EXPR,SUBJ,TRIAL,LEAD,COUNTER,(DATA(I,J),J=1,2)
25     FORMAT (I5,T1,I1,2I2,I1,T4,2(2X,F8.3))
       IF(I.NE.1)GO TO 26
       LTD-ID
26     IF (EOF (1).EQ.0.0)ENDD=L
30     IF(ID.NE.LID)GO TO 35
       IF (I.EQ.1)GO TO 31
       IF(I.NE.1.AND.DATA(I,1).GT.DATA(I-1,1))I=I+1
       GO TO 32
31     I=I+1
32     IF(I.LE.270)GO TO 20
       PRINT *," MORE THAN 270 DATA POINTS"
35     BACKSPACE 1
       I=I-1
       ID-IX=1
       T=XIND (1)
40     IF (DATA(ID,1).EQ.T)GO TO 55
       IF (DATA(ID,1).LT.T.AND.DATA(ID+11).GT.T)GO TO 45
       ID=ID+1
       GO TO 40
45     IF(ID.GT.1.AND.ID.LT.I)GO TO 50
       X(IX)=RLGRINT(1,DATA(ID-1,1),DATA(ID-1,2),T)
       IX=IX+1
       GO TO 60
50     X(IX)=RLGRINT(2,DATA(ID-1,1),DATA(ID-2,2),T)
       IX=IX+1
       GO TO 60
```

APPENDIX A (continued)

```
55    X(IX)=DATA(ID,2)
60    IF(ID.LT.I)GO TO 40
      CALL FTFREQ(X,IND,XIND,XYMV,ACV,FREQ,PS,XCOV,XSPECT,AMPHAS,XFER,CO
     +HER,IER)
      IF(IER.EQ.129)STOP "IND VAL OUT OF RANGE"
      IF(IER.EQ.130)STOP "XIND VAL OUT OF RANGE"
      IF(IER.EQ.67)PRINT *,"************* WARNING ************* PS ESI
     +IMATE < 0 --- SET ID 0"
      CALL SUM(PS,FREQ,POWER,FRQ)
      PRINT 65,NAME,EXPR,SUBJ,TRIAL,LEAD,(FRQ(II),POWER(II),II=1,5)
65    FORMAT ( 2X,*POWER SPECTRUM FOR *,A1D,*SUBJECT*,I2,*TRIAL*,I2,*
     +LEAD *,I2/5(2X,2F20.10/))
      PRINT(2,65)NAME,EXPR,SUBJ,TRIAL,LEAD,(FRQ(II),POWER(II),II=1,5)
      IF(END D.EQ.0) GO TO 10
      END
      FUNCTION RL GRINT(NORD,X,Y,>)
      DIMENSION X(NORD,2)
      N=2*NORD
      RLGRINT=0.0
      DD 10 I=1,N
      RNUM-DENOM-1.0
      DD 5 J=1,NORD

      IF(I-J)1,5
      RNUM-RNUM*(P-X(J)
      DENOM=DENOM*(X(I)-K(J))
      CONTINUE
      RLGRINT=RLGRINT+(RYUM/DENOM)*Y(I)
      RETURN
      END
      FUNCTION RECOCE(FREQ)
      DIMENSION FMAX(5)
      DATA FHAX/4., 1.,13.,35.,60./
      IF(FREQ.LT.0) GO TO 99
      DD 10 I=1,5
10    IF(FREQ.LE.FMAX(I))GO TO 15
15    RECODE=I
99    STOP "BAD FREQUENCY"
      RETURN
      END
      SUBROUTINE SUM(PS,FREQ,POWER,FRQ)
      DIMENSION PS(61),FREQ(51),POWER(5),FRQ(5)
      DO 10 I=1,61
      FREQ=RECODE(FREQ)
10    CONTINUE
      J=1
      DO 20 I=1,5
      POWER(I)=0.0
15    IF(FRED(J).NE.I)GO TO 2C
      POWER(I)=POWER(I)+ >(J)
      J=J+1
```

APPENDIX A (continued)

```
890=      GO TO 15
900=20    CONTINUE
910=      RETURN
920=      END
22.52.28..000004 PAGES PRINT. 000096 LINES PRINT. FOR $ 000.10 at R62.
```

APPENDIX B

DIGITIZER DESCRIPTION

APPENDIX B

DIGITIZER DESCRIPTION

The following material is taken from "THE DIGITIZER" a handout copyrighted by the MSU Board of Trustees June 27, 1979; and used at the MSU Computer Laboratory.

> "The digitizer is a device that will determine X and Y coordinates of a specified point. It is faster, more accurate and much easier to use than rulers or grids.
>
> The Computer Laboratory's sophisticated, microprocessor-controlled model is very versatile. Its complete capabilities are described in the Micro Datatizer Reference Manual. Reference copies are available in Room 313 Computer Center. Copies may also be borrowed for one week at the assigned reading desk on the second floor of the Undergraduate Library. The dititizer itself is located in the shift supervisor's office, Room 207A Computer Center. Reserve the digitizer at the Service Window in Room 208 or by calling 353-6639.
>
> To use the digitizer you must be authorized to use the interactive system on the MSU 6500 computer (Source 'S' on your problem number application). Most accounts are authorized with a connect-time limit of one hour. That is, you are allowed to remain logged in at a terminal for a maximum of one hour. To allow yourself ample time to use the digitizer you may wish to increase this limit.
>
> To determine your current connect-time limit, log in and use the command:
>
> AUTHORF,DISPLAY,CT.
>
> For more information about authorization (e.g. how to increase your connect-time limit) see the consultants in Room 313 Computer Center, or refer to Section 2.8 of the Interactive System User's Guide.
>
> Figure 1 illustrates the physical components of the digitizer. You will prepare to use the digitizer by first setting up the digitizer then by connecting the digitizer to the 6500. Both procedures are described here.

Digitizer Set-up

1. Turn on the power switches for the CRT terminal and the digitizer. The power switch for the CRT terminal is a black knob on the face of the terminal. Turn it clockwise and allow the terminal to warm up. The brightness can be adjusted by turning this same knob. The power switch for the digitizer is a toggle switch located on the right front of the digitizer.

2. Turn on the lights for the digitizer surface. The two light switches are on the front right of the digitizer. One or both may be switched on.

3. Adjust the digitizer work surface. The digitizer's surface may be raised or lowered with the foot switch on the front of the pedestal. This switch appears as a small panel at the center of the very bottom of the pedestal and is operated by touching the toe of your shoe on the left or right side of the panel as required. The tilt of the surface may also be varied. The lever under the right-hand side of the surface releases a lock that allows the surface to be tilted. Return the lever to the lock position after you've adjusted the surface.

4. Place materials to be digitized under the protective plastic sheet. Fasten them to the surface with tape to keep them from moving.

Note: Steps 5 through 7 describe set-up mode procedures on the digitizer. Use the digitizer keyboard to enter the necessary commands.

The keyboard/display unit is the primary communication channel between the user and the digitizer. The display provides sixteen character positions and is used to display digitized points, setup information and store data. The keyboard is equivalent to a typical terminal keyboard.

For most keyboard input situations one character position blinks. This indicates where the next keyboard-entered character will be placed. For Setup Mode commands, entering the command mnemonic causes certain stored information to be displayed. Stored information may consist of a command variable's current state or data generated by digitizing operations.

The carriage return key (RETURN) serves as the general "line terminator." For example, entering a command mnemonic followed by RETURN causes the command to be carried out. When set up data has been entered or edited, pressing the RETURN key saves the data and returns to the command entry point. Should an error message appear, pressing RETURN also moves back to the command entry point.

Characters shown on the display may be edited by typing the desired characters on the keyboard. The new data, now shown on the display, may be returned to storage by pressing the RETURN key. If data is examined without editing, the RETURN function simply terminates the command. Several other functions are available for editing:

a. To move the blinking character position to the right without changing any characters (i.e., non-destructively), type CONTROL-A (hold the CONTROL key down while typing the letter A).

b. To move the blinking character position to the left non-destructively, press the RUBOUT key.

c. If, during editing of a value, you want to start over, the original stored value may be recalled by typing CONTROL-C.*

For multi-line commands (such as format specification) terminate the last line by pressing the HERE IS key.

5. Set axis rotation, offsets, and scaling. The easiest way to do this is with a two or three point set-up. Using the digitizer keyboard type the command 'TP', then press the RETURN key.

   The Two/Three Point Setup* provides a rapid method for establishing axis rotation, offsets and scaling. The required factors are based on two or three digitized points and the corresponding chart coordinates for each. The first two points must lie on the X axis or on a line parallel to the X axis (i.e. the Y coordinates must be the same). Also, the points should be as far apart as possible for maximum accuracy. If the Y axis scale factor is the same as the X axis scale factor, only these two points need be entered. If the Y axis scale factor is different, a third point and its Y coordinate must be entered. The third point must have the same X coordinate as point 1. The steps for two/three point setup are:

Step	Display Shows	Action by Operator
1	DTZ (X1,Y1)	digitize first point
2	(current X coordinate) = X1	Enter X coordinate for point 1, enter a space, press RETURN
	(current Y coordinate) = Y1	Enter Y coordinate for point 1, enter a space, press RETURN

*Adapted from the Micro Datatizer Reference Manual.

3	DTZ (X2,Y1)	Digitize second point (X2 > X1)
4	(current X coordinate) = X2	Enter X coordinate for point 2, enter a space, press RETURN
5	SX >< SY?	If X scale = Y scale, press RETURN, If Y scale is different, type Y
6	DTZ (xL,Y3)	Digitize third point (Y3 > Y1)
7	(current Y coordinate) = Y3	Enter Y coordinate for point 3, enter a space, press RETURN

6. Set the output format (see the Micro Datatizer Reference Manual, Addendum.) Using the digitizer keyboard, type the command 'FM1', then press the RETURN key. The display will show a colon (:). Type your format.

   Example:

   X9.3'' ''Y9.3:

   This will give nine characters each for the X and Y coordinate (including the decimal point), five to the left and three to the right of the decimal point. There will be a blank between the X and Y coordinates. If you run off the end of the line press RETURN and continue on the next line. You have up to six lines to enter the format. When you finish the format, press the HERE IS key.

7. Press the ALT MODE key to enter digitizing mode.

6500 Interface

8. Log in at the CRT terminal.

9. Type this command on the terminal keyboard:

   %ALTER,NUL=STARTOUT.

10. Then type this command:

    TPREAD,lfn.

    where 'lfn' is the name of the file (1 to 7 characters, first character must be a letter) that will contain the data collected from the digitizer.

    This command will cause the system to begin reading lines into the file "lfn". The lines will not be processed until entry is completed.

    You may ignore the "SET TERMINAL TO FULL DUPLEX" message.

11. Digitize points one at a time by placing the cross hair over the point and pressing any one of the black buttons. If you entered your format incorrectly in Step 6 you will get a format error message. Press RETURN on the digitizer keyboard and repeat Steps 6 and 7, then begin digitizing again at Step 11.

12. When you have finished digitizing your data, press the ESC key on the CRT terminal.

13. When you get a "READY" message on the CRT terminal you are ready to process your data. You can list it at the terminal by using this command:

    LISTTY,I=lfn.

    "lfn" should be the same file name you used in Step 10.

    You can save the file for later processing with the CATALOG command. (See the SCOPE/HUSTLER Reference Manual, Chapter 5.

14. Log out and turn of the lights, Digitizer power controller, and CRT terminal."

APPENDIX C

EEG METHODS

APPENDIX C

EEG METHODS

A. ELECTRODES

Purpose: The objective of the EEG is to measure and record the distribution of electrical potential over the scalp as it varies with time. The differences in potential between points on the scalp are very small (10 to 200 microvolts).[1] The EEG is a complex biological amplifier which amplifies these potential differences and from them produces recordings of ink-pen deflections. It is the job of the electrodes to connect the conducting fluid of the tissue to the input circuit of the amplifier.

Electrode Potential:

An electrode placed in a conducting solution has a potential difference between itself and the solution. This potential difference varies with the type of metal of which the electrode is made and with the temperature. The electrode potential arises from the passage of ions from the metal to the solution and from the solution to the metal. These rates of exchange are not equal, thus, causing a potential difference. Electrode potentials are measured with respect to a reference electrode generally consisting of hydrogen absorbed on platinum black.

Electrodes of the same metal should have a potential difference of zero. However, impurities cause a non-zero potential even in electrodes of the same metallic composition. To minimize electrode potential differences a saline bridge is used between the electrode and the scalp.[2]

Electrode Polarization:

Electrodes used in EEG recording should be made of metals which pass a steady current at low voltage. Such electrodes are called non-polarized, or reversible.[3]

Types of Electrodes:

Three types of electrodes can be used to record from the scalp: pad, disc, and needle. A pad electrode is typically a silver rod belled at the end and fitted with a sponge or felt pad contained in gauze. Disc electrodes are small metal cups of various metals.

Needle electrodes are usually made of platinum or stainless steel.

Electrodes can also be inserted through the nostrils (nasopharyngeal electrodes) or through considerable muscle tissue (asphenoidal electrodes).[4]

Electrode Application:

Pad electrodes: are usually held in place with a head cap. The scalp area beneath each electrode is cleaned by rubbing it with a cotton wool pad moisted with methyl alcohol or acetone. Pad electrodes should be dampened with saline solution before application. However, the upper portion where the lead is attached should remain clean and dry. This type of electrode is suitable for recordings up to one hour in length.
Disc electrodes: are stuck to the scalp with an adhesive (collodion). When all electrodes are in place, each is injected with electrode jelly through a hole in the top. The scalp area under each electrode should be cleaned before application with methyl alcohol or acetone. Following recording, the electrodes can be removed by dissolving the adhesive with acetone. (DO NOT GET ACETONE IN THE SUBJECT'S EYES!).
Needle electrodes: must be throughly sterilized. Consult manufacturers suggested methods or recommended texts (see bibliography) for further directions.[5]

Electrode Methods:

The three basic methods involved in deriving a signal from the electrodes are called bipolar, unipolar, and average reference. The bipolar method is referred to as scalp-to-scalp recording and each channel is connected between two electrodes both of which are likely to be affected by EEG potentials. The unipolar or scalp-to-reference technique involves using one electrode which is common to all or to a group of channels. Lastly, in the average reference technique all of the electrodes on the scalp are connected to a single point and the potential at the point is the average of the potentials at the scalp electrodes.[6]

The 10-20 System:

The International Federation of Societies for Electroencephalography and Clinical Neurophysiology has recommended an arrangement of electrodes known as the 19-20 system of electrode position. It is based on measurement from the following scalp points: nasion, inion, and left and right pre-auricular points. Measurements are made with a tape or flexible ruler as follows:
"(1) Measure the distance from nasion to inion along the midline through the vertex and make a preliminary mark at the midpoint C_z.

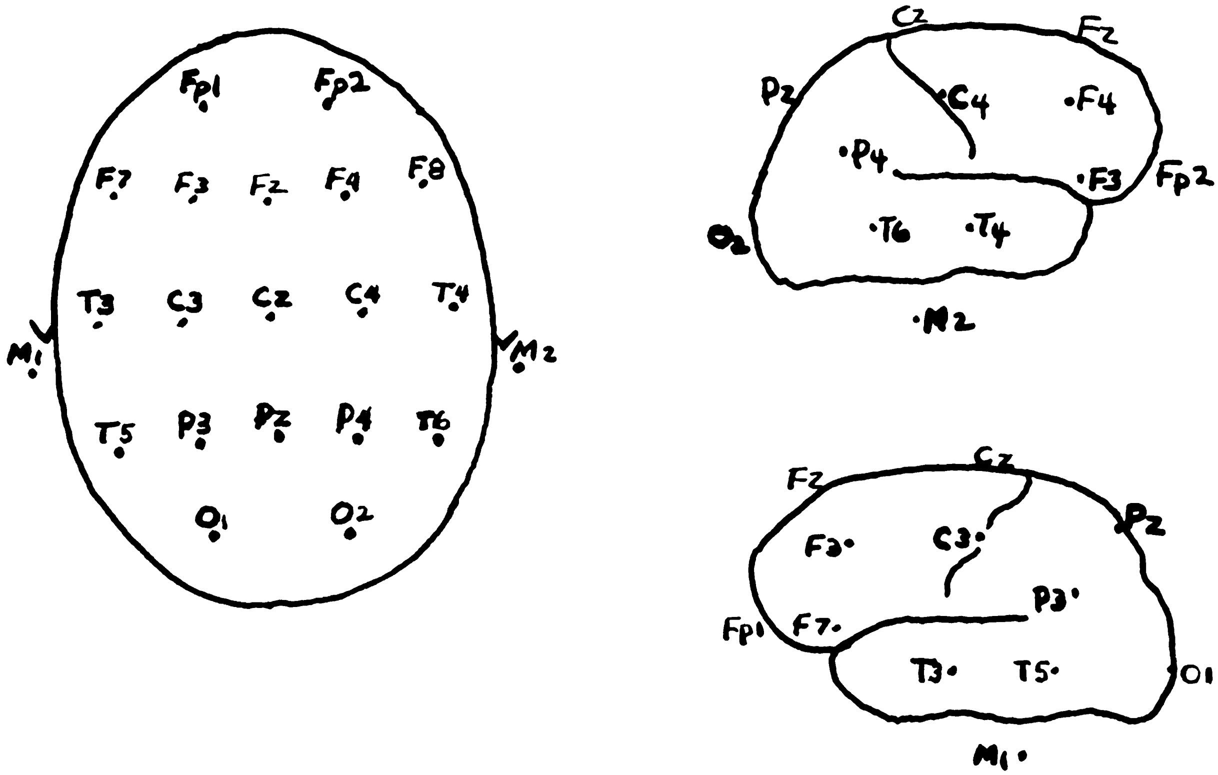

Figure 3. Positions of electrodes in the 10-20 system.

Illustration from <u>The EEG in Clinical Practice</u>

ELECTRODES (Continued)

(2) Check that this point is midway between the preauricular points, each of the latter being felt as a depression at the root of the zygoma just anterior to the tragus.

(3) Reapply the tape to the midline and mark points at 10,20,20,20,20, and 10 per cent of the total nasion-inion distance. These are the positions of F_p,F_z,C_z, P_z, and 0.

(4) Reapply the tape transversely and mark points at 10,20,20,20,20, and 10 per cent of the total distance between the auricular points. These are the positions of T_3,C_3,C_z,C_4, and T_4. Note the odd numbered positions are always on the left.

(5) Measure the distance between F_p and 0 through T_3 and mark points at 10,20,20,20,20, and 10 per cent of this length. These are the positions of F_{p1},F_7,T_3,T_5 and 0_1.

(6) Repeat this procedure on the right side and mark the positions of F_{p2},F_8,T_4,T_6 and 0_2.

(7) Mark the position F_3 such that it is equidistant from F_p1 and C_3 and equidistant from F_z and F_7.

(8) Mark the positions of F_4,P_3, and P_4 in a similar manner."[7]

Electrodes are, thus, placed in a number of arrays with the distances between adjacent electrodes being equal. The arrays are shown in diagram with the letters having the following designations: F=frontal, T=temporal, P=parietal, 0=occipital, F_p=frontal pole, and C=central sulcus.[8]

B. MONTAGES

Because the number of EEG recording channels is less than the number of electrodes applied to the scalp, a recording cannot be made from all the electrodes all the time. Several patterns of connection between electrodes and amplifiers must be used successively. Each pattern is called a montage. The following suggestions on montage design have been made by the International Federation: "(1) Recording channels should be connected in sequence to rows of electrodes along anteroposterior or transverse lines. (2) The sequences should run from the front to the back of the head and from right to left. (3) For

> bipolar recordings, channels should be connected so that the black lead of a given amplifier is anterior to or to the right of the white lead."[9]

C. CHARACTERISTICS OF THE RECORDING SYSTEM

The characteristics of the recording system include: sensitivity, linearity, frequency response, phase response, and noise level."[10]

Sensitivity:
: is the magnitude of input voltage that is required to produce a pen deflection. The common value for an EEG is 50mV/cm. Sensitivity is composed of the gain of the amplifier and the sensitivity of the pen writer (measured in volts per centimeter deflection).

Linearity:
: is said to exist if the pen deflection is proportional to the amplitude of the input signal.

Frequency Response:
: The signals produced by the EEG can be broken down into a series of sine wave components having different amplitudes and frequencies. To avoid distortion the system sensitivity must be constant for all its frequencies.

Phase Response:
: Two sine waves can have identical frequencies but be displaced in cycle with respect to each other as in diagram
This displacement is called a phase difference. A phase difference usually exists between the input and output of a recording system such as the EEG. Distortion can occur if these displacements are different at different frequencies.

Noise Level:
: distorts a signal. It is the small fluctuating output that is recorded even when there is no input signal. It consists of random current fluctuations, and thermal agitation of electrons in resistive components even without current flow. Noise increases with the system's bandwidth. Therefore, it is important to restrict the bandwith as much as possible.

D. WAVE FORMS

The EEG produces tracings which represent potentials within the brain. However, interference does occur and it is necessary to discriminate potentials arising from the brain from extraneous potentials called artefacts.

<u>Delta Waves</u>	
Frequency	less than 4Hz.
Amplitude	varies
Location	varies
Features	abnormal in adulthood during walking trace, can be localized or diffuse, normal in sleep patterns
<u>Theata Waves</u>	
Frequency	4-7Hz.
Amplitude	varies
Location	varies depending on age
Features	seen in temporal regions in waking records
<u>Alpha Waves</u>	
Frequency	8-13Hz.
Amplitude	10-150 microvolts
Location	occipital, parietal
Features	sinusoidal, bilateral, synchonous, present eyes closed, attenuates when eyes are open
<u>Beta Waves</u>	
Frequency	14Hz.
Amplitude	up to 25 microvolts
Location	normally frontal regions, can be posterior dominant
Features	can appear in spindling fashion, can be increased with brarbituates

<u>Slow Waves, Fast Waves</u>

Slow waves are less than 8 Hz. and fast waves are greater than 13 Hz.

<u>Wave Description</u>

Three wave measurements include:

<u>Amplitude</u>- This is the distance from the baseline to the peak or through in millimeters.

<u>Frequency</u>- This is the number of cycles per second. (1 Hz. = 1 cps)

<u>Phase</u>- This is the relationship of the peaks of two or more waves to one another in degrees or radians.

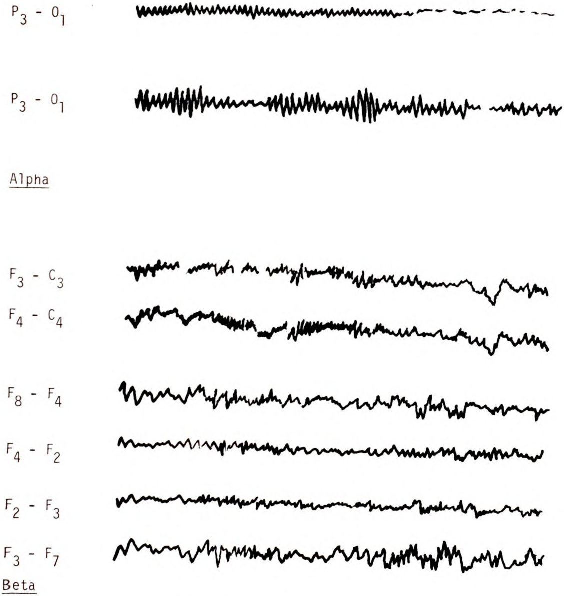

Figure 4. Alpha and Beta Waveforms

Illustrations taken the EEG Handbook

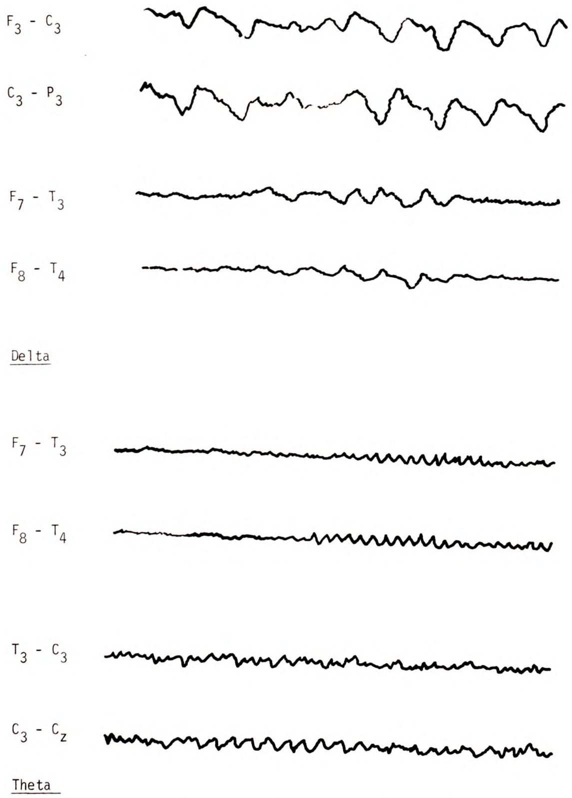

Figure 5. Delta and Theta Waveforms
Illustrations taken from EEG Handbook

E. ARTIFACTS

Artifacts are potentials that arise from sources other than the brain. Artifacts can arise even in a well shielded room. Two major causes are the electrodes and the subject.

Electrode Artifacts

Electrode artifacts appear as sharp potentials, square waves, asymmetries, popping, spiking, slow potentials, 60 cycle hum.

Subject

Pulsation-	It is indicated by rhythmic moderate amplitude slow waves.
EKG-	This is very common and the EKG should always be monitored.
Eye movement-	Lid or eyeball movements can cause artifacts.
Muscle-	This artifact is often caused by the subject feeling tense or uncomfortable.
Sweating	A hot room can cause sweating that lifts the electrodes away from the scalp causing artifacts.

F. VISUAL ANALYSIS

The major features which should be described in reviewing the EEG record can be listed as follows:

"1. The most persistent rhythmical feature--this might be the alpha rhythm.

2. Other rhythmical features, such as delta, theta, or beta rhythms.

3. Discrete features of relatively long duration, such as an episode of spike and wave activity.

4. Discrete features of relatively short duration, such as isolated spikes or sharp waves.

5. The activity remaining when all the previous features have been described--sometimes called the background activity.

6. Artefacts, when these are of such a nature as possibly to give rise to ambiguity in interpretation.

Each of the above features is then described in terms of some or all of the following parameters or variables.

1. Amplitude

2. Frequency, in the case of rhythmical features

3. Waveform, in the case of both rhythmical features

4. Location or spatial distribution

5. Incidence or temporal variability

6. Responsiveness to stimuli and to evocation procedures."[11]

Notes:

1. Laidlaw, p.A.

2. R. Cooper, et. al. EEG Technology London: Butterworths, 1969, pp.9-11.

3. Cooper, pp.11-12.

4. Cooper, pp.18-19.

5. Cooper, pp.78-80.

6. Cooper, pp.26-30.

7. Cooper, p. 75.

8. Laidlaw, p. 2.

9. Cooper, p.77.

10. Cooper, pp.42-47.

11. Cooper, pp.117-118.

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APPENDIX D

FRACTALS

APPENDIX D

FRACTALS

Complexity, Fractals, and the Hausdorff-Besicovitch Dimension

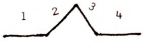
In Nature there are many patterns whose boundaries are irregular and fragmented. Euclidean geomentry is of little help in describing patterns such as Brownian motion, or the boundaries of oceanic islands, and clouds. Although we tend to think of circles, squares, and other Euclidean shapes as common; curves that have no tangents are the rule in Nature and regular curves, such as the circle, are really special cases. The measurement of irregular curves has long been a problem for mathematicians. Prominent names like Weirstrass, Cantor, Peano, Lebesgue, Hausdorff, Koch, Sierpinski, and Besicovitch have all been associated with the study of this phenomenon.

Recently, a new term has been proposed to name such irregular curves. The term fractals has been coined by Dr. Benoit Mandelbrot of IBM's Watson Research Center. Dr. Mandelbrot has also proposed a method of measurement and identification for these curves. A fractal curve is defined as a set of points "for which the Hausdorff-Besicovitch dimension strictly exceeds the topological dimension." To understand this definition it is necessary to take a closer look at what is meant by the term "dimension." We shall consider two definitions. The first is the topological definition which was put in final shape by Menger and Urysohn in 1922. It is the definition most persons are familiar with in which every set of points in Euclidean space is assigned a real number called its dimension. Hence, we call lines one-dimensional, planes two-dimensional, and cubes three-dimensional. The topological dimension is always a whole number.

The second definition of dimension is termed the Hausdorff-Besicovitch dimension. This dimension need not be an integer and can take on fractional values. The larger the Hausdorff-Besicovitch dimension, the more complex the fractal curve. To determine if a curve is a fractal it can be measured. Whenever you measure anything, you choose a unit of measure. In so doing you automatically rule out measurement of detail that is smaller than your unit. Thus, if you were to remeasure using a smaller unit, you would obtain a greater total length. (See the example on page 93).

To determine if a curve is fractal you choose several different units of length and measure the curve's total length using each of these units. Then a plot is made on log/log paper of the total curve lengths vs. unit lengths. If the plot approximates a straight line, the curve is a fractal and the slope of this plotted line is the curve's Hausdorff-Besicovitch dimension.

Irregular fractal curves have a unique characteristic. They are self-similar. This means that small segments of the curve resemble the overall curve. An example of this is shown below:

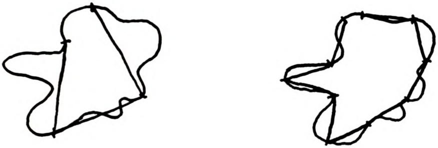


This curve has
four segments

If each segment is made to
resemble the overall curve,
then the curve is self-
similar.

Figure 6. Self-Similarity

If the above process of replacing each segment by one resembling the overall curve were carried on ad infinitum, the resulting curve would be exactly self-similar. However, in Nature fractals are only statistically self-similar. That is, their segments are identical in distribution to the whole.



1 inch   1/2 inch

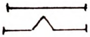
Figure 7. Different Lengths With Different Measuring Units

Length using 1 inch unit = 3 inches

Length using 1/2 inch unit = 4 1/2 inches

Fractals also have the characteristic of complexity. The greater length a curve packs into a certain interval of space the more complex the curve. This can be seen in the following example:

A.



A. is made by repeatedly replacing a line by one 4/3 as long.

B.

B. is made by repeatedly replacing a line by one 8/4 as long.

Figure 8. Complexity

The curve approached by sequence A is less complex than that approached by sequence B.

The Hausdorff-Besicovitch dimension described above is a measure of the curve's complexity. Thus, a curve whose Hausdorff-Besicovitch dimension is 1.7 is more complex than one whose dimension is 1.3.

In summary, then, Dr. Mandelbrot and the Hausdorff-Besicovitch dimension have given us a method for measuring irregular curves (fractals) and for determining their relative degree of complexity.

APPENDIX E

STIMULUS MATERIALS

The eleven stimulus figures that follow were taken from Fractals: Form, Chance, and Dimension by Benoit B. Mandelbrot. W.H. Freeman and Company. Copyright c1977.

APPENDIX E

STIMULUS MATERIALS

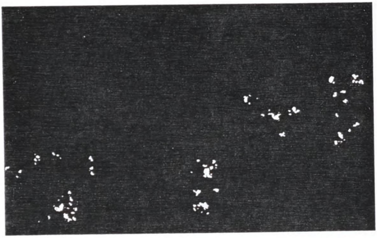


Figure 9. D=1.0

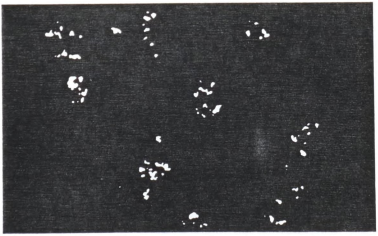


Figure 10. D=1.0

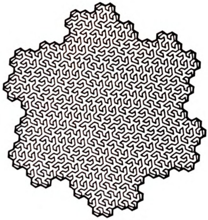


Figure 11. D=1.1

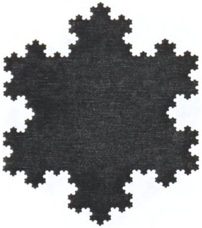


Figure 12. D=1.3

Figure 13. D=1.4

Figure 14. D=1.5

Figure 15. D=1.5

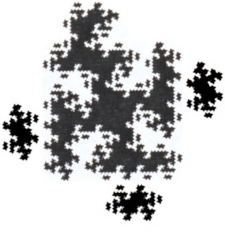


Figure 16. D=1.6

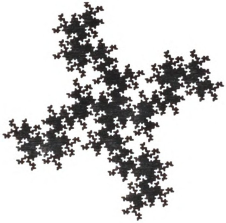


Figure 17. D=1.67

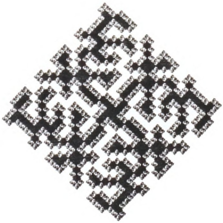


Figure 18. D=1.7

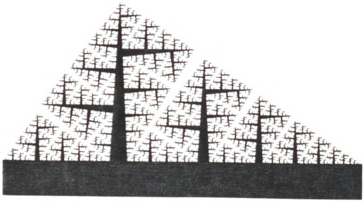


Figure 19. D=1.9

APPENDIX F

FOURIER TRANSFORM

APPENDIX F

FOURIER TRANSFORM

What it is:

The Fourier transform is a mathematical method used to resolve a wave into its component parts. It uses the following formula: $\int_{-\infty}^{\infty} f(x)\, e^{-i2\pi xs} dx = F(s)$. The $\int$ sign indicates that the area under the curve (wave) is to be found. `f(x)´ is the function describing the waveform, and e with its exponents is a complex number involving sine and cosine. F(s) is the frequency breakdown of the wave.

How it works:

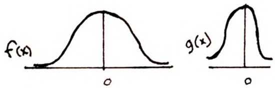


Figure 20. Wave Form and Frequency

Suppose you have a waveform, f(x), and a pure frequency, g(x), and you want to know how much of f(x) is contributed by g(x).

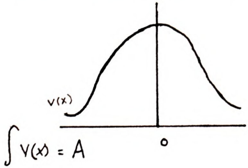


Figure 21. The Integral

You could first multiply the points in f(x) by those in g(x). This would give you a new curve v(x). Now you could take the integral of v(x). This would give you a number. Call it A.

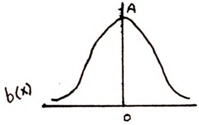


Figure 22. Height at Zero point

We got A by multiplying f(x) by g(x) when the center of both curves were at zero. We can now use A to define the height of a new curve b(x) at its zero point.

Figure 23. Phase Shifts

To get the height of the rest of b(x) we must continue to multiply f(x) by g(x) at different phase shifts and thus get other numbers for the area under the v(x) curve to use in describing the height of our new curve b(x).

The resultant curve, b(x), is the interaction of f(x), g(x). However, the above process is a bit simplified. The Fourier is more complex since you aren't just taking the integral of f(x) g(x) but $\int f(x)\, e^{-2\pi xs} dx$. Nevertheless, the idea is the same.

How it relates to spectra:

Waveforms and spectra are Fourier transforms of each other. F(s) in the Fourier formula is called the spectra. It is the result of performing a Fourier on a waveform. $|F(s)|^2$, the square of F(s), is called the energy spectrum or power spectrum.

Fast Fourier Transform is an approximation of the Fourier Transform.

It is a process described by Cooley and Tukey (1965). Fast Fourier is a rapid method of data analysis which employs a digital computer for calculation.

APPENDIX G

SUBJECT FORMS AND DIRECTIONS

APPENDIX G

SUBJECT FORMS AND DIRECTIONS

Directions to Subject

During this experiment you will be shown a series of figures. They will be presented to you in the T-scope so you'll be asked to look into the viewer. Each figure will be presented for 20 seconds. Please attend to it with your eyes open and as little eye or muscle movement as possible. Any noise or movement may be picked up by the EEG, therefore, at the end of 20 seconds I will tap your right shoulder. This will be the signal for you to relax and close your eyes for a 30 second rest period. When the rest period is over, I will again tap your shoulder. At this time open your eyes and view the second figure for 20 seconds. This sequence of events will be repeated for 11 different figures with a 30 second eyes closed rest period after each one. The viewing of all 11 figures will take approximately 9 minutes. Do you have any questions before we begin the experiment?

CONSENT FORM

1. I have freely consented to take part in a scientific study being conducted by:

   ____

   under the supervision of: ____________________________

   Academic Title: __________________________________

2. The study has been explained to me and I understand the explanation that has been given and what my participation will involve.

3. I understand that I am free to discontinue my participation in the study at any time without penalty.

4. I understand that the results of the study will be treated in strict confidence and that I will remain anonymous. Within these restrictions, results of the study will be made available to me at my request.

5. I understand that my participation in the study does not guarantee any benefit results to me.

6. I understand that, at my request, I can receive additional explanation of the study after my participation is completed.

7. To my knowledge, I have no history of psychological disorder or epilepsy.

8. I understand that this is not a Clinical Center project. Therefore, I am not considered a Clinical Center patient.

   Name: ____________________________ Date: ____________________

   Signed: ________________________________

   (Parent or guardian, if not 18)

Instructional Development & Technology
College of Education

SUBJECT DATA FORM

______ Code Number

1) Age ______ (in years) 2) Sex ______ 3) Handedness ______ (R/L) 4) Eye Dominance ______ (R/L)

2) What is your "native" language ______ 6) Do you speak another? ______ (Yes/No)

7) Sheehan Scores ______

8) Level of Education (in years) ______ 1-5 ______ 6-10 ______ 11-15 ______ 16-20 (please check one)

9) Field of Study/Specialization ______ (please print one)

10) Have you ever participated in a study which used an EEG recording? ______ (Yes/No)

11) If yes to #10, please describe ______

______

12) Have you ever studied or practiced Transcendental Meditation or related relaxation techniques? ______ (Yes/No)

13) If yes to #12, how long? ______ 2 weeks ______ 1 month ______ more than 1 month ______ 1 year ______ more than 1 year

14) Have you ever been involved in a study which used a tachistoscope (t-scope) such as the one in this study? ______ (Yes/No)

15) If yes to #14, please describe briefly ______

______

16) Have you ever participated in a psychological experiment which involved imagery, or visual perception tests? ______ (Yes/No)

17) If yes to #16, please describe briefly ______

______