

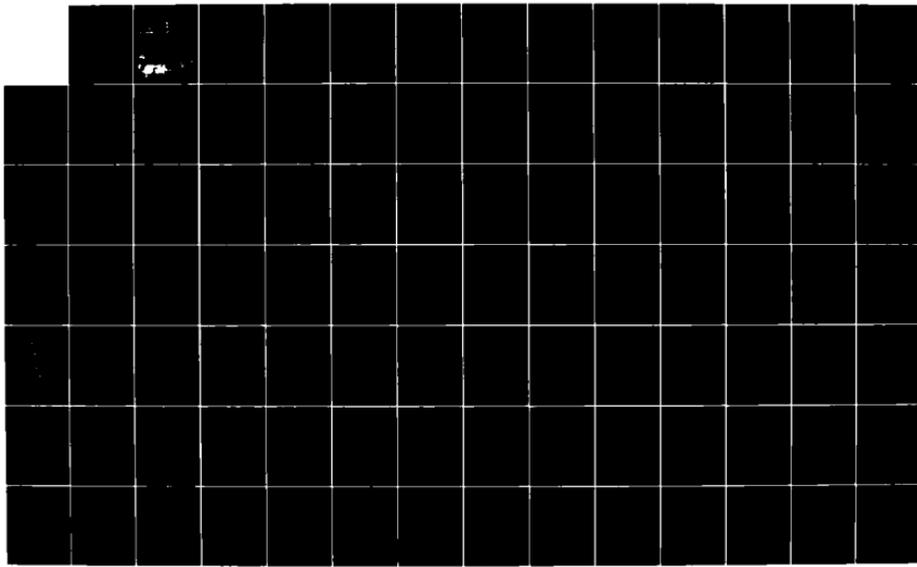
AD-A124 842

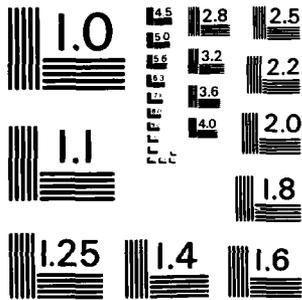
A MODEL FOR HUMAN VISUAL PROCESSING WHICH EXPLAINS
PERCEPTIONS OF MOTION... (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI... R L CARTER
DEC 82 AFIT/OE/EE/82D-23 F/O 5/10

1/2

UNCLASSIFIED

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A 124 842

1

AIR FORCE INSTITUTE OF TECHNOLOGY



AIR UNIVERSITY
UNITED STATES AIR FORCE

WHICH EXPLAINS PERCEPTIONS
OF MOTION-AFTER-EFFECTS

THESIS

AFIT/GE/EE/8. D-23

Roger L. Carter
Capt USA

SCHOOL OF ENGINEERING

DTIC
ELECTE
FEB 24 1983
A

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

This document has been approved
for public release and sale in
distribution is unlimited.

83 02 022 214

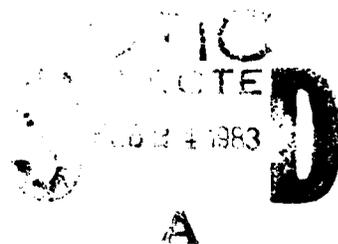
AFIT/GE/EE/82D-23

A MODEL FOR HUMAN VISUAL PROCESSING
WHICH EXPLAINS PERCEPTIONS
OF MOTION-AFTER-EFFECTS

THESIS

AFIT/GE/EE/82D-23

Roger L. Carter
Capt USA



Approved for public release; distribution unlimited

AFIT/GE/EE/82D-23

A MODEL FOR HUMAN VISUAL PROCESSING
WHICH EXPLAINS PERCEPTIONS OF MOTION-AFTER-EFFECTS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

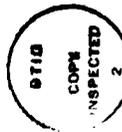
Roger L. Carter, B.S.E.E.

Capt

USA

Graduate Electrical Engineering

December 1982

A rectangular stamp with a grid pattern. It contains some faint, mostly illegible text. A large handwritten letter "A" is written across the bottom portion of the stamp.

Approved for public release; distribution unlimited.

Preface

The kernel of this thesis, an attempt to explain motion-after-effects in human visual processing, evolved from discussions with Dr. Matthew Kabrisky, Air Force Institute of Technology. The development of a theoretical model for human visual processing, and the conduct of the psycho-physical experiments to support the model, were extensions of an original hypothesis that motion-after-effects are a result of a predictive system which permits binocular fusion with varying retinal image size and displacement disparity patterns. My ability to develop this thesis to its conclusion was made possible by the constant encouragement I received from Dr. Kabrisky, and his willingness to explore my new ideas.

I am also indebted to Dr. Allan Pantle, Miami of Ohio University, for his advice in the design of computer generated visual stimulus displays, and his willingness to provide both an authoritative and an objective view of my ideas. I wish further to thank Dr. Richard Fenno for his efforts in editing and critiquing my writing so that the final product might clearly communicate my intent.

Finally, I wish to express my appreciation to my wife, Connie, whose assistance and support have been a significant factor in not only this work, but in everything of worth which I have accomplished.

Contents

	<u>Page</u>
Preface	ii
List of Figures	v
List of Tables	vii
Abstract	viii
I. Introduction	1
II. Existing Theory	3
Properties and Structure of Human Visual Processing	3
Functional Components of Visual Processing	6
Visual Perception	11
Binocular Perception	12
Motion Perception	16
Motion-After-Effects	18
III. Theoretical Development	24
Visual Inputs and Perception During Uniform Motion	24
Production of MAE	39
Physical Structure of Visual Processing	44
Experimental Proposals	48
IV. Experimental Design and Procedure	50
Limits of Human Binocular Fusion	50
Equipment	50
Procedure	54
MAE Related to Location in the Visual Field	60
Equipment	60
Procedure	61
V. Experimental Results	66
Limits of Human Binocular Fusion	66
Reported Perceptions	66
Quantitative Results	70
MAE Related to Location in the Visual Field	75
Correlation Between Binocular Fusion and MAE	79

Contents

	<u>Page</u>
VI. Conclusions and Recommendations	84
Conclusions	84
Recommendations	89
Project Summary	92
Bibliography	93
Appendix A: Programs to Support an Experiment on the Limits of Binocular Fusion	97
Appendix B: Instructions for Experiment with Binocular Fusion	108
Appendix C: Questionnaire for Experiment with Binocular Fusion	112
Appendix D: Program Listing for Experiment with MAE Thresholds and Duration	113
Appendix E: Instructions for Experiment with MAE Thresholds and Duration	116
Appendix F: Raw Data Example for Experiment on the Limits of Binocular Fusion	118
Appendix G: Raw Data Example from Experiment on MAE	120
Vita	123

List of Figures

<u>Figure</u>	<u>Page</u>
1 Model of the Structure of Human Visual Processing	4
2 Relationship of Image Size to Location of an Object in the Visual Field	25
3 Sequential Binocular Processing of a Visual Stimulus on a Frontal Plane	27
4 Graphs of the Image Size Disparity vs. Head Position	29
5 Processing of Sequential Monocular Retinal Inputs During Head Rotation to Permit Perception of a Single Stationary Object in the Visual Field	32
6 Data Flow Diagram of Visual Processing Related to Perception of Motion Associated with Objects in the Visual Field	34
7 Data Flow Diagram for Processing Binocular Retinal Inputs Leading to a Perception of Object Motion	37
8 Hypothesized Role of Lateral Geniculate Nucleus in Providing Mappings Displaced in Time to Primary Visual Cortex	45
9 Relationship of Proposed Model Processes to Physical Structures in Humans	47
10 Equipment Configuration for the Experiment on the Limits of Human Binocular Fusion	52
11 Adjustable Platform Constructed for the Cromemco Color Monitor	53
12 Adjustable Platform to Provide a Chin Rest and to Support an Adjustable Mirror	55
13 Equipment Configuration for the Experiment Measuring the Parameters of MAE as a Function of Position in the Visual Field	62
14 An Example of the Time Interval Method used in Analyzing the Raw Data from an Individual's Reports in the Experiment with MAE Thresholds for Stimulus Duration	76

List of Figures

<u>Figure</u>	<u>Page</u>
15 An Example of the Family of Stimulus Duration Threshold Curves Associated with each Category	78
16 Scattergram and Parameters Related to the Kendall tau Test for Correlation of Performance Between Limits for Binocular Fusion and MAE Stimulus Thresholds	83

List of Tables

<u>Tables</u>	<u>Page</u>
1 Arithmetic Means of Individual's Limits for Binocular Fusion	72
2 Results of Data from an Experiment on the Parameters of MAE as a Function of Location in the Visual Field	80

Abstract

A theoretical model for human visual information processing was developed which attributes functional roles to the cerebellum, lateral geniculate nucleus, and cerebral cortex. The lateral geniculate nucleus is believed to provide sequential monocular mappings as inputs to the primary visual cortex, which uses this information for binocular integration, detection of motion, and other of its functions. The cerebellum is hypothesized to function within a predictive feedback loop to provide information to the cortex essential to reconcile differences in monocular image sizes and displacements.

In an experiment with the limits of human binocular fusion, two separate limits were discovered. When dichoptic images are first perceived to represent a single object, the limit for fusion is greater than when no initial reference for a single object association is given.

A second experiment measured the stimulus duration thresholds for motion-after-effects. Correlation of performance by subjects in the two experiments was used to conclude that similar mechanisms are involved in binocular fusion and the processing of perceptions leading to motion-after-effects. Within the visual processing model developed, both binocular fusion and the existence of motion-after-effects are related to the existence of a predictive feedback loop. Thus the correlation of the performances could be predicted by the author's theoretical model.

I. Introduction

Human visual processing is the transformation of the retinal input stimulus at the two eyes into a perception of the physical environment lying within an individual's field of vision. Since the retinal inputs involve a pair (in the case of binocular vision) of two-dimensional pictures, data available at the retina must be transformed into a three-dimensional perception of the world. Perception, and the method by which perception is derived, is important, then, in determining how an individual will react to his environment. The following section on existing theory reviews what is known about the way the visual system processes retinal inputs, with particular attention to the properties, structure, and functions of each major component. Finally, the subject of visual perception is covered by a review of known human perceptions to certain visual stimuli.

After a presentation of existing theory, a theoretical development of a model for human visual processing is presented. The model is developed based on what are determined to be required processes in transforming the retinal mappings induced by visual stimuli into perceptions which agree with known human perceptions. The scope of the model is limited to the perception of single objects in motion. The specific objective of the model is to attempt to explain the phenomena of motion-after-effects from a system model designed to maintain perception of single

objects in motion.

The visual processing model is then used to predict the outcome of two experiments. The first experiment conducted measured the limits of binocular fusion for objects of different size when presented to each of the two eyes. The second experiment measured the stimulus duration thresholds for motion-after-effects as a function of the position of the stimulus in the visual field.

The results of these experiments are then presented and their relationship to the validity of the hypothetical model is discussed.

II. Existing Theory

Properties and Structure of Human Visual Processing

A model of the human visual processing system is presented in Figure 1. The pathways shown between physical components represent the transmission of information along nerve cells or neurons. Neurons are specialized cells which are the basic building blocks of the entire nervous system. Each neuron senses the chemical balance at the junctions of its inputs and when a critical balance is reached, responds by firing a sudden voltage increase along its output or axon. At the termination of the axon, the voltage spike causes release of chemicals into a junction, or synapse, with corresponding inputs to one or more other neurons. These neurons sense the change, fire, and thus continue the transmission. Information is thus relayed by the frequency at which a neuron fires. Since both the pathways and component structures of the visual processing system rely on neurons for information transmission and transformation, the firing rates of neurons have been a source of extensive study.

The activities of neurons, with associated inputs and outputs, are believed to be interrelated to perform specified tasks and functional calculations. Attempts to determine the physical location of neurons involved in certain tasks and calculations have been based on the characteristic firing rates of individual neurons studied within the brain. In these studies the firing rates of

individual neurons have been linked to controlled stimuli. An assumption is then made that, since the firing rate of the neuron appears related to the stimulus, the neuron must be involved in the performance of tasks or calculations required to perceive and react to the stimulus.

An inherent problem exists in the use of firing rates to specify the nature of neural calculations. Because of the numerous interconnections between neurons, the firing rate of any one neuron, or set of neurons, may relate only to the nature of a single variable within a complex calculation. Neighboring neurons could even represent separate variables within separate and independent calculations. To illustrate this idea, the example of two simple functions, $A = B + C$ and $D = E + F$, is taken. Knowledge of the variation of B and E does not provide sufficient information to determine the values of either A or D. Nor can the functions themselves be determined. The interconnectivity of neurons within the human visual system suggests the operation of functions far more complex than simple summation of variables. The existence of neurons with known characteristic firing rates, with respect to some specific stimuli, can then be used to argue the existence, within a physical structure, of a variable with the same variation characteristics. The operands of the function would be held within the physical structure which determines how the output of one neuron affects other neurons. This relationship between neuron firing rates and the

interconnectivity of neurons is important since a great deal of what is known about the structure of visual information processing centers depends on either the rates, the interconnectivity, or both.

Functional Components of Visual Processing

As shown in the model at Figure 1, the visual stimulus is received at either or both of the two eyes. The existence of binocular vision (simultaneous input from two eyes) is important since the images projected onto the two retinas will normally contain disparities. Disparity is due to each projection defining a different angle to the point of fixation. The horopter (the spatial field projecting images containing no disparity to the two eyes) has been studied and found to be an extremely complex configuration (Shipley and Rawlings 1970). Thus, during normal binocular viewing, disparities will always exist between the two visual input fields. Disparities of a different nature can also be introduced by object motion (motion by an object in the visual field), eye movement, and head or body movement.

The inputs obtained at each retina are then relayed through the corresponding optic nerves to the lateral geniculate nucleus (LGN) within the thalamus (Guyton 1976). Studies of the firing rates associated with input and output neurons of the LGN suggest that little, if any, visual processing takes place within the LGN (Tat So and Shapley 1981). The inputs are sent nearly unaltered to the primary visual cortex.

Area 17 of the primary visual cortex is believed to hold a homeomorphic mapping of the visual inputs received from the two retinas. In microelectrode experiments, neurons in area 17 have been found to display activity related to either monocular (input from one eye) or binocular (input from two eyes) characteristics (Freeman and Bonds 1979). The density of monocular and binocular neurons has been further found to be dependent on the visual experience of an individual during a critical period of development (Banks, Asliu, and Letson 1975). In a series of other experiments, neural firing rates in area 17 have been attributed with characteristics specific to orientation and direction of motion of the visual stimulus (Hubel and Wiesel 1959).

Though little is known of the exact function of area 18 of the cortex, it is known to receive input from area 17 and is generally believed to play a major role in the processing of visual information. Among other functions, area 18 is thought to be involved in the process of pattern recognition and the correlation of retinal disparity information leading to the perceptions of depth (Tyler 1973) and motion.

In the model, area 18 is shown to provide output to an area labeled perception. In studies to date, perception is better related to a theory than to a physical location in the brain. Its depiction in the model does not represent known physical structure or signal transmissions. It remains a hypothetical element with hypothetical inputs and

outputs.

Additional outputs from area 18 have been postulated to end in the superior colliculus (McIlwain and Fields 1970). Though the superior colliculus is believed to play a role in saccadic eye movements, monkeys who have lost partial function of the superior colliculus still show saccadic eye movements (Robinson and Goldberg 1977). In experiments which involved both real and apparent motion induced by eye movements, over 60% of the neurons in the superior colliculus were able to differentiate real motion (Robinson and Wurtz 1976). The ability to determine real motion was not, however, found in studies of neurons within the cortex. Due to the latency periods between motion and corresponding firing rates, the eye movement signal which permits differentiation of real motion is not believed to originate in either the retina or eye muscles.

The cerebellum, as shown in the model, receives inputs from numerous sources, including vestibular (i.e., from the semi-circular canals), proprioceptive neck, proprioceptive extraocular, and visual sources related to retinal slip or disparity (Lisberger and Fuchs 1978; Suzuki, Noda, and Kase 1981). Extensive research is available on the major components of the cerebellum, with the majority of the research aimed at discovering the role of the cerebellum in the "fine" control of muscle coordination. The cerebellum is generally thought to provide a feedback loop to the motor cortex. In providing feedback data, the cerebellum is

believed to be capable of predicting future positions of moving body parts. The cerebellum is believed to perform predictions based on a full range of tactile, auditory, visual, vestibular, and oculomuscle inputs. Evidence of the role of the cerebellum has been found in monkeys and humans who lack complete cerebellum function. In the case of a monkey, the animal was unable to predict the visual approach of an object and would repeatedly bump into objects. Humans who have suffered damage to the cerebellum have been discovered to "overshoot" objects when reaching for them. Both of these examples show at least a lack of ability to predict or anticipate the approach of an object.

The concept of the cerebellum acting as a feedback device to permit the motor cortex to react to approaching objects has been expanded to explain the learning of skilled motor functions (Guyton 1976). Skilled motor functions performed for the first time are thought to require the latency involved in the prediction and transmission of a feedback signal from the cerebellum to the cortex. As a skilled motor function is repeated, the learning process allows increased prediction without input and eventually may eliminate the feedback requirement. Thus, individuals are able to perform skilled motor functions with increasing speed. The establishment of a rapid motor pattern is then being controlled directly by the cortex. During rapid motor patterns, the cerebellum is thought to act as an error corrector rather than as a

predictor, its normal role. In this case, the cerebellum signals to the motor cortex error corrections to be made after the action has been taken, rather than providing input toward the action itself.

In more detailed studies with microelectrodes, components of Purkinje cell activity in the flocculus of the cerebellum have been discovered which are related to eye and head velocity. Further, during periods when both head and eye movements were invoked, the resulting neuron activity could be predicted by performing a vector summation of the individual eye and head components (Lisberger and Fuchs 1978). These findings have led to the conclusion that the flocculus modifies the vestibuloocular reflex (the reflex signal sent to the optic muscles to correctly track an object) by performing calculations dependent on vestibular, eye movement, and retinal error inputs.

Lobules VI and VII of the cerebellar vermis have also drawn considerable research effort. Inputs to the vermis include tactile, visual, auditory, proprioceptive neck, proprioceptive extraocular, and vestibular (Suzuki, Noda, and Kase 1981). Among neural firing characteristics discovered in the vermis are spikes located at points corresponding to visual targets off the point of fixation and whose discharge precedes saccadic eye movements to fixate the new target. Tonic (relatively non-varying rates) outputs from Purkinje Cells related to eye position were also present (Kase, Miller, and Noda 1980). Purkinje cells

have additionally been documented which fire in phase with either retinal target velocity (while eyes are fixed) or eye tracking velocity (Kase et al. 1979). The phase lags between actual target/eye motion curves and the firing rate curves varied with target/eye velocity and in all cases were less than the lag time which would be predicted by the latency inherent in the neural circuits (Suzuki, Noda, and Kase 1981). Thus a predictive calculation is implied in the nature of Purkinje cell activity within lobules VI and VII of the vermis.

In summarizing their research, Suzuki et al (1981, p.1135) found the neural characteristics to suggest that the Purkinje cells of lobules VI and VII of the vermis "may sum weighted retinal image acceleration and velocity to form time derivatives of visual stimulus movement that contribute to predictive mechanisms attributed to the cerebellum." Thus a resulting output would contain the neural correlate of target velocity, an element which could perform a function in the calculation of resultant visual perception.

Visual Perception

As mentioned previously, perception is the end result of the visual processing system. The relationship between the actual world and visual perception has most likely evolved from the requirements imposed by nature upon the species. Interpretation, or perception, may then be based on what is determined to be the most likely occurrence in nature. This is a determination which may be incorrect when

the visual stimuli do not correspond with naturally occurring events for which the system has been developed. Studies of perception have used these inferences. Since the physical location of perception is not known, psychophysical experimentation has been applied to determine the perception induced by controlled visual stimuli. Controlled stimuli, however, do not necessarily depict naturally occurring events, and the concept may not accurately describe the physical scene. Through documentation of perceptual errors in determining the actual state of the physical environment, conclusions can then be drawn about the nature of the calculations involved in perception. With this in mind, three areas of human visual perception will be reviewed: perception related to information obtained by binocular vision, perception of motion by an object in the visual field, and perception of motion-after-effects.

Binocular Perception: The existence of two visual inputs appears to be more than simple redundancy of an element essential to survival. The overlapping of the visual images introduces disparities which contain a great deal of information beyond that available from a single source. As mentioned earlier, the manner in which the two inputs are used in developing perception has been found to be dependent, in some degree, on the visual experience of an individual during a critical period of development (Banks, Asliu, and Letson 1975). Eye movement and visual stimulation during this period are essential to the normal

cortical development (Freeman and Bonds 1979). In individuals with abnormal binocular experience, differences in perception at low contrast thresholds have been observed (Levi, Harworth, and Smith 1979). Evidence exists to suggest that the differences in perception between individuals with normal and abnormal development are caused by differing concentrations of monocular and binocular neurons of the visual cortex (Blake and McCormack 1979). A conclusion which can be drawn from the evidence is that the calculations leading to perception in the binocular system have a degree of plasticity. Further, the cortex is a likely location for at least one level of integration of the binocular information.

The existence of disparate inputs has led to two areas of research in the study of binocular perception. The first involves determining how the disparity information is used in forming perception. The second is aimed at discovering how disparity is dealt with in the development of perception of a single environment or object.

The human visual system is presumed to have the ability to develop depth perception (stereopsis) through the use of disparities in background and foreground images (in relation to the object of fixation). In the absence of any depth cues except disparity, humans are able to perceive relative depth. Psycho-physical experiments have shown that humans can interpret stereoscopic cues from dichoptically presented patterns when the stimulus pairs are separated by up to 50

msec (Ross 1976). The location of this transformation has been postulated to reside within the cortex because of the apparent relationship of stereoscopic vision with the density of binocular cells in the cortex (Packwood and Gordon 1975). Beyond stereopsis, no discussion of additional direct use of binocular disparity in the enhancement of perception could be found in the literature. However, additional information is available to the brain from the relationship of binocular disparity during observation of a target in motion. This subject will be expanded upon later.

A second area of research has attempted to discover the limits and processes involved in binocular fusion (the perception of a single object from separate disparate inputs). During experiments involving dichoptic viewing (separate visual stimuli presented to each eye), the limits of binocular fusion have been quantified. Recent work with the disparity limits of binocular fusion leads to conclusions that a disparity gradient rather than the disparity magnitude is involved in the determination of a limit (Burt and Julesz 1980). In either case, research points to a functionally constant relationship for fusion given stationary dichoptic disparities.

Several theories have attempted to explain the mechanics of binocular integration. One such theory, energy summation, supposes that the integration of binocular inputs involves the summing of energy levels from

corresponding retinal points. A second, probability summation, assigns probabilities to the perception of each monocular input through a relation to its corresponding energy levels. The binocular probability is then defined on a relationship of the monocular probabilities. Though in specific experimental applications these theories appear to fit the data, in a set of experiments by Cohn and Laxley (1976) neither theory of integration was able to accurately predict the characteristics of binocular thresholds. Instead, these experiments with binocular thresholds support a theory that integration involves two sets of independent mechanisms. One mechanism sums the energy levels while the second computes their difference. The outputs of these two mechanisms are then sent to a central processing center. No conclusion was drawn by Cohn and Laxley as to the exact nature of calculations held within the central processing center.

Monocular suppression is another theory that has been used to explain the perception of a single environment given disparate inputs. In this theory, the input from one eye is suppressed while input from the other eye provides the sole input to perception. Examples of monocular suppression can be experimentally proven. However, Blake and Camisa (1978) found that monocular suppression was evident only when disparities exceeded a given magnitude. Thus monocular suppression appears to be present only when the disparity is large enough to sufficiently confuse the mechanism

attempting to determine a single perception.

Earlier assumptions that fusion was being produced by torsional eye movements have been contradicted by experiments involving fusion with no measureable eye movement (Kertesz and Jones 1970).

It is important to note that experimental evidence taken on stereoblind subjects (individuals incapable of determining depth through disparity cues alone) has shown that these individuals maintain their ability to fuse objects (Richards 1970). Thus, fusion and binocular perception appear to involve separate mechanisms. Related studies of visual processing suggest that the information required for stereoscopic depth perception is extracted prior to the point where fusion is produced (Grimson 1980).

Motion Perception: Determination of an object's motion in a visual scene requires a system which must be capable of filtering out information related to apparent motion induced by the almost constant movement of the eyes, head, and body. This ability, one might guess, involves a multi-layered computation of extremely high complexity. This hypothesis about complexity may be supported by the fact that extensive research in this area has as yet been unsuccessful in integrating the behavior of the motion detecting system into a model capable of predicting its varied behavior.

Experiments have revealed some characteristics of motion perception. The perceived direction of motion has been found to be altered when an individual is first

adapted to motion in a specific direction (Levinson and Sekuler 1976). Similar studies have shown that simultaneous motion in two differing directions will alter the perceived direction of the motion of each. The degree of alteration in this case was dependent on the actual angle between the original stimulus directions (Marshak and Sekuler 1979). Results of this kind have been used to support the theory that perception of motion is derived from motion and direction detectors within the cortex. The alterations noted were attributed to fatigue of these detectors, a theory which has received much support in the literature since the discovery of cortical neurons displaying firing characteristics tuned to motion and direction.

In a series of experiments using fine points of light to suggest complete form, Johansson (1975, p.84) discovered that "continuous perspective transformations always evoke the perception of moving objects with a constant size and shape." His theory of the perception of moving objects, termed vector extraction, says that the visual system determines certain objects to be rigid and to be moving in a manner consistent with the rigidity of the object. In this theory, the visual system would extract the vector motion component of the rigid object from all points on the object to determine the motion of the points relative to the object itself.

Regan *et al* (1979) have shown that the perception of motion in depth can be elicited by either changing the

size of an object or changing the magnitude of its dichoptic disparity.

The correspondence between eye motion and perception has been shown to be interdependent. Perception has been found to be dependent on eye motion from experiments in which individuals whose eyes had been immobilized perceived motion when they attempted to move their eyes (Tolhurst and Hart 1972). Another set of experiments determined that individuals would produce eye tracking motions related to perceived motion rather than actual motion (Steinbach 1976). Thus perception and eye motion each seem to depend on the results of the other.

In the study of a multistable movement display (a display which elicits two separate alternating perceptions) Pantle and Picciano (1976) found evidence that two separate motion detection systems exist. A slow perceptual mechanism was believed to involve preliminary processing of form while a second mechanism, which could respond to shorter periods of stimulus presentation, did not require the processing of form.

The consensus of all the motion studies reviewed was that the mechanism for determining motion is at the cortical level. There appears also to be consensus about the existence of perhaps numerous functionally independent modules being used in motion processing. Each module plays a specific role in the development of the final perception.

Motion-After-Effects: The discovery of motion-after-

effects (MAE) has led to attempts to understand the nature of human motion perception through the study of this irregularity. MAE are a visual phenomena involving the appearance of motion in the direction opposite to a stimulus of constant velocity and direction, which are observed after the stimulus is halted. Motion-after-effects produced by both spirals of constant velocity and spatially periodic functions of constant velocity and direction have been used in such studies. Though a great deal is understood about the characteristics of MAE and stimulus methods to produce MAE, as yet no theory to explain the reasons for this processing fault has received general acceptance.

Among properties known to affect the production of MAE is their contingency upon stimulus orientation and color (Favreau and Corballis 1976). Stimulus patterns of specific visual orientation will produce MAE tuned to the same retinal orientation. MAE have been reported for more than 24 hours after the presentation of a stimulus when the pattern is oriented on the retina matching the original stimulus (Masland 1969). Expanding on work with orientation and motion contingent after-effects by McCollough and Hepler (Hepler 1968), Favreau et al (1972) were able to show a color contingency for MAE. In their experiment, Favreau et al had subjects observe red contracting and green expanding spirals during an adaptation period. The subjects then reported red stationary spirals to expand and green stationary patterns to contract. These color contingent MAE

could be stimulated 24 hours and more after the adaptation period. Since color after-effects do not exhibit interocular transfer, Murch performed a series of experiments to determine if the color contingency of MAE could be transferred (Favreau and Corballis 1976). Murch found that MAE were transferred but their color contingency was not. The contingency of MAE on orientation and color tends to support the fact that MAE are produced at a level in the visual system which to some degree has previously processed and "recognized" the visual pattern. An objection to this conclusion is the presence of MAE immediately after the adaptation period when the stimulus pattern is no longer present.

It has been noted that tracking eye movements can reduce or eliminate MAE (Weisstein, Maguire, and Berbaum 1977). A subject who follows the motion by matching his eye movement to the velocity of the stimulus will report little or no MAE. In a related experiment, however, Tolhurst and Hart (1972) found that constant sinusoidal movement of the eyes across a stationary stimulus will result in the subject reporting MAE. These results seem to contradict each other. In any case, they clearly point to the fact that MAE cannot be explained solely by the presence or absence of eye movements. Instead, it would appear that MAE are derived from the presence of retinal disparity patterns.

Arguments against this role for retinal disparity

patterns in the production of MAE also exist. In numerous experiments MAE have been reported from monocular viewing of a pattern in constant motion. Monocular viewing should relay no disparity information to the visual system. In some of these experiments the existence of interocular transfer of MAE has also been confirmed (O'Shea and Crassini 1981). What would seem an equally strong argument against an association between retinal disparity and the production of MAE is the fact MAE have been reported in areas of the visual field where no actual stimulus motion was present (Weisstein, Maguire, and Berbaum 1977). In these experiments the subjects were given a stimulus which permitted them to perceive motion in an area of their visual field where no actual motion existed. They then reported MAE within the same visual areas where motion was perceived, yet no real motion or retinal disparities were present from the stimulus. To explain these results, it might be concluded that retinal disparities are first used to produce perception, which then acts as an input to a processing level directly related to the production of MAE.

Certain stimulus requirements to produce MAE have been quantified. First, it has been observed that the production of MAE is limited to the cases in which the stimulus elicits the perception of "smooth" motion (Banks and Kane 1972). Smooth motion means that the subject will perceive no jumps in the movement of the stimulus. To produce such smooth motion requires successive stimulus movements of less than

15-30 minutes of visual angle (Braddick 1974). Also, the video frames must be displayed less than 30 msec apart. Surprisingly, these limits have been found to be independent of each other in producing the perception of smooth motion.

Studies of MAE have shown them to display certain generally accepted characteristics. The most visible of these is that MAE have exponentially decaying velocities during the period when the subject is reporting their existence. Some experiments report a second phase of MAE to involve reversing stabilization where the visual scene appears to alternate in direction just prior to the end of its observation (McKenzie and Hartman 1961).

Experiments to establish a relationship between stimulus velocity and duration versus reported velocity and duration of MAE have found the following: (1) increasing the stimulus velocity decreases the reported velocity and duration of MAE; (2) increasing stimulus duration increases the reported velocity and duration of MAE (Sekuler and Pantle 1967). However, the findings of Sekuler and Pantle do not totally agree with earlier findings reported by McKenzie and Hartman (1961) which could be a result of the inherent difficulties in quantifying the duration and velocity of MAE. In the performance of experiments on the duration of MAE, it is important to note that subjects display differing levels of uncertainty in reporting the end of an exponentially decaying event (Benson and Reason 1966). Thus it becomes difficult to establish the true duration of MAE

perceived by any one individual.

Beyond characteristics associated with velocity and duration, MAE have been reported which represent vector summations of dichoptically presented stimulus motions of different orientation (Riggs and Day 1980). The MAE travel in a direction opposite to the vector sum of the separate stimulus directions. These findings continue to support the theory that the production of MAE is handled at a level of visual processing at or beyond the point of binocular fusion.

The most prevalent theory to explain MAE is that they are caused by "fatigue," or adaptation of neurons tuned to motion and direction within the cortex (Favreau and Corballis 1976). This theory has difficulty in explaining long term MAE (over 24 hours after the experimental adaptation period) when no apparent problems were reported by the same subjects in normal viewing during the intervening period. Also, Levinson and Sekuler (1976) reported marked alteration in the perception of motion direction in experiments which did not produce MAE. If alteration of the direction of motion, concluded to be caused by neural fatigue, did not also involve reports of MAE, then it is possible to conclude that the "fatigue" theory cannot explain fully the production of MAE by the human visual system.

III. Theoretical Development

If MAE are not created through the fatigue of cortical neurons tuned to orientation and motion, then the problem is to determine what causes the visual system to produce such a fault. MAE are obviously a result of computations required to process uniform motion. The answer must lie then in the system used to process perception of uniform motion. The following theoretical discussion will begin at the inputs caused by different mechanisms which interact during the viewing of uniform motion. By comparison of the physical inputs to the perceptual output, the nature of the computational process will then be hypothesized. Based on the hypothetical process, a theory based on what is known about the human visual information processing system will be presented. Finally, a set of experiments to judge the validity of the theory will be proposed.

Visual Inputs and Perception During Uniform Motion

Significant characteristics of the retinal inputs include the following three distinct patterns of disparity: image size variation, retinal disparity (caused by binocular inputs or depth in three-dimensional scenes) and retinal slip (a pattern of disparity caused by movement of an object in the visual field or physical movement by the individual). Figure 2 shows the geometric reasoning behind image size variation when a visual stimulus is presented on a frontal plane (a two-dimensional plane parallel to the subject's

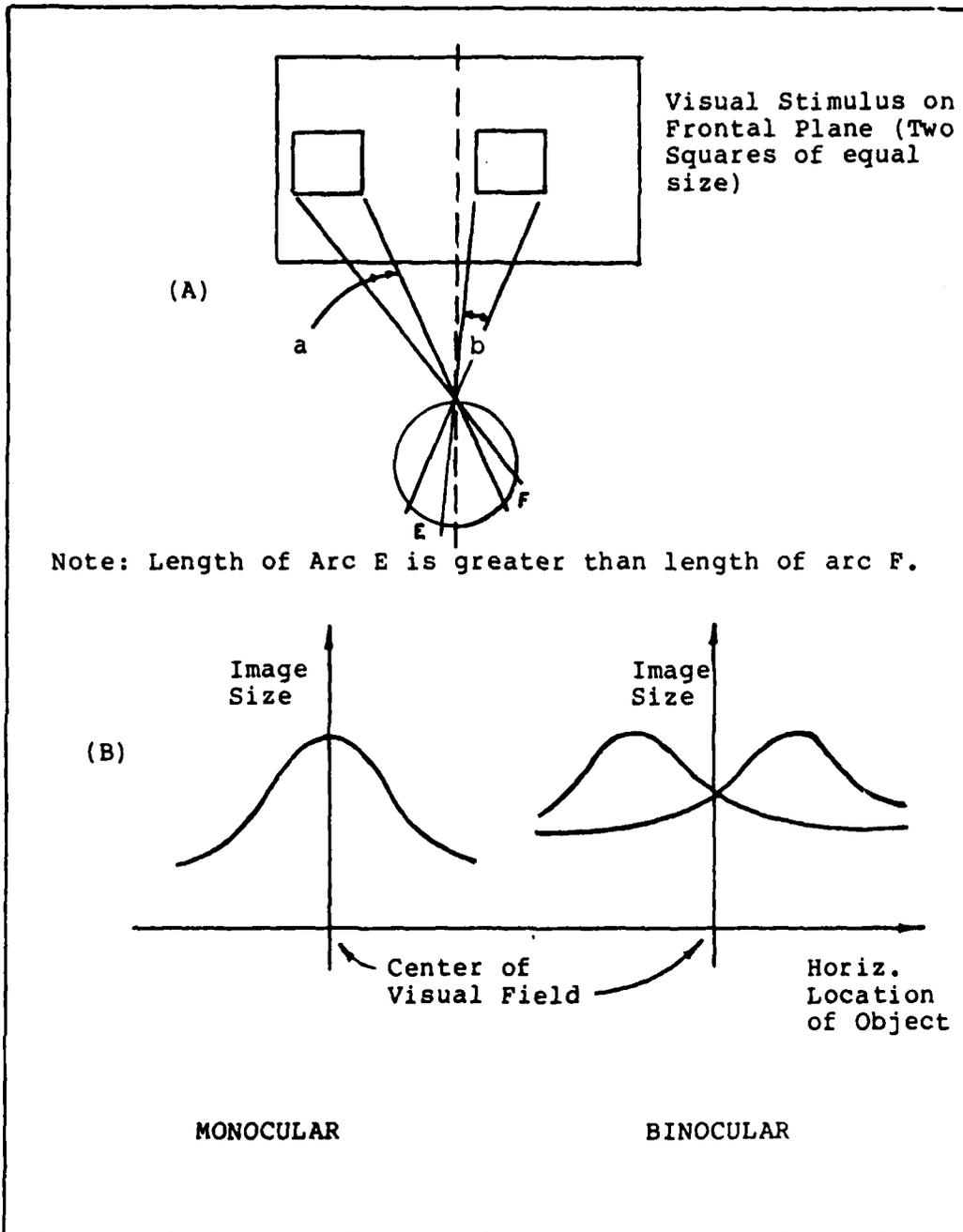


Fig 2. Relationship of Image Size to Location of an Object in the Visual Field. A) Geometry of Relationship B) Graphs of Image Size vs. Horizontal Position of an Object in the visual field.

chest). Since most experiments involve presentations of visual stimuli on a frontal plane, these inputs cannot be ignored. The variation of the image size is a function of the location of an object in the visual scene. The closer an object is to the monocular fixation point, the larger the retinal image that will be produced.

Figure 3 shows the input characteristics caused by binocular viewing of a frontal plane with a stationary stimulus. As discussed previously, the inputs from the two eyes introduce images of different size to the binocular integration process. In this case, when the eyes simultaneously view the same stimulus, the images of the same object are also displaced. Retinal disparity, as this image displacement is called, has been the subject of most experiments to determine the nature of binocular fusion. The output, or perception, determined by binocular integration, expands the field to include the periphery of both eyes and "sees" singular objects. Thus the binocular integrator must be capable of eliminating the disparities in image size and location.

Before a discussion of the nature of inputs caused directly by uniform target motion, certain input features which are normally present should be investigated. These inputs involve changing references due to controlled head movements, alterations in the orientation of the body, and controlled eye movements. Each of these factors plays an almost continuous role in determining human perception.

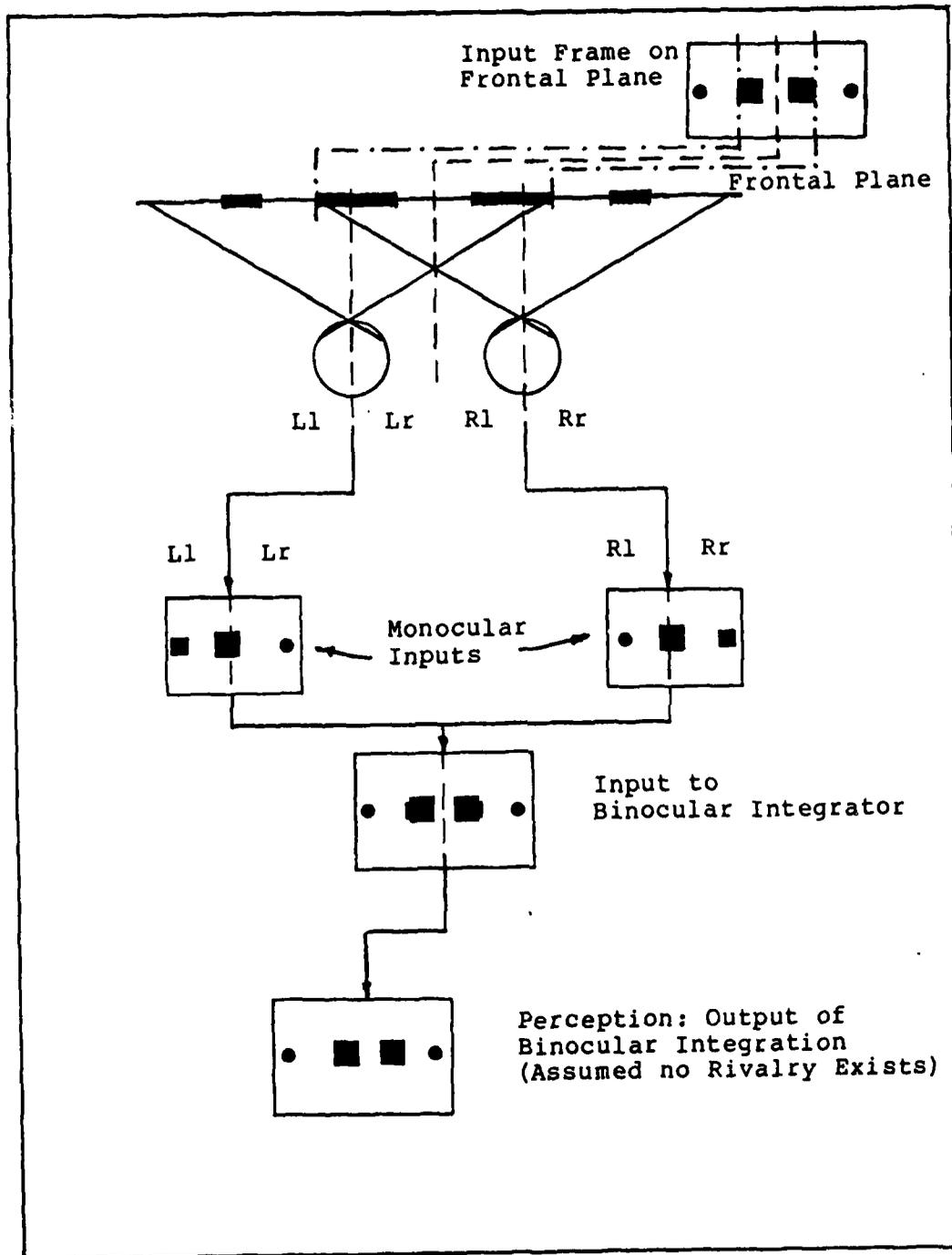


Fig 3. Sequential Binocular Processing of a Visual Stimulus on a Frontal Plane.

If it is assumed that the eyes remain stationary and the body orientation is fixed, then image size patterns induced by head movements alone will, in general, follow the graphs shown in Figure 4. Certain assumptions are implicit in these graphs. First of all, it is assumed that head movements describe a circular path, an assumption which may not be true because of the physical structure of the head and the manner in which it pivots upon the neck. However, though this assumption alters what might be the true magnitude of the image-size disparity, it would not alter the overall relationship observed for horizontal head movement, nor the constant size disparities related to vertical head movements. It should also be noted that horizontal head movements across objects cause image-size variations similar to the graphs for the stationary case.

One difference does exist though, between horizontal head movement and stationary image-size curves. Since motion of the head alters the distance from the eyes to the frontal plane, the curves will rise and drop more sharply than the curves depicting the image-size versus object location in the field in the absence of head movement. The argument for the existence of nearly constant image-size disparities in vertical head movements is consistent with the geometry shown earlier, since the object does not change horizontal location in the visual field. In assessing the graphs of Figure 4 it should also be noted that the magnitude of the image-size disparity is not quantified.

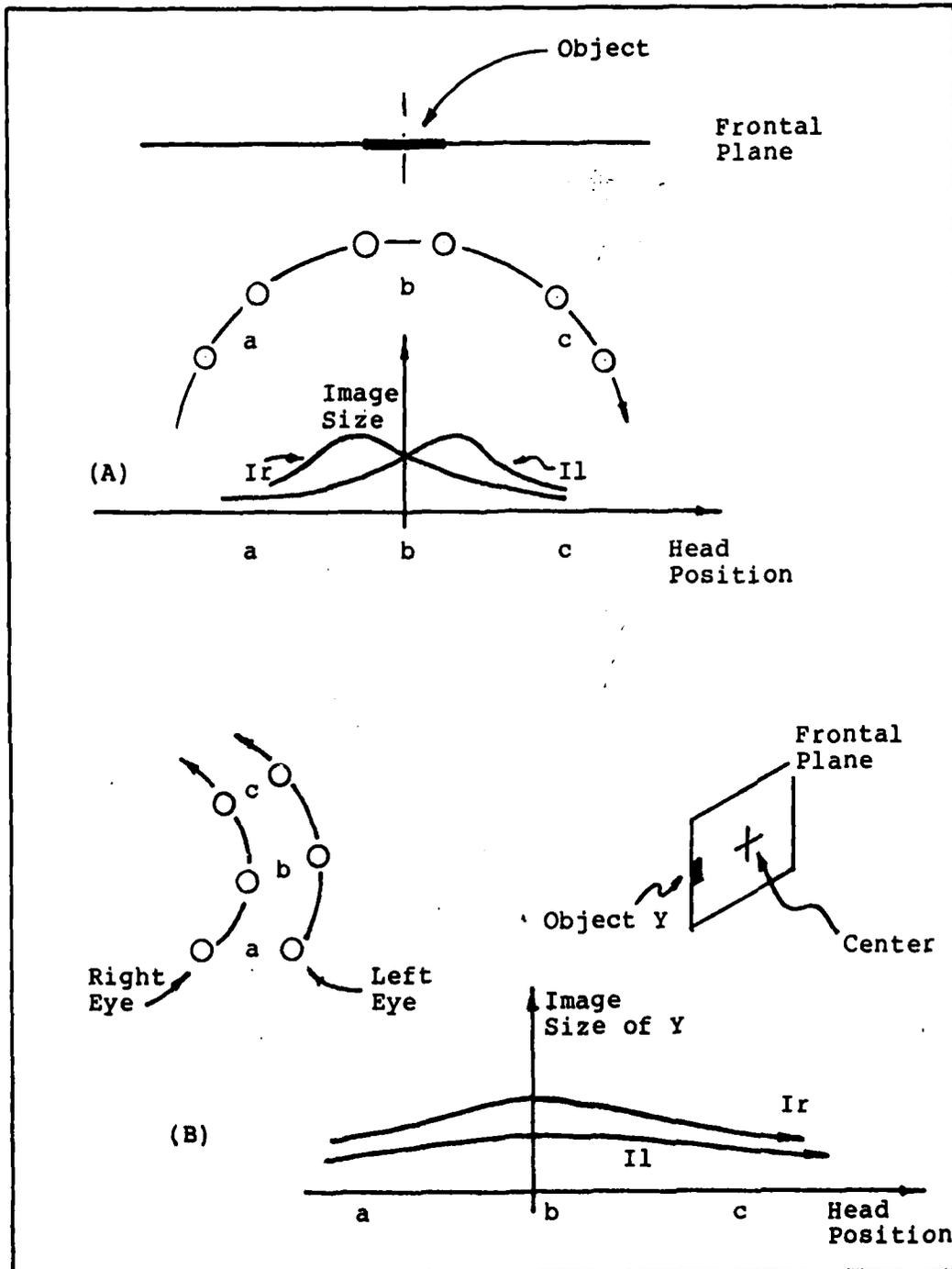


Fig 4. Graphs of the Image Size Disparity vs. Head Position
 A) Graph of Image Size for Horizontal Head Rotation. B) Graph of Image Size for Vertical Head Movements.

The magnitude would be dependent on several factors, the most important of which would be the distance between the viewer and the object being viewed. At viewing distances significantly greater than the distance between the viewer's eyes, the magnitude of the size disparity would likely become too small to play a role in the processing of information obtained from the visual inputs. The limit where image-size disparity becomes too small to be detected by the visual system has not been quantified and should not be confused with the limits of binocular fusion of points. Stereoscopic vision, which uses disparity cues, is known to involve a separate level of processing than binocular fusion (Richards 1970). In addition to the image-size variation induced, the entire visual scene is moving across the retinas at a velocity and direction opposite to the motion of the head. Thus a component of retinal slip velocity is introduced by head movements. Additionally, disparities caused by binocular image displacement will be introduced as the object location varies in the visual plane.

From human experience, or simple self-experimentation, it can be shown that stationary objects in the plane of fixation are not perceived to move during head movements. They do, however, differ in their orientation to background and foreground objects as the head moves. Another important feature of perception during head movements is that there appears to be no difficulty in maintaining binocular fusion for objects encountered in the visual field.

Since the detection of motion by an object is generally regarded to be determined by either a change in the object's orientation or size in relation to its background and foreground, the human visual system must be compensating for head movement in computing perception. The failure of head movement to produce double vision of objects implies the system is also overcoming the retinal image-size disparities induced.

Figure 5 depicts, in successive frames, how the combination of retinal slip, retinal disparity, and image-size variation might interact during head movement from left to center. If the system continues to perform binocular fusion to eliminate confusion, then a perceptual integrator can be hypothesized which attempts to match retinal slip velocity to that expected by the head velocity. In this manner, stationary objects could be identified. It might be guessed that some limit exists on the head movement velocities under which this system can continue to correctly determine visual information received. Self experimentation tends to support the idea of this limit.

Inputs caused by alterations in body orientation and eye movement are similar to those induced by head movements. In each case, retinal slip opposite in direction and velocity to the movement, and retinal disparity and image-size variation as functions of an object's location in the visual field, are introduced. To determine perception, however, the system now needs information related to eye and

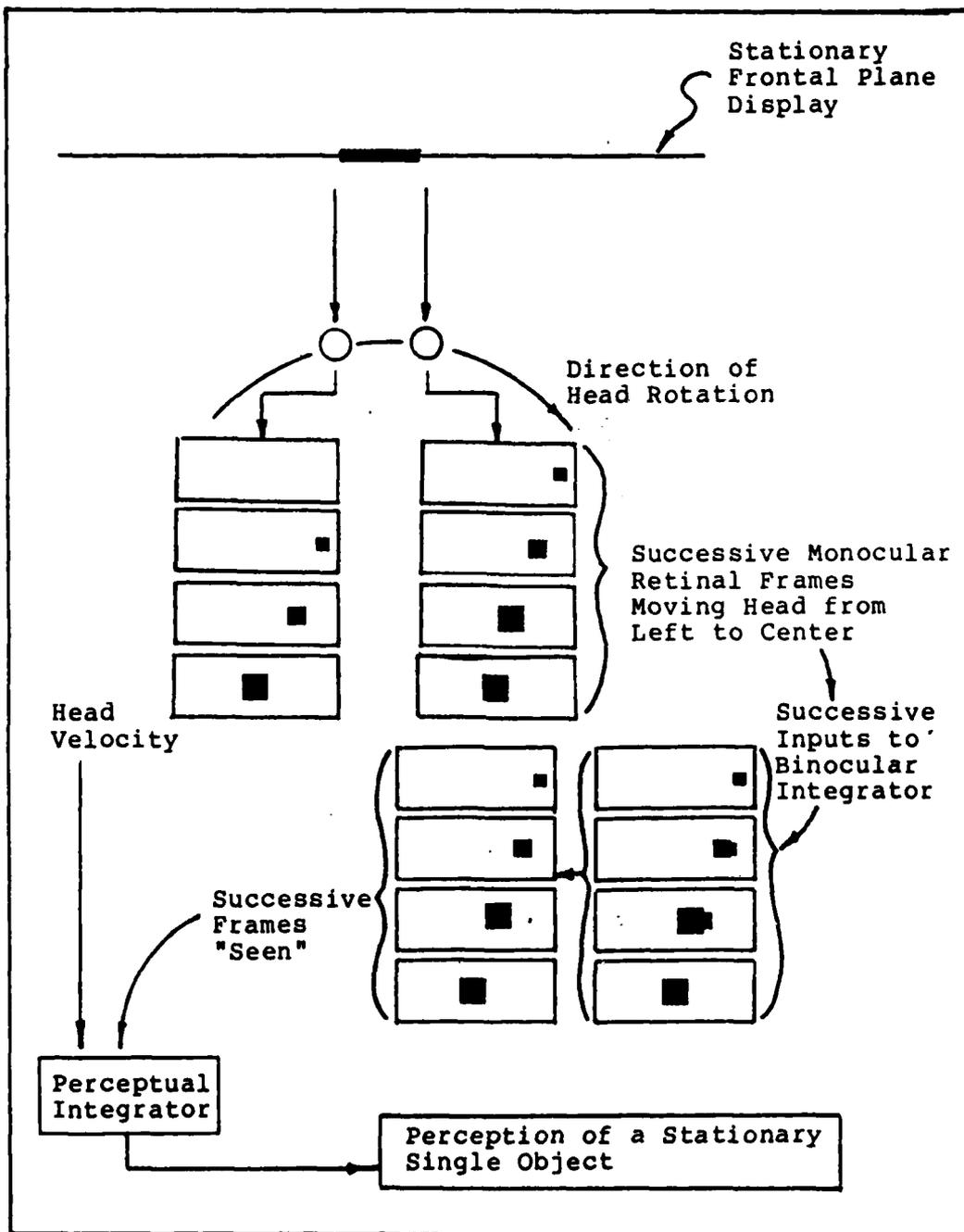


Fig 5. Processing of Sequential Monocular Retinal Inputs During Head Rotation to Permit Perception of a Single Stationary Object in the Visual Field.

body orientation velocity vector components. For alterations in body orientation, this information is available from the semi-circular canals. In the case of eye movements, information either from the optic muscles, or more probably their controlling mechanism, could provide the necessary input. A diagram of the possible data flow which can be hypothesized at this point is given in Figure 6.

The case of uniform object motion within the visual frontal plane can now be considered. Uniform motion can be observed either by tracking the object with the eyes or by keeping the eyes fixed. From the earlier discussion it can be seen that the image-size disparity and retinal disparity input functions will, in each case, be similar to those observed for eye, head, and body movements. The main difference will lie then in the introduction and compensation for retinal slip velocities introduced by eye movement. For eye tracking, the system can determine object motion by locating images in the plane of fixation whose slip velocity does not match the slip velocity induced by related eye movement. With the physical system held steady, the presence of retinal slip will indicate motion.

Another look should now be taken to determine the implications of the data flow diagram built from the knowledge of the visual inputs and perceptual outputs. First of all, we may ask whether it is necessary to place binocular integration before the perception of motion. This sequence was developed from the nature of the monocular

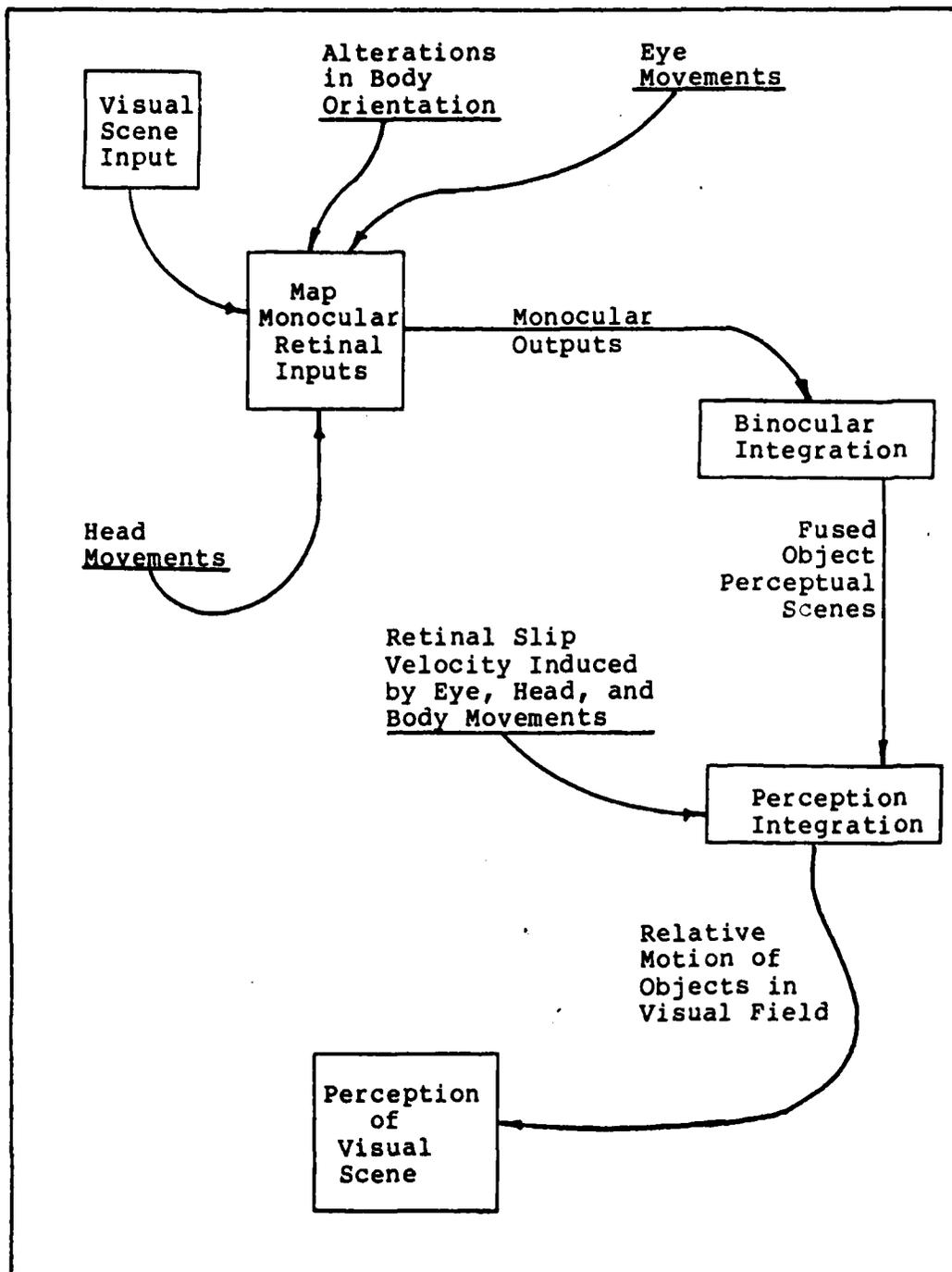


Fig 6. Data Flow Diagram of Visual Processing Related to Perception of Motion Associated with Objects in the Visual Field.

inputs. The computation of retinal slip velocity is simplified if ambiguous data due to image-size and displacement disparity are first extracted. Computer implementation techniques which indicate the extraction of stereoscopic disparity cues prior to binocular integration (Grimson 1980) also support this view, since in the system presented, disparity information would not be available beyond the point of fusion.

A second point to be made about the system developed is to determine what expected retinal slip velocity would result from physical movements. It is easy to see how the perceptual integrator can pick out the vector sum of the eye, head, and body movements if given appropriate input data. But this velocity, derived as a direct result of physical movements, will induce retinal slip velocities which vary with the distance to an object in the field. The further an object is from the viewer, the slower the retinal slip velocity induced by physical movement. To perceive motion, a logical selection for the perceptual integrator would be to compute an induced retinal slip velocity for the plane of fixation. This procedure would seem appropriate since the plane of fixation is the plane of greatest interest. If this is correct, then a degree of uncertainty would be present in determination of motion by background and foreground objects. Once again, subjective tests appear to validate this conclusion.

A final topic relating to the visual processing system

described here is the nature of a binocular integrator and, specifically, the limits to the disparity this system could be expected to handle. The question is whether the limits of binocular fusion can be described as maximums of a constant functional value or whether the limits can be caused to vary. Subjective experiments, where individuals view a visual scene with one eye looking through a lens of varying focal length (i.e. a "zoom" lens), support the idea of a variable maximum for binocular fusion. The point of fusion in these experiments is different for the instances when the scenes are initially fused and the instances when they are initially seen as double. This variable maximum of disparity magnitude for fusion implies that a feedback signal is present to allow the binocular integrator to predict and maintain "singleness" when disparate monocular images are previously known to represent a single object. The feedback signal would need to be able to inform the integrator to expect single object disparities of a magnitude based on the full range of input variations being induced by the physical alteration of the visual scene.

Based on the previous discussion, the data flow diagram (Figure 6) can be expanded to that shown in Figure 7. The numerous processing levels in Figure 7 begin to depict the complexity of deriving perception from visual scenes. Each of the processes shown would require many additional processing levels to perform their functions.

The data flow diagram, with its related processing, has been hypothesized based on the nature of successive "samples" of visual scene inputs. The depiction of the human visual processing system as a sampling mechanism appears to agree with some of the known facts. Experiments by Braddick (1974) with the production of "smooth" motion, using successive stimulus presentations, support the idea of the visual system deriving perception from visual samples. As reported earlier, Braddick found subjects reported smooth motion when the object displacement was less than 15-30 minutes of visual angle. He further discovered the displacement required to produce smooth motion to be independent of the time interval between presentations. If the system processes against successive samples, then the independence of the two parameters would be expected. The limit for time between frames would be directly related to the visual system's sampling rate, while the limit for object displacement would be a result of the processes required to identify objects and compute their relative slip velocities. Since motion perception can only be determined by a relation between present and past states, and the required processing of visual data will involve certain latencies, there appears to be a valid argument for depicting the human visual system as a "sampler."

It should also be added that the retention of past states agrees with experiments conducted by Ross (1976) which showed that humans can derive stereoscopic cues from

dichoptically presented stimulus pairs when up to 50 msec separates corresponding frames of a pair. The smooth motion limit of approximately 30 msec between samples would predict that the system would take a third sample approximately 60 msec after the first. Within experimental error, these results can be taken together to hypothesize a system which processes information based on a most recent and a previous sample. Using this hypothesis to explain the experiment by Ross, a time delay greater than 50 msec would have caused a third sample to be taken and the stereoscopic cues associated with the previous two samples would have been lost.

The idea of visual sampling does cause some intuitive problems since this method of processing would involve synchronization of the system. To synchronize processes the visual system would require synchronization signals to be sent between processes. This appears unlikely in a system whose structure suggests asynchronous computations to produce continuous output functions. Further, in microelectrode investigations of the visual cortex, the firing rate characteristics of neurons display continuous output functions related to the visual stimulus inputs, a result which does not suggest "sampling" has occurred.

Production of MAE

The data flow diagram in Figure 7 has been constructed without regard to how a system so designed would produce MAE. This was done since MAE are not part of the normal

visual processing but are instead an inadvertant concomitancy of a system constructed to produce correct perception of visual stimuli. Whether the system constructed can explain such a fault becomes a test of the system's validity in depicting the nature of human visual processing.

From the diagram produced, it is apparent that MAE should be a direct result of an incorrect output from the process used to determine objects in motion. For this process to produce a false output would imply either the incorrect computation of the expected slip velocity related to stationary objects or an incorrect computation of the retinal slip velocity associated with objects. The fact that MAE appearing immediately after the stimulus period can be observed in the absence of the stimulus suggests that the expected slip velocity calculation is the more likely cause. Yet an investigation of the processes shown to produce the expected slip velocity gives no clear reason why this system would fail after observing uniform motion (unless neural fatigue is to be considered the underlying cause).

A first look at the processes involved in the calculation of retinal slip associated with objects in the visual field seems to give no clue as to why this system would "fail" after observing uniform motion. As long as the feedback loop remains intact, the binocular integrator should continue to properly locate fused objects in the

visual field. When the objects are properly located in the field, the calculation of their related retinal slip velocities should continue to be computed correctly. The result would then be the correct perception of their relative motion. However, if the feedback loop drops out after "learning" the characteristics of a uniform stimulus pattern, and the stimulus pattern is later altered, the binocular integrator will improperly locate objects in the field based on its expectations of the "learned" response pattern. In this case all objects in the area of the learned response would be assigned incorrect relative slip velocities.

This appears to be a rather bizarre occurrence. Yet precedence for a system of this type exists. The human motor response system is believed to use the cerebellum as a feedback loop to allow correct coordination of motor movements (Guyton 1976). Further, the ability to "learn" rapid motor movements has been hypothesized to result from the removal of the latency involved in the feedback loop of the cerebellum. After "learning" a constant response pattern, the motor cortex is thought to continue to respond to the "learned" nature of the pattern. If a similar feedback system is used in visual processing, then uniform motion could invoke a learned response and thus eliminate the feedback loop used by the binocular integrator. The result upon altering the stimulus pattern would then be a series of corrective actions until the feedback loop is

re-established. This series of corrective actions could lead to a decaying function similar to those attributed to MAE.

If learned response patterns are at the root of MAE, that fact would help to explain the reports of MAE up to 24 hours after the uniform motion stimulus period. The retention of a learned response to an event would produce MAE much as humans learn to rapidly respond with motor actions to a given event. In the case of the production of long-term MAE, it has been reported that the stimulus scene must be located at the same point in the visual scene as the original stimulus pattern (Masland 1969). Thus the re-introduction of the visual scene with the same orientation could be said to cause the subject to recognize a learned event and react accordingly.

The fact that MAE can be color contingent may arise from the fact that the process of object identification is hypothesized to occur before a determination of the relative object slip velocity. Learned response to the event then occurs upon recognition of the object and event. This same relationship to the process of object identification could explain why MAE have been observed in an area of the visual field where only "phantom" motion is present (Weisstein, Maguire, and Berbaum 1977).

The vector summation results from MAE and from normal motion perception also seem to conform to the data processing model presented. If, as in the experiments producing vector sums, the computation of relative object

retinal slip velocity must be made on ambiguous data transposed onto the same areas of the visual field, it would not be surprising to have it yield a summation. After all, the system is trying to determine slip velocity associated with a single object at a point in the field. The transposition of ambiguous retinal slip data would not be a naturally occurring event since in the physical world only one object can define a space.

Since this hypothesis about the production of MAE is centered on a binocular system, then MAE produced by a single monocular stimulus must be considered. To explain this phenomenon, it must be assumed that the binocular integration process remains a part of the circuit in spite of the fact it is receiving only a single monocular input. In the model shown at Figure 7 the process which determines visual alterations of objects, and receives "induced physical alterations" as input may well be relaying the information to the binocular integrator to ignore data from the closed eye. In this manner the binocular integrator could continue to output objects correctly placed in the field. Also the feedback loop would remain functional in correcting for physical alterations and image-size disparity as objects move within the visual field. If, as hypothesized, "learned" response drops the feedback loop out during the viewing of uniform motion, then the system would again produce incorrect results when the stimulus is altered. Since the system is designed to interact on the

results of binocular vision, the interocular transfer of MAE, as reported, is not surprising either.

By using the idea of a learned response to explain MAE, the validity of the data flow diagram (Figure 7) can be argued. The final requirement is to relate the processes of the data flow diagram to the known physical structures which might perform these processes.

Physical Structure of Visual Processing

As reported earlier, the retinal inputs are transmitted to the primary visual cortex with no apparent processing performed in the Lateral Geniculate Nucleus (LGN). However, an investigation of the LGN, with its layered structure, can provide an insight to its possible function. In the previous discussion it was asserted that to correctly interpret motion, the visual system would require both a present and previous visual input scene. One method of attaining sequential visual mappings would be to provide a transmission latency between successive mappings. This method is depicted in Figure 8 and coincides well with the known structure of the LGN. Since microelectrode experiments on individual neurons would not disclose the dual latency patterns of the LGN output, the functional importance of the LGN could easily have been missed.

If the LGN does provide the cortex with multiple visual mappings, separated in time, then the next question is what functions are performed by the visual cortex. At present the data do not clearly indicate the exact manner of

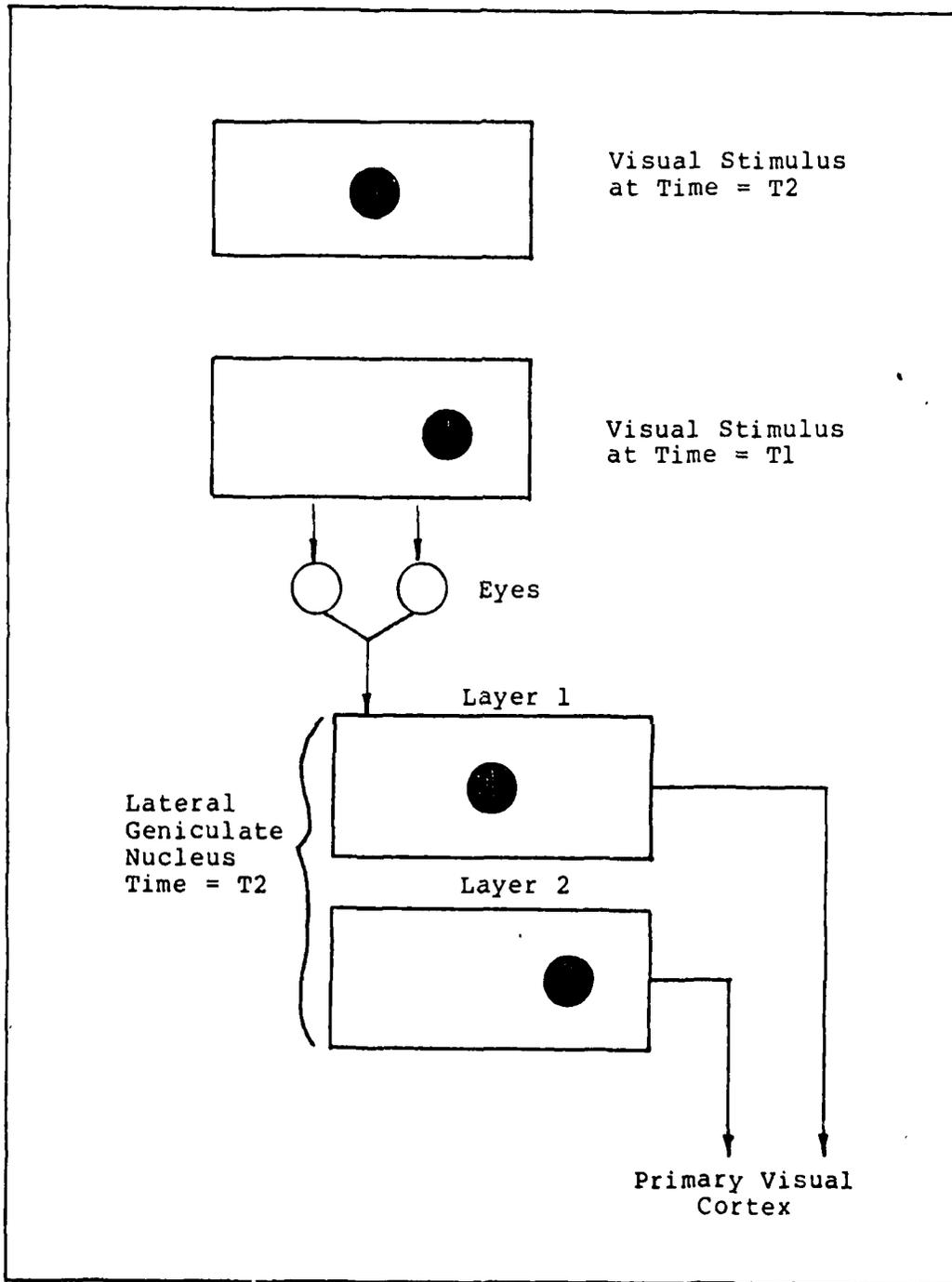


Fig 8. Hypothesized Role of Lateral Geniculate Nucleus in Providing Mappings Displaced in Time to Primary Visual Cortex.

cortical processing. The reported existence of neurons tuned to orientation and motion direction cannot be used to conclusively argue the existence of any of the hypothesized processing centers. As discussed earlier, reported cortical neuron characteristics may only suggest the presence of a single variable within a far more complex function. In any case, the high order processes hypothesized would most likely reside at the cortical level. Among the processes hypothesized, the cortex would likely perform binocular integration, object identification, calculation of induced and object related slip velocities, determination of motion, and the integration of perception.

Based on the available range of input data to the cerebellum, and the hypothesized role it might play in the production of MAE, the determination of the effects of physical and object movement would likely be performed by the cerebellum.

A composite diagram is shown in Figure 9 with data processes displayed within the boundaries of their hypothesized physical locations. Admittedly this diagram evolved from a series of intuitive leaps. Most significantly, the roles attributed to the LGN and cerebellum are not found in the literature about visual information processing. Since these roles have not been explored, little evidence exists to support the theory presented. At this point the model can be defended only on the apparent need for the processing functions described and

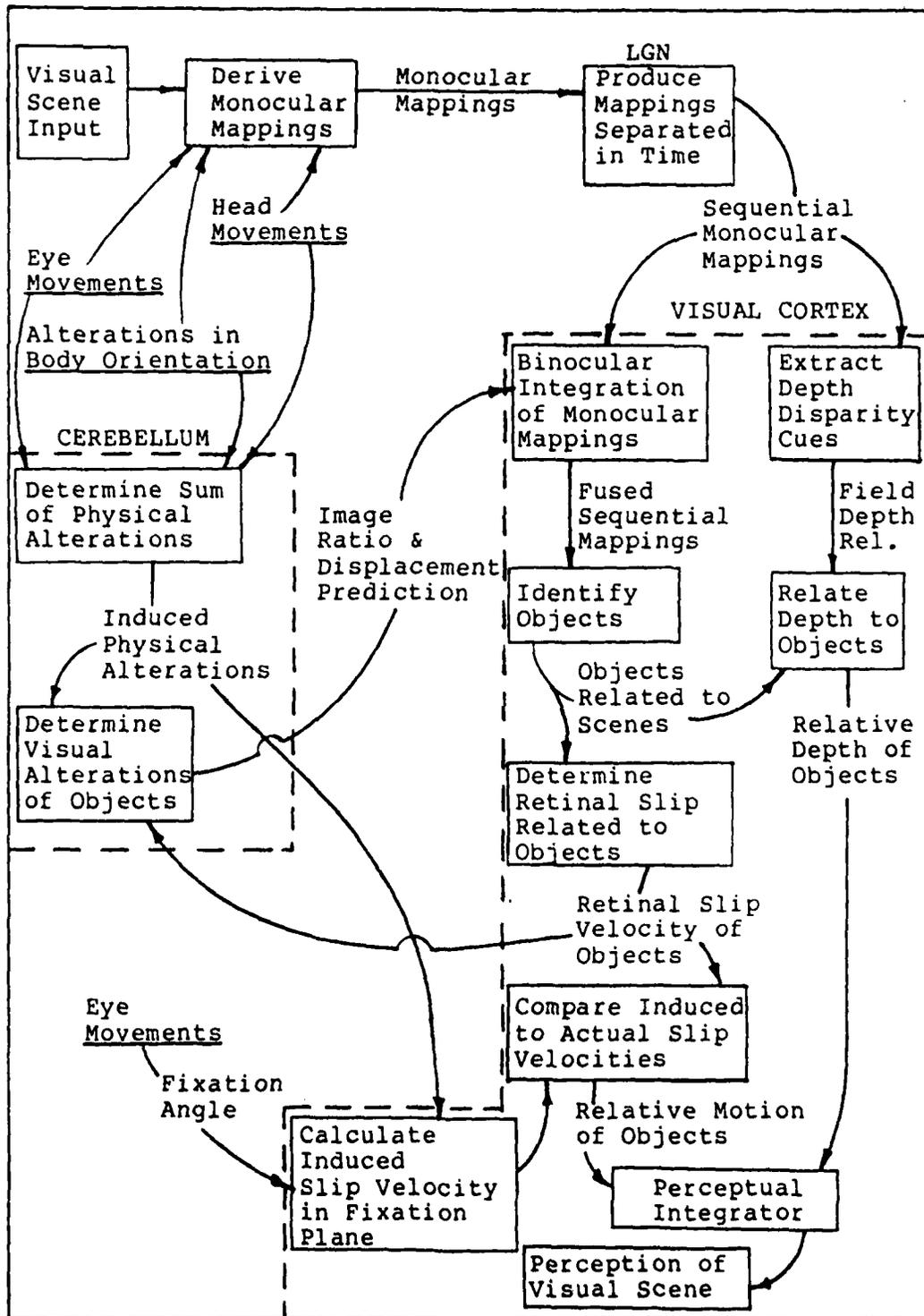


Fig 9. Relationship of Proposed Model Processes to Physical Structures in Humans.

the possibility, based on structure and known available inputs, of the LGN and cerebellum performing their ascribed roles.

If Pantle and Picciano (1976) are correct that two motion detection systems exist, then this model would describe the system requiring object identification. It would intuitively make sense that humans might also have a "reflex" motion detection system which avoids the latencies inherent in this model. Such a second system could well be used to signal a defensive reaction to perceived motion.

Experimental Proposals

The following sections describe psycho-physical experiments that were conducted in an attempt to assign a degree of validity to the model. The objective of the experiments was to quantify the existence of a variation in the maximum limit of binocular fusion and to determine if the production of MAE is related to the position of the uniform motion stimulus in the visual field. The theory that a feedback loop exists to aid binocular integration is based on the fact that fusion can be maintained beyond a normal limit when the monocular images have previously been identified as a single object. If this assumption can be quantified, then it would provide credence to the existence of the predictive feedback loop.

MAE were hypothesized to result from the learning of a uniform pattern variation which allowed the binocular integrator to function in the absence of input from the

feedback loop of the cerebellum. In this case, an alteration in the "learned" stimulus pattern would cause the system to incorrectly locate fused objects in the integrated visual field. Based on this hypothesis, visual adaptation to uniform motion in the periphery, where less variation occurs in image-size and image displacement, should invoke less MAE than uniform motion centered on the foveal area. A psychophysical experiment to determine if this expected result is obtained is also discussed in the following sections of this report.

Since both MAE and binocular fusion have been hypothesized to depend on a feedback loop from the cerebellum to the cortex, it would appear likely that a correlation could exist between the data collected from each experiment. The possibility of the existence of such a correlation will also be discussed later.

IV. EXPERIMENTAL DESIGN AND PROCEDURE

Limits of Human Binocular Fusion

In this experiment an attempt was made to determine the characteristics of human binocular integration. As mentioned earlier, the specific purpose was to investigate the limits of binocular fusion. Thirteen male graduate students in Electrical Engineering participated as subjects. Two of the subjects reported prior to the experiment that they were red-green colorblind. Additionally one subject reported to be asimetric (near-sighted in one eye and far-sighted in the other eye). A fourth subject reported to have weak ocular muscles in his left eye. Seven of the thirteen wore corrective lenses.

Equipment: Two microprocessors were used to produce separate visual stimuli. The first, a Cromemco Z-2D microprocessor with two 48-K video memory boards and a digital-to-analog video board, was used to produce visual stimuli which were presented to the subject's left eye. Two 5 1/4 inch Cromemco disk-drives were used for program storage. Video presentations were displayed on a Cromemco RGB 13 inch high resolution monitor. The color and contrast controls were set at mid-range and the brightness control to its highest setting. Fortran-IV programming language was used along with the Cromemco SDI software graphics library. During the experiment, a black poster board frame was taped to the Cromemco monitor. The frame covered the front of the monitor, allowing the subject to view only the central

portion of the monitor screen. The exposed screen area was 9 1/2 inches in width and 7 1/4 inches in height. A Heathkit H-19 monitor and keyboard were used to enter programs and to communicate with the Cromemco microprocessor. Experimental data were output to an Anadex Silent Scribe printer.

The second microprocessor, a TRS-80 Color Computer with 32-K RAM, was used to produce visual stimuli which were presented to the subject's right eye. A Radio Shack CTR-80A cassette recorder was used for program storage. Video presentations were displayed on an RCA 13 inch color television screen. The color and contrast controls were set at mid-range and the brightness control to its lowest setting. The Extended Basic programming language, provided with the TRS-80 Color Computer, was used to produce the required graphics. As with the Cromemco, a black poster board frame was taped onto the front of the RCA screen exposing only a portion of the screen 9 1/2 inches in width by 7 1/4 inches in height. A Radio Shack joystick control was used during the experiment to allow subject's to communicate with the TRS-80 microprocessor. Experimental data were output to a Decwriter IV printer.

Figure 10 depicts the equipment configuration during the experiment. From the center of each screen to the floor was 110 cm. To position the height of the Cromemco monitor, and to tilt the screen forward to be perpendicular to the floor, an adjustable platform was constructed (Figure 11).

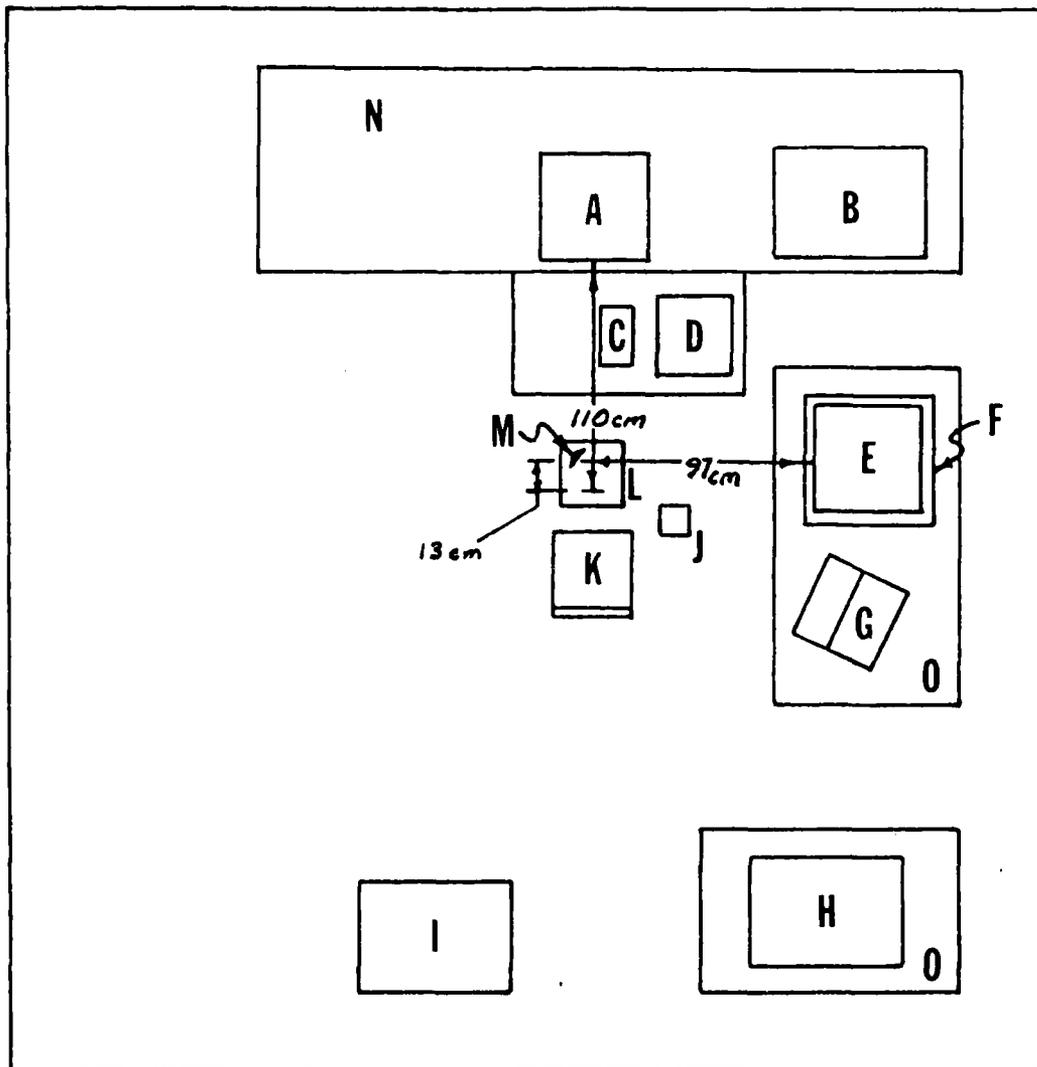


Fig 10. Equipment Configuration for the Experiment on the Limits of Human Binocular Fusion. A) RCA 13 in TV B) Decwriter IV Printer C) CTR-80A Cassette Recorder D) TRS-80 Color Computer E) Cromemco Color Monitor F) Adjustable Monitor Platform G) Heathkit H-19 Monitor H) Cromemco Z-2D microprocessor I) Anadex Silent Scribe Printer J) Joystick Control K) Chair L) Chin Rest M) Adjustable Mirror N) Laboratory Bench O) Desk

To provide a stable chin rest, and to permit centering of the two visual scenes on the subject's eyes, an adjustable platform was built (Figure 12). Mounted on the platform was an automotive side-mirror with a 5 in. by 5 in. flat reflective mirror taped securely to it. The automotive mirror was used since it provided an easy method of obtaining a pivotal joint for adjustment of the flat reflective mirror. The flat reflective mirror was used by the subjects to view the Cromemco screen.

The use of two differing video screens resulted in differences in luminance, contrast, and hue. The luminance of the RCA screen was approximately 40 ft-lamberts while that of the Cromemco screen was 5 to 10 ft-lamberts. Both screens were type P22A phosphors. During the experiment the room was lit by fluorescent lighting with the lights directly over the experimental area turned off to reduce glare. No attempt to match contrast or luminance of the screens was made since, in trials prior to the experiment, it was determined that the differences did not significantly interfere with the observations to be tested. The colors of the stimuli were changed during the experiment in an attempt to determine if any statistical difference could be found in the test data related to color. Contrast and luminance of the two screens remained constant throughout the experiment.

Procedure: Prior to beginning the experiment, each subject was introduced to the equipment and controls to be

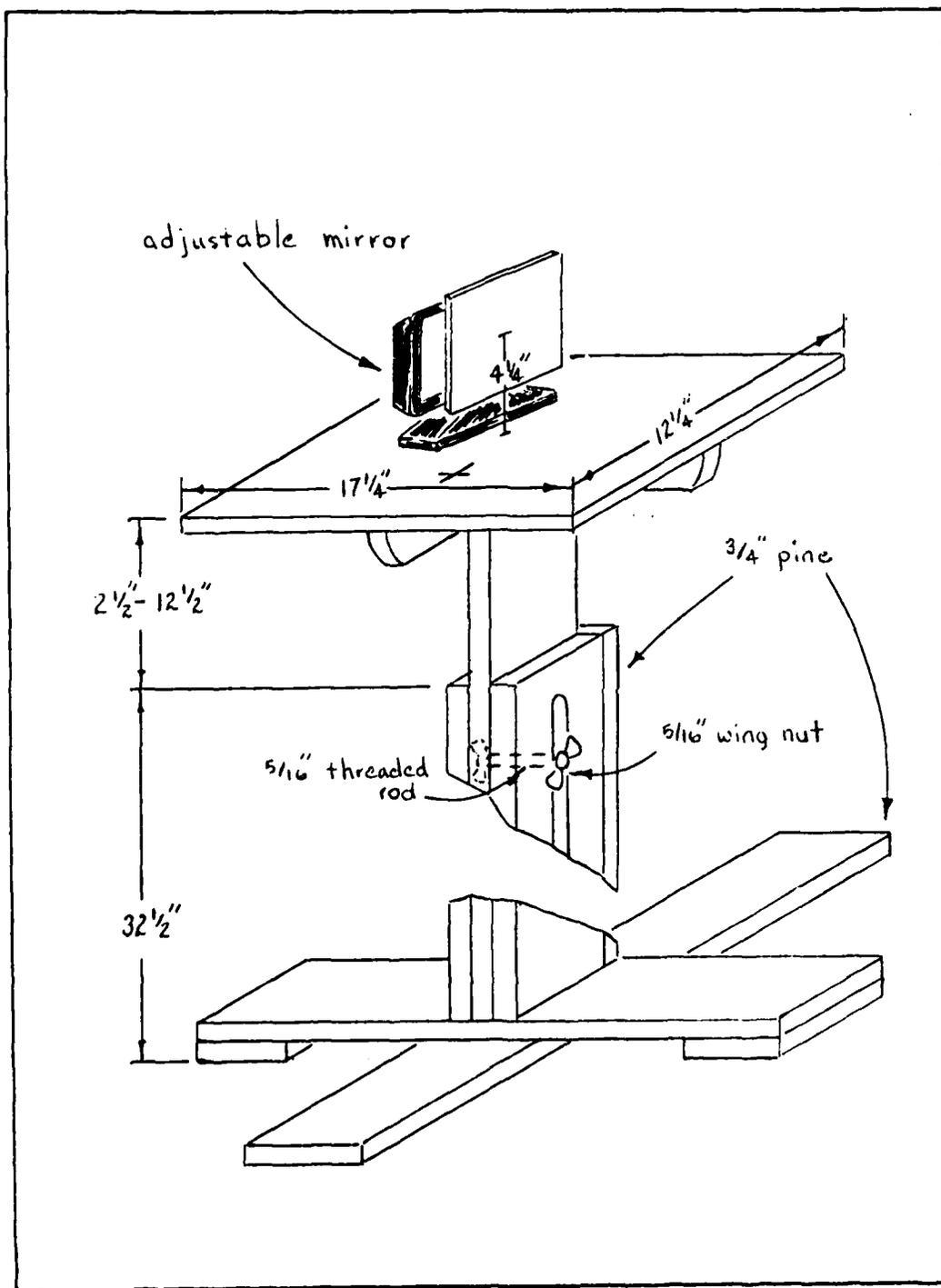


Fig 12. Adjustable Platform to Provide a Chin Rest and to Support an Adjustable Mirror.

used. The subject was then asked to read a set of instructions (Appendix A). After the subject completed the instructions, the experiment monitor assisted the subject in adjusting the equipment so that each screen was centered within the visual field of the subject's eyes. This was accomplished by having the subject adjust the mirror to center a solid green square within a larger green square frame. The square frame was first presented to the right eye (from the RCA screen) while the left eye viewed a solid square (from the Cromemco). The order of presentation was then reversed. Because of perception difficulties, caused by binocular rivalry, the subject was told to only be concerned that the squares were "generally" centered. In tests performed prior to the experiment it was discovered that a degree of tolerance existed in centering the scenes without significantly affecting the data.

After the subject had centered the scenes, the conduct of the experiment was left to the programmed control of the two microprocessors. The two programs (Appendix B) were designed to prompt the subject with messages. By following the instructions provided on the screens (mostly the RCA since messages on the Cromemco were reflected off the mirror backwards) the subjects were able to conduct the experiment without additional direct intervention by the experiment monitor. In the initial segment of the experiment, subjects were taken through a learning phase. Throughout this phase a solid green square centered on a black background was

displayed on the Cromemco (left eye). The square was 6.5 cm on each side with a small black square (approximately 2mm), for a focal point, at its center.

The subjects were first instructed to observe as a solid green square (6.5 cm) centered on a black background was displayed on the RCA (right eye). This square also contained a small focal point (approximately 2 mm) at its center. The subjects next observed as the green square on the RCA expanded from 6.5 cm to 17.8 cm. The rate of expansion of the square was 1.62 cm/sec. During two observations of the expanding square, the subjects were instructed to fixate on the small focal point and determine at what point a smaller square distinctly appeared inside the larger square. On a third trial the subject was asked to press the control button on the joystick (connected to the TRS-80 color computer) when the second square appeared.

The subjects were next told to observe as the square on the RCA screen contracted from 17.8 cm to 6.5 cm. The rate of contraction of the square was 1.62 cm/sec. Again the subjects were told to fixate on the black focal point. While the larger square contracted the subjects were told to observe at what point the smaller inner square and the larger contracting square appeared to become one square. The subjects were next told to press the joystick control when it appeared the two squares had become one square. Pressing the control momentarily (1 second) halted the contraction before it continued. After one trial the

subjects were asked if the inner square immediately reappeared. If so, they were instructed to again press the control as the squares appeared to become one square and to continue to press the control again until the second square did not reappear. The subjects were then given five trials at performing this test. This completed the learning phase of the experiment.

During the initial portion of the testing phase the subjects observed expanding and contracting squares in alternating tests on the RCA screen. The size and speed parameters, as described earlier, remained the same throughout the tests. The scene displayed on the Cromemco was always a solid 6.5 cm square on a black background with a small black square (used as a focal point) at its center. The small black square (focal point) on the RCA screen was only present when a random number from 1 to 10 was greater than 4. Thus the focal point was absent from the RCA screen in approximately 40% of the tests during this phase.

In the first series of 10 tests (5 with the square expanding and 5 with it contracting) the squares on both screens were green. When subjects pressed the control while the squares were expanding, the expanding square was erased from the screen. The size of the square when the control was pressed was then sent to the printer along with other information describing the test just completed. A 7 second delay was imposed between each test. When the square contracted, the size of the square when the control was last

pressed was sent to the printer. Each time the control was pressed as the square contracted, the contraction halted for one second, then continued. The square would always continue until it reached 6.5 cm before sending the data to the printer. In all test cases the speed of expansion and contraction was held constant at 1.62 cm/sec.

Ten tests were then taken in the same manner with the color of the square presented on the Cromemco changed to red. The initial testing phase was completed when 10 additional tests were conducted with the color of the squares on both the RCA and Cromemco changed to white. With the exception of the color changes no other experiment parameters were altered.

The second, and final portion of the testing phase was conducted with the expanding and contracting squares appearing on the Cromemco (left eye). During these tests the RCA always displayed a 6.5 cm square with a focal point at its center. All parameters except color were kept the same as in the first series of tests. To signal the Cromemco the subjects were instructed to first press the "space" on the H-19 keyboard and then press any letter key.

Three sets of 10 data elements were taken, as before, with the expanding and contracting squares appearing on the Cromemco. For the first set the squares on both the Cromemco and RCA were white. During the second set the square on the RCA was white and the squares appearing on the Cromemco were green. For the final set of 10 data elements,

the squares on both the Cromemco and RCA were green.

Upon completion of the testing each subject was asked to complete a questionnaire (Appendix C). The experiment monitor then had each subject describe verbally what they had observed and at what point in their observations they would respond. This was done to insure the data collected were associated with the observations to be measured.

MAE Related to Location in the Visual Field

In the second experiment subjects were tested to determine the relationship between their reported MAE and the location of the stimulus in their visual field. The subjects used were the same individuals who, one week earlier, participated in the first experiment. Each of the participants reported after the experiment to have either previously witnessed MAE or that they were aware of the existence of MAE in human perception.

Equipment: Throughout the experiment a series of visual stimuli were presented on an RCA 13 inch color television screen. The television signal was transmitted from a TRS-80 Color Computer with 32-K RAM. The Extended Basic programming language was used to produce the required graphics displays (Appendix D). A Radio Shack CTR-80A cassette recorder was used for program and graphics storage. To allow the subjects to communicate with the computer, a Radio Shack joystick control was used. A Decwriter IV printer was used for data output.

To control the subject's viewing position, the adjustable chin rest platform, described in the first experiment, was again used. For this experiment the mirror and its mount were removed.

Next to the television a sheet of black poster board was mounted upright to provide a uniform background. The poster board also served to permit the location of a peripheral focal point used in the experiment. The equipment configuration and the location of the focal points are shown in Figure 13.

The room was lit with fluorescent lights, with the lights directly over the experimental area turned off to reduce glare. The luminance of the RCA screen was approximately 40 ft-lamberts on a P22A phosphor screen. The brightness control was set to its lowest position with contrast and color settings in their midrange.

Procedure: Each subject was initially seated in the chair with the chin rest platform positioned directly in front of the television screen. The experiment monitor then read aloud the first paragraph of the instructions (Appendix E) and described a visual scene which was presented on the screen. The scene observed was a series of vertical black and green bars, 6 mm in width, enclosed within a black frame measuring 14.0 cm x 13.5 cm. A black square (5 mm) was centered in the frame.

Translated into degrees of visual angle, the pattern frame was 6.2 degrees in width when the viewer was directly

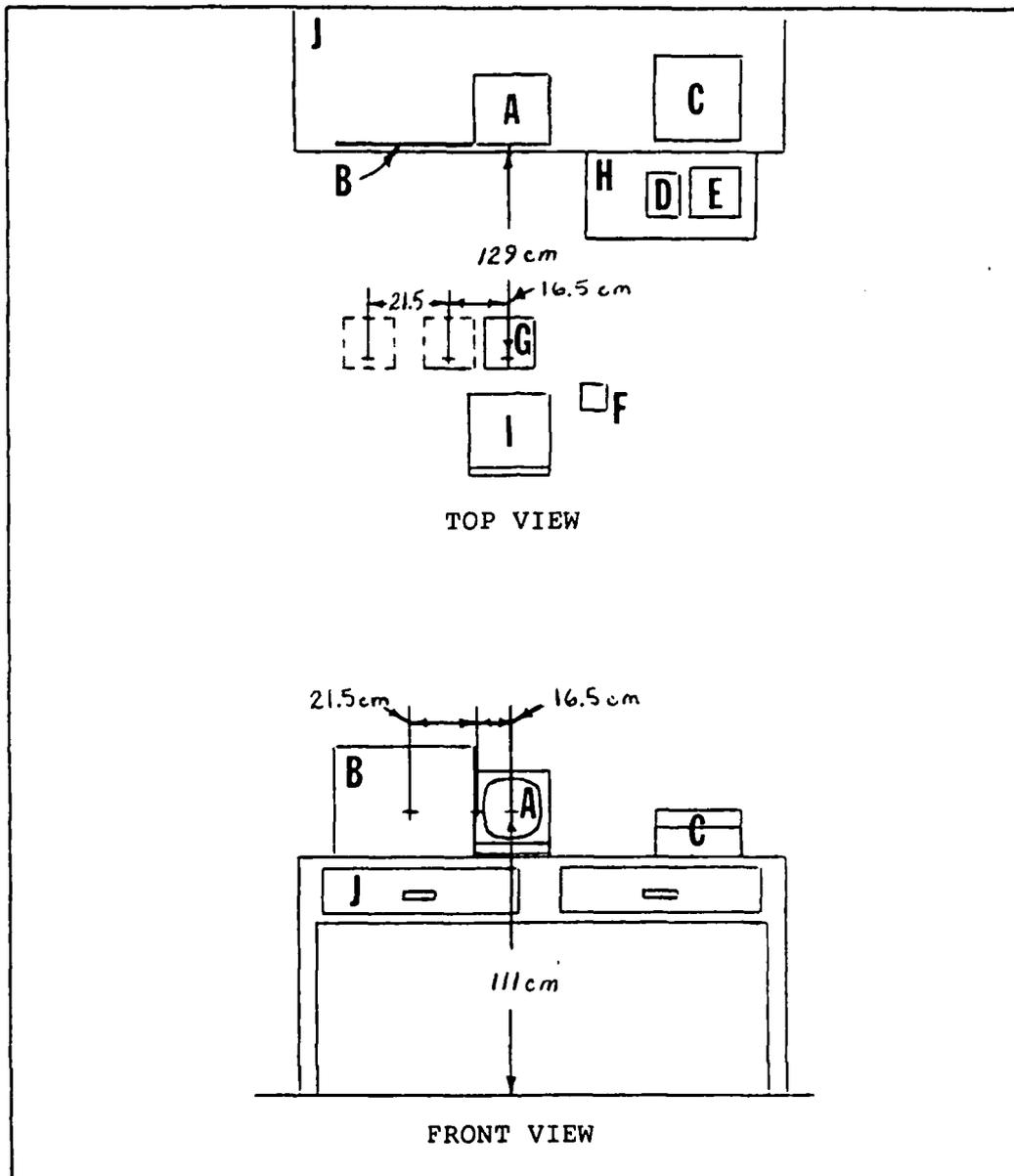


Fig 13. Equipment Configuration for the Experiment Measuring the Parameters of MAE as a Function of Position in the Visual Field. A) RCA 13 in Color TV B) Black Poster Board C) Decwriter IV Printer D) CTR-80A Cassette Recorder E) TRS-80 Color Computer F) Joystick Control G) Adjustable Chin Rest H) Desk I) Chair J) Laboratory Bench

in front of the screen. The spatial frequency of the vertical square wave pattern was 1.9 cycles/degree.

A green background surrounded the pattern on the screen. When the pattern appeared, the vertical bars initially moved to the right at 4.3 degrees/sec for 2.7 seconds. The vertical bars then halted and the pattern remained on the screen for 2.6 seconds.

The subject was then instructed to place his chin on the chin rest and observe the pattern while fixating on the small black square in the center of the pattern. The subject was further instructed to attempt to determine if there was any leftward movement of the pattern immediately following the halting of the rightward moving vertical bars. The experiment monitor also advised the subject that the leftward movement, if present, would not involve movement of the bars across the focal point. Instead the subject was told to look for a leftward movement by the entire pattern. The same scene, as just described, was presented four times. When the subject observed leftward movement of the pattern he was to press and release the control button on the joystick.

The second paragraph of the instructions (Appendix E) was then read aloud to the subject. The subject then observed three trials where the bars moved rightward for 13.3 seconds. The subject was to press the control button when he observed leftward motion of the pattern and hold the button until the motion ceased. The stationary pattern

would remain on the screen as long as the subject pressed the control button. After each trial a blank green screen was displayed for 11 seconds. One second before each trial began a tone would sound. No data were collected during these trials (the printer was turned off). This completed the learning phase of the experiment.

The testing phase of the experiment consisted of two tests, each of which was taken with the subject seated in one of three positions. A separate focal point was assigned to each position (Figure 13). The subject was given two different tests at each position. Starting with position 1, with the pattern centered in the visual field, the tests were then taken consecutively at positions 2, with the pattern 7.3 degrees off the center of the visual field, and position 3, with the pattern 17.1 degrees off the center of the visual field. The same sequence of positions was then re-tested. Both tests involved the presentation of the same video pattern as described in the learning phase.

In the first test performed at each position the bars were moved rightward for a period of time determined by a random number. Based on the value of the random number, the duration of the moving bars varied from 0.13 seconds to 2.67 seconds in increments of 0.13 seconds. After the vertical bars halted, the subject viewed the stationary pattern for up to 2.6 seconds, pressing the control to indicate if he observed leftward movement of the pattern. After each test the pattern was removed and a blank green screen was

displayed for 11 seconds. One second prior to each test a tone would sound. This same test was repeated ten times, with the results of each sent to the printer.

Upon completion of ten repetitions of the first test, a second test was performed at each position. In the second test the same pattern was displayed as before. In this series of tests the duration of the rightward moving vertical bars was held constant at 13.3 seconds. When the bars halted, the subjects were to press and hold the control button during the period they observed leftward movement of the pattern. Three repetitions of this test were performed with 11 seconds between tests, and a tone provided one second before initiation of the next repetition. The length of time subjects reported leftward movement was sent to the printer after each repetition. During the tests the subjects were given 5.3 seconds to report leftward movement of the stationary pattern before it was assumed no leftward movement was observed.

Completion of three repetitions of the second test completed the testing at each position. Subjects were then moved to the next position in the experiment sequence and the tests repeated until all three positions were tested twice.

V. EXPERIMENTAL RESULTS

Limits of Human Binocular Fusion

Of the thirteen graduate students who participated twelve reported similar perceptions. The data taken from the twelve subjects were used to determine the subjects' relative limits for perception of a single object when given disparate visual stimuli to the two eyes. The following discussion will first cover the general perceptions reported and then the quantitative results of the data collected.

Reported Perceptions: When the squares presented to each eye were of the same size, the form remained stable. The color of the square, however, alternated between the colors presented to each eye. This bi-stable perception was believed to result from binocular rivalry. Since color after-effects do not display interocular transfer (Favreau and Corballis 1976), it is likely the perceptual integrator must decide between the color input from each eye. With no additional information to judge the importance of each monocular input, the perceptual integrator becomes unstable, producing the alternating color rivalry reported.

A significant finding, reported by the subjects of this experiment, was that regardless of the color observed, the focal point appeared to remain in the middle of the square. This occurred even when the focal point was only present on the screen of the color not reported. It is hypothesized that the importance given the focal point in the instructions, prior to the experiment, caused the subjects'

binocular integrator to keep this form present even when local rivalry allowed the other eye to determine the color of the surrounding square.

As one of the squares began to expand the subjects initially reported seeing only one square. The color of this square remained stable and was always reported to be the color of the square actually expanding. The importance of the boundary motion of the expanding square is believed to have caused the perceptual integrator to have stabilized on the color associated with the motion. Here again, the focal point was reported to have remained within the subject's visual perception even when it was only present on the square which was not expanding.

As the one square continued to expand, the subjects reported a period when a "dark fuzz" appeared as an outline of a square the size of the nonexpanding square. At a further point in the expansion, the nonexpanding square from the opposite eye would suddenly, and distinctly, appear within the expanding square. It is believed that at the point when the smaller square appeared the individual's capability to fuse the two squares had been exceeded. Prior to this point it is hypothesized that a feedback loop, involving the cerebellum, was allowing the visual system to predict the size disparity of the two squares and to fuse the forms into a perception of one square. This belief is drawn from the model of visual processing previously derived and shown at Figure 9.

Additional support for a predictive feedback loop was provided by unsolicited reports from the experimental subjects. In their responses on the post experiment questionnaire, three students mentioned that if they happened to blink their eyes while the square was expanding, then the second inner square would immediately appear. Follow up questions posed to the other subjects found several to believe they had also observed the same phenomena. Others were unsure and could not report definitely if blinking their eyes had caused the second square to appear.

The act of blinking one's eyes would disrupt the continuous predicative feedback loop hypothesized to maintain binocular form fusion. A disruption in the feedback loop would then be predicted by the visual processing model to result in loss of the perceived singleness of the two disparate squares, a prediction which is consistent with the results.

The second portion of the experiment, involving a contracting square, proved to be an inherently difficult experiment for the subjects to produce consistent data. The experiment began with the disparity in size of the squares well beyond an individual's ability to fuse the two forms. Because of this, binocular rivalry, as discussed earlier, was present. Rivalry caused the subjects to observe a bi-stable perception where the smaller square would appear and disappear. This bi-stable perception would cause the

subjects to report fusion of the squares when, in fact, rivalry had caused the second smaller square to momentarily disappear. This problem was discovered prior to initiation of the experiment. To allow for the interference of rivalry, the contraction of the square was halted and would then continue after each response. If the smaller square reappeared the subjects would again respond when the two squares appeared to become one. By successively responding, then watching for the second square to reappear, a point would be reached where the subjects reported the perception to stabilize as one square contracting. The final response, where the perception of a single contracting square stabilized, was taken as the actual point where the size disparity came within the individual's limit to fuse the two forms. Though subjects uniformly reported observing the stabilized perception to occur, the experimental uncertainty, caused by binocular rivalry, introduced a great deal of variance in the data collected. In spite of the problems encountered, the subjects consistently found the point of perceptual stabilization on a single object to be significantly lower for the contracting versus the expanding square. This observation, which will be quantitatively discussed later, agrees with both the subjective observations earlier mentioned and the predictions which would be made based on a visual processing model incorporating a predictive feedback loop to the binocular integrator.

As with the expanding square, the color of the stabilized contracting square was always that of the square which was actually contracting. The focal point was reported by some subjects to be missing for a short period of time when the contracting square was first displayed on the screen at its full size. However, as soon as the square began to contract the subjects again reported its presence, even when the color of the square, associated with the stimulus actually displaying a focal point, was not observed.

Quantitative Results: At the conclusion of the experiment, 60 data points had been taken on each subject. An example of the raw data collected is provided in Appendix F. Using the Chi-square method of best fit (Nester, Wasserman and Whitmore 1978, p. 395-402) with $\alpha = 0.05$, the data collected for each subject was found to fit a Poisson distribution for both the expanding and contracting tests. This result was expected since the probability of data points being less than the size of the stationary square was zero.

The Mann-Whitney test (Nester, Wasserman and Whitmore 1978, p. 370-375), with $\alpha = 0.05$, was used to examine the correlation of data from different sample populations. For eight of ten subjects the data taken from tests where the colors were different showed a positive correlation. Of the two which did not display correlation, the data fell slightly beyond the limits with $\alpha = 0.05$, and could be a

result of the small samples involved.

When data taken from tests with the expanding/contracting square in either the left or right eye were examined, correlation was found for seven of ten subjects. The subjects whose data did not correlate showed significant differences in the data taken when each eye observed the alterations. One of the three had previously reported to have weak ocular muscles in the left eye. No direct relation could be found for the lack of correlation of data taken from the remaining two subjects.

One subject reported after the experiment that he observed both squares throughout the experiment. For this reason, his data were not examined for correlation. Experimental disparities, which corrupted some of the data points taken from two subjects, left insufficient sample sizes to conclusively determine the presence of correlation between data populations.

Table 1 contains the arithmetic means of data samples taken from the different experimental test cases. Since the distribution was discovered to be Poisson, the actual limits of an individual's ability to fuse objects would be slightly less than those shown. With the limited number of data elements taken from each test, no attempt was made to specify the actual limit for each individual. The observation that, for all twelve subjects, the limit of fusion was greater when the square expanded, was taken as sufficient evidence to support the hypothesis. The

TABLE 1

Arithmetic Means of Individual's Limits for Binocular Fusion

TEST CONDITIONS		EXPERIMENT SUBJECT					
		DWD	SAH	RJO	GHG	REH	JEF
Right Eye							
Color Test							
G-G	Inc	12.2	11.3	11.1	9.2	10.1	14.0
	Dec	7.2	8.0	7.4	7.1	7.2	8.0
R-G	Inc	9.8	13.7	8.5	8.7	13.5	11.0
	Dec	7.0	8.8	7.4	7.0	7.1	8.7
W-W	Inc	9.0	9.8	9.5	9.8	12.3	13.2
	Dec	6.6	8.5	7.2	7.0	6.9	8.5
All	Inc	9.7	11.9	9.7	9.2	10.2	13.6
	Dec	7.0	8.4	7.4	7.0	7.1	8.4
Left Eye							
Color Test							
W-W	Inc	***	10.5	8.1	8.5	10.1	12.4
	Dec	***	7.7	6.9	7.1	6.9	7.9
G-W	Inc	***	9.8	8.0	8.4	8.8	11.2
	Dec	***	7.6	7.3	7.0	6.8	7.9
G-G	Inc	8.7	11.3	9.4	8.5	10.4	13.7
	Dec	6.6	8.2	7.2	6.6	7.0	8.2
All	Inc	8.7	10.3	8.2	8.5	9.8	12.5
	Dec	6.7	7.8	7.1	6.9	6.9	8.0
Combined							
	Inc	9.2	11.0	9.0	8.9	10.0	13.1
	Dec	6.8	8.1	7.2	7.0	7.0	8.2

*** During the testing of DWD, the programing synchronization was temporarily lost. As a result, the data from the initial tests, with his left eye as the eye of origin, were not collected.

TABLE 1 Continued

Arithmetic Means of Individual's Limits for Binocular Fusion

TEST CONDITIONS		EXPERIMENT SUBJECT					
		TWG	DES	DAH	KNF	RDM	EWK
Right Eye							
Color Test							
G-G	Inc	10.1	10.8	13.4	13.7	14.7	10.2
	Dec	8.4	7.2	6.8	7.8	8.0	7.9
R-G	Inc	11.0	9.9	12.6	13.7	12.7	10.2
	Dec	8.3	7.3	6.9	7.5	9.1	7.5
W-W	Inc	11.2	10.5	14.2	14.1	15.0	12.0
	Dec	10.4	7.0	7.0	8.1	10.1	7.9
All	Inc	10.8	10.4	13.3	13.8	14.1	10.8
	Dec	8.9	7.2	6.9	7.8	9.1	7.8
Left Eye							
Color Test							
W-W	Inc	11.3	9.9	16.0	11.1	15.5	11.3
	Dec	9.7	7.1	7.1	7.3	8.1	7.5
G-W	Inc	9.8	9.4	13.5	10.8	10.1	10.4
	Dec	6.9	6.6	6.8	7.1	7.4	7.5
G-G	Inc	9.4	9.9	15.8	10.5	14.0	10.5
	Dec	6.8	6.6	6.9	7.3	9.1	8.2
All	Inc	10.2	9.7	14.8	10.8	13.2	10.7
	Dec	7.8	6.7	6.9	7.3	8.2	7.7
Combined							
	Inc	10.5	10.1	14.0	12.3	13.7	10.8
	Dec	8.3	6.9	6.9	7.5	8.6	7.8

Note: Subject GA reported in the post-experiment interview that he never lost sight of either square. His data were thus not tabulated or used in tests for correlation.

hypothesis is that perception of a single object can be maintained by a predicative feedback loop as the retinal image sizes vary when the retinal images are first perceived to represent a single object. When the square contracted, and no previous relation was given to the two retinal images, the limit where the two images fused to a perception of one object was significantly lower.

In reviewing the results of the experiment at Table 1 it is also evident that the limits of fusion appear to differ among individuals. The difference in limits among individuals could be explained for the tests involving contracting squares by the interference resulting from binocular rivalry. However, for the tests involving the expanding squares, interference caused by binocular rivalry can not explain the individual differences. When the square expanded, the appearance of a second square was distinct, with no rivalry present prior to its appearance. Thus the results from this experiment show that the capability to fuse forms does vary among individual subjects.

The range of values for the limit of binocular fusion when the squares expand is from a square size of approximately 8.9 cm to 14.0 cm. Translated into the ratio of disparity in image size between retinal images, this range becomes 1.37 to 2.15. Similarly, the translated range of limits found for different individuals when the square contracted is 1.05 to 1.32.

The data in Table 1 suggest that the normal limit as

the square expands is approximately 10 cm. The difference in visual angle subtended by the two squares at this limit is from 3.4 degrees to 5.2 degrees. Assuming the normal limit as the square contracts to be approximately 7.5 cm, the difference in visual angle subtended by the two squares at the limit is from 3.4 degrees to 3.9 degrees.

MAE Related to Location in the Visual Field

The thirteen subjects who participated all reported the observation of MAE produced by the moving vertical square wave stimulus. The test to determine the stimulus duration threshold resulted in data with a large degree of variation. Similarly, data received on the duration of MAE also showed significant variation. The variation was expected since, as reported from the literature earlier, reports on MAE involve a subjective determination by the participants.

An example of the raw data collected from the tests on each individual is shown in Appendix G. For analysis of the data related to stimulus duration thresholds, the reports were averaged over a stimulus duration interval of 0.67 seconds. The characteristics of the averages plotted were then used to draw a best fit curve for each test sample. An example of this method is shown with the graph in Figure 14, which plots the raw data contained in Appendix G. This method was used since there were insufficient data to allow a more rigorous statistical approach because of the variation in subjective reports. By using this method the threshold characteristics for individuals could be

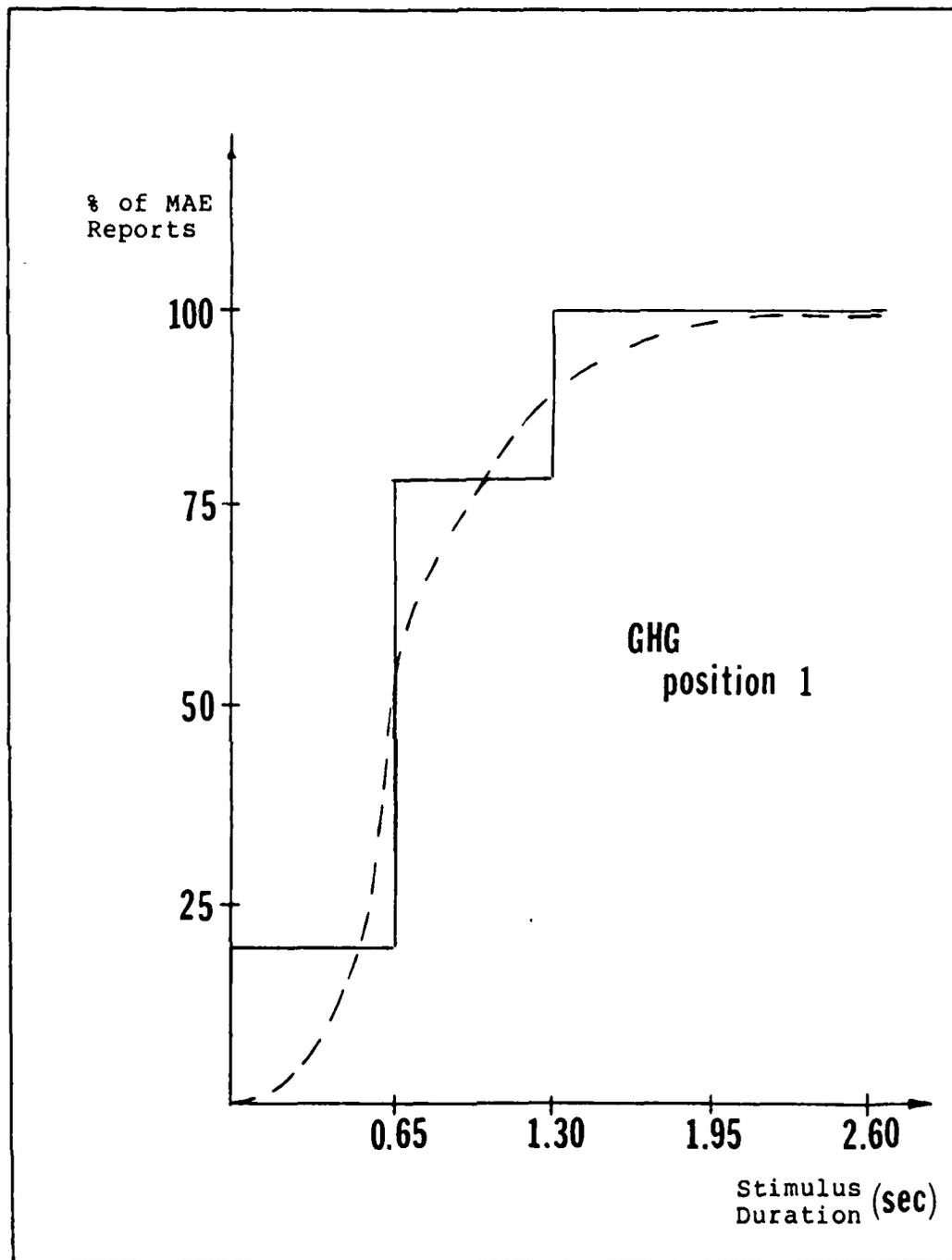


Fig 14. An Example of the Time Interval Method used in Analyzing the Raw Data from an Individual's Reports in the Experiment with MAE Thresholds for Stimulus Duration.

categorized.

Eleven of the thirteen subjects displayed a family of threshold curves which were considered "normal." Each of these individuals' thresholds increased as the location of the stimulus moved further into his periphery. Four of the eleven considered normal were further categorized as "normal-high" since their thresholds were significantly higher than the other eight. These individuals reported little if any MAE when the stimulus was positioned off the center of their visual field. An illustration of the family of curves for the different categories is shown in Figure 15.

The two remaining subjects were categorized as displaying "abnormal" families of curves (Figure 15). Both subjects consistently reported MAE in the center of their visual field and in their far periphery. However neither individual observed any MAE when the stimulus was in their near periphery. No correlation with reported visual defects could be discovered to explain their variation from the other eleven participants.

The fact that eleven of the thirteen subjects reported higher stimulus duration thresholds in their periphery supports the prediction that the lesser binocular image-size variation in the periphery would provide less stimulation to the learning process hypothesized to be involved in the production of MAE.

To permit comparison of relative thresholds between

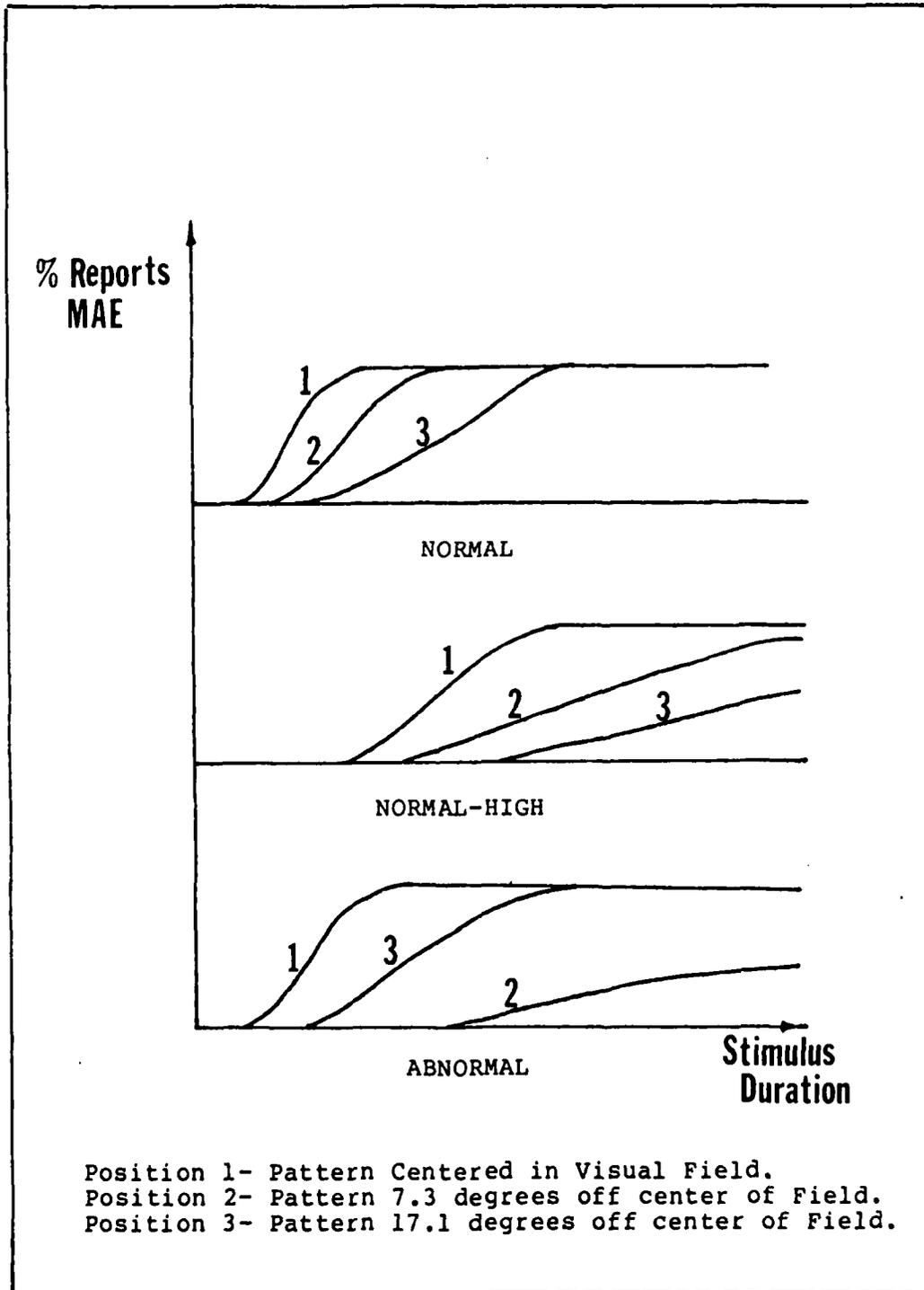


Fig 15. An Example of the Family of Stimulus Duration Threshold Curves Associated with each Category.

individuals, the point on each estimated curve where the percentage of reports of MAE equaled 50% was determined. Once again, because of the small data sample, this method of analysis can be argued to be statistically weak. However the justification for using this method is that it permitted comparative ranking.

Using the methods described for analysis of the threshold data, and determining the means for duration of MAE at each position, the results provided in Table 2 were obtained.

In view of the results in Table 2 certain general observations can be made. Differences between individuals' stimulus duration thresholds were significant. In test cases where some individuals consistently reported MAE with stimulus durations of one second or less, others would not report MAE when the stimulus duration was up to 2.7 seconds.

Another observation which can be made is that, for eight of the thirteen subjects, an increase in their threshold of MAE in the periphery corresponded with a drop off in the duration of MAE. Again the small sample size and the subjective nature of an individual's reports prevent making any direct correlation between the threshold for MAE and the duration of MAE.

Correlation Between Binocular Fusion and MAE

Though a lack of knowledge concerning the mechanisms involved in human learning prevents the prediction of what correlation there should be between the parameters of

TABLE 2

Results of Data from an Experiment on the
Parameters of MAE as a Function of Location in Visual Field

SUBJECT	THRESHOLD (sec)			DURATION (sec)			CATEGORY OF FAMILY OF CURVES
	Position			Position			
	1	2	3	1	2	3	
KNF	0.3	>2.7	>2.7	6.6	**	**	Normal-High
TWG	1.0	1.6	1.6	6.8	6.2	4.0	Normal
GHG	0.8	1.2	2.0	6.3	5.8	4.0	Normal
RJO	1.3	1.5	>2.7	5.2	3.9	2.5	Normal
DWD	0.5	0.7	*	6.5	7.1	7.7	Normal
REH	0.7	0.9	1.2	7.0	8.5	6.1	Normal
GA	0.7	>2.7	>2.7	4.7	**	**	Normal-High
RDM	1.9	>2.7	>2.7	4.5	2.9	**	Normal-High
SAH	0.7	0.8	1.4	5.3	5.0	2.5	Normal
EWK	0.9	2.4	1.6	2.7	3.2	1.9	Normal
DAH	2.7	>2.7	>2.7	3.4	**	**	Normal-High
JEF	2.7	>2.7	1.2	4.9	3.3	1.8	Abnormal
DES	1.3	>2.7	1.3	3.7	**	4.3	Abnormal

* Individual was tested prior to increasing the random number maximum from 10 to 20.

** At least twice the individual reported no MAE.

binocular fusion and MAE, the fact that each is hypothesized to depend on the same predictive feedback loop would indicate a correlation should exist. Because of this the results from each experiment were analyzed together to determine if any correlation could be found between an individual's ability to fuse objects and his reports of MAE.

On first examination of the data from each of the experiments, a subjective correlation was observed. Subjects who tended to have extremely high limits for binocular fusion also exhibited high stimulus duration thresholds to produce MAE. An examination of Tables 1 and 2 reveals that of the four subjects whose collective mean limit for binocular fusion (when the square was expanding) was greater than 12.0 cm, all were classified as either "normal-high" or "abnormal" in the experiment with thresholds for MAE. Of the eight remaining subjects, who reported lesser limits for binocular fusion, all but one were classified as "normal" based on their family of curves in the experiment with thresholds for MAE.

To test for correlation in a more rigorous manner, Kendall's tau test (Robson 1973, p. 56-60) at the $P = 0.05$ level was applied to the ranking of individuals by their collective means for binocular fusion and by their thresholds at position 2 for MAE. Data related to position 2 in the experiment with thresholds for MAE was used in the test for correlation since individuals displayed less variance in their reports at this position. It is believed

that since position 2 involved threshold times in the midrange of the stimulus durations tested, the subjects were able to better differentiate in subjective reports on the presence of MAE.

The scattergram and relevant test parameters are shown in Figure 16. The Kendall tau test provided a positive correlation between the performance of the participants in the two experiments.

The correlation discovered provides evidence that the visual information processes involved in producing binocular fusion also are involved in the perceptual fault which results in MAE. Since binocular fusion is hypothesized to involve a predictive feedback loop to the cortex, and MAE are believed to result from a learned cortical response which eliminates the latency of the feedback loop to provide fusion, then a correlation between experimental data could be predicted. However, the exact nature of the correlation could not be predicted, nor can the correlation discovered be adequately explained, since the manner in which humans learn a patterned stimulus is not well defined. The correlation can be used only to provide further evidence for the structure of the hypothesized model of visual information processing (Figure 9).

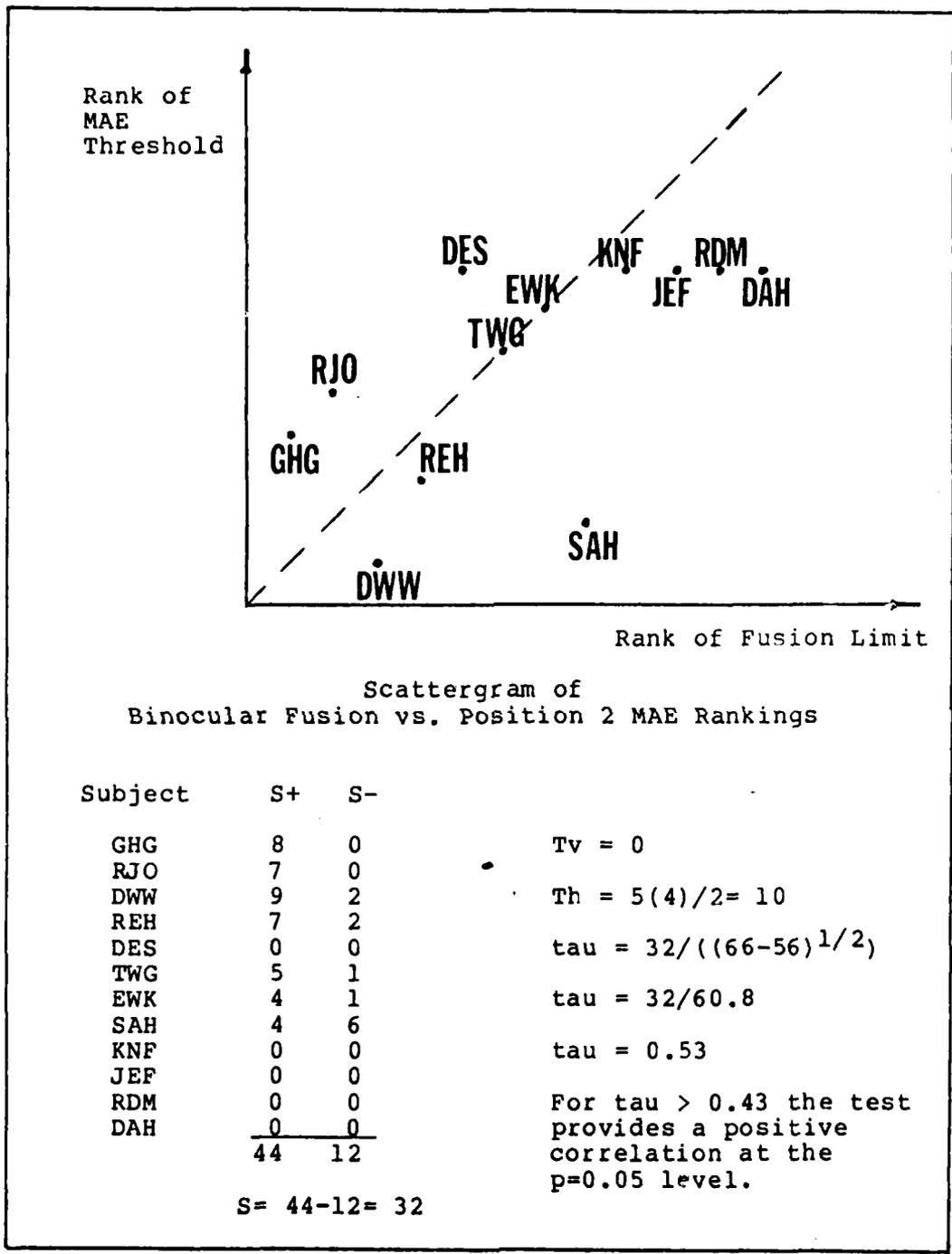


Fig 16. Scattergram and Parameters Related to Kendall tau Test for Correlation of Performance Between Limits for Binocular Fusion and MAE Stimulus Thresholds.

VI. Conclusions and Recommendations

Conclusions

A hypothetical model has been developed to show how human visual information processing is accomplished. The model was derived by postulating the existence of processes based on what were concluded to be essential requirements. The requirements were determined by the information manipulation needed to obtain a correct visual perception from a system which receives visual inputs from two eyes. The model was designed to specifically address how the perception of motion and the perception of single objects could be determined. The ultimate objective was to evaluate the model developed in this manner, based on its ability to explain the phenomenon of MAE.

The model developed (Figure 9) attributed visual processing functions to the cerebellum, lateral geniculate nucleus, and cerebral cortex. The cerebellum was hypothesized to provide a predictive measurement for both the binocular image size ratio and image displacement to the area of the cortex performing binocular integration. The lateral geniculate nucleus (LGN) was attributed with the function of providing monocular mappings, displaced in time, as inputs to the same area of the cortex. Then, the cortex was hypothesized to develop a single fused visual scene by using the monocular inputs from the LGN and the predictive measurements from the cerebellum. From the fused scene the

cortex was further hypothesized to perform the information processes associated with object identification, computation of retinal slip velocities associated with objects, and computations to determine actual motion of an object in the visual field.

The visual processing model was then compared to known perceptions induced by controlled stimuli. Specifically, the model was examined to determine its effectiveness in the perceptions involved in uniform motion and MAE.

Perceptions of single objects from images moving across the retina were hypothesized to depend on a predictive feedback loop to the cortex which permits compensation for image-size variation and image displacement. By so compensating, the cortex could thus determine single objects from separate monocular inputs which involve disparity.

MAE were concluded to be caused when the cortex learned a response pattern and thus no longer required the predictive feedback provided by the cerebellum. The basis for the functional relationship between the cerebellum and cortex was associated with their similarly hypothesized roles in muscle coordination activities (Guyton 1976) and recent micro-electrode experiments investigating the cerebellum (Kase et al. 1979). It was concluded that the role of the cerebellum proposed in the model was consistent with previously published findings and could provide an explanation for MAE observed over 24 hours after the adaptation to a stimulus.

The function of the LGN to provide successive monocular inputs separated in time was based on the need for information from successive frames to permit motion detection and the suitability of the known physical nature of the LGN to this function. Though no experimental evidence was provided, it was concluded that this hypothesis shows no disagreement with neurological studies of the LGN (Tat So and Shapley 1981). These studies have shown that little or no processing is performed by the LGN. However, since these studies involved single micro-electrode investigations, the time relationship of differing layers of the LGN mappings would not have been clearly evident.

Functions attributed to the cortex were inferred from previous studies and requirements for visual information processes developed from an investigation of the properties of the monocular retinal inputs which lead to perception. No experimental evidence was collected to strengthen the hypothetical processes hypothesized to be performed within the cortex.

In an experiment which measured an individual's ability to fuse objects presented separately to each eye, two separate limits were discovered. Separate images will continue to be perceived as one object, with a larger image size disparity limit, if they are initially seen as representing one object. The range of image-size, taken from data collected on twelve subjects, was discovered to be from 1.37 to 2.15 for the case when the images were first

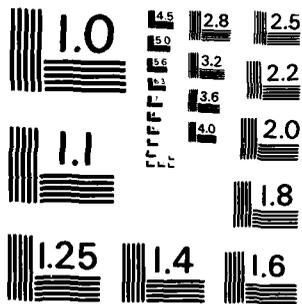
AD-A124 842

32
A MODEL FOR HUMAN VISUAL PROCESSING WHICH EXPLAINS
PERCEPTIONS OF MOTION.. (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. R L CARTER
DEC 82 AF17/GE/EE/82D-23 F/G 5/10

UNCLASSIFIED

NL

END
DATE
FILED
3 83
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

associated to a single object. With no prior association of the images, the same subjects displayed ratio limits from 1.05 to 1.32. The existence of the two separate limits provides evidence for the predictive feedback loop hypothesized to be used in the integration of the monocular inputs.

In the same experiment, further evidence was provided to support the hypothesis of a feedback loop. In post-experiment interviews, the subjects reported that blinking their eyes during the tests would immediately result in double-vision (the object in each eye being observed simultaneously). Since the act of blinking one's eyes would disturb the continuity of the predictions, this result is consistent with the existence of a predictive feedback loop used in binocular integration.

The experiment was conducted using different contrast levels in the presentations to the two eyes. Subjectively the difference in contrast was concluded not to interfere with the ability to fuse the forms presented. During the experiment, different colors were associated with squares seen by each eye. Correlation tests at $\alpha = 0.05$ showed no apparent difference in sample populations of experimental tests taken with different colors. When the image variation was located in either the left or right eye, three of twelve subjects displayed a distinct difference in the fusion limits obtained. The remaining subjects displayed no significant difference at $\alpha = 0.05$ in their fusion limits

when the eye of origin for variation was changed.

From similar perceptions reported by twelve of the thirteen subjects, certain properties of binocular integration were concluded. Since the subjects reported the presence of a focal point when it was not displayed to the eye from which they were simultaneously reporting the color and size of the square, it was concluded that binocular integration could involve the inclusion of all forms given importance. In this manner, forms, or objects, observed in only one monocular scene could be integrated into a visual perception which selectively builds a view of the entire visual field. Additional support for this conclusion was taken from the fact that the same subjects also reported to observe the color of the fused forms to always be that of the square which was varying in size. In this case the motion of the boundary from one of the monocular inputs allowed the system to stabilize on its associated color. Binocular rivalry could not satisfactorily explain this observation since perception of the focal point would remain though it was on the opposite screen within a square whose color was not observed.

In a second experiment the stimulus duration threshold of MAE and the duration of MAE were both examined as a function of the location of the stimulus in the visual field. Since the hypothesized model explained MAE as being related to the learning of a uniform pattern of image-size and image displacement variation, it was predicted that the

threshold for MAE would drop off in the periphery where less variation occurs.

The results of the experiment, for stimulus duration thresholds, showed eleven of the thirteen subjects displayed a family of threshold curves which matched the results predicted. Though the thresholds determined varied between individuals, each of the eleven subjects evidenced a larger threshold as the stimulus was moved further into their periphery.

Since binocular fusion and MAE were hypothesized to both be dependent on the same physical mechanisms, it was predicted that a correlation would exist between an individual's ability to fuse forms and his thresholds for MAE. The exact correspondence could not be predicted because of a lack of a well-defined model for how a pattern is learned. When the ranking of an individual's performance was compared with the Kendell tau test at the $P = 0.05$ level, a positive correlation was found. Subjects with high limits for fusion also displayed high stimulus duration thresholds for MAE. The correlation provides evidence that binocular fusion and MAE do depend on similar mechanisms. In regard to the visual processing model presented, correlation of the data from the two experiments provides further evidence for the role assigned to a predictive feedback loop.

Recommendations

To provide a better data base for statistical analysis,

it is recommended that the experiment with the stimulus duration thresholds for MAE be expanded. The 20 data points accumulated at each stimulus location did not permit a truly rigorous approach to determining the threshold of an individual. Less variation in an individual's reports of MAE might be obtained by increasing the range of stimulus durations presented. In the experiment performed, less variation was observed if an individual's threshold was in the mid-range of the durations tested.

For future attempts to determine the limits of form fusion, it would be beneficial if the eye of origin, for the object varying in size, could be a random selection. The use of two micro-processors without a communication link did not permit random selection for eye of origin in the experiment performed. Random selection of eye of origin could provide a better test for correlation of data between the two sample populations.

The subjective evaluation that fusion was independent of contrast, above the individual's contrast threshold, should be explored. If this fact is true, then it would give evidence for binocular fusion based solely on detection of form boundaries.

Though correlation between data from the two experiments was used to support the existence of a predictive feedback loop, the association of the cerebellum to the feedback loop was not established. A definitive experiment on this hypothesis remains to be conducted with

subjects who have known deficiencies in the functioning of their cerebellum. Similar studies to determine the relationship of the cerebellum to muscle coordination have been conducted (Guyton 1976).

The hypothesis that the LGN provides separate monocular mappings displaced in time could be tested by micro-electrode experiments determining the firing rate characteristics of neurons in different layers of the LGN. Neurons in different layers, whose firing rates can be associated with a controlled stimulus, should exhibit a time delay relationship if the hypothesis is true.

In the development of the visual processing model it was hypothesized that the system compensates for physically induced retinal slip velocities. It was further stated that this compensation must be conducted based on a given reference plane. The reference plane hypothesized was the plane containing the fixation points. One experimental proposal to test this hypothesis would be to set an individual in a rotating chair with a fixation point at a constant distance which rotated with the chair. As the chair and fixation point are rotated at a known velocity the subject would then be required to report on the motion of objects at different distances in the visual field. If the hypothesis is correct, the accuracy of an individual's ability to report motion should be directly related to the distance the object is from the plane of the fixation point.

Project Summary

The hypothetical model presented in Figure 9 exhibits numerous process relationships not previously reported. Yet the requirements to form perception from binocular vision seem to imply that either the process relationships presented or related processes must exist. A review of the results of previous studies of visual information processing does not show serious conflict with the process relationships hypothesized. However, this model does differ significantly in the viewpoint taken in drawing conclusions from some of the results of previous studies.

If importance is to be attributed to this model, that importance derives from its difference in viewpoint rather than its exactness in describing the full range of human visual perceptions. In fact, the development of the model in Figure 9 was limited in scope to a high level processing view of a system involved with perception of moving objects. The tests provided were limited to those associated with the hypothetical relationship of a predictive feedback loop to binocular integration. Further tests of the validity of the proposed model are left to future studies and experiments.

Project Summary

The hypothetical model presented in Figure 9 exhibits numerous process relationships not previously reported. Yet the requirements to form perception from binocular vision seem to imply that either the process relationships presented or related processes must exist. A review of the results of previous studies of visual information processing does not show serious conflict with the process relationships hypothesized. However, this model does differ significantly in the viewpoint taken in drawing conclusions from some of the results of previous studies.

If importance is to be attributed to this model, that importance derives from its difference in viewpoint rather than its exactness in describing the full range of human visual perceptions. In fact, the development of the model in Figure 9 was limited in scope to a high level processing view of a system involved with perception of moving objects. The tests provided were limited to those associated with the hypothetical relationship of a predictive feedback loop to binocular integration. Further tests of the validity of the proposed model are left to future studies and experiments.

Bibliography

- Banks, M. S.; Asliu, R. N.; and Letson R. R. 1975. Sensitive period for the development of human binocular vision. *Science* 190:675-77.
- Banks, W. P. and Kane, D. A. 1972. Discontinuity of seen motion reduces the visual motion aftereffect. *Perception & Psychophysics* 12:69-72.
- Benson, A. J. and Reason, J. T. 1966. Individual differences in after-effects of apparent motion. Part II: Judgement of exponentially decaying signals, impulsiveness, and motion sickness susceptibility. Flying Personnel Research Committee unclassified report 226b.
- Blake, R. and Camisa, J. 1978. Binocular vision always monocular? *Science* 200:1497-99.
- Blake, R. and Cormack, R. H. 1979. Psychophysical evidence for a monocular visual cortex in stereoblind humans. *Science* 203:274-75.
- Braddick, O. 1974. A short-range process in apparent motion. *Vision Res.* 14:519-527.
- Burt, P. and Julesz B. 1980. A disparity gradient limit for binocular fusion. *Science* 208:615-17.
- Cohn, T. E. and Lasley, D. J. 1976. Binocular vision: Two possible central interactions between signals from two eyes. *Science* 192:561-63.
- Favreau, O. E.; Emerson, V. F.; and Corballis, M. C. 1972. Motion perception: A color-contingent aftereffect. *Science* 176:78-79.
- Favreau, O. E. and Corballis, M. C. 1976. Negative aftereffects in visual perception. *Sci Amer* 235:42-48.
- Freeman, R. D. and Bonds, A. B. 1979. Cortical plasticity in monocularly deprived immobilized kittens depends on eye movement. *Science* 206:1093-95.
- Grimson, W. E. L. 1980. A computer implementation of a theory of human stereo vision. MIT Artificial Intelligence Laboratory memo 565.
- Guyton, A. C. 1976. The textbook of medical physiology. 5th ed. Philadelphia: W. B. Saunders Co.
- Hepler, N. 1968. Color: A motion-contingent aftereffect. *Science* 162:376-77.

- Hubel, D. H. and Wiesel, T. N. 1959. Receptive fields of single neurons in the cat's striate cortex. *J. Physiol.* 148: 574-591.
- Johansson, G. 1975. Visual motion perception. *Sci Amer* 232:76-88.
- Kase, M.; Miller, D. C.; and Noda, H. 1980. Discharges of purkinje cells and mossy fibres in the cerebellar vermis of the monkey during saccadic eye movements and fixation. *J. Physiol.* 300:539-55.
- Kase, M. et al. 1979. Target velocity signals of visual tracking in vermal purkinje cells of the monkey. *Science* 205:717-20.
- Kertesz, A. E. and Jones R. W. 1970. Human cyclofusional response. *Vision Res.* 10:891-96.
- Levi, D. M.; Harworth R. S.; and Smith III, E. L. 1979. Humans deprived of normal binocular vision have binocular interactions tuned to size and orientation. *Science* 206:852-54.
- Levinson, E. and Sekuler, R. 1976. Adaptation alters perceived direction of motion. *Vision Res.* 16:779-81.
- Lisberger, S. G. and Fuchs, A. F. 1978. Role of primate flocculus during rapid behavioral modification of vestibulocular reflex. I. Purkinje cell activity during visually guided horizontal smooth-pursuit eye movements and passive head rotation. *J. Neurophysiol.* 41:733-63.
- Marshak, W. and Sekuler, R. 1979. Mutual repulsion between moving visual targets. *Science* 305:1399-401.
- Masland, R. H. 1969. Visual motion perception: Experimental modification. *Science* 165:819-21.
- McIlwain, J. T. and Fields, H. L. 1970. Superior colliculus: Single unit responses to stimulation of visual cortex in the cat. *Science* 170:1426-28.
- McKenzie, R. E. and Hartman, B. 1961. The effects of size, speed, and inspection time on the duration of the spiral aftereffect. School of Aerospace Medicine, USAF Aerospace Medical Center unclassified report 62-13.
- Nester J.; Wasserman W.; and Whitmore G.A. 1978. Applied statistics. Boston: Allyn and Bacon, Inc.
- O'Shea, R. P. and Crassini, B. 1981. Interocular transfer of motion after-effect is not reduced by binocular

- rivalry. *Vision Res.* 21:801-804.
- Packwood, J. and Gordon, B. 1975. Stereopsis in normal domestic cat, siamese cat, and cat raised with alternating monocular occlusion. *J. Neurophysiol.* 38:1485-98.
- Pantle, A. and Picciano, L. 1976. A multistable movement display: Evidence for two separate motion systems in human vision. *Science* 193:500-502.
- Regan, D.; Beverley, K.; and Cynader, M. 1979. The visual perception of motion in depth. *Sci. Amer.* 241:136-51.
- Richards, W. 1970. Stereopsis and stereoblindness. *Exp. Brain Res.* 10:380-88.
- Riggs, L. A. and Day, R. H. 1980. Visual aftereffects derived from inspection of orthogonally moving patterns. *Science* 208:416-18.
- Robinson, D. L. and Wurtz, R. H. 1976. Use of an extraretinal signal by monkey superior colliculus neurons to distinguish real from self-induced stimulus movement. Armed Forces Radiobiology Research Institute report # SR76-28.
- Robinson, D. L. and Goldberg, M. E. 1977. Visual mechanisms underlying gaze: Function of the superior colliculus. Vol.1, Elsevier/North-Holland: Biomedical Press.
- Robson, C. 1973. Experiment, design and statistics in psychology. Baltimore: Penguin Books Inc.
- Ross, J. 1976. The resources of binocular perception. *Sci. Amer.* 234:80-86.
- Sekuler, R. and Pantle, A. 1967. A model for after-effects of seen movement. *Vision Res.* 7:427-39.
- Shipley, T. and Rawlings, S. C. 1970. The nonius horopter I. History and theory. *Vision Res.* 10:1225-62.
- Steinbach, M. J. 1976. Pursuing the perceptual rather than the retinal stimulus. *Vision Res.* 16:1371-76.
- Suzuki, D. A.; Noda, H.; and Kase, M. 1981. Visual and pursuit eye movement: Related activity in posterior vermis of monkey cerebellum. *J. Neurophysiol.* 46:1120-39.
- Tat So, Y. and Shapley, R. 1981. Spatial tuning of cells in and a bundle of lateral geniculate nucleus of the cat: X and Y relay cells and perigeniculate interneurons. *J. Neurophysiol.* 45:107-120.

Tolhurst, D. J. and Hart, G. 1972. A psychophysical investigation of the effects of controlled eye movements on the movement detectors of the human visual system. Vision Res. 12:1441-46.

Tyler, C. W. 1973. Stereoscopic vision: Cortical limitations and a disparity scaling effect. Science 181:276-78.

Tyler, C. W. 1975. Spatial organization of binocular disparity sensitivity. Vision Res. 15:583-90.

Weisstein, N.; Maguire, W.; and Berbaum, K. 1977. A phantom-motion aftereffect. Science 198:955-57.

APPENDIX A

Programs to Support an Experiment on the Limits of Binocular Fusion

The following program listing was executed on a TRS-80 Color Computer with 32K RAM and Extended Basic. The purpose of the program was to present interactive commands and visual stimulus scenes in support of a dichoptically displayed experiment with the limits of human binocular fusion.

Program Parameters:

PT = Random Variable determining
presence of the Focal Point
T = Determines color of Square
NR = Current test number
FL = Fusion Limit
CR\$ = Color of Square on Cromemco
TR\$ = Color of Square on TRS-80
F\$ = Presence of Focal Point
ST\$ = Test Conditions

```
10 PRINT#-2," TEST# CROMEMCO TRS-80 FOCAL POINT  
CONDITIONS SIZE"  
20 FOR I=1 TO 3: PRINT#-2,CHR$(10): NEXT I  
30 PT=5: T= 0: NR= 1  
40 SCREEN 0,0: CLS  
50 PRINT@96,"IN THIS PART OF THE EXPERIMENT"  
60 PRINT@128,"YOU WILL NEED TO CENTER A SOLID"  
70 PRINT@160,"SQUARE WITHIN A FRAME BY ADJUST-"  
80 PRINT@192,"ING THE MIRROR. AFTER EACH"  
90 PRINT@224,"ADJUSTMENT PRESS BOTH THE CONTROL ON THE  
TRS AND A <SPACE>  
100 PRINT@288,"FOLLOWED BY ANY LETTER ON THE CROMEMCO."  
110 PRINT@384," PRESS CONTROL TO CONTINUE."  
120 GOSUB 1280: GOSUB 1330: GOSUB 1390  
130 GOSUB 1280: GOSUB 1330: GOSUB 1480  
140 GOSUB 1280: GOSUB 1330  
150 SCREEN 0,0: CLS  
160 PRINT@128,"YOU WILL NOW START THE LEARN-"  
170 PRINT@160,"ING PHASE. REMEMBER TO FOCUS ON"  
180 PRINT@192,"THE BLACK DOT. HERE'S AN EXAMPLE"  
190 PRINT@224,"OF WHAT YOU WILL SEE."  
200 GOSUB 1230: GOSUB 1570: 1910: GOSUB 1230  
210 SCREEN 0,0: CLS  
220 PRINT@64," WE WILL START BY"  
230 PRINT@96," EXPANDING THE SQUARE."  
240 GOSUB 1970  
250 SCREEN 0,0: CLS  
260 PRINT@64," DID YOU SEE THE"  
270 PRINT@96," SECOND SQUARE APPEAR?"  
280 PRINT@416," WATCH AGAIN!"
```

```

290 GOSUB 1970
300 SCREEN 0,0: CLS
310 PRINT@64," THIS TIME PRESS THE"
320 PRINT@96," CONTROL WHEN THE SECOND"
330 PRINT@128," SQUARE APPEARS."
340 GOSUB 1970
350 SCREEN 0,0: CLS
360 PRINT@64," YOU'VE GOT IT!"
370 GOSUB 1230: CLS
380 PRINT@96," "NOW YOU WILL GET A CHANCE TO SEE"
390 PRINT@128," WHAT HAPPENS WHEN THE SQUARE"
400 PRINT@160," SHRINKS."
410 PRINT@192," TAKE A LOOK!"
420 GOSUB 2080
430 SCREEN 0,0: CLS
440 PRINT@64," DID YOU SEE THE SQUARES"
450 PRINT@96," BECOME ONE SINGLE SQUARE?"
460 PRINT@416," WATCH AGAIN!"
470 GOSUB 2080
480 SCREEN 0,0: CLS
490 PRINT @64," THIS TIME STOP IT BY PRESS-"
500 PRINT@96," ING THE CONTROL WHEN YOU"
510 PRINT@128," THINK THEY FUSE TO ONE."
520 GOSUB 2080
530 SCREEN 0,0: CLS
540 PRINT@64," DID THE OTHER SQUARE"
550 PRINT@96," REAPPEAR IMMEDIATELY?"
560 PRINT@416," TRY AGAIN!"
570 GOSUB 2080
580 SCREEN 0,0: CLS
590 PRINT@64," NOW IF THE 2ND SQUARE REAPPEARS"
600 PRINT@128," -THEN WAIT TILL IT BEGINS TO"
610 PRINT@160," SHRINK AND STOP IT AGAIN."
620 PRINT@224," -CONTINUE UNTIL THE 2ND SQUARE"
630 PRINT@256," NO LONGER REAPPEARS AFTER YOU HALT
IT."

640 GOSUB 1230
650 GOSUB 2080
660 CLS
670 PRINT@64," THIS IS HOW THE TESTS WILL"
680 PRINT@96," BE TAKEN SO TRYIT A FEW"
690 PRINT@128," MORE TIMES."
700 PRINT@192," REMEMBER TO KEEP STOPPING IT"
710 PRINT@224," UNTIL THE 2ND SQUARE NO LONGER"
720 PRINT@256," REAPPEARS!!"
730 FOR H=1 TO 3
740 GOSUB 2080
750 NEXT H
760 SCREEN P,0: CLS
770 PRINT@64," GREAT!! I THINK YOU'VE GOT IT."
780 GOSUB 1280: GOSUB 1280: CLS
790 PRINT@64," THE TEST PHASE WILL NOW BEGIN."
800 PRINT@128," DON'T WORRY YOU ARE DOING FINE."
810 GOSUB 1230: CLS

```

```

820 PRINT@64, "FOR THE FOLLOWING TESTS USE THE"
830 PRINT@96, "CONTROL TO INDICATE WHEN THE"
840 PRINT@128, "SQUARES BECOME ONE, WHEN CONTRACTING,
OR TWO SQUARES"
841 PRINT@192, "APPEAR WHEN EXPANDING."
850 TR$= "GREEN": CR$= "GREEN"
860 FOR M= 1 TO 5
870 PT=RND(10): GOSUB 1970: ST$= "TRS-INC": GOSUB 2180
880 PT=RND(10): GOSUB 2080: ST$= "TRS-DEC": GOSUB 2180
890 NEXT M
900 SCREEN 0,0: CLS
901 PRINT@96, "DID YOU REMEMBER TO KEEP YOU EYES
FIXED ON THE FOCAL POINT?"
902 GOSUB 1230: CLS
910 PRINT@96, "PRESS <SPACE> ON THE CROMEMCO
FOLLOWED BY ANY LETTER."
920 GOSUB 1230: CR$= "RED"
930 FOR M= 1 TO 5
940 PT=RND(10): GOSUB 1970: ST$= "TRS-INC": GOSUB 2180
950 PT=RND(10): GOSUB 2080: ST$= "TRS-DEC": GOSUB 2180
960 NEXT M
970 SCREEN 0,0: CLS
971 PRINT@96, "REMEMBER--LOOK FOR THE 2ND SQUARE
AS IT EXPANDS AND TRY TO"
972 PRINT@160, "KEEP THE 2ND FROM REAPPEARING
WHEN IT CONTRACTS."
973 GOSUB 1230: CLS
974 PRINT@96, "DON'T FORGET TO KEEP YOUR EYES ON
THE FOCAL POINT."
975 PRINT@224, "YOU ARE DOING FINE--KEEP UP THE
GOOD WORK!"
976 GOSUB 1230: CLS
980 PRINT@96, "PRESS <SPACE> ON THE CROMEMCO
FOLLOWED BY ANY LETTER."
990 GOSUB 1230: CR$="WHITE": TR$= "WHITE": T=1
1000 FOR M=1 TO 5
1010 PT=RND(10): GOSUB 1970: ST$= "TRS-INC": GOSUB 2180
1020 PT=RND(10): GOSUB 2080: ST$= "TRS-DEC": GOSUB 2180
1030 NEXT M
1040 SCREEN 0,0: CLS
1050 PRINT@128, "YOU'RE GOING DOWN THE HOME STRETCH
NOW!!"
1060 GOSUB 1230: CLS
1070 PRINT@96, "FROM NOW ON YOU WILL NEED TO USE
THE <SPACE> ON THE"
1080 PRINT@160, "CROMEMCO TO STOP THE
EXPANDING/CONTRACTING"
1090 PRINT@224, "SQUARE."
1100 GOSUB 1230: CLS
1110 PRINT@128, "REMEMBER TO PRESS ANY LETTER ON
THE CROMEMCO EACH TIME"
1120 PRINT@192, "AFTER PRESSING THE <SPACE>!!"
1130 GOSUB 1230: CLS
1140 PRINT@128, "PRESS <SPACE> FOLLOWED BY ANY

```

```

                                LETTER ON THE CROMEMCO TO"
1150 PRINT@192, "CONTINUE."
1160 GOSUB 1230: T=1:GOSUB 1570: GOSUB 1910: GOSUB 1330
1170 T=0: GOSUB 1570: GOSUB 1910
1180 GOTO 1180
1190 *****SUBROUTINES*****
1200 '
1210 ' DELAY FOR 7 SECONDS
1220 '
1230 FOR I=1 TO 3400: NEXT I
1240 RETURN
1250 '
1260 ' PAUSE FOR 2 SECONDS
1270 '
1280 FOR I=1 TO 975: NEXT I
1290 RETURN
1300 '
1310 ' WAIT FOR CONTROL BUTTON
1320 '
1330 B = PEEK(65280)
1340 IF B <> 254 THEN 1330
1350 RETURN
1360 '
1370 ' DRAW SQUARE FRAME & WAIT
1380 '
1390 PMODE 4,1
1400 SCREEN 1,0: PCLS
1410 LINE (84,52)-(172,140),PSET,B
1420 B= PEEK(65280)
1430 IF B <> 254 THEN 1420
1440 RETURN
1450 '
1460 ' DRAW SOLID SQ. & WAIT
1470 '
1480 PMODE 4,1
1490 SCREEN 1,0: PCLS
1500 LINE (78,46)-(178,146),PSET,BF
1510 B= PEEK(65280)
1520 IF B <> 254 THEN 1510
1530 RETURN
1540 '
1550 ' DRAW SMALL TEST SQUARE
1560 '
1570 PMODE 4,1
1580 SCREEN 1,T: PCLS
1590 LINE (87,63)=(169,129),PSET,BF
1600 RETURN
1610 '
1620 ' DRAW LARGE TEST SQUARE
1630 '
1640 PMODE 4,1
1650 SCREEN 1,T: PCLS
1660 LINE (24,0)-(232,192),PSET,BF
1670 RETURN

```

```

1680 '
1690 'CONTRACT SQ. & PAUSE ON CONTROL.  RETAIN SIZE OF
      ' SQUARE ON LAST PAUSE (FL).
1700 '
1710 FOR I=0 TO 63
1720 LINE (24+I,0+I)-(232-I,192-I),PRESET,B
1730 FOR J=1 TO 5
1740 B= PEEK(65280):  IF B =254 THEN 1770
1750 NEXT I
1760 GOSUB 1280:  PCLS :  RETURN
1770 FL=64-I:  FOR K=1 TO 450:  NEXT I:  GOTO 1720
1780 '
1790 ' EXPAND SQ. UNTIL CONTROL.  RETAIN SIZE OF SQ. WHEN
      ' HALTED (FL).
1800 '
1810 FOR I=0 TO 63
1820 LINE (87-I,63-I)-(169+I,129+I),PSET,B
1830 FOR J=1 TO 5
1840 B= PEEK(65280):  IF B=254 THEN 1860
1850 NEXT I
1860 FL=I:  FOR I=1 TO 975:  NEXT I
1870 PCLS:  RETURN
1880 '
1890 ' DRAW FOCAL POINT
1900 '
1910 LINE (127,95)-(129,97),PRESET,BF
1920 RETURN
1930 '
1940 ' EXPAND SQUARE TILL CONTROL.  FOCAL PT ON TRS-80 AT
      ' RANDOM.
1950 ' OUTPUT:  FL= FUSON LIMIT
1960 '
1970 GOSUB 1230:
1980 GOSUB 1570
1990 IF PT < 5 THEN 2010
2000 GOSUB 1910
2010 GOSUB 1280
2020 GOSUB 1810
2030 RETURN
2040 '
2050 ' CONTRACT PAUSING FOR CONTROL.  FOCAL PT ON TRS-80 AT
      ' RANDOM.
2060 ' OUTPUT:  FL = FUSION LIMIT
2070 '
2080 GOSUB 1230
2090 GOSUB 1640
2100 IF PT <5 THEN 2120
2110 GOSUB 1910
2120 GOSUB 1280
2130 GOSUB 1710
2140 RETURN
2150 '
2160 ' PRINT TEST RESULTS
2170 '

```

```
2180 X$= "      "  
2190 IF PT > 4 THEN 2220  
2200 F$= " NO"  
2210 GOTO 2230  
2220 F$= "YES"  
2230 PRINT#-2, "      " NR "      " CR$ "      " X$ TR$ "      " F$  
      X$ "      " ST$ X$ FL  
2240 PRINT#-2, CHR$(10)  
2250 NR= NR+1: FL= 0: RETURN
```

The following program is written in Fortran IV and was executed on a Cromemco Z-2D with two 48K video memory boards and a video digital-to-analog board. The software available in the Cromemco SDI video library was also used in programming. The purpose of the program was to provide interactive commands and video stimulus displays in support of a psycho-physical experiment on the limits of human binocular vision.

Program Parameters:

Jcolor = Color of Square
 Nbr = Current test number
 Jsize = Value of loop parameter
 when Square halted
 Size = Size of Square in
 centimeters
 Trs = State of TRS-80 display
 Kstate = Test conditions

```

PROGRAM Fusion.for
C
C
  dimension i(9)
  data i(1),i(2),i(3),i(4),i(5)/4,119,50,119,190/
  data i(6),i(7),i(8),i(9)/259,190,259,50/
C
  write (2,10)
10  format (/, ' TEST# CROMEMCO TRS-80
      1          ' FOCAL POINT',
          ' CONDITIONS SIZE', //)
C
  call grafix
  call init
C
C  Declare background as black and define colors.
C
  call defclr (0,0,0,0)
  call defclr (1,15,0,0)
  call defclr (2,15,15,15)
  call defclr (3,4,15,0)
C
C  Draw solid square to center the dichoptic scene.
C
  call xarea (139,70,239,170,3)
  call wait
C
C  Draw square frame to center the dichoptic scene.
C
  call xarea (139,70,239,170,0)
  call xpoly (3,i)
  call wait
C

```

C Draw small green test squares to support TRS-80
C phase of experiment.
C

```
call testsq (3)
call wait
call testsq (1)
call wait
call testsq (2)
call wait
```

C Perform test sequences.
C
C

```
nbr= 1
call seq (2,.true.,nbr)
call seq (3,.true.,nbr)
call xarea (0,0,378,240,3)
call xtext (20,60,0,'PRESS CONTROL BEFORE
CONTINUING.^')

call delay
call seq (3,.false.,nbr)
call xtext (20,20,0,'CONGRATULATIONS!^')
call xtext (20,60,0,'YOU'RE FINISHED!!!^')
END
```

C ***** SUBROUTINES *****
C
C

C Subroutine SEQ alternately performs tests on
C expansion and contraction.
C Input: jcolor= Specified color
C

```
Subroutine SEQ (jcolor,trs,nbr)
do 100 j=1,5
  call xarea (0,0,378,240,0)
  call delay
  call testsq (jcolor)
  call inter
  call expand (jcolor,nbr,trs)
  call xarea (0,0,378,240,0)
  call delay
  call contr (jcolor,nbr,trs)
100 continue
return
end
```

C Subroutine TESTSQ draws a square with a focal point
C for the experimental phase.
C Input: Jcolor= Color of the square.
C

```
Subroutine TESTSQ (jcolor)
call xarea (0,0,378,240,0)
call xarea (139,80,239,160,jcolor)
```

```

C      Draw small green test squares to support TRS-80
C      phase of experiment.
C
      call testsq (3)
      call wait
      call testsq (1)
      call wait
      call testsq (2)
      call wait

C
C      Perform test sequences.
C
      nbr= 1
      call seq (2,.true.,nbr)
      call seq (3,.true.,nbr)
      call xarea (0,0,378,240,3)
      call xtext (20,60,0,'PRESS CONTROL BEFORE
                  CONTINUING.^')

      call delay
      call seq (3,.false.,nbr)
      call xtext (20,20,0,'CONGRATULATIONS!^')
      call xtext (20,60,0,'YOU'RE FINISHED!!!^')
      END

C
C      ***** SUBROUTINES *****
C
C      Subroutine SEQ alternately performs tests on
C      expansion and contraction.
C      Input: jcolor= Specified color
C
      Subroutine SEQ (jcolor,trs,nbr)
      do 100 j=1,5
         call xarea (0,0,378,240,0)
         call delay
         call testsq (jcolor)
         call inter
         call expand (jcolor,nbr,trs)
         call xarea (0,0,378,240,0)
         call delay
         call contr (jcolor,nbr,trs)
100    continue
      return
      end

C
C      Subroutine TESTSQ draws a square with a focal point
C      for the experimental phase.
C      Input: Jcolor= Color of the square.
C
      Subroutine TESTSQ (jcolor)
      call xarea (0,0,378,240,0)
      call xarea (139,80,239,160,jcolor)

```

```

        call xarea (188,119,190,121,0)
        return
        end
C
C      Subroutine EXPAND expands the test square and halts
C      when a control signal is received. At the end of
C      each test the results are then output to the printer.
C
      Subroutine EXPAND (jcolor,nbr,trs)
      logical trs
      dimension i(9)
      call reset (i)
      jhalt= 0
      i(1)= 4
      do 650 l=0,80
         jhalt= inp(l)
         if (jhalt.eq.32) go to 660
         i(2)= 139-l
         i(3)= 80-l
         i(4)= 139-l
         i(5)= 160+l
         i(6)= 239+l
         i(7)= 160+l
         i(8)= 239+l
         i(9)= 80-l
         call xpoly (jcolor,i)
         do 650 j=1,7000
650      continue
660      call prin (l,jcolor,nbr,trs,.true.)
         nbr= nbr+1
         return
         end
C
C      Subroutine DELAY imposes a 7 second delay in the
C      program execution.
C
      Subroutine DELAY
      do 750 j=1,400
         do 750 k=1,1000
750      continue
         return
         end
C
C      Subroutine INTER causes a pause in the program
C      execution.
C
      Subroutine INTER
      do 850 j=1,110
         do 850 k=1,1000
850      continue
         return
         end
C

```

```

C      Subroutine PRIN prints out the results of the test
C      just completed.
C
      Subroutine Prin (jsize,jcolor,nbr,trs,kstate)
      logical trs,kstate
      if (jcolor.eq.2) go to 890
      if (trs.and.kstate) write (2,910) nbr,jsize
      if (trs.and..not.kstate) write (2,915) nbr,jsize
      if (.not.trs.and.kstate) write (2,920) nbr,jsize
      if (.not.trs.and..not.kstate) write (2,925) nbr,jsize
      go to 990
890    if (kstate) write (2,900) nbr,jsize
      if (.not.kstate) write (2,905) nbr,jsize
900    format (' ',i4,'      WHITE      WHITE      YES',
1      ' ',i4,'      CRO-INC      ',i4)
905    format (' ',i4,'      WHITE      WHITE      YES',
1      ' ',i4,'      CRO-DEC      ',i4)
910    format (' ',i4,'      GREEN      WHITE      YES',
1      ' ',i4,'      CRO-INC      ',i4)
915    format (' ',i4,'      GREEN      WHITE      YES',
1      ' ',i4,'      CRO-DEC      ',i4)
920    format (' ',i4,'      GREEN      GREEN      YES',
1      ' ',i4,'      CRO-INC      ',i4)
925    format (' ',i4,'      GREEN      GREEN      YES',
1      ' ',i4,'      CRO-DEC      ',i4)
990    return
      end

C
C      Subroutine WAIT waits for the control button to be
C      pressed after initially pausing to protect itself
C      from previous calls.
C
      Subroutine WAIT
      do 1050 j=1,200
        do 1050 k=1,1000
1050    continue
      jcont= 0
1060    jcont= inp(1)
      if (jcont.ne.32) go to 1060
      return
      end

C
C      Subroutine RESET resets the values of the i-array to
C      the dimensions of the small experimental square.
C
      Subroutine RESET (i)
      dimension i(9)
      i(2)= 139
      i(3)= 80
      i(4)= 139
      i(5)= 160
      i(6)= 239
      i(7)= 160
      i(8)= 239

```

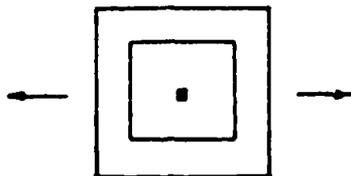

APPENDIX B

Instructions for Experiment with Binocular Fusion

INSTRUCTIONS

You are about to participate in a psycho-physical experiment studying the limits of binocular vision. In a series of test cases you will be asked to respond based on what you can see. There are no right or wrong answers! It is only important that you attempt to follow the instructions given and report what you see.

Throughout this experiment you will be asked to respond when you either observe a single square become a square-within-a-square, or vice versa. When the square expands, you may at some point observe a second distinct smaller square appear as shown below. At the point you make this observation respond by pressing the appropriate button.



(OUTSIDE SQUARE EXPANDING)

In other trials you will first see a large square surrounding a smaller square. As the larger square begins to shrink you may at some point see the two squares become one. When the two become one you will be asked to respond. This one is tricky since sometimes, immediately after you push the button, the second square will reappear. This is caused by "binocular rivalry" and is not the observation sought in this experiment. Instead it is desired that you wait until the two squares have "fused." This point can be determined since the second square will not "immediately" reappear. To allow you to see and learn the difference, a "learning" phase will be presented when the contracting square will halt momentarily after each time you press the button. During this learning phase try to determine where the percept of one square becomes stable. Do not worry about the colors fading in and out. The distinct forms are what you should look for.

In all test trials a small black dot will appear in the center of the screen. Use this dot as a focal point. It is important you keep your eyes fixed on this point during the individual tests. If at any time you notice the dot disappear, then report this on completion of the experiment.

At different points in the experiment the color of the squares will change. Do not worry about it. The forms of the squares are the important feature to watch for.

You are now ready to begin. Pick up and hold in your left hand the control connected to the "TRS-80". Now locate with your right hand the <SPACE> bar on the "Cromemco." The red button on the TRS-80 control will be your way of communicating with it and will be referred to as the "CONTROL." When it is necessary for you to communicate with the Cromemco, you will be asked to press the <SPACE> and, after the <SPACE>, to press any letter on the keyboard. This might seem a little awkward so you might want to try it a few times before starting up the program.

In the initial portion of the experiment you will be instructed to center a solid square within a square frame. You can do this by adjusting the mirror on the chin rest platform. It adjusts just like the mirrors on your car. Don't get too concerned about whether you have the box exactly centered. When you believe them to be generally centered, then continue. Once you have performed the centering procedure, keep your chin on the platform and your head steady until you have completed the experiment. All

further instructions will be displayed on the monitor. .

If you understand the instructions, place your chin on the platform, centered on the line provided, and begin.

APPENDIX C

Questionnaire for Experiment with Binocular Fusion

PSYCHO-PHYSICAL EXPERIMENT ON THE LIMITS
OF BINOCULAR VISION

NAME: _____
Please Print LAST, FIRST, MI

AGE: _____ SEX: _____

DATE: _____ TIME: _____

Did you ever lose sight of the focal point when the squares
were either contracting /expanding?

Have you ever had any vision related illnesses or problems?
If so please describe and include your age at onset.

During the experiments did you have any problem in the
perception of the squares? If so please describe.

Please provide any additional thoughts or comments you might
have concerning the conduct of this experiment.

THANK YOU FOR YOUR COOPERATION AND ASSISTANCE!!!

APPENDIX D

Program Listing for Experiment with MAE Thresholds and Duration

The following program listing was executed on a TRS-80 Color Computer with 32K RAM and Extended Basic. The purpose of the program was to display interactive commands and visual stimulus scenes to support a psycho-physical experiment measuring the stimulus duration thresholds for motion-after-effects and the duration of motion-after-effects to a stimulus of constant duration.

Program Parameters:

SQWV-3 = Machine language program stored on tape containing the video frames to be used.
DR = Number of times the video sequence is to be executed.
TIMER = Internal timer provided with extended basic language.

```
10 PCLEAR 8
20 POKE 150,180 'Set printer baud rate
30 CLOADM "SQWV-3" 'Load video memory
150 CLS
160 PRINT@160," READY TO START!!"
170 GOSUB 1040
180 FOR G=1 TO 5
190 GOSUB 990: SOUND 200,3: FOR D=1 TO 486: NEXT D
200 DR= 20: GOSUB 570: GOSUB 870
210 SCREEN 0,0: CLS
220 PRINT@160," PRESS <C> TO CONTINUE!"
230 GOSUB 1040
240 NEXT G
250 GOSUB 1100
260 PRINT@160," PRESS <C> TO BEGIN TEST!"
270 GOSUB 1040
280 FOR B=1 TO 2
290 FOR P=1 TO 3
300 PRINT#-2," POSITION @" P CHR$(10)
310 FOR G=1 TO 10
320 GOSUB 990: SOUND 200,3: FOR D=1 TO 486: NEXT D
330 DR=RND(20): GOSUB 570: GOSUB 870
340 SCREEN 0,0: CLS: GOSUB 990
350 IF C$="NO" THEN 380
360 PRINT#02," DURATION= " DR " REPORTED MAE" CHR$(10)
370 GOTO 390
380 PRINT#-2," DURATION= " DR " NO MAE REPORTED"
CHR$(10)
390 NEXT G
400 GOSUB 1100
```

```

410 PRINT#-2, CHR$(10)
420 SCREEN 0,0: CLS
430 PRINT@160," PRESS <C> TO CONTINUE!!"
440 GOSUB 1040
450 NEXT P
460 NEXT B
470 END
480 '
490 '
500 '*****SUBROUTINES*****
510 '
520 '
530 '
540 ' CONSECUTIVELY DISPLAY PAGES 1 TO 8. USE THE TIMER
550 ' TO PROVIDE VERTICAL SYNC.
560 '
570 FOR K=1 TO DR
580 TIMER=0
590 PMODE 0,1
600 SCREEN 1,0
610 IF TIMER=0 THEN 610
620 PMODE 0,2
630 SCREEN 1,0
640 IF TIMER=1 THEN 640
650 PMODE 0,3
660 SCREEN 1,0
670 IF TIMER=2 THEN 670
680 PMODE 0,4
690 SCREEN 1,0
700 IF TIMER =3 THEN 700
710 PMODE 0,5
720 SCREEN 1,0
730 IF TIMER=4 THEN 730
740 PMODE 0,6
750 SCREEN 1,0
760 IF TIMER=5 THEN 760
770 PMODE 0,7
780 SCREEN 1,0
790 IF TIMER=6 THEN 790
800 PMODE 0,8
810 SCREEN 1,0
820 NEXT K
830 RETURN
840 '
850 ' DISPLAY PAGE 1 AND TEST FOR CONTROL.
860 '
870 PMODE 0,1
880 SCREEN 1,0
890 FOR D=1 TO 150
900 C= PEEK(65280): IF C=254 THEN 940
910 NEXT D
920 C$="NO"
930 RETURN
940 C$="YES"

```

```

950 RETURN
960 '
970 ' DELAY FOR 5 SECONDS
980 '
990 FOR D=1 TO 2430: NEXT D
1000 RETURN
1010 '
1020 ' WAIT FOR "C" TO CONTINUE
1030 '
1040 A$=INKEY$
1050 IF A$ <> "C" THEN 1040
1060 RETURN
1070 '
1080 ' TEST DURATION OF MAE
1090 '
1100 PRINT@160," PRESS<C> TO BEGIN DURATION TESTS!
1110 PRINT#-2,CHR$(10) " DURATION TESTS",CHR$(10)
1120 DR=100
1130 GOSUB 1040
1140 GOSUB 990: GOSUB 990
1150 SOUND 200,3: FOR D=1 TO 486: NEXT D
1160 FOR I=1 TO 3
1170 GOSUB 570
1180 PMODE 0,1
1190 SCREEN 1,0
1200 TIMER=0
1210 FOR K=1 TO 300
1220 C= PEEK(65280): IF C=254 THEN 1260
1230 NEXT K
1240 PRINT#-2," NO MAE REPORTED" CHR$(10)
1250 GOTO 1290
1260 C=PEEK(65280): IF C=254 THEN 1260
1270 PRINT#-2," DURATION= " TIMER/60 " SECONDS" CHR$(10)
1280 IF I=3 THEN 1320
1290 SCREEN 0,0: CLS
1300 GOSUB 990: GOSUB 990
1310 SOUND 200,3: FOR D=1 TO 486: NEXT D
1320 NEXT I
1330 PRINT#-2, CHR$(10)
1340 RETURN

```

APPENDIX E

Instructions for Experiment with MAE Thresholds and Duration

INSTRUCTIONS

Psycho-Physical Experiment on MAE

Two separate tests will be shown. In the first you will observe a rightward moving vertical square-wave. After a varying observation period you will observe the pattern halt its rightward movement. At that time, if the pattern appears stationary, then no response is required. If you detect a leftward movement of the pattern, however slight, then immediately press the control button. Throughout the test period, while the pattern is displayed, you will be asked to maintain your fixation on a specified focal point. It is important you do so, and attempt not to blink when the pattern is present. Between each test the screen will be blanked. A tone will sound one second prior to the initiation of each test.

(Observe 5 Trials)

The second test will present the same rightward moving square wave one second after a tone. This time, rather than just pressing the control to indicate the detection of leftward motion, you will be asked to press the control "firmly" and continue pressing it until the leftward motion ceases. Again keep your eyes on the specified focal point during the tests.

(Observe 3 Trials)

Don't be concerned if you do not observe any leftward movement. It won't always occur!! Motion is not across the focal point but rather the whole pattern will move.

APPENDIX F

Raw Data Example for Experiment
On the Limits of Binocular Fusion

SUBJECT: REH

TEST#	CROMEMCO	TRS-80	FOCAL POINT	CONDITIONS	SIZE(CM)
1	GREEN	GREEN	NO	TRS-INC	11.1
2	GREEN	GREEN	NO	TRS-DEC	7.6
3	GREEN	GREEN	YES	TRS-INC	10.9
4	GREEN	GREEN	YES	TRS-DEC	7.7
5	GREEN	GREEN	NO	TRS-INC	9.7
6	GREEN	GREEN	YES	TRS-DEC	6.5
7	GREEN	GREEN	YES	TRS-INC	8.1
8	GREEN	GREEN	YES	TRS-DEC	6.9
9	GREEN	GREEN	NO	TRS-INC	10.5
10	GREEN	GREEN	YES	TRS-DEC	7.4
11	RED	GREEN	NO	TRS-INC	9.5
12	RED	GREEN	YES	TRS-DEC	6.5
13	RED	GREEN	YES	TRS-INC	7.7
14	RED	GREEN	NO	TRS-DEC	7.2
15	RED	GREEN	NO	TRS-INC	8.3
16	RED	GREEN	NO	TRS-DEC	7.7
17	RED	GREEN	YES	TRS-INC	7.6
18	RED	GREEN	YES	TRS-DEC	6.9
19	RED	GREEN	YES	TRS-INC	7.9
20	RED	GREEN	NO	TRS-DEC	7.0
21	WHITE	WHITE	YES	TRS-INC	14.4
22	WHITE	WHITE	YES	TRS-DEC	6.7
23	WHITE	WHITE	NO	TRS-INC	12.8
24	WHITE	WHITE	NO	TRS-DEC	6.7
25	WHITE	WHITE	YES	TRS-INC	15.6
26	WHITE	WHITE	NO	TRS-DEC	7.2
27	WHITE	WHITE	YES	TRS-INC	10.0
28	WHITE	WHITE	NO	TRS-DEC	6.9
29	WHITE	WHITE	NO	TRS-INC	8.4
30	WHITE	WHITE	NO	TRS-DEC	7.0
31	WHITE	WHITE	YES	CRO-INC	11.4
32	WHITE	WHITE	YES	CRO-DEC	6.9
33	WHITE	WHITE	YES	CRO-INC	8.9
34	WHITE	WHITE	YES	CRO-DEC	6.5
35	WHITE	WHITE	YES	CRO-INC	8.5
36	WHITE	WHITE	YES	CRO-DEC	7.1
37	WHITE	WHITE	YES	CRO-INC	13.0
38	WHITE	WHITE	YES	CRO-DEC	7.1
39	WHITE	WHITE	YES	CRO-INC	8.8
40	WHITE	WHITE	YES	CRO-DEC	6.8
41	GREEN	WHITE	YES	CRO-INC	8.8
42	GREEN	WHITE	YES	CRO-DEC	6.5
43	GREEN	WHITE	YES	CRO-INC	8.1

TEST#	CROMEMCO	TRS-80	FOCAL POINT	CONDITIONS	SIZE(CM)
44	GREEN	WHITE	YES	CRO-DEC	6.6
45	GREEN	WHITE	YES	CRO-INC	8.5
46	GREEN	WHITE	YES	CRO-DEC	6.8
47	GREEN	WHITE	YES	CRO-INC	8.1
48	GREEN	WHITE	YES	CRO-DEC	7.2
49	GREEN	WHITE	YES	CRO-INC	10.5
50	GREEN	WHITE	YES	CRO-DEC	6.8
51	GREEN	GREEN	YES	CRO-INC	11.4
52	GREEN	GREEN	YES	CRO-DEC	6.9
53	GREEN	GREEN	YES	CRO-INC	9.7
54	GREEN	GREEN	YES	CRO-DEC	7.5
55	GREEN	GREEN	YES	CRO-INC	10.4
56	GREEN	GREEN	YES	CRO-DEC	6.5
57	GREEN	GREEN	YES	CRO-INC	10.2
58	GREEN	GREEN	YES	CRO-DEC	7.5
59	GREEN	GREEN	YES	CRO-INC	10.1
60	GREEN	GREEN	YES	CRO-DEC	6.5

APPENDIX G

Raw Data Example from
Experiment on MAE

SUBJECT: GHG

14 OCT 1982 1400 HRS

POSITION # 1

THRESHOLD TESTS

DURATION = 9	NO MAE REPORTED
DURATION = 6	REPORTED MAE
DURATION = 8	REPORTED MAE
DURATION = 2	NO MAE REPORTED
DURATION = 4	NO MAE REPORTED
DURATION = 19	REPORTED MAE
DURATION = 3	NO MAE REPORTED
DURATION = 19	REPORTED MAE
DURATION = 4	REPORTED MAE
DURATION = 10	REPORTED MAE

DURATION TESTS

DURATION = 5.1 SECONDS
DURATION = 6.5 SECONDS
DURATION = 8.0 SECONDS

POSITION # 2

THRESHOLD TESTS

DURATION = 13	NO MAE REPORTED
DURATION = 5	NO MAE REPORTED
DURATION = 1	NO MAE REPORTED
DURATION = 14	REPORTED MAE
DURATION = 1	NO MAE REPORTED
DURATION = 4	REPORTED MAE
DURATION = 19	NO MAE REPORTED
DURATION = 1	NO MAE REPORTED
DURATION = 17	REPORTED MAE
DURATION = 6	NO MAE REPORTED

DURATION TESTS

DURATION = 7.3 SECONDS
DURATION = 4.9 SECONDS
DURATION = 6.0 SECONDS

POSITION # 3

THRESHOLD TESTS

DURATION = 4	NO MAE REPORTED
DURATION = 17	NO MAE REPORTED
DURATION = 8	NO MAE REPORTED
DURATION = 1	NO MAE REPORTED
DURATION = 17	REPORTED MAE
DURATION = 17	REPORTED MAE
DURATION = 11	NO MAE REPORTED
DURATION = 6	NO MAE REPORTED
DURATION = 3	NO MAE REPORTED
DURATION = 18	REPORTED MAE

DURATION TESTS

DURATION = 4.1 SECONDS
DURATION = 3.0 SECONDS
DURATION = 1.1 SECONDS

POSITION # 1

THRESHOLD TESTS

DURATION = 10	REPORTED MAE
DURATION = 7	REPORTED MAE
DURATION = 13	REPORTED MAE
DURATION = 6	REPORTED MAE
DURATION = 7	NO MAE REPORTED
DURATION = 1	NO MAE REPORTED
DURATION = 18	REPORTED MAE
DURATION = 6	REPORTED MAE
DURATION = 9	REPORTED MAE
DURATION = 12	REPORTED MAE

DURATION TESTS

DURATION = 5.2 SECONDS
DURATION = 6.9 SECONDS
DURATION = 6.2 SECONDS

POSITION # 2

THRESHOLD TESTS

DURATION = 1	NO MAE REPORTED
DURATION = 18	REPORTED MAE
DURATION = 4	NO MAE REPORTED
DURATION = 20	REPORTED MAE
DURATION = 17	NO MAE REPORTED
DURATION = 4	NO MAE REPORTED
DURATION = 7	REPORTED MAE
DURATION = 14	REPORTED MAE
DURATION = 17	REPORTED MAE
DURATION = 8	REPORTED MAE

DURATION TESTS

DURATION = 5.4 SECONDS
DURATION = 5.5 SECONDS
DURATION = 5.7 SECONDS

POSITION # 3

THRESHOLD TESTS

DURATION = 10
DURATION = 20
DURATION = 7
DURATION = 19
DURATION = 11
DURATION = 10
DURATION = 13
DURATION = 5
DURATION = 7
DURATION = 3

REPORTED MAE
REPORTED MAE
NO MAE REPORTED
REPORTED MAE
NO MAE REPORTED
NO MAE REPORTED
REPORTED MAE
REPORTED MAE
NO MAE REPORTED
NO MAE REPORTED

DURATION TESTS

DURATION = 6.1 SECONDS
DURATION = 4.5 SECONDS
DURATION = 4.9 SECONDS

Vita

Roger L. Carter was born on 18 February 1950 in Lawrence, Kansas. He graduated from Lawrence High School and attended the University of Kansas from which he received the degree of Bachelor of Electrical Engineering in January 1976. Upon graduation he received a commission in the U.S. Army Ordnance Corps through the ROTC program. In addition to attendance at several military logistics schools, he served as a Maintenance Officer in the Third Infantry Division, located in West Germany, from 1976 to 1980. Among military honors he has received are the Army Commendation Medal, Meritorious Service Medal, U.S. Army Europe award for Individual Support of German-American Interoperability, and the Herbert W. Alden Award as the outstanding graduate of the Ordnance Officer Advanced Course. Since entering the School of Engineering, Air Force Institute of Technology, in May 1981, he has been initiated into the Eta Kappa Nu honor society for Electrical Engineers.

Permanent address: 2022 Vermont St.

Lawrence, Kansas 66044

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER AFIT/SS/EE/82D-23	2. GOVT ACCESSION NO. AD-A124842	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) A MODEL FOR VISUAL INFORMATION PROCESSING WHICH EXPLAINS MOTION-AFTER-EFFECTS		5. TYPE OF REPORT & PERIOD COVERED M.S. Thesis	
		6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) Dr. Roger L. Carter		8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Institute of Technology (AFIT-EE) Wright-Patterson AFB, Ohio 45433		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE December, 1962	
		13. NUMBER OF PAGES 134	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified	
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES Approved for public release: 14W AFR 19647 LYNN E. WOLANER Dean for Educational Development Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433 4 JAN 63			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Motion-after-Effects Cerebellum Visual Information Processing perception Binocular Fusion Lateral geniculate nucleus			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A theoretical model for human visual information processing was developed which attributes functional roles to the cerebellum, lateral geniculate nucleus and cerebral cortex. The lateral geniculate nucleus is believed to provide sequential monocular mappings as inputs to the primary visual cortex, which uses this information for binocular integration, detection of motion, and other of its functions. The cerebellum is hypothesized to function within a predictive feedback loop to provide information to the cortex essential to reconcile differences in monocular image sizes and displacements.			

In an experiment with the limits of human binocular fusion, two separate limits were discovered. When dichoptic images are first perceived to represent a single object, the limit for fusion is greater than when no initial reference for a single object association is given.

A second experiment measured the stimulus duration thresholds for motion-after-effects. Correlation of performance by subjects in the two experiments was used to conclude that similar mechanisms are involved in binocular fusion and the processing of perceptions leading to motion-after-effects. Within the visual processing model developed, both binocular fusion and the existence of motion-after-effects are related to the existence of a predictive feedback loop.

UNCLASSIFIED

END

DATE
FILMED

3-83

DTIC