UNIVERSITY OF CINCINNATI

May 9 1952

I hereby recommend that the thesis prepared under my supervision by Oddist Murphree *entitled* Maximum Rates of Form Perception and the Alpha Rhythm: An Investigation and Test of Current Nerve Net Theory *be accepted as fulfilling this part of the requirements for the degree of* Doctor of Philosophy

Approved by:

Arthur G. Bills

Form 663—G.S. and T.C.—1M—4-51

MAXIMUM RATES OF FORM PERCEPTION AND THE ALPHA RHYTHM: AN INVESTIGATION AND TEST OF CURRENT NERVE NET THEORY

A dissertation submitted to the

Graduate School of Arts and Sciences
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

1952

by

Oddist Murphree

B.A. University of Arkansas 1948

ACKNOWLEDGEMENTS

The writer gratefully acknowledges the cooperation of many persons in the Veterans Administration and at the University of Cincinnati. Without their aid and guidance this study would hardly have been possible. Dr. Thelma E. Brown and Dr. Ranald M. Wolfe, Chief Psychologists with the Veterans Administration, readily supported plans for the gathering of the data.

Dr. Arthur G. Bills, Dr. George W. Kisker, and Dr. Herbert Weaver, of the University of Cincinnati, have given freely of their time and knowledge in their encouragement and guidance of the writer. Dr. Weaver's recommended modification of the experimental design was directly responsible for clarity in the results which would have otherwise remained hidden.

Mr. Clinton C. Brown, Graduate student in Psychology at the University of Cincinnati, gave unhesitatingly of his time and advice in the design of the apparatus used in this research. To these persons this writer is profoundly grateful.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

INTRODUCTION

Progress in heretofore separate fields of inquiry has now produced an awareness by increasing numbers of scientists of a unity or at least a considerable overlapping from one field of endeavor to another. This unity has been most profound in psychology, neurology, mathematical, biology, physics and electrical engineering. During the last decade specialists in these fields came to feel that there was an essential similarity between neural and electrical processes in their respective nets and to certain systems of symbolic logic. The common element which has been emphasized has to do with the utilization of "information", "signal", "control and communication", etc., and the word cybernetics has been coined to refer to these studies. One of the cornerstones in this development is the part played by synchronous processes, scanning and "feed-back", and some scientists, often concerned with brain functions, feel that they have discovered how these processes explain perception; at least so far as the neurophysiological events play a part.

This study is an attempt to subject to experimental check the implications of some hypotheses which cyberneticists and nerve-net theorists have advanced. It is concerned with the relation between the cerebral alpha rhythm (basic resting occipital rhythm) and two related perceptual phenomena--maximum rates of form perception and apparent motion. These problems have been of great importance to psychology as well as to philosophy. Gestalt psychology received its impetus from studies of apparent motion, and the survival of this field as an adequate theoretic system may yet depend on how this question, which Wertheimer raised, is settled.

The philosophic position assumed in this study is similar to that expressed by Betrand Russell (29) i.e., that there exists a real world; that it can, in part, be perceived; that a perceptual experience does depend to some extent on the objective stimulus. It is further assumed that nearly independent lines of causality possessing quasi-permanence operate in perception. This is meant as a modification of the old idea of representative perception, and is a rejection of Hume's interpretation of causality as merely habitual occurrences.

Ordinarily, perception of form or shape is the result of some pattern of stimulation on the retina of the eye. Likewise, the perception of motion, visually, is usually the result of a changing spatial or form pattern through time. The change in this instance is a continuous or gradual one. The progression of the image across the retina of the perceiver seems usually to be the primary physiologic basis for the perception. Apparent motion, however, may be perceived when two discrete spatially separate stimuli are presented in appropriate temporal order. It is not clear in this case whether the added continuity in the percept is purely retinal or due to other processes further back in the neurologic system.

When successive presentations of differing forms are increased in rate one is able to retain their usual spatial and temporal clarity only up to a few exposures per second. Beyond that rate the fusion or mixing of the shapes is such that a unitary perception of a changing shape in continuous motion is experienced. At higher rates the motion ceases and the different forms are seen as one composite or mosaic, all parts of which are simultaneously present. It is this loss of temporal information which results in the experience of simultaneity that is basic to this study. The intention is to demonstrate that factors other than retinal play a major role.

HISTORICAL DEVELOPMENT

This research is related to the work of Sherrington and Lorente de No' (18) though it is specific to the work of McCulloch and Pitts (20,21), Wiener (33), Culbertson (5,6), Rashevsky (26) and others who have introduced new concepts and mechanisms in regard to transmission and preservation cf information and in mathematical biophysics in general. This point will be developed in greater detail later. The concern now is with those students of neurology and electroencephalography who paved the way through the gradual accumulation of detailed knowledge.

Lorente de No' (18) demonstrated reverberating cyclic nervous processes experimentally and morphologically. His long years of study make him the father of modern neurology. He opened immense possibilities by contributing the finding that neuron impulses do more than "travel one way" from receptor to effector in so many isolated channels. One of the laws he postulated is that any neuronal aggregate always receives fibers from those nuclei to which it sends fibers of its own. This allows a basis for the physiologic faith underlying the work of later theoreticians who constructed hypothetical nerve nets which would carry out nearly any prescribed function.

Polyak (25) and Bartley (1,2) have reached similar conclusions on many issues after years of rather independent research. Both these prominent researchers view the area of visual perception as the battle ground on which opposed theories of brain function stand or fall. Polyak became, after a time, firmly opposed to gestaltists, "transcendental" field theorists and others similarly minded as he grew more convinced that elemental neurons by their interconnections furnished all the facts necessary for a theory of visual perception. He deplored doctrines built on data gathered phenomenologically, psychologically or through mathematical speculation. In his work, morphologic and histologic evidence is presented of neurons whose function it is to integrate and act interdependently to transmit information through a neuronal constriction. He clearly established a "point-for-point" correspondence between the retina and the striate area of the occipital cortex even though there is approximately a 100; 1 reduction in the number of channels connecting the two. He estimates that the retina possesses more than 100 million receptors but that the optic tract has little more than one million neurons. A large number of the optic tract neurons serve the function of centering the eye or lining it up accurately toward the object to be seen. They are thus not in the service of primary perceptual paths. It is only in the fovea proper that each neuron-receptor has a "private line" back to the lateral geniculate body and thence to the brain. The usual case is for more than one retinal element to be served by only one ganglion fiber in the optic tract. Culbertson (5,6) points out that this situation is most likely the case with the other senses and inter-sensory integrations as well as throughout the whole cortex. Indeed, he calculates that the only way in which our brains can remain as small as they are is just because of this neuroeconomy. This situation is likened to a television system in which there is correspondence between two manifolds (camera and viewing screen) though the connecting medium does not allow separate private lines from each camera element to each screen element. An all important synchronized scanning makes this arrangement possible.

The Electroencephalogram

Gibbs and Gibbs (13), noted American electroencephalographers, dedicate their basic work to Hans Berger, a German psychiatrist, who attempted successfully to record the electrical activity of the human brain in 1924. Berger noted that the most prominent rhythm from the brain had, in normal adults, a frequency of approximately ten per second, and designated it the alpha frequency. Along with that discovery it became known that all living tissues display electrical activity; and that it apparently originates in the individual cell. But the problem of the constituency of the cyclic emissions of neuronal aggregates has remained largely unsolved. Gibbs believes the cyclic form consists of the spike potentials of aggregates of discharging neurons. The phenomena might be diagrammed in the manner shown below. The pattern of impulses emitted by a particular fibre (A) may be represented by vertical lines along a horizontal time line.

Another fibre (B) might fire with a different pattern.

The overall or summated pattern of these two fibres in combination with the activity from a third fibre (C) may be represented by an envelope drawn to express the total potential that would be recorded by an appropriate instrument.

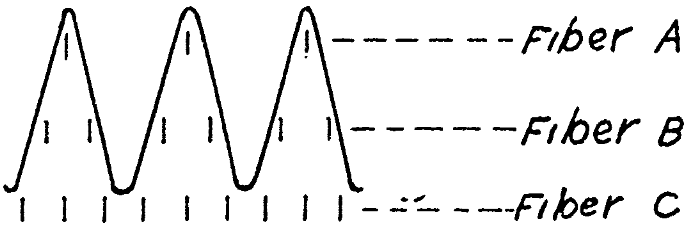


Figure 1. Proposed Constituency of the Cyclic Envelope (Gibbs, 13, p 24)

Walters (35), English electroencephalographer and theorist, agrees with the interpretation above and views the cyclic rhythm as a neurologic scanning which makes it possible for the brain to deal with complex visual material with a minimum number of neuron elements. He is thus aligned with Culbertson on the idea of neural economy. Walters constructed toy-like devices which "scanned their environments" and displayed, according to him, (1) exploration, (2) memory, (3), avoidance of dilemmas, (4) free will (in the sense of indeterminacy), and (5) social behavior. Walters' rationale in defining the above terms appears sufficiently close to ordinary usage and one is impressed by his discussion. He considers the ratio of the complexity of the toys to that of the human brain to be on the order of 6 : 1,000,000,000, and challenges anyone to see that much difference between human behavior and that of his machines.

Electroencephalographic recording has benefited immensely by progress in electronic engineering. In dealing with exceedingly small quantities electronic methods are by far the best. It is now commonplace to record potentials simultaneously from eight different areas of the brain continuously for hours at a time. Potentials of a few millionths of a volt are readily measured. (For sample records, six simultaneous channels, see appendix A)

It is characteristic of neurologists and electroencephalographers that they believe they are able to draw definite conclusions about the conscious state of the subject through the sole medium of his brain wave tracings. Certainly, a drastic advance in electroencephalography would have momentus import for psychology. Man has had to "stay on the outside" to study the organism. Sometimes he was able to see dim correlates posthumously in sporadic clinic cases. The x-ray was severely limited and its use confined to rather gross changes in the brain. Psychologists and philosophers had to infer the nature of the activity in the human brain. It was, in a way, like being presented with a watch and having to hypothesize the works in the unopened case from the activity on the face (Einstein). Thus, to the degree that the electroencephalogram is developed we have a "royal road" of neural and psychic significance, and can then study, without harming, the intact organism and be closer to the central processes than ever before.

One note of pessimism may be sounded. Wiener likens the electroencephalogram to a record which might be obtained by measuring the heat off the tubes of an electronic device such as a radio. He stresses the fact that information and signal are entirely different from energy. (In this he says he opposes Rashevsky and other communication theorists.) We are, he says, primarily interested in the complexity of the signals going on inside of the radio--not the minimum necessary amount of heat needed to operate it. While it may never be possible to record with exactness the action of any particular cortical neuron, it seems safe to say in compromise that at present levels of recording we are getting more than metabolic heat. Considerable changes accompany the mere opening of the subjects' eyes when an electroencephalogram is being recorded.

Halstead was able to "drive", that is modify the alpha frequencies of monkeys by means of intermittent photic stimulation. Toman and Bartley (1) showed that the alpha frequency of most human subjects can be made to change by means of a flickering light. Facilitation is greatest when the flicker of a strong light is near alpha frequency. Bartley assumed that the same neurons were involved with both alpha and peripheral visual stimulation. Before the procedures in this study were begun an attempt was made to influence or drive the alpha frequencies of subjects' utilizing the same illumination intensities as those in the procedures which followed. No changes in the subjects' alpha rhythms were noted; thus the illumination value which the apparatus emitted was sufficiently reduced.

The Cyberneticists' Approach

The cyberneticists' and nerve net theorists' approach to neural phenomena is a continuation of ideas maintaining a purely mechanistic basis for behavior. This approach is nearest, however, that border between mechanism and teleology than any other present development. The philosopher F.S.C. Northrop (22) sees this approach as having bridged the gap between the two heretofore antithetical doctrines of teleology and mechanism. In evaluating the epoch making work of McCulloch and Pitts (20) i.e., "How We Know Universals", he says that mechanism is not opposite to purpose, only "randomness" is. In this approach he sees mechanism for a purpose or goal. Insofar as the cyberneticists' machines can give invariant responses to classes of stimuli, in a way, to universals rather than to particulars only, he has a point. For full agreement with Northrop, however, one might insist on an adequate definition of "randomness" which would eventually lead to the demand for an agreement on "probability" and it is doubtful if present day theorists are able to do this, (Carnap, "The Two Concepts of Probability" 10, p. 330-348). It may depend on the level of viewpoint.

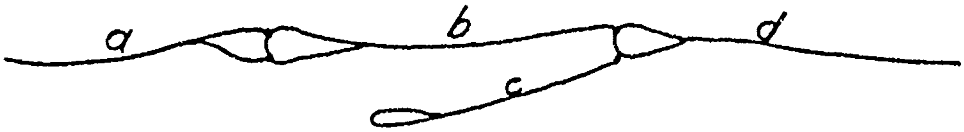
Logic Applied to Neural Functioning

The question has been raised as to how nerve-net theorists treat the concepts of synaptic variation and transmission. Rashevsky (26), Wiener (33), Culbertson (5) and others see a direct analogy between two-valued logical systems and neuron transmission characteristics of an"all or none" nature (seen also in "binary" computing machines). It is usual, in their work, to postulate discrete values (quantized rather than immensely complex continuous functions) for the time taken for neuron activity and for synaptic thresholds. These synaptic thresholds are usually considered to vary from only one value to one other valueonly one unit different, or not ever to change at all. In some systems of postulates the synapse changes only once in the life time of the organism. A symbolic proposition, in which the synapse is invariant, i.e., has one threshold, is of the following simple form. Consider two neurons as shown below.

Here,

$$B(t) .\equiv. A(t-1)$$

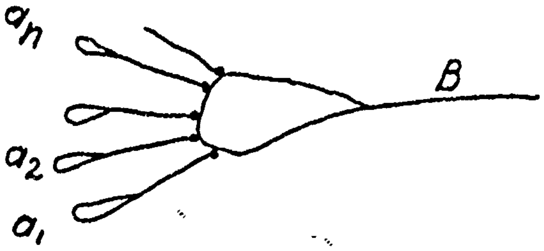
read B fires at time t if and only if A fires at t minus 1. Similarly, if 4 neurons are considered as shown in the following manner,



the proposition now reads,

$$d(t) .\equiv. a(t-2) . c(t-1).$$

This reads d fires at time t if and only if a fires at t minus 2 and c fires at t minus 1. Consider also, a generalized step such as is represented below. Let n neurons (a_1 a_2 . . . a_n) synapse with one end bulb each on B. Let the threshold of the synapse equal 1.



The proposition now becomes,

$$B(t) .\equiv. \sum_{i=1}^{i=n} a_i (t-1).$$

This is read B fires at time t if and only if there fires at time t minus 1, the sum of a_i from i equals 1 to i equals n. From these beginnings extremely complex systems have been considered, (Culbertson).

Shimbel (31) points out that such systems as the one described above require a "locked-in-phase" relation existing throughout the entire net as well as high reliability on each individual neuron. He prefers statistical considerations of large aggregates of neuronal elements. Culbertson, however, shows how the system with its modified postulates is adequate. Granted that biological phenomena may not coincide with the integral and discrete values, it is possible to validly use them and make use (as he thinks the nervous system does) of phase correcting devices, filters, etc. G. Walters would seem to agree with him. He believes the brain uses frequency modulated information to an extremely complex degree.

The central problem facing the visual neuroanatomists is to explain a neurologically invariant response to shape or form regardless of its size or orientation. One can say that when this is done the system has abstracted form. It was the theoretic (and this is the most important, 32) solution of this problem which led Northrop to emphasize the value of McCulloch and Pitts' work. The nervous system thus reacts, at times, to universals rather than to particulars. According to McCulloch and Pitts (20), the retinal response pattern must be transmitted back to the optic cortex, taken through transformations which are related as a group (Wiener, p 156-167), coded and reduced to some sort of an average which is matched or compared with a standard. Wiener, Walters, and McCulloch agree that the alpha rhythm forms a necessary part of a scanning process by allowing regulated excitation of neuron manifolds such that all dimensions of the incoming pattern can be scanned, compared, recorded as to degree of conformity, etc. The number of dimensions is seemingly rather large and one would need an understanding of Riemannian or other non-Euclidian regions for full understanding of the phenomena. For us, though, the pertinent fact is that the alpha rhythm has been postulated as performing the regulatory function in form perception. With Culbertson it also regulates the rate of retinal image input to the optic system. With the others it plays a more purely occipital role.

The Question of Quantized Perception

This thesis is a study of the maximum rapidity with which temporally separate spatial stimuli may be perceived. It is thus a determination of the length of the time quantum which must separate successive spatial stimuli impinging on the retina. Perception, then, may be considered a blend of small "bundles" or discrete quanta which have time values of short duration that may not be reduced without distorting the spatial and temporal clarity of the experience. It is assumed that this is analogous to the duration of the cyclic process necessary in any synchronized scanning process commonly utilized by engineers in computing machines, television and communication problems.

Previous psychologic research, though not cast in the same theoretic frame of reference as this study, has yielded significant data. Woodworth (34) has shown that tachistoscopic exposures which allow for only one percept can be as long as 150 to 200 milliseconds. This is approximately the length of time taken by one alpha cycle. Studies on the following and reading movements of the eyes have shown that these movements regularly occur at rates near 4 to 6 per second. It is assumed that perceptions are made between movements at that rate, and require a time interval on the order of that taken by one alpha cycle.

Renshaw (28), using the lightning calculator Finkelstein as subject, obtained world's records for minimum time exposures for perception of the maximum number of digits. Renshaw's goal was a maximum perceptual span and he trained Finkelstein until little further increase in performance could be expected. The data show that as the number of digits is gradually increased up to and including nine digits, a corresponding though extremely small, increase in time is required for accurate perception. The mean time for this number of digits was .003 seconds. However, when one more digit is added to this row, the time requirement increases from the above value to .264 seconds. It is further noted that the perception of eleven digits required .531 seconds; twelve digits .750. The perceptual time quantum is near .2 seconds in each case. One might say that Finkelstein had to wait until another quantum of temporal opportunity had materialized in order to extend his perceptual span.

Stein (34, p 689) demonstrated that there is a loss in temporal appreciation by presenting all the letters making up a word in one tenth of a second. The reading subject could not detect whether the letters were presented from the beginning-forward or in the reverse order. This suggests that form presentations on the order of the alpha frequency lose their temporal clarity. Though these investigators saw little or no relation between their results and the cerebral alpha rhythm, one possible theoretic position attributes all the above findings to manifestations of one synchronously controlled nerve net.

THE PROBLEM

Various nerve nets may be postulated which would transmit spatial information through its many stages and transformations. These hypothetical constructs must all meet a certain requirement: *if spatial information is to be preserved there must be a corresponding reduction in the clarity or exactness with which a particular net preserves temporal information*. This is the oft-referred-to exchangeability of space and time in neural patterns (McCulloch 20,21 and Culbertson 5). In order that corresponding neurons in two different manifolds may function in a highly correlated fashion, it is necessary for both manifolds to have a *periodic or cyclic control*. This control prescribes when respective neurons may fire and discharge impulses, and the time required by this control cycle results in the loss in temporal acuity referred to above. The cyclic function might be accomplished in more than one way: (1) the nerve nets might have their own cells with particular rhythms of discharge--in which case, as Walters pointed out, the cycle is inside the cell,

(2) they may be synchronized by the action of an external net. The alpha rhythm may therefore be evidence of the presence of such a synchronizing device. If so, certain implications follow in regard to the relation between the frequency of the alpha rhythm and the maximum temporal discriminatory powers of processes in which the alpha rhythm plays a part. These implications are most relevant in the perception of shape or form. The problem then, is to determine the relationship between the alpha rhythm and the rate of form perception with reference to the preservation of spatial and temporal relations of visually received stimuli. It follows also that since apparent motion begins at that rate where separate form images become distorted, it also then will stand in a similar relation to the alpha rhythm.

HYPOTHESES

A. The alpha rhythm (basic resting occipital rhythm) is an index of certain neurological processes necessary for the transmission of neural patterns which mediate the perception of form. These processes are periodic in nature and when measured in terms of electrical potential, constitute the alpha rhythm. These processes are the basis for the loss in temporal acuity in rapid successive form perceptions.

B. Apparent motion is a manifestation of a partial failure or loss in efficiency in the perceptual process by the retino-cortical nerve net in the transmission of spatial and temporal information. There is an interactional equivalence of the space and time information (in neural terms) such that neither of these are presented accurately for perception and there results the neural pattern for the perception of motion. Apparent motion, resulting from the nerve net which transmits form images, will have certain relations to the alpha rhythm.

If the above is true the following corollaries should be true:

Corollary I. No form images may be perceived at a rate faster than the alpha frequency for a particular individual.

Corollary II. Differing forms presented successively and at rates faster than alpha frequency will not be perceived in temporal separation as presented but will be perceived as in motion or in simultaneous existence, depending on the ratio of their rate of presentation to the alpha rhythm of a particular individual.

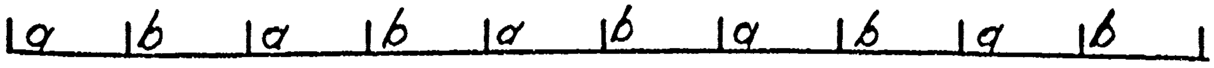
That rate of form presentation at which apparent motion ceases (threshold of simultaniety) will be proportionate to the alpha rhythm.

The maximum rate at which separate images can be perceived will be proportionate to the alpha rhythm.

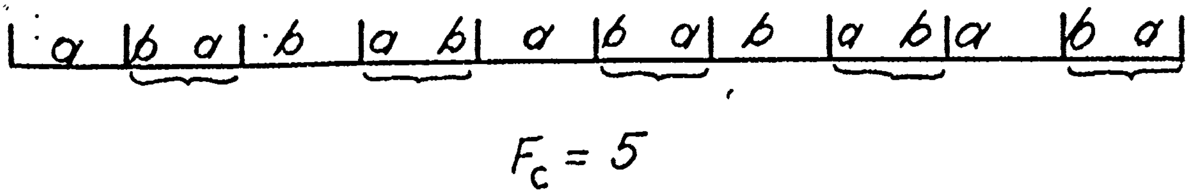
Corollary III. Segments of a composite form which may combine to make up a unit form, when presented tachistoscopically at or above alpha frequency will be seen as fused into a composite form whose elements are simultaneously present.

If we represent a ten per second alpha frequency as events on a time dimension of one second duration,

and represent the exposures of two different forms separated by 1/10 second intervals in a similar manner, it is seen that when superimposed they have the following relations.



Now, if the rate of form presentation exceeds the present rate, say by an amount F_c, it is seen that the following phase relation holds.



We may thus let F_c stand for the amount by which the alpha frequency is exceeded by the form presentation rate F and also for the frequency of coincident exposures of the forms within an alpha cycle. Thus,

$$F_c = F - \alpha$$

where F equals the rate of form presentation, α equals the alpha frequency and F_c equals the frequency of coincident exposures per second. If we allow N separate forms the equation may be generalized to read

$$F_c = F - \alpha(N-1).$$

It is preferable to seek that point at which fusion begins and if we postulate that this point is reached where F_c is just equal to zero, the threshold may be expected when the equation reads

$$F = \alpha(N - 1).$$

$$F_c = 0$$

This prescribes a relationship to alpha and form perception rates which is linear and positive and disregards any logarhythmic function which is often present in psychophysical phenomena. It also assumes no volley effect or multiple net functioning in form perception as such and therefore is unlike auditory neural phenomena. Many factors, however, which are known to have an effect of changing thresholds, were, in the experiment, kept constant. These were the area of the stimulus, intensity of illumination, distance to stimulus, etc. For an individual with 10/second alpha frequency the number of forms or form elements N, and their threshold rates producing fusion F , into a composite form should be related in the manner shown in the graph below.

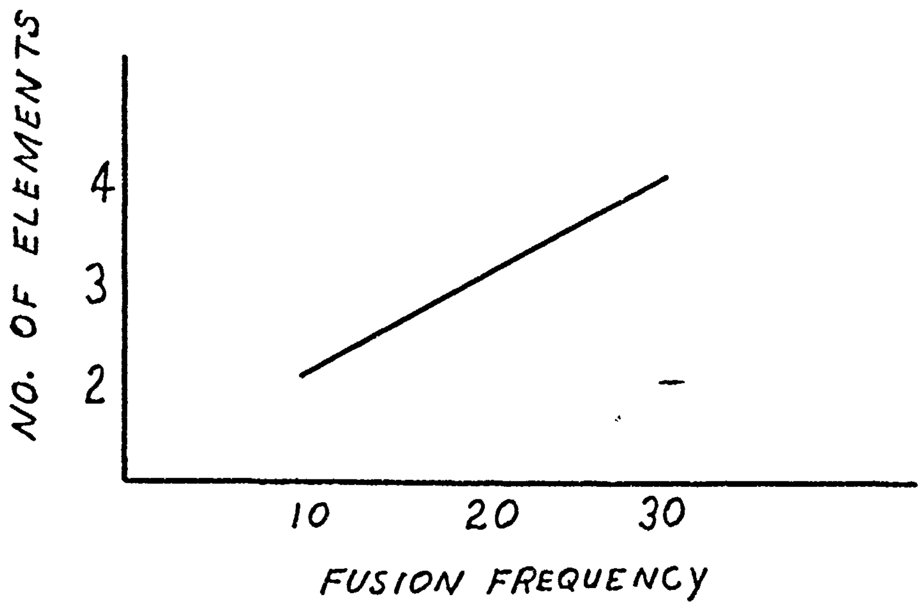


Figure 2. Relation of number of elements in a composite form and the rate at which they should fuse.

Our experiment will be concerned with composite forms of 2, 3, and 4 identical elements.

THE EXPERIMENTAL DESIGN

The experiment was designed to test each of the above corollaries. In addition, since the opportunity was easily available, the design included the entry of a figure-ground-reversal procedure. It was hoped to determine whether the frequency of reversal of a figure and ground sufficiently rapid for a simultaneous perception of a blended or fused area would also be related to the alpha frequency. Critical flicker fusion of "on-off" light on a similar area was also obtained in order to rule out "retinal lag" or other interference relative to non-spatial factors. That is, the fusion of the forms should take place well below critical flicker fusion (cff).

The Selection of Subjects

Fifty subjects were selected from the files of the electroencephalographer at the Veterans Administration Hospital, Chillicothe, Ohio, on the basis of their alpha frequency as determined by the neurologic consultant. It is an extremely difficult matter to obtain subjects possessing frequencies below nine per second or above twelve per second. The distribution obtained exhausted the extreme ranges from the more than two thousand tracings on record at the hospital. For each alpha frequency the following number of subjects were studied.

TABLE I. Number of Subjects in Relation to Alpha Frequency

Frequency	No. Subjects
12-13	4
11-12	12
10-11	9
9-10	13
8-9	12
Total	50

M 10.16 per sec.

S.E. 1.29

Using the principle of matched groups it is assumed that the significant differences in the separate groups are either limited to their alpha differences or that what variations were present influenced our study in no systematic way. The alpha frequencies were not determined to values below one unit per second because available measurements were not determined to a closer degree of accuracy. There is some variability within the individual which often approaches one cycle per second and therefore limits the accuracy of any overall determination for that individual.

The experimenter deliberately remained in ignorance of the frequency of any subject until after the data were collected, since he worked rather closely with the subjects in the operation of the apparatus and could have therefore been instrumental in modifying their responses. This problem is a common one in psychologic research. The groups were completed in a random fashion such that consecutive procedures on subjects from any one group were minimized. (For further data concerning subjects see Appendix C.)

The Apparatus

The apparatus was essentially a device which could be made to expose and illuminate various stimuli at controlled and variable rates, (see Figure 3).

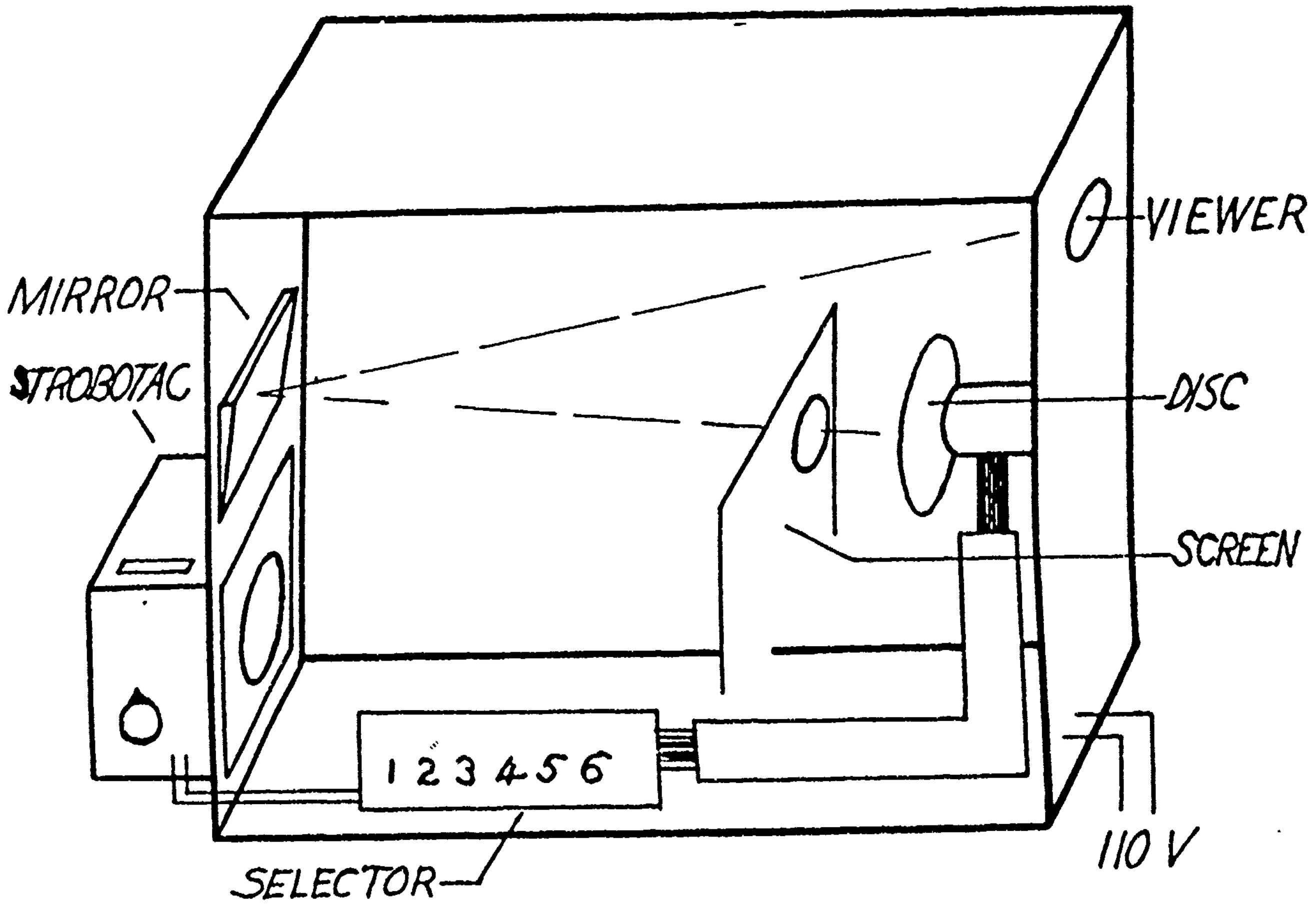


FIGURE 3. APPARATUS IN NEAR LIGHT-TIGHT BOX. DISTANCE FROM VIEWER TO DISC THROUGH MIRROR IS 94 CENTIMETERS (APP. 42 INCHES).

The heart of the apparatus consists of a spinning disc onto which the flash of a strobotac is directed through a screen with a shutter operated window. The strobotac emits a five millisecond flash either at a determined and controlled frequency or whenever an external contact is operated. An electric commutator on the same axis with the spinning disc was the external contactor in this design. An array of switches enabled the experimenter to select the particular stimuli to be exposed. In operation, when the desired stimulus appeared in the window of the screen, it was automatically illuminated quite analogous to the firing of appropriate cylinders in an internal combustion engine. It should be pointed out that the strobotac also operates as a tachometer and by this means the speed of rotation of the disc is quickly determined.

The Procedures

Specific procedures for each subject were as follows, and in the order discussed. One exception is that the last twenty-five subjects were given an additional task of identifying one form which was exposed in a different position and orientation successively at slower and slower rates until identification was complete.

Procedure 1.	Purpose:	Introduction of subject to situation and adapt his eyes.
	Events:	Subject was engaged in conversation for approximately two minutes with room light extinguished. Shown apparatus.
Procedure 2.	Purpose:	Further adaptation of eyes and determination of CFF.
	Events:	Subject was asked to place his eyes at the viewer and fixate a small white area illuminated by the strobotac light. CFF obtained.
	Instructions:	"You see that by turning a knob on this instrument I can control the flickering light on the white spot. Your task is to say 'now' when the flicker gets so fast that you can no longer see it . . . Now let me know by again saying 'now' when the light begins to flicker again".
	Msc:	Thresholds were recorded progressing up and down the scale.

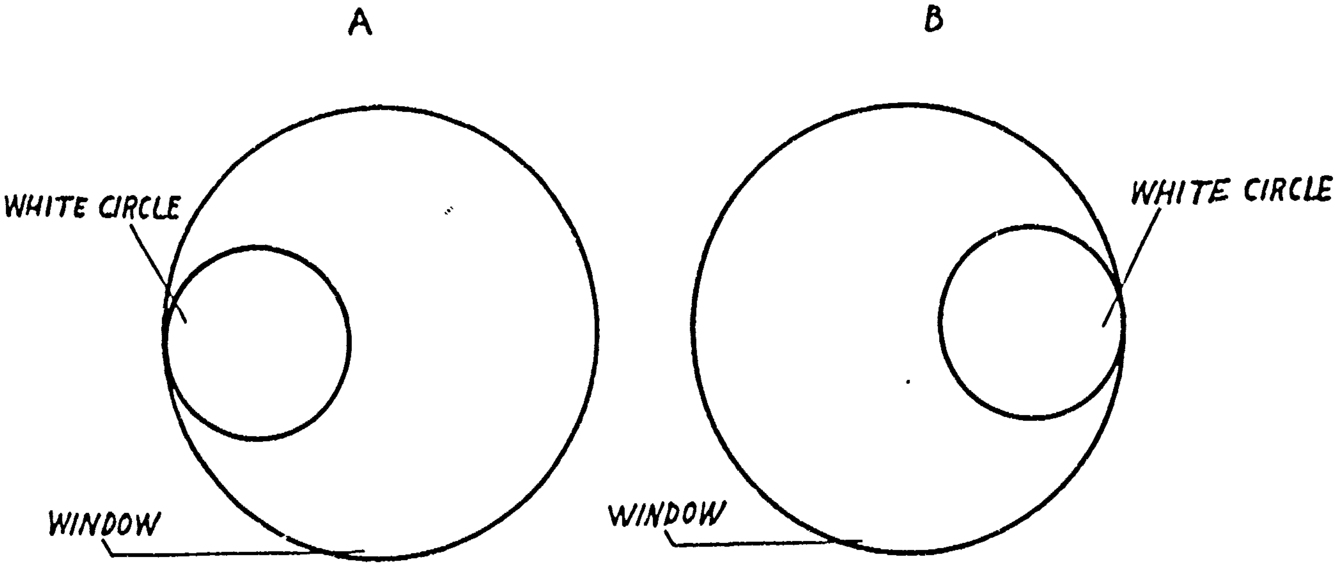
Procedure 3.

Purpose: Determination of threshold of simultaniety, i.e., when apparent motion ceases.

Events: The rate of presentation of two separate white circles in adjacent positions alternately, was increased and decreased until the subject reported cessation and beginning of motion respectively.

Instructions: "You say 'now' when the little white circles quit jumping back and forth . . . say 'now' when they begin jumping again. They may always blink or flicker but we're interested in when they are in motion for you."

Misc: Appropriate speeds were recorded.



Stimuli for Procedure 3.

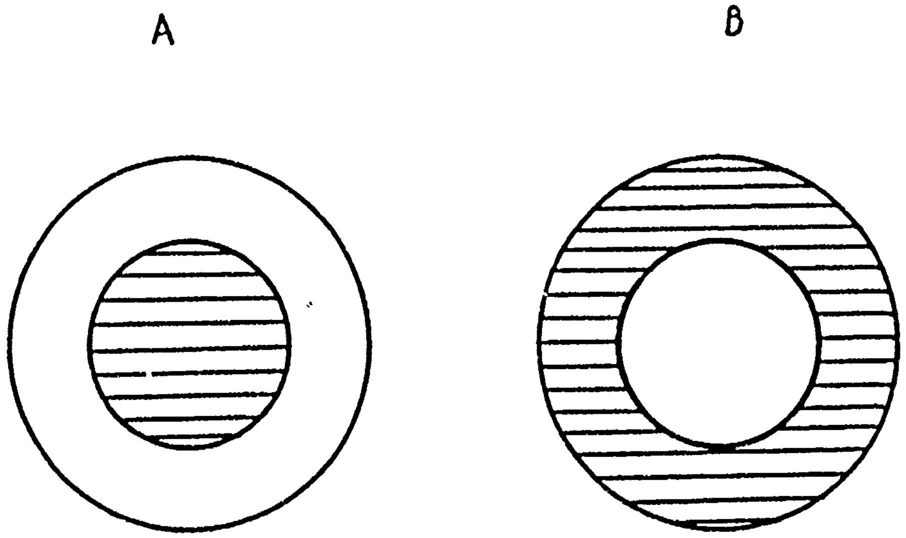
"A" alternates with "B"

Procedure 4. Purpose: Determination of fusion rate of figure and ground reversal.

Events: Rates of alternate presentations of stimuli were increased and decreased in the usual manner as the subject reported fusion and separation respectively.

Instructions: "You say 'now' when you can no longer see the separate flashes of the ring and the circle, that is, when they blend and look something like this." (Subject was shown a solid uniform grey area by means of a control switch.) "Now, again when they are no longer blended but are flashing separately."

Misc: Speeds were recorded.



Stimuli for procedure 4.

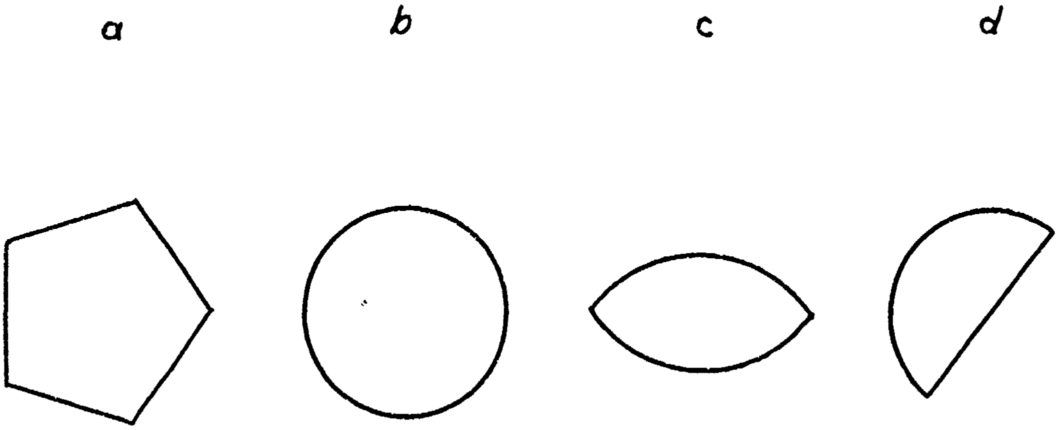
"A" alternates with "B"

Procedure 5. Purpose: Determination of threshold rate of form perception.

Events: The successive presentation of four separate forms was reduced in rate gradually until the subject identified all forms.

Instructions: "You see that thing changing shape and wiggling don't you? Now, as I slow this machine more and more the motion will stop and finally you will be able to see the different things that is made of. Name or describe them when you can."

Misc: The rates of presentation at which the separate forms were perceived were recorded.



Stimuli for Procedure 5.

a b c d were presented successively and continuously at gradually reduced rates.

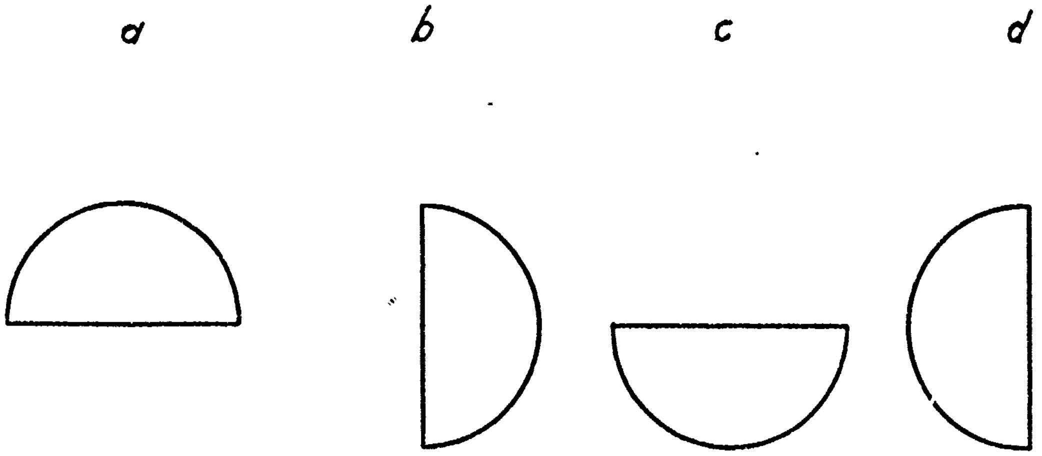
Procedure 5a. Purpose: Determination of the threshold at which a single form is identified as it is presented in separate positions and orientations.

(Last 25 N)

Events: The machine was slowed gradually until the subject could identify the single form presented.

Instructions: "What you see now that looks like a circle made up of pie-shaped segments will change. You tell me what the circle breaks up to look like."

Misc: As the machine is slowed the apparent motion begins, subsides and the figure of a half-circle becomes distinguishable. That rate is recorded.



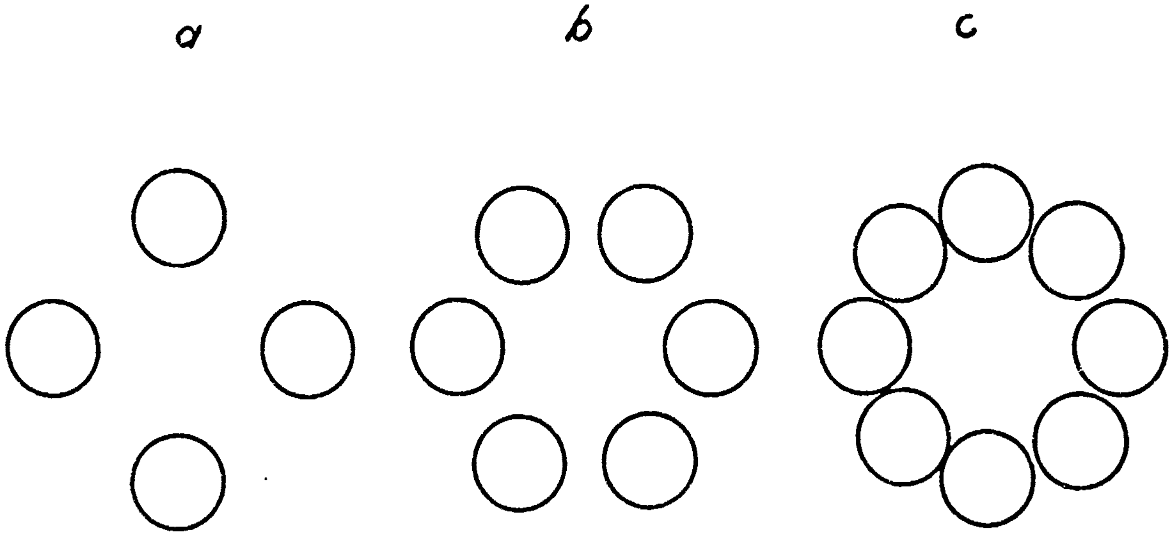
Stimuli for Procedure 5a.

a b c d are presented successively and at gradually reduced rates.

<u>Procedure 6.</u> Purpose: Determination of the rate (threshold) at which a composite form of 2,3 and 4 elements fuses, i.e., is seen as a simultaneously existing mosaic.

Instructions: "You see those dots going round and round? You say 'now' when they stop and form a ring . . . and again when the ring breaks up and the motion starts again. You might-count the dots aloud -- the ring will have six dots."

Misc: Instructions were similar for a procedure obtaining fusion thresholds for composite forms of 2 elements and 4 elements. The rates were recorded.



Stimuli for Procedure 6.

a b c are the composite forms as they appear when fused

The element which, through successive presentations in appropriate positions, comprises the composite forms is shown below.

Element of composite forms

When presented successively in appropriate angular positions the forms on the preceding page emerge.

RESULTS

The results were not as predicted. The overall picture is best seen in Figure 4. The means of the performances of the separate groups on thresholds of form identification, apparent motion, figure-ground reversals and fusion (of the two element form) are connected. Each color represents the performance of all subjects on a particular procedure. (Fusion of three and four element forms occurred at frequencies which are off scale on this graph.) It is pointed out that the group displaying twelve to thirteen alpha frequencies composed only four members and is therefore statistically less reliable than the others when any particular result is considered though it still displays the trend of the data. Subjects possessing this frequency are extremely difficult to find.

The relations between the types of performances are similar and, for all subjects show a curvilinear relationship to alpha. The correlation ratios, their probable errors and (a better test of significance) epsilon-square confidence levels, are given in Table II. If we assign to each of the

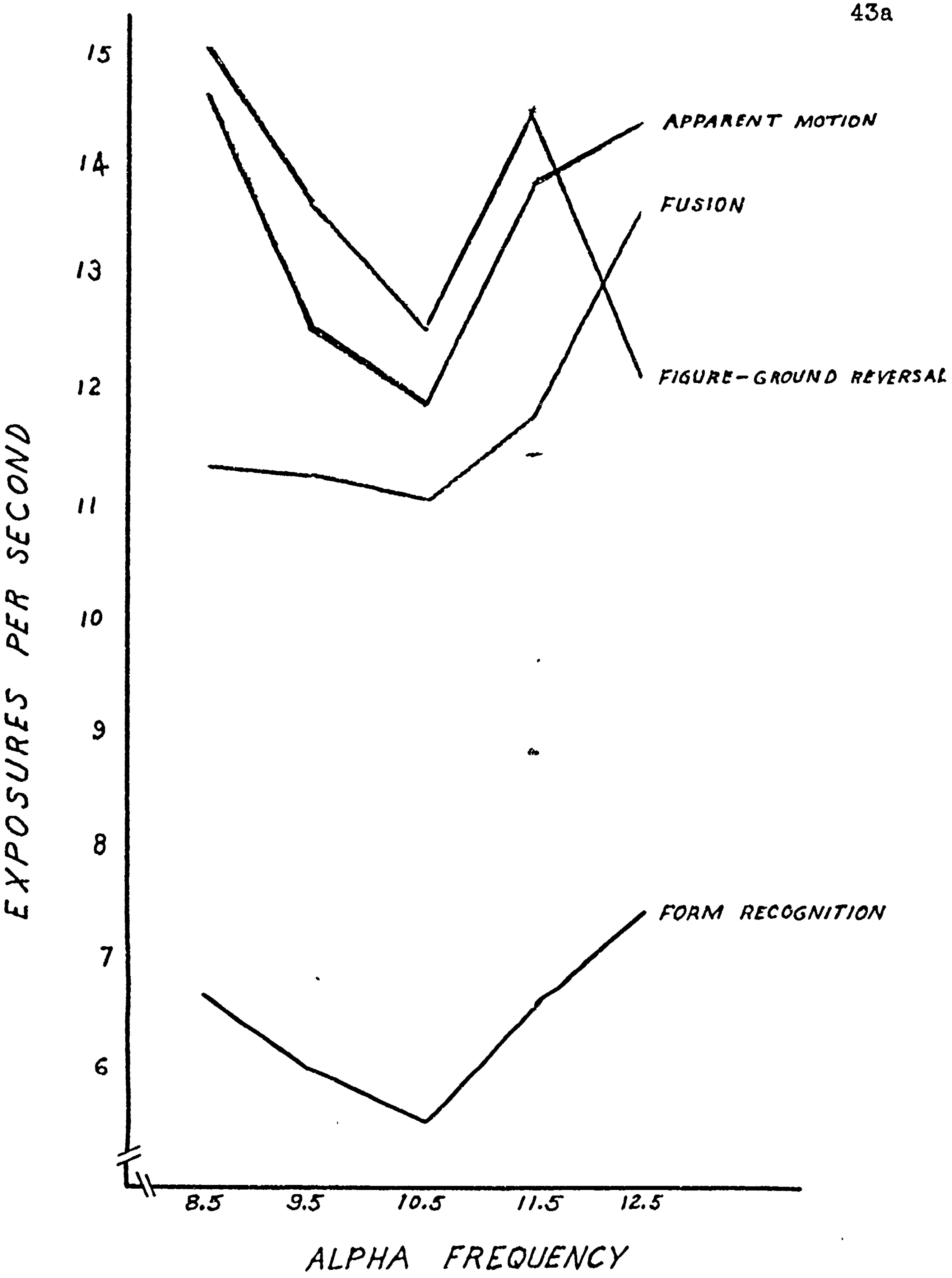


Figure 4. The Relation Between Alpha and Performance

fifty subjects a score, his mean, to represent his performance on the combined procedures of apparent motion, figure-ground reversal, form recognition and fusion, the overall statistical results may be seen (Tables II and III).

TABLE II. Statistical Significance of Relation Between Alpha Frequency and Performances on the Various Procedures

Types of Performance	Statistical Measures		
	Cor. Ratio*	P.E.	Confidence Level
Form recognition	.48	.079	1%
Apparent Motion	.57	.065	1%
Figure-ground Reversal	.44	.077	<5% > 1%
Fusion of 2 Elements into Composite Form	.35	.086	>5%
Fusion of 3 Elements into Composite Form	.30	.087	>5%
Fusion of 4 Elements into Composite Form	.29	.088	>5%

* The correlation of performance with alpha--not alpha with performance.

TABLE III. Statistical Significance of Relation between Alpha and Mean Overall Performance on Form Recognition, Apparent Motion, Figure-Ground Reversal and Fusion on 2, 3 and 4 elements into Composite Forms.

Statistical Measures	— Mean Performance
Cor. Ratio*	.56
P. E.	.066
Level of Confidence	1%

* The correlation of performance with alpha --not alpha with performance.

While all the procedures did not pass rigorous tests of significance they display the same general relation to a lesser degree. This is true of all the procedures save critical flicker fusion. It is seen that this phenomenon took place at such high frequencies that there is no possibility of assigning the fusion and recognition thresholds to this source. It is seen that these thresholds stand in a specific relation to the alpha frequency. A theoretic discussion concerning the possible meaning of the relation will be presented in the next section.

Results Specific to Corollaries

Corollary I. No form images may be perceived at a rate faster than the alpha frequency for a particular individual.

The means of form recognition rates for the different groups never exceeded the alpha frequency. (Table IV shows the means and standard errors of the separate procedures)

TABLE IV. Means and Standard Deviations (score units --exposures per second) of Performances on the Various Procedures

Types of Performance	Statistical Measures	
	Mean	S.E.
Form Recognition	6.34	1.45
Apparent Motion	13.36	1.73
Figure-Ground Reversal	13.82	2.24
Fusion of 2 Elements into a Composite Form	11.48	1.72
Fusion of 3 Elements into Composite Form	19.00	2.17
Fusion of 4 Elements into Composite Form	26.08	3.51

The form recognition score (the average of the rates at which the subject identified his second and third form) exceeds the alpha rhythm possessed by an individual in one case. If we take as the form recognition score that rate at which the subject recognized his second form rather than the average (which is slightly more reliable) between the second and third, it is seen that the alpha frequency is exceeded in two individual cases. Considering the question as to how the perception of the first recognized form rate compares to alpha--one of the forms used was unreliable and reasonably easily seen because of its regular pointed outline. It is therefore best to take as the subject's score either the second form perception rate or the average between the second and third. In any case that rate at which the forms could be seen as a percept rather than "finally figured out" was well below alpha frequency. It seems safe to say that Corollary I is verified.

Corollary II. Differing forms presented successively and at rates faster than alpha frequency will not be perceived in temporal separation as presented but will be perceived as in motion or in simultaneously existence, depending on the ratio of their rate of presentation to the alpha rhythm of a particular individual.

> That rate of form presentation at which apparent motion ceases (threshold of simultaneity) will be proportionate to the alpha rhythm.
>
> The maximum rate at which separate images can be perceived will be proportionate to the alpha rhythm.

It is apparent from the data that form recognition and apparent motion were significantly related to the alpha rhythm but not in the manner implied by this corollary. Though this corollary implies a linear relationship the results are clearly that of a curvilinear one such as to negate the corollary as stated. It is seen that the corollary is not irrelevent but that the relationship must be one of a different character than that postulated.

> Corollary III. Segments of a composite form which may combine to make up a unit form, when presented tachistoscopically at or above alpha frequency will be seen as fused into a composite form whose elements are simultaneously present.

This corollary and the equations which followed must be interpreted as standing in a similar manner to the obtained results in corollary II above. A comparison between the predicted values as means for the entire fifty subjects and the obtained values is given in Table V below.

TABLE V. Obtained and Predicted Means for all 50 Subjects (score units--exposures per second) for Fusion of 2,3 and 4 Elements into Composite Form.

No. of Elements	Predicted	Obtained
2	10	11.48
3	20	19.00
4	30	26.08

While the agreement is certainly more than negligible, when one compares the values deduced from the equation with the values experimentally obtained from the specific groups of alpha, the results are completely negative. The fusion of the composite forms does not stand in a direct, linear, positive relation with alpha.

DISCUSSION

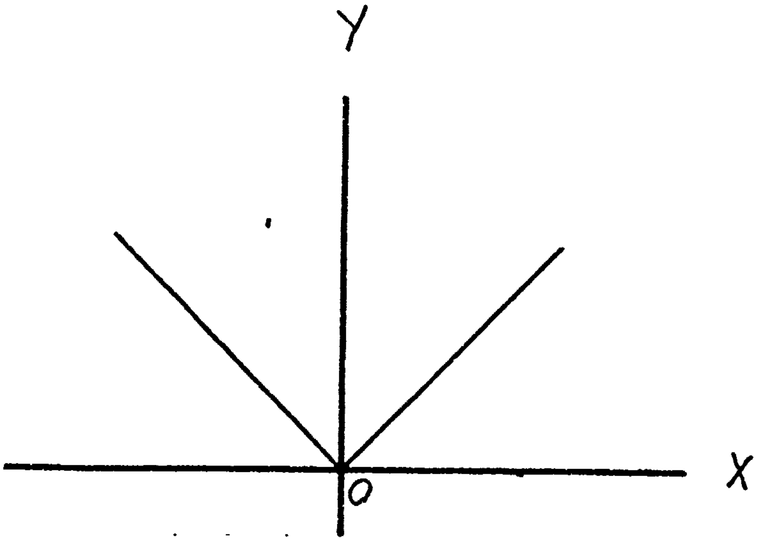
An accidental relation such as that obtained seems hardly possible. One is now faced with the question as to the meaning of the curvilinear relation; what changes must be made in the original viewpoint. Under these circumstances one is compelled to "reason backwards". The conclusions should, however, be reasonable and perhaps deductions from any new theory can be related to the data obtained. Two possibilities will be presented; the second more fully than the first.

The results might conceivably be depressed by some factor possessed by the central (and most frequent) ranges of alpha. It might be possible to relate the depression in the center of the curve to the fact that this frequency of alpha is the most common in the population and somehow different in quality from the other frequencies. A statement by Gibbs (13, page 22) is relevant here. It is in effect an assertion that in a system of oscillators with equal amplitudes that oscillator whose frequency is most stable will predominate. One further assumption would be that the central region of alpha, because it is most common, is also the most stable, and therefore withstands flickering disturbance most. The above is presented as one possibility.

One other way of viewing the results would be to say that the ends of the curve may have been raised by the action of a factor in addition to the one above, or by a factor operating alone. One might approach this suggestively through analytic geometry. In analytic geometry one may find curves roughly similar to the one obtained by equations of either the first or second order. The obtained curve is somewhat like an hyperbola, wherein, it is interesting to note, the curve results from a constant difference between two points. Our obtained curve appears most like an equation of the first degree of the general form,

$$y = m\,|x|\,.$$

This is read, y equals absolute value of x multiplied by some constant m. Such a curve, as it stands now, lies at the origin of a coordinate system and has the following appearance when m equals 1.



$y = m\,|x|\,. \qquad m = 1$

But our obtained curve lies in the upper right quadrant. We can translate the curve shown above to the region of our obtained curve for the best possible approximation of super-position. The theoretic equation now reads

$$y - k = m\,|x - h|\,,$$

y minus k equals the constant m times the absolute difference between x and h. The constants k and h are the necessary modifications of the previous y and x in order for the curve to be translated to the new position. By this means the curve may be expressed anywhere in the coordinate system. We may now substitute appropriate values in the theoretic equation with assurance that they hold for this region (as an approximation). It is seen that y corresponds to performance and x corresponds to alpha frequency. The constants are taken from the graph. In Figure V, a comparison is made between the curve determined in this theoretic fashion and the values obtained by combining the means of form recognition and apparent motion, our two main procedures. The constant m has the value of 1 and the other constants become

$$k = 8.7$$

$$h = 10.3$$

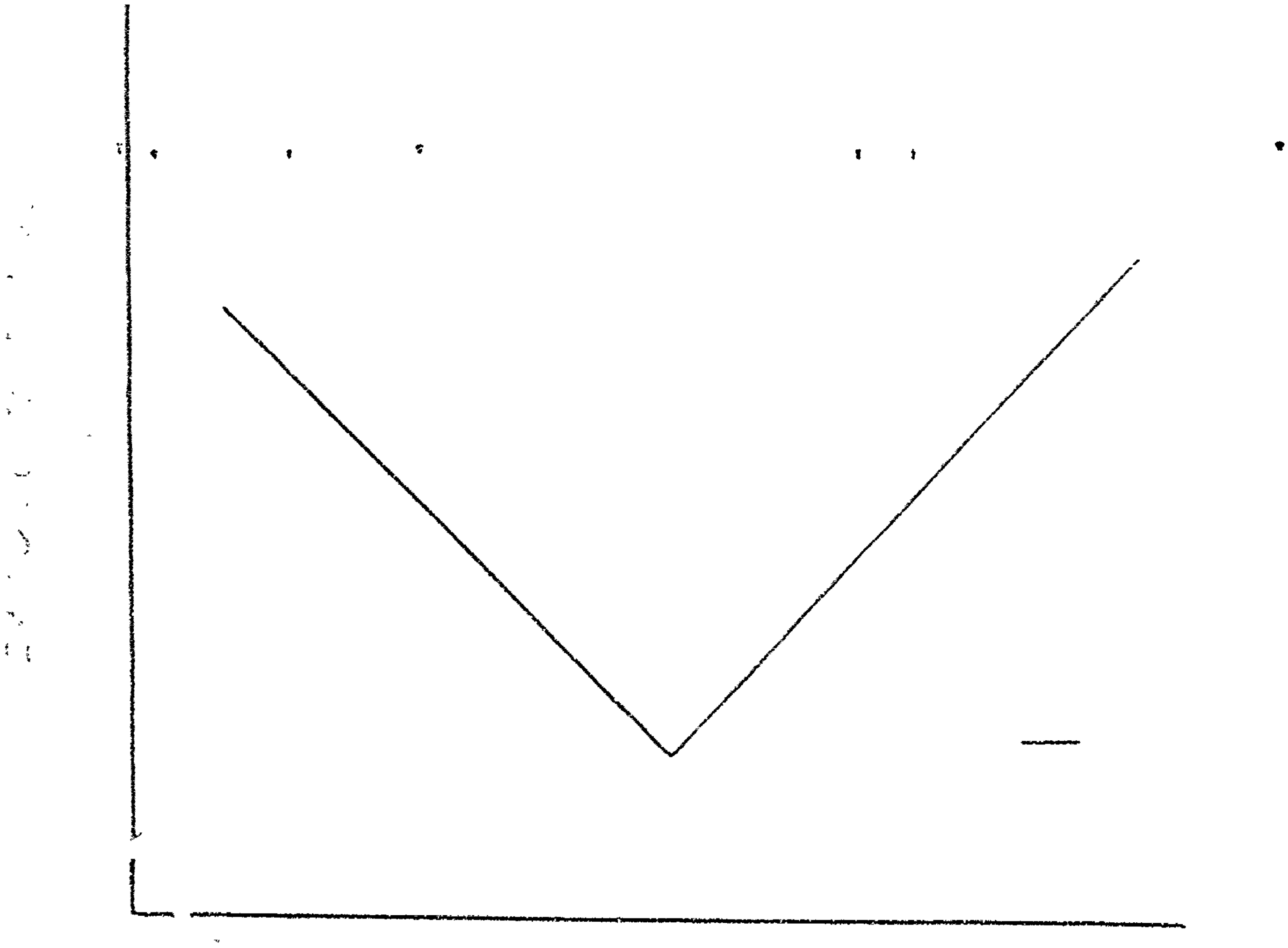
The equation approximating our data may now be written

$$p - 8.7 = |\alpha - 10.3| ,$$

where p is the performance and α is the alpha frequency. Or,

$$p = 8.7 + |\alpha - 10.3| .$$

The fact that the above curve can be obtained by utilizing the difference between alpha frequency and another value in the region of the alpha frequency is of extreme importance. Suppose we postulate that



this other value represents, in the nerve net, another frequency displaying that rate. We actually need only observe that our subjects possess this frequency as a central tendency and have small dispersion from it in a manner not correlated with the alpha frequency. <u>Support is strongly lent to the idea that the portion of the nerve net displaying this other frequency is the retina</u>. It may therefore well be that as regards thresholds, the time span of simultaneity (separation of two events as far apart in time as is still perceived as simultaneous) is lengthend for those subjects whose alpha and retinal rhythms approach the same value or frequency. Bartley states, "It has become evident that the retina possesses an intrinsic rhythm . . . (and these) have a sensory significance . . .", (1, p 328). It may well be that the operation of the alpha and retinal frequencies, when similar in value, cause an interference such as to produce fusion earlier than when a larger difference exists.

Granit and Therman (1, p 278) report that electroretinograms display full regular waves with a frequency of 10.3 per second when photic stimuli impinges on the retina at that frequency. Above that frequency the electroretinogram does not follow the stimulation completely and either has every other wave diminished or not present at all. This coincidence with our finding of 10.3 as a constant, probably attributable to the retina, lends strong support to the idea that the intrinsic rhythm of the retina has this value as a mean.

In order to utilize the equation above for other procedures the constants m and k assume a different value but the constant h always remains 10.3. Performance is now curvilinearly related to alpha and linearly related to the difference between alpha and another value, 10.3.

It might be of interest to compute the mean time interval which separates the beginning and ending of a series of events which are nevertheless seen as simultaneous. If we use the data from the apparent motion and fusion procedures and compute the mean time span for all fifty subjects, we obtain the value .095 sec. The mean value of the alpha cycle of our subjects is .098 sec. There is thus little doubt that the nerve net which mediates form perception has, in this case, a quantum factor near that predicted by theory.

In order to submit the hypotheses to accepted statistical tests and in order to simplify the data, chief interest has been shown in the central tendencies and dispersions of the scores assigned to represent the performances of the subjects. Unless great semantic care is exercised these central tendencies and dispersions become artifacts and erroneously considered. There is a tendency to have the mean represent the scores made by all subjects and to let the standard error represent "the dispersion of the group". These abstractions are so far removed from the actual series of events which took place that a great deal of information is lost. Statistically considered, no differentiation is made between the subject who makes a slow response because he is ill at ease in an unfamiliar environment and the subject wants to be exceptionally sure and careful, or between either of these and a third subject who has the delusion that he invented the apparatus and has been unfairly committed to prevent his reaping the reward. One usually assumes that these variations do not bias the controlled experiment in a systematic way but one can never be sure.

Generalizations from experimental data have value through the principals of induction and analogy. Other individuals in other popul ations possessing similar alpha frequencies are expected to possess similar perceptual characteristics expressed by the means and dispersions of our experimental groups. Individually, however, they can hardly be expected to vary around their means because of the same particular reasons. There might not be encountered a second subject who felt he invented the apparatus or one who tended to argue so much that his percepts were reported unreliably. It is assumed that though these same situations might not be expected again other factors having a similar effect would operate. This problem of induction and analogy is present in all science. The problem is minimized in an experiment of this sort out it achieves extreme importance in some clinical settings where hypotheses are applied to the individual patient. In this latter case the specific variations and differences may be the most significant facts in the situation.

Nerve-net theorists have also been concerned with the rich variety of responses to supposedly simple stimuli. This variety might be accounted for in the following manner: two different types of nerve nets probably operate in perception. The first type is believed to be specific in its operation and may be expected to function repetitively in much the same way. It is inherited and similar from one individual to another. The second, however, is believed to be non-specific, to function in a rather generalized manner, to be very plastic (especially in young persons) and excedingly modifiable by experience, and to on-going processes at the time new information is introduced. The effect of this second non-specific assembly was intended to be minimized by designing the stimuli for this experiment so that they diplayed the least possible complexity.

CONCLUSIONS

The following may be concluded from this study:

1. There is a significant relation between the alpha rhythm and the temporal aspect of rapid successive spatial perceptions. This relation may be

considered as curvilinear, or, possibly linear to the difference between alpha and some other value, which in central tendency, coincides with that of alpha.

2. Strong support is indicated for the view that maximum rates of form perception, apparent motion, figure-ground reversals (at appropriate rates), and fusion of separate spatial elements into a simultaneously perceived composite form or shape are mediated by a nerve net of which the alpha rhythm is an integral part.

Culbertson's view of an alpha controlled retina is not supported except indirectly; Both frequencies have a similar central tendency. It seems more probable that alpha controls only the central nervous processes.

To the degree that a study is successful, support is lent that field of endeavor from which it comes. In this case the genuine effective relation between psychology and cybernetics, including particularly mathematical biophysics, is enhanced. It might be thought that the success of either of the fields of cybernetics or mathematical biophysics would reduce rather than enhance psychologic considerations. For, to the extent that a response from an organism is mechanical its "meaning" and perhaps its "mental aspects" might be lost. Northrop disagrees. He sees mechanisms as supplementary to ideas. Inasmuch as psychology has long tried to be mechanistic it appears that harmony rather than discord with the mathematical and nerve-net theorists will prevail.

SUGGESTIONS FOR FURTHER RESEARCH

It will be remembered that the data of Renshaw, though directed toward a different purpose in mind, demonstrated to a remarkable degree the quantizing factor around which this study is oriented. It is likely that the same approach would have been a better one in its particular way than the one used. It would be necessary to obtain a group of subjects displaying the appropriate alpha frequencies and train them sufficiently well so that there would be little doubt as to the length of the quantum factor when it appeared.

It seems possible also to shed light on the part played by retinal factors and to study the relation to the alpha factor through a binocular approach. When one of two stimuli is always presented to one eye and the other to the remaining, central factors should be more clearly manifested.

If possible, experimentation of this sort should be done at the same time an electroencephalogram is recorded. In that way one could be sure he was not "driving" the alpha with his own apparatus.

The use of drugs might overcome one of the most severe handicaps in this type of study--the extremely narrow range of alpha frequencies. It should be determined if the apparent shift in frequency due to drug influence (a barbiturate for example) is equivalent to a naturally faster or slower rhythm in another individual. If that were true the research could then proceed with ease.

BIBLIOGRAPHY

1. Bartley, S.H. Vision: A Study of its Basis. New D. Van Nostrand Company, 1941.

2. Bartley, S.H. "Some Effects of Intermittent Photic Stimulation." J. Exp. Psychol., 25, 462.

3. Brillouin, L. "Life, Thermodynamics and Cybernetics." Am. Sci., 1949, 37, 554-568.

4. Brillouin, L. "Thermodynamics and Information Theory." Am. Sci., 1950, 38, 594-599.

5. Culbertson, J.T. "A Mechanism for Optic Nerve Conduction and Form Perdeption: I." Bull. Mathe. Biophysics.

6. Culbertson, J.T. Consciousness and Behavior: A Neural Analysis of Behavior and of Consciousness. Dubuque, Iowa, Wm.C.Brown, 1950.

7. Darrow, K.K. "The Quantum Theory." Scientific American. 1952, v 186, 47-54.

8. Dunbar, M. J. "Feedback Systems and Oceanography." Am. Sci. 1950, 38, 599-603.

9. Edwards, A.L. Statistical Analysis. New York, Rinehart & Company, 1946.

10. Feigl, H. and Sellars, W. Readings in Philosophical Analysis. Appelton Century-Crofts, New York, 1949.

11. Gardner, M. "Logic Machines." Scientific American. 1952, v 186, no.3, 68-73.

12. Garrett, H.E. Statistics in Psychology and Education. Lonhmans, Green & Co., New York 1947.

13. Gibbs, F.A. and Gibbs, E.L. Atlas of Electroencephalography. 1950, v 1, Addison-Wesley Press: Cambridge, Mass., 1950.

Bibliography (cont'd.)

14. Guilford, J.P. Psychometric Methods. McGraw-Hill Book Co.

15. Klein, G.S. "The Relation Between Motion and Form Acuity in Para-foveal and Peripheral Vision and Related Phenomena." Arch. Psychol. 1942, 275, 5-71.

16. Knox, G.W. and Kisker, G.W. "Flicker Induction and the Role of Molar Properties in the Critical Flicker Frequency." J. Psychol. 1940, 10, 231-235.

17. Kohler, W. and Held, R. "The Cortical Correlate of Pattern Vision." Science. 1949, 109, 552.

18. Lorente de No', R. "The Vestibular Occular Reflex Arc. Arch. Neurol. and Psychiat. 1933, 30 245-291.

19. Luneburg, R.K. Mathematical Analysis of Binocular Vision. Princeton, N.J.: Princeton University Press. 1947, v 1.

20. McCulloch, W.S. and Pitts, W. "How We Know Universals: The Perception of Auditory and Visual Forms." Bull. Mathe. Biophysics. 1943, 5, 115-133.

21. McCulloch, W.S. and Pitts, W.A. "A Logical Calculus of the Ideas Immanent in Nervous Activity." Bull. Mathe. Biophysics. 1943, 5, 115-133.

22. Northrop, F.S.C. "The Neurological and Behavioristic Psychological Bias of the Ordering of Society by Means of Ideas." Science. April 23, 1948, v 107.

23. Ogle, K.N. Psychophysics: "Visual Space Sense." Medical Physics. 1950, 2, 748-753.

24. Ostow, M. "The Entropy Concept and Psychis Function." Am. Sci. 1951, v 39.

25. Polyak, S.L. The Retina. Chicago: The University of Chicago Press, 1941.

26. Rashevsky, N. "Nervous System: Mathematical Theory of its Functions." Medical Physics. 1950 2, 595-603.

27. Raymond, R.C. "Communication, Entrophy and Life." Am. Sci. 1950, 38, 273-378.

28. Renshaw, S. "The Visual Perception and Reproduction of Forms by Tachistoscopic Methods." J. Psychol. 1945, 20, 217-232.

29. Russell, B. Human Knowledge: Its Scope and Limits. Simon & Schuster, New York. 1948.

30. Russell, B. A History of Western Philosophy. Simon & Schuster, New York. 1945.

31. Shimbel, A. "Contributions to the Mathematical Biophysics of the Central Nervous System with Special Reference to Learning." Bull. Mathe. ,Biophysics. 1950, 12, 241-275.

32. Weinberg, M. "Mechanism in Neurosis." Am. Sci. 1951, v 1, 39, 74-98.

33. Wiener, N. "Cybernetics: Control and Communication in the Animal and the Machine." John Wiley & Sons, New York, 1948.

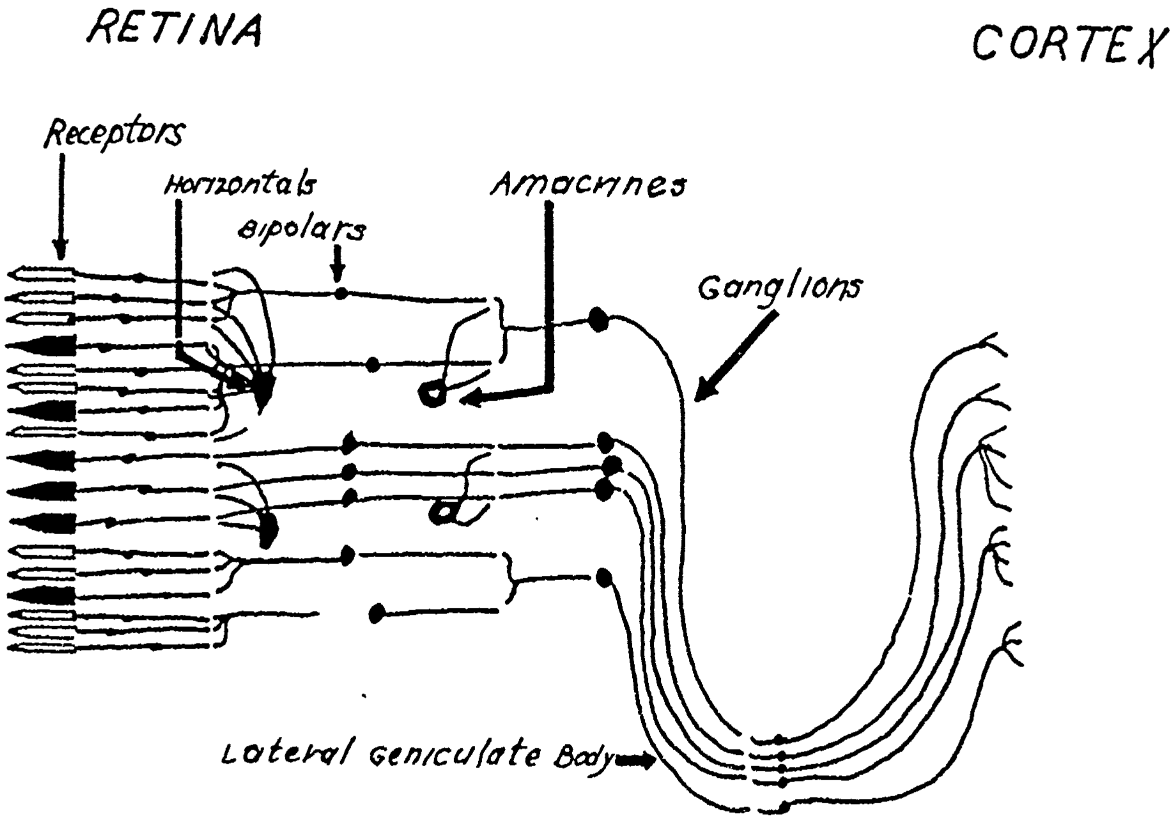
34. Woodworth, R.S. Experimental Psychology. Holt & Co. New York, 1938.

35. Walters, G. (The twenty-fourth Maudsley Lecture) "The Functions of Electrical Rhythms in the Brain." J. Ment. Sci. 96, 1-31.

APPENDIX A

APPENDIX B

THE OPTIC SYSTEM



There is point-for-point correspondence between receptors and optic cortex. Fovea receptors have 'private' lines.

APPENDIX C

SUBJECTS

The range of the subjects' ages is from 19 years to 65. The mean age for the entire group is 34.53 years.

The diagnostic category distribution of subjects is tallied below. The performances of the subjects is given individually in the following three pages. The procedures are listed: form recognition A, apparent motion B, figure-ground reversal C, fusion of 2,3 and 4 elements D, E and F. All figures are the rates at which the respective thresholds were reported.

Distribution of Disease Categories

Disorder	No. Subjects Included
Schizophrenia, paranoid	7
Schizophrenia, simple	2
Schizophrenia, unclassified; mixed	6
Manic-depressive	3
Depressive	4
Psychosis, unclassified	5
Neurosis, anxiety	7
Neurosis, Passive-dependent	5
Neurosis, aggressive reaction	1
Neurosis, compulsive	1
Neurosis, inadequate personality	3
Neurosis, unclassified	5
Mental defective	1

INDIVIDUAL DATA

	Subject	Procedures					
		A	B	C	D	E	F
12-13	RLH	8.	12.7	9.5	11.7	16.	18.
	SEH	5.7	14.4	9.9	16.5	25.5	32.8
	REG	6.6	12.1	14.	12.6	20.4	28.
	WJS	8.7	17.4	14.	13.3	20.6	28.
	Mean	7.25	14.15	11.85	13.52	20.63	26.70
11-12	RKG	6.6	13.2	16.5	12.	18.5	22.8
	EVK	7.4	13.1	15.5	11.6	22.1	27.4
	CFM	4.7	13.1	13.6	14.3	17.8	27.5
	MK	6.3	14.7	14.3	9.7	17.6	26.
	PJT	6.2	14.	12.9	11.9	18.9	22.6
	GLM	7.4	11.6	17.3	11.7	19.1	23.9
	RMS	5.9	14.4	14.6	11.3	18.2	25.6
	CAD	6.9	12.4	15.5	9.2	17.2	24.
	JDS		13.	16.3	11.4	18.	27.8
	SB	7.3	16.5	11.4	12.2	20.9	33.2
	RDC	6.5	12.	12.7	11.1	19.9	26.7
	WB	6.6	16.2	12.9	13.1	19.9	29.5
	Mean	6.53	13.68	14.46	11.63	19.01	26.42
10-11	GSM	7.1	13.3	14.7	9.5	18.3	16.4
	WEP	4.7	10.3	11.6	11.2	18.3	20.2
	NC	3.2	11.9	12.4	10.7	18.2	24.8
	EFB	3.7	12.5	13.5	11.3	15.2	26.6

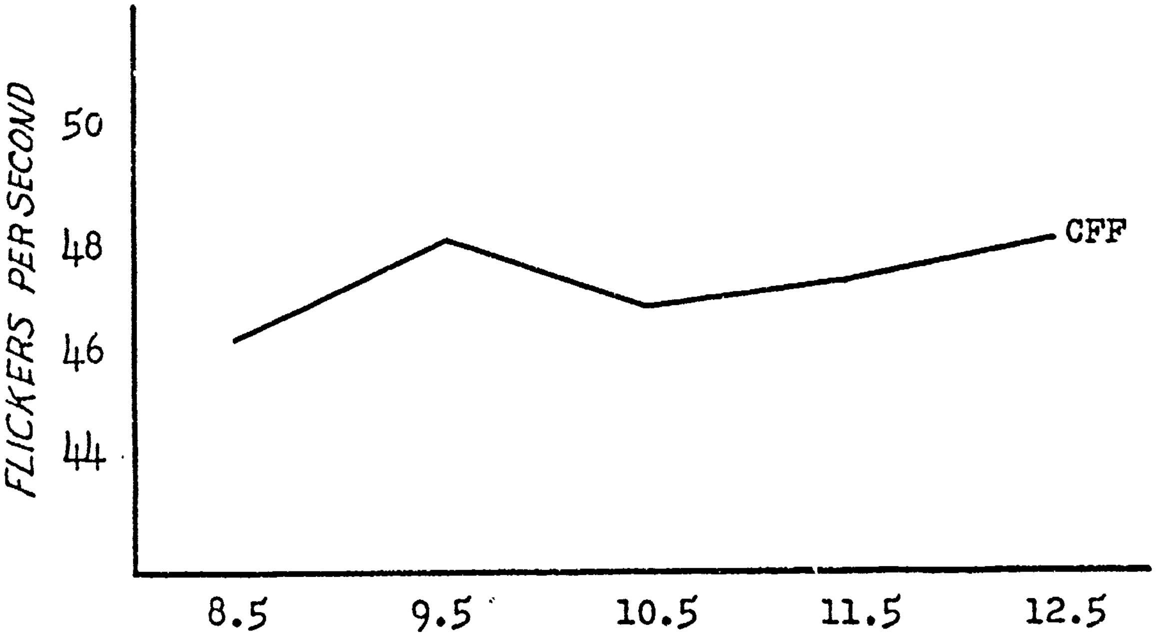
Individual Data (Continued)

	Subject		Procedures					
			A	B	C	D	E	F
	AM		6.3	12.9	10.2	9.8	19.2	31.7
	SBM		5.2	11.5	13.3	12.8	19.5	25.
	JCM		6.3	11.2	13.8	11.1	19.4	24.4
10 - 11	RJC		6.6	13.1	14.7	12.4	23.	27.4
	HOD		7.6	10.5	8.4	11.	18.7	30.
		Mean	5.63	11.9	12.5	11.	18.9	25.2
	TT		8.7	13.5	16.3	13.2	20.4	26.8
	DOG		6.6	12.1	12.7	11.	21.6	22.6
	SJL		5.4	12.3	11.9	9.9	17.9	24.
	AAA		3.5	13.1	13.6	11.2	16.6	31.
	FD		6.3	13.7	13.4	14.9	17.1	26.1
	WFB		3.8	11.2	14.	9.6	15.8	22.
	RCG		7.1	13.1	12.8	12.4	20.8	33.7
9 - 10	FN		4.7	14.3	14.4	10.9	15.4	28.8
	DRG		8.7	11.1	14.2	10.1	17.9	26.9
	HLA		6.9	13.	14.5	11.3	22.6	29.6
	SWL		3.6	11.7	12.3	11.5	19.2	26.7
	MEA		7.4	12.	12.3	10.	16.9	26.
	WAT		5.6	12.6	15.	10.	16.7	25.8
		Mean	6.02	12.59	13.65	11.23	18.38	26.94
	COR		9.7	17.5	16.4	11.4	21.4	28.4
	BC		5.6	13.9	13.5	14.	21.2	26.8
	MGF		7.5	13.2	13.8	13.2	20.	26.

Individual Data (Continued)

Subject		Procedures					
		A	B	C	D	E	F
CDL		6.8	11.9	12.1	13.9	20.5	26.
AWS		6.2	15.6	18.3	9.4	19.3	20.
FP		4.5	13.	10.1	6.1	19.2	25.
JS		6.4	14.	14.8	9.8	16.7	28.3
AH		7.4	15.3	14.7	10.2	18.8	22.5
HHF			17.8	12.	11.3	15.8	23.1
FRF		6.8	15.5	17.5	10.9	18.6	24.8
AW		7.	14.3	19.	12.2	23.	26.4
	Mean	6.78	14.69	15.02	11.27	19.18	25.28

Critical Flicker Fusion

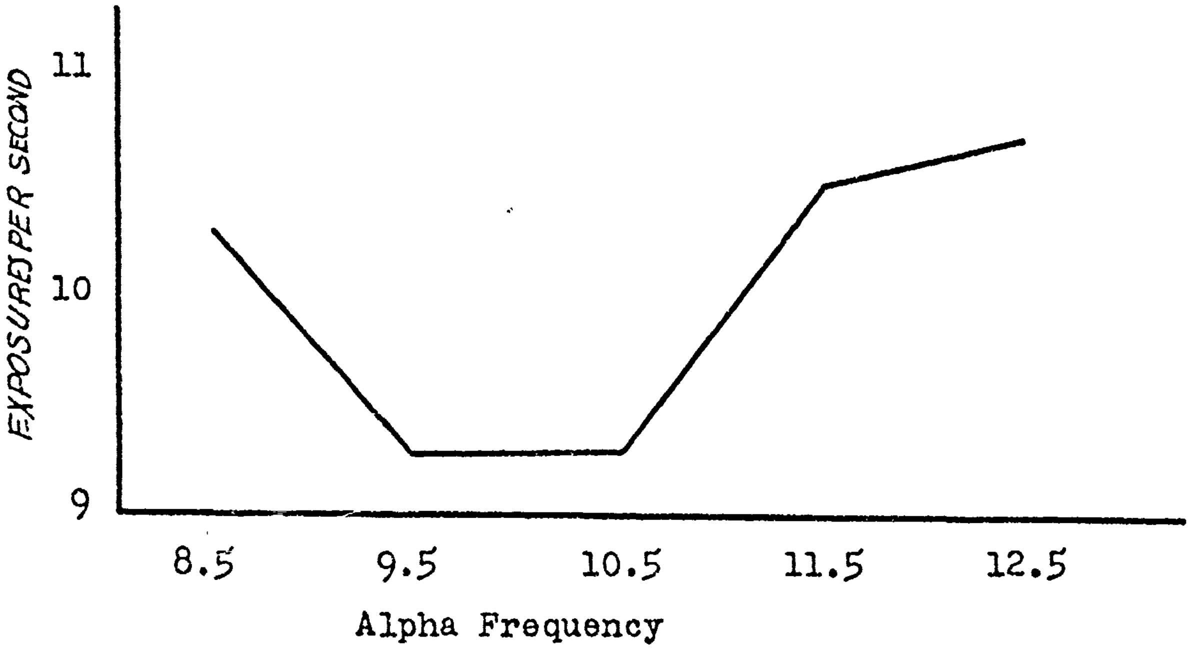


Alpha frequency

The relation of Critical Flicker Fusion to alpha rhythm. There is little difference between groups.

The Identification of the Single Form

For the last 25 subjects a single form was exposed in different positions and orientations successively. This form was identified differentially by the separate groups of subjects (separate on the basis of their alpha rhythm) in much the same manner as other procedures. Though the correlation ratio was mildly present $(\eta_{\alpha.Arf.} = .34)$ it was not statistically significant. The graphic relation is shown below.



The graphic relation of identification rates to the alpha frequency in the case of a single form for 25 subjects.