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FLRRIS, Steven Howard, 1943-  
INTEROCULAR APPARENT MOVEMENT IN DEPTH  
AND ITS RELATION TO STEREOPSIS.

The City University of New York, Ph.D., 1970  
Psychology, experimental

**University Microfilms, A XEROX Company, Ann Arbor, Michigan**

INTEROCULAR APPARENT MOVEMENT IN DEPTH  
AND ITS RELATION TO STEREOPSIS

by  
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A dissertation submitted to the Graduate  
Faculty in Psychology in partial fulfillment  
of the requirements for the degree of Doctor  
of Philosophy, The City University of New  
York.

1970

This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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### Acknowledgements

The author wishes to thank Dr. Nicholas Pastore for his extensive assistance, advice and encouragement. I am also grateful to Dr. Jack Orbach and Dr. Eric Heinemann for their many worthwhile suggestions, and to Dr. Lloyd Kaufman and Dr. Daniel Ehrlich for their helpful comments. This research was supported in part by a research grant to Dr. Pastore from The City University of New York and a dissertation grant to the author, also from The City University of New York. The use of the tachistoscope in Dr. Orbach's laboratory was made possible by National Institute of Mental Health Grant MH-03830.

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## List of Abbreviations and Definitions

AM. Apparent movement, irrespective of the nature of stimulation.

Movement perceived as a result of the alternate presentation of two stimuli.

AM in depth. AM in which the path of perceived movement does not remain within the plane of the two stimuli.

Interocular AM. AM produced by interocular presentation of stimuli.

Each eye is stimulated by only one of the two stimuli.

L. A figure in the visual field produced by stimulation of the left eye.

LR. Stimulus arrangement in which the L figure is situated to the left of the R figure in the visual field.

N. Nasal. A nasal stimulus arrangement gives rise to stimulation of the two nasal hemiretinas.

Oscillation in depth. AM in depth in which a figure is perceived to swing to and fro, through an arc of about  $180^{\circ}$ , ahead or behind the plane of the alternating stimuli.

R. A figure in the visual field produced by stimulation of the right eye.

RL. Stimulus arrangement in which the L figure is situated to the right of the R figure in the visual field.

T. Temporal. A temporal stimulus arrangement gives rise to stimulation of the two temporal hemiretinas.

TIAM. Tridimensional interocular apparent movement. Oscillation in depth produced by interocular presentation of stimuli.

TIAM predominance effect. A difference in the results for two stimulus arrangements with respect to the type of oscillation in depth (ahead or behind) which is generally perceived.

### Abstract

When two triangles are alternately presented, one with a vertex pointing to the left and the other with a vertex pointing to the right, the observer perceives a single triangle oscillating in depth about a vertical axis. The vertex may swing in an arc either ahead or behind the plane of the figures. However, when the presentation of stimuli is interocular (each eye stimulated by only one of the two figures) a predominance effect occurs: Stimulation of the two nasal hemiretinas gives rise predominantly to oscillation behind, and stimulation of temporal hemiretinas gives rise predominantly to oscillation ahead. This phenomenon is consistent with a rule which specifies that a single right eye to left eye stimulation cycle gives rise to counter-clockwise rotation, and a left eye to right eye cycle gives rise to clockwise rotation. The number of "ahead" reports in 10 trials/condition was the response measure used in two series of experiments. The experiments of Part I demonstrated the following concerning the predominance effect: (a) Interocular presentation of stimuli is a necessary condition for the effect. (b) The effect occurs for semi-circles as well as triangles, with at least twice as many ahead reports for temporal stimulation than for nasal stimulation. (c) The effect can be produced using a tachistoscope with polarizing filters, and also by using a stereoscope. (d) The effect does not depend upon continuous binocular fixation or differential eyemovement. (e) The effect does not depend upon nasal versus temporal stimulation, but depends upon a difference between conditions in the relative position of the stimulus figures in the visual field (whether the figure presented to the left eye is perceived to the left or right of the figure

presented to the right eye). (f) Simultaneous presentation of contrasting stimulus arrangements increases degree of individual consistency with the effect, but for some Ss there is an unexplained upper-lower position effect. (g) The effect does not occur for vertical movement. (h) Increasing the separation between figure and fixation line does not influence the effect.

In Part II it was hypothesized that the predominance effect is related to stereoscopic depth localization of double images. The stimulus arrangements producing motion behind and ahead give rise to percepts which are equivalent, respectively, to uncrossed and crossed double images (unfused disparate images). Since uncrossed double images are localized behind the fixation plane and crossed images are localized ahead of the fixation plane, there is a correspondence between the nature of the depth localization associated with the double images and the nature of the oscillation in depth which is perceived when the stimuli are alternated. Results a, e and g, above, are consistent with the double image hypothesis since only interocular presentation produces retinal disparity, nasal or temporal stimulation of both retinas is not required to produce double images, and vertical disparity (involved in vertical movement) does not produce stereopsis. Results of further experiments indicated the following: (a) Dots in planar apparent movement are localized ahead or behind the fixation line. (b) Continuous viewing of both stimuli gives rise to an ahead-behind depth localization predominance effect which corresponds to the motion effect, and which is not due to differential eye convergence. (c) An upper-lower position effect occurs for depth localization which is similar to the position effect found for oscillation in depth. (d) Figures which appear tilted behind in depth

give rise primarily to oscillation behind as a result of the shorter motion path required for motion behind. (e) Triangles appear tilted ahead or behind in depth (apparently due to greater disparity at the vertices), thus suggesting the manner in which stereopsis might influence the oscillation in depth which is perceived. (f) When a report of perceived movement is obtained immediately after a report of either depth localization or of tilt in depth, there is a significant relationship between the two types of reports.

Introduction

Apparent or stroboscopic movement (AM) is perceived when two separate visual stimuli are presented successively under proper spatial and temporal conditions. The AM phenomenon investigated here occurs when stimuli eliciting perception of AM in depth are presented interocularly.<sup>1</sup> When conditions are properly arranged, AM in depth rather than planar AM is perceived. Thus when two triangles having a common vertical side are alternately presented (Fig. 1), the path of apparent movement does not lie in a plane. The observer generally perceives a single triangle moving to and fro in depth about a vertical axis (Cf. Higginson, 1926). The vertex of the triangle, which appears to swing in an arc of about  $180^\circ$  in a horizontal plane, may oscillate either ahead of behind the plane of the figures. This type of AM will be referred to as oscillation in depth. In interocular AM, each eye is stimulated by only one of the two stimuli (Cf. Wertheimer, 1912). The interocular procedure can be distinguished from the procedure for monocular AM, in which only one eye is stimulated by the two stimuli, and binocular AM, in which the two stimuli stimulate both eyes.

Langfeld (1927) was apparently the first to observe AM in depth produced by interocular stimulation. Tridimensional interocular AM (TIAM) has more recently been investigated by Pastore.<sup>2</sup> For the triangle figures described above, some observers initially perceive oscillation in depth ahead of the plane and others perceive movement behind the plane. With prolonged observation, spontaneous reversals are frequently perceived in which movement ahead changes to movement behind or vice versa. Com-

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<sup>1</sup>A review of studies dealing with AM in depth and interocular AM is presented in Appendix I.

<sup>2</sup>Unpublished research, 1966.

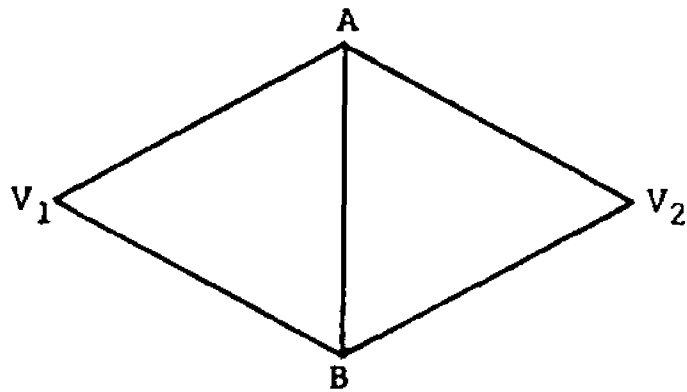


Fig. 1. Stimulus figures ( $ABV_1$  and  $ABV_2$ ) which when alternately presented give rise to perception of  $AM$  in depth. A single triangle is perceived which swings to and fro in depth about vertical axis  $AB$ . The vertex oscillates between  $V_1$  and  $V_2$  through an arc of about  $180^\circ$  in a horizontal plane.

plete rotations ( $360^\circ$ ) are also sometimes perceived. Pastore found, however, that the nature of the movement perceived could be controlled by manipulating the locus of exposure to the two eyes. Specifically, stimulation of nasal hemiretinas generally led to the perception of a single triangle moving behind the plane and stimulation of temporal hemiretinas generally led to the perception of a triangle moving ahead of the plane (20 ss). Stimulus arrangements for producing nasal (N) and temporal (T) stimulation are illustrated in Fig. 2. When these arrangements are viewed stereoscopically they give rise to two visual fields which are identical. The diagrams of Fig. 3 show what is happening on the retina.

Although the N and T conditions give rise to distinct behind and ahead types of perceived motion, Pastore formulated a rule that would coordinate these perceived motions to phases of a single type of movement. In this formulation, attention is confined to a single cycle in which one stimulus is presented and removed followed by presentation and removal of the second stimulus. If considered as though viewed from above, movement of the triangle ahead or behind is equivalent to a  $180^\circ$  rotation in a clockwise or counterclockwise direction (see Fig. 4A). Fig. 4B illustrates the fact that for a single left eye to right eye cycle, N stimulation (giving rise to behind movement) and T stimulation (giving rise to ahead movement) both involve rotation in a clockwise direction. Thus a single type of rotation (clockwise) can be coordinated with the two types of observed motion (ahead and behind). Since it is arbitrary as to whether a single cycle begins with stimulation of the left or right eye, a similar direction of rotation rule involving counterclockwise rotation can be formulated for a right eye to left eye cycle (Fig. 4C).

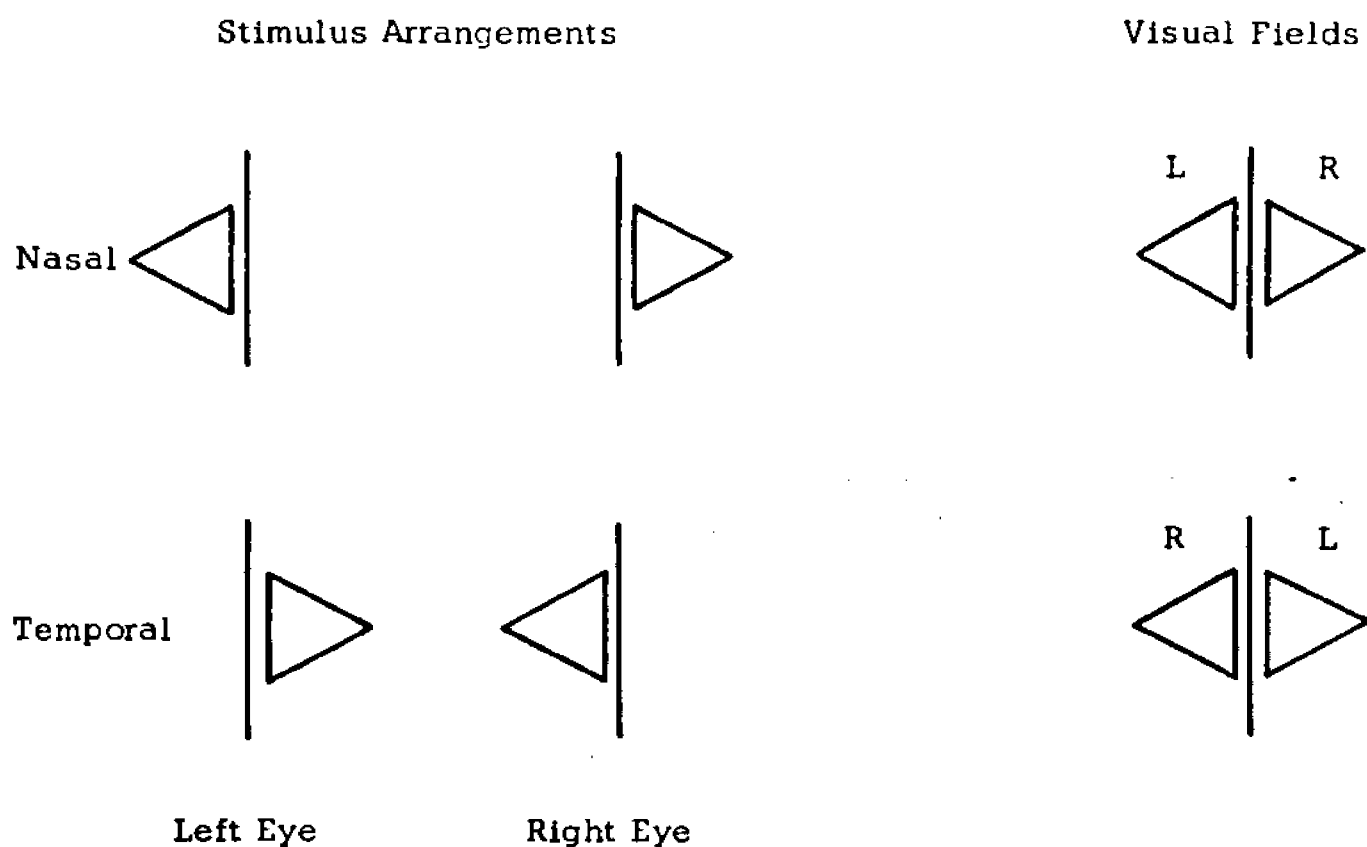


Fig. 2. Illustration of the stimulus arrangements producing nasal and temporal stimulation of the two retinas. Fusion of the two vertical lines in a stereoscope results in the perception of the visual fields at right. L triangles are perceived as a result of stimulation of the left eye and R triangles as a result of stimulation of the right eye. Fixation is maintained on the vertical line.

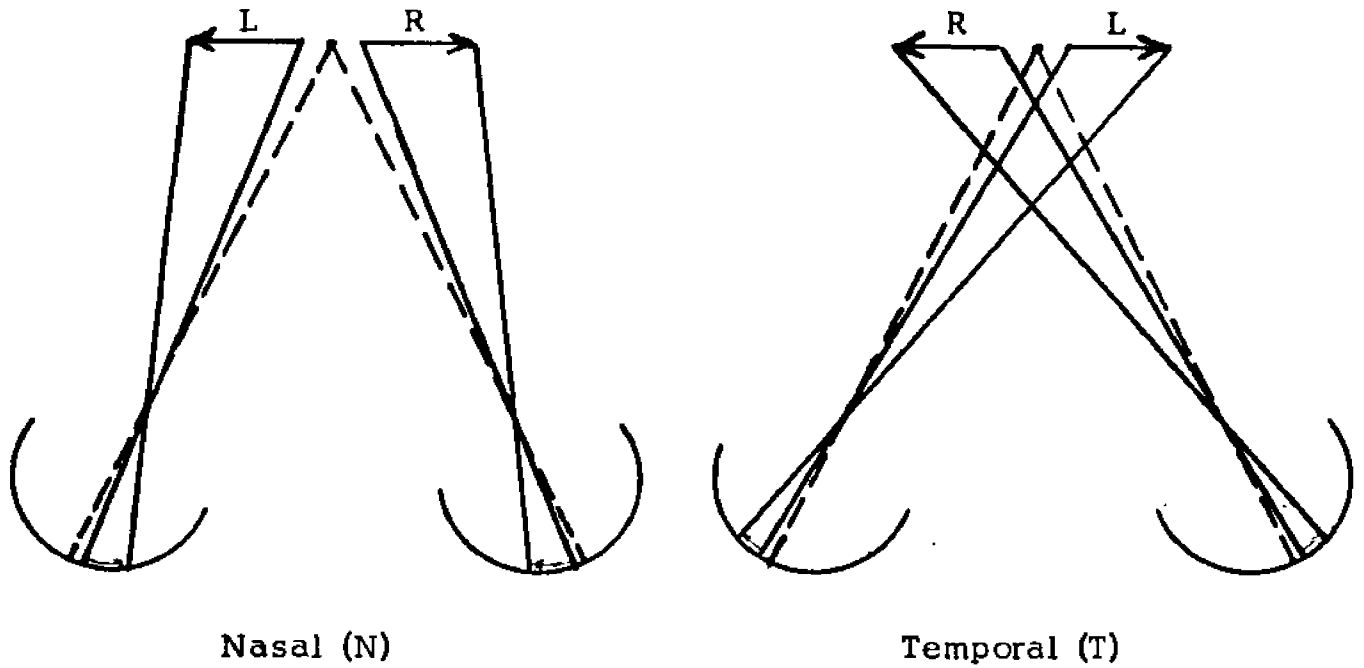


Fig. 3. Schematic diagrams of the retinal stimulation resulting from the N and T stimulus arrangements. The arrows represent the L and R triangles in top view and the dotted lines represent the lines of sight. With central fixation, the N arrangement produces stimulation of the two nasal hemiretinas and the T arrangement the two temporal hemiretinas.

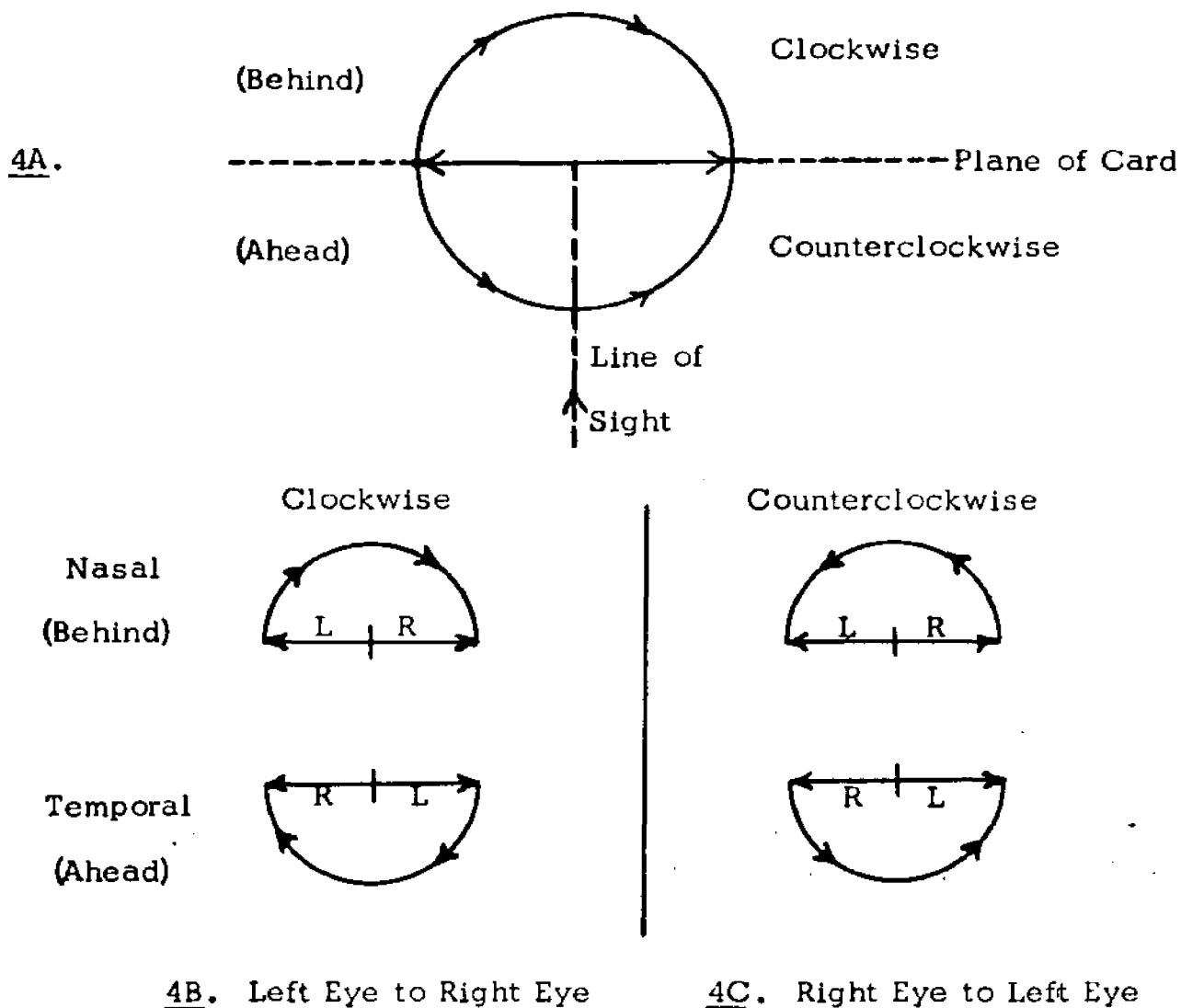


Fig. 4. Illustration of the direction of rotation rule. Horizontal arrows represent R and L triangles in top view. Fig. 4A indicates that ahead or behind movement can be interpreted as clockwise or counterclockwise rotation. Fig. 4B shows that for a single cycle beginning with stimulation of the left eye, the rotation is clockwise for both nasal and temporal conditions. For a cycle beginning with the right eye, the rotation is counterclockwise (Fig. 4C).

Although it is possible to observe a single cycle and report on the direction of rotation, it is more practical to present the alternation sequence repetitively and obtain reports of movement ahead or behind. The perception of movement behind for N stimulation and movement ahead for T stimulation is equivalent to observations which are consistent with the direction of rotation rule.

Pastore and Ferris sought to verify the difference between N and T conditions with respect to type of movement perceived for a larger group (N=55) of observers.<sup>3</sup> Two stimulus cards, each with an N and T arrangement, were viewed in an original model of the Brewster stereoscope. Stimuli were 1/2 in. white equilateral triangles on a black background. The right and left sides were each illuminated by a separate neon bulb. Each bulb was alternately illuminated for 500 msec.; the interval between presentations was approximately zero. The sequence (left bulb on, left bulb off, right bulb on, right bulb off) recycled repetitively. Ss gave a report for the N condition and the T condition for each card. About 90% of the 220 reports spontaneously given by the Ss were of oscillation in depth.<sup>4</sup> Of these reports, about 73% of those pertaining to N conditions were of movement behind, and about 78% of those pertaining to T conditions were of movement ahead. This strong tendency for N stimulation to elicit perception of movement behind and T stimulation to elicit perception of movement ahead was consistent with previous results.

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<sup>3</sup>Pastore, N. & Ferris, S. H. Interocular apparent movement in depth: A motion predominance effect. Unpublished experiment, 1967.

<sup>4</sup>The remaining reports concerned the following types of percept: Alternation (no movement), a movement in the plane which Ss expressed difficulty in defining, and a pendulum-like planar rotation in which a vertex of the triangle serves as the axis of rotation.

In order to simplify further reference to the phenomenon verified above, the following terminology will be introduced: TIAM predominance effect will refer to the tendency of N stimulation to produce movement behind and T stimulation to produce movement ahead. The present research is a further investigation of this phenomenon. The rationale for the experiments and the hypotheses tested are discussed separately in the introduction to each experiment. In Part 1 of this report a series of experiments designed to establish the generality of the TIAM predominance effect is discussed. In Part 2, a theory is proposed to explain the effect which hypothesizes the involvement of stereopsis. A second series of experiments designed to determine the validity of the theory is then discussed.

## General Method

### Subjects

A total of 101 undergraduates (33 males and 68 females), derived chiefly from introductory psychology courses, served as subjects. Four other Ss were rejected because of inability to obtain proper fusion. Of the 101 Ss, 82 returned for a second experimental session. Several experiments were usually run in each session. Availability and convenience determined in which experiments and in how many a given S took part. The prior performance of an S was never a factor.

### Apparatus

Tachistoscope. A three-channel instrument (Scientific Prototype Model GB) was used in Experiments 1 and 2. Stimulus figures were drawn in heavy black pencil on 5 x 7 in. white cards. Fields 1 and 2 of the tachistoscope were used to present stimulus cards for the right and left stimulus figures. When desired, Field 3 was used to present a central red fixation cross. The viewing distance was 48 in. The eyepieces of the tachistoscope contained two oppositely oriented polarizing filters separated by a septum. Insertion of appropriate polarizing filters into Fields 1 and 2 permitted the separate stimulation of the two eyes. Thus the stimuli could be presented interocularly as well as binocularly and monocularly. When the filters were inserted, illumination levels were increased in order to retain stimulus brightness equal to that without filters. In order to produce AM, the right and left fields were alternately illuminated for 500 msec. with a 50 msec. interstimulus interval. Alternation cycled continuously and automatically, with the fixation cross (Field 3) illuminated at all times. Viewing took place in a lighted room.

Stereoscope. In all other experiments a modified telebinocular

stereoscope (Keystone No. 46 Telebinocular) was used. This instrument has a standard stimulus card holder which slides on a track behind the viewer. It was modified by substituting an opaque box with an open front face for the standard holder. A partition inside the box formed separate right and left chambers. A 2 watt neon bulb (GE NE-34) was placed at the rear of each chamber. The two bulbs were wired to a four-channel timing relay (Hunter Model 1514) by means of two three-position switches which were mounted adjacent to each other on top of the box. With both switches in position 1 the bulbs were off, in position 2 they were steadily on, and in position 3 the bulbs alternated on and off repetitively. The parameters of stimulation were again 500 msec. on, and 50 msec. between presentations. The right and left stimulus figures were drawn in dark pencil, on one 5 x 7 in. white card, with a 3 in. separation between the lines to be fused. Stimulus cards were inserted in a slot at the open face of the box. Since the cards were translucent, the right and left fields were separately and uniformly illuminated from behind by the two neon bulbs. The stimulus presentation was always interocular. By sliding the box along the track, the subject was able to adjust the distance of the stimulus card in order to obtain fusion of appropriate lines of the right and left stimulus patterns. Viewing distance thus varied for different  $\underline{S}$ s, but the average was about 6-1/2 in. It was not practical to determine stimulus sizes in terms of retinal angle since the amount of magnification produced by the stereoscope's lens system varies as a function of viewing distance. Viewing took place in a dark cubicle.

### Procedure

Prior to their initial session each  $\underline{S}$  was given the following general

instructions before looking into the viewer:

This experiment has nothing at all to do with personality or intelligence, so do not look for any hidden meanings. Also, there are no right or wrong answers. The experiment simply involves reporting what you see, and whatever you see determines your answers. Anything you see is correct.

The right and left stimulus figures were interocularly presented. Both figures were illuminated simultaneously and continuously. When the tachistoscope was used, appropriate switches were operated by E. But with the stereoscope, S was instructed to move both switches on the box into position 2. It was then ascertained whether S perceived a visual field in which appropriate portions of the two figures (such as the two fixation lines) were fused. With the tachistoscope, it sometimes took S a few seconds to obtain fusion. With the stereoscope, S was allowed to adjust the position of the box to facilitate proper fusion. S was now told which part of the stimulus field he was to fixate upon. Depending on the experiment, either a separate red cross, the vertical line joining the two figures, or a separate line between the figures was used for fixation.

The two figures were next presented in alternation. With the telestereoscope, this was accomplished by instructing S to move the switches to position 3. S was now given the following instructions:

You should now see a single triangle in motion from side to side. Is that correct? [E waited for S's response] As the triangle flips from one position to the other, the point of the triangle may swing in depth, either toward you, ahead of the plane, or away from you, behind the plane. Do you see it turn in depth? Which do you see, motion toward you or away from you?

The apparatus was now turned off. For the stereoscope, this was accomplished by having S move the switches to position 1. Then, using a pencil to simulate the moving triangle, E demonstrated to S the type of motion seen in order to verify the verbal report of motion ahead or behind. The alternate type of motion (ahead or behind) was then demonstrated and

S was told the following:

Your task is very simple. There will be a series of trials. Each time you look into the viewer you are to watch the triangle move back and forth a few times and then report whether the motion is ahead or behind. You may always see it one way or the other, or you may sometimes see it ahead and other times behind. If the movement you perceive should change in the middle of a trial, report the initial motion. Remember, there are no right or wrong answers.

When the stereoscope was used, the following additional instructions were given:

At the start of each trial you are first to move the switches to position 2 and view the stationary field to be sure you see it properly. If you have any difficulty, you may make adjustments in the position of the box. As soon as you see the figures correctly, move the switches to position 3. Then report on the nature of the motion you perceive and immediately turn the switches to position 1.

Having S view the stationary field prior to each motion report with the stereoscope led to proper fixation at the start of each trial. For both instruments, the point within a timing cycle that each trial began was entirely random. The motion was generally viewed for 1-4 sec., depending upon how long it took S to make a report. The intertrial period was about 15 sec. when the tachistoscope was used and about 10 sec. with the stereoscope.

Additional instructions were sometimes given which were specific to the conditions of the particular experiment involved. When an S returned for a second session, he was reminded of the procedure and of the type of motion reports to be made.

Each of the stimulus arrangements was presented ten times, in random order. For example, with four conditions there are 24 possible sequences. For each S, ten of these possible orders were randomly selected to determine the ordering of each of the ten successive four trial sequences.

E recorded an "ahead" or "behind" report for each trial. Occasion-

ally there were reports either of a full  $360^\circ$  rotation or of a pendulum motion in the plane. These responses, which occurred in less than 1% of the trials, were not recorded; the trial was repeated later in the series. Thus in some cases a few extra trials were presented, but a fixed number of reports were always recorded. The number of ahead reports (out of ten) for each S on each stimulus condition was chosen as the measure of motion preference. Statistical analysis of this measure involved ANOVA (repeated measures design), and this analysis was followed, when appropriate, by the Scheffe' multiple comparison test (Winer, 1962). In cases where the homogeneity of variance assumption was not met, the Friedman test (Siegel, 1956) was used in ascertain whether the conclusions based on ANOVA were valid.

**Part I**

**The Generality of the TIAM Predominance Effect**

The TIAM predominance effect has been demonstrated under relatively restricted conditions. In order to determine the generality of the effect, experiments were designed to answer the following questions:

1. Is the effect unique to the Brewster stereoscope?
2. Does the effect occur only for interocular stimulus presentation?
3. Does the effect occur when there is better control over eye fixation? Are eyemovements related to the effect?
4. Is the effect unique to a triangular figure?
5. Are N and T the only interocular conditions for which the effect occurs?
6. Can the strength of the effect be increased by presenting contrasting arrangements simultaneously?
7. Does the effect occur when the TIAM is in a vertical rather than a horizontal direction?
8. Is the effect influenced by the amount of horizontal separation between figure and fixation line?

## Experiment 1: Binocular, Monocular and Interocular Tachistoscopic Presentation

Since the Brewster stereoscope was the only instrument used in the two preliminary experiments, it is possible that the TIAM predominance effect is a function of this apparatus. Furthermore, the fixation line was interocularly presented. While one eye was stimulated, no fixation line was presented to the other eye. Thus proper fixation may not have been maintained, possibly contributing to the predominance effect. Also, motion reports pertaining to oscillation in depth have not been obtained for binocular and monocular stimulus presentation. The present experiment was designed to determine whether the predominance effect occurs with another apparatus, whether the effect occurs when the fixation stimulus is presented continuously to both eyes, and whether the effect occurs only for interocular stimulus presentation. The tachistoscope, the instrument used in the present experiment, differs from a stereoscope in that it does not have a lens system. This instrument permits continuous binocular presentation of a fixation stimulus and permits binocular and monocular as well as interocular presentation of stimuli.

### Method

#### Subjects and Stimulus Conditions

Twenty Ss, appearing for the first time, were used. The stimuli were two equilateral triangles, 1-1/2 in. on a side, pointing in opposite directions (see Fig. 5A). Each triangle subtended a horizontal retinal angle of 1-1/2°. There were five conditions:

Binocular (B). The two triangles were presented to both eyes simultaneously.

Right eye (R). The triangles were presented to the right eye only, left eye occluded.

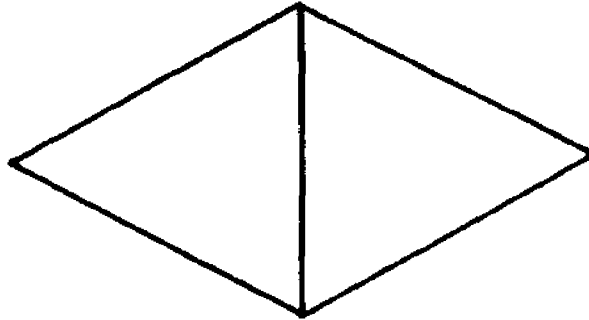
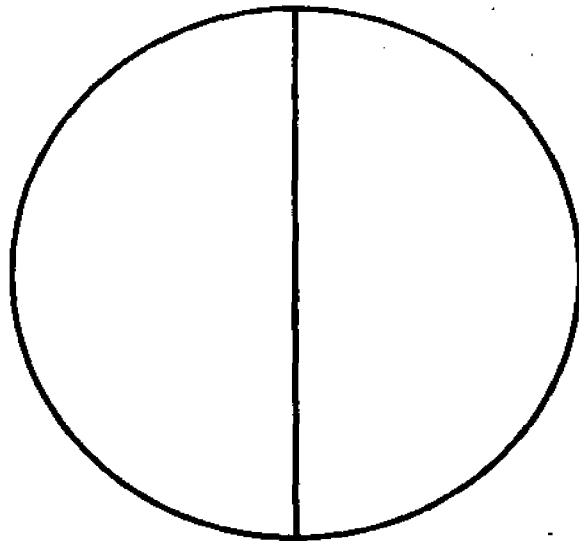
5A.5B.

Fig. 5. Combined visual fields of Experiment 1 (5A) and Experiment 2 (5A and 5B).

Left eye (L). The triangles were presented to the left eye only, right eye occluded.

Nasal (N). The right triangle was presented to the right eye and left triangle to the left eye, leading to nasal stimulation of each retina.

Temporal (T). The right triangle was presented to the left eye and left triangle to the right eye, leading to temporal stimulation of each retina.

### Procedure

After receiving the general instructions and before being shown the stationary view of the two triangles, the binocular fixation cross (Field 3) was exposed. S was instructed to fixate on the cross at all times. After receiving the remaining instructions, Ss were given the following additional instructions:

Generally you will use both eyes to view the triangles. However, sometimes I will want you to use either the right eye alone or the left eye alone. If I say "right eye" or "left eye" before a trial, simply close or cover the other eye during the viewing period. If I do not specify which eye to use, then use both eyes.

The stimuli were presented in alternation and data were collected for the five conditions.

### Results

The results are summarized in Table 1. See Appendix II for individual subject data and summaries of statistical analysis for all experiments. There was a significant difference in frequency of ahead reports for the five conditions ( $F=7.12$ ,  $df=4/76$ ,  $p < .01$ ). The results for the non-interocular conditions, B, R and L, did not differ significantly from each other ( $p > .05$ ). Slightly more than half of the reports were ahead for B and R, and slightly less than half for L. The T condition resulted in the greatest number of ahead reports, although not significantly greater than

TABLE 1

Experiment 1: Mean "Ahead" for Monocular, Binocular  
and Interocular Stimulus Presentation

Stimulus condition	Mean "ahead"	S.D.
Binocular	5.50	2.97
Right eye	5.10	2.14
Left eye	4.50	2.67
Nasal	3.10	2.70
Temporal	5.70	2.49

B, R or L ( $p$ 's  $>.05$ ). However, for the N condition, more than two-thirds of the reports were of motion behind, and this differed significantly from the T, as well as the B and R conditions ( $p$ 's  $<.01$ ). Thus, temporal stimulation produced results which were similar to the binocular and monocular results, but differed from the results for nasal stimulation.

Individual differences were apparent. Some Ss tended to favor motion ahead and others motion behind, while some showed no particular preference. A few perceived the motion in one particular way regardless of condition. However, there were more ahead reports for T stimulation than for N stimulation for 15 of the 20 Ss, the difference exceeding two for half of the subjects. In no case did the number of aheads for N exceed the number for T. Parenthetically, a few Ss remarked that the fixation cross was distracting.

#### Discussion

The difference in perceived motion between N and T conditions is consistent with the results of the two preliminary experiments. Thus more than half of the T reports were ahead, and more than two-thirds of the N reports were behind. Since the TIAM predominance effect has been confirmed with the tachistoscope, this phenomenon does not depend on the use of a particular apparatus. Inasmuch as the B, R and L conditions did not differ from each other, the predominance effect is specific to interocular stimulation.

In this experiment a continuously visible binocular fixation cross was used. As a result, proper fixation and fusion was more likely to have been maintained than in the two original experiments. Therefore, lack of adequate control over fixation in those studies is not likely to have been related to the predominance effect. However, since the

presence of the binocular fixation cross may have been distracting, it may have affected the results.

## Experiment 2: The Role of Stimulus Shape and Binocular Fixation

One purpose of this experiment was to determine whether the TIAM predominance effect occurs only for triangles. Frequency of ahead reports for N and T conditions were compared for triangles and semicircles. A second purpose of the experiment was to determine whether the presence of the binocular fixation cross influences the predominance effect.

### Method

#### Subjects and Apparatus

Forty Ss, appearing for the first time, were used. The tachistoscope was again used to present stimuli.

#### Stimulus Conditions

There were three treatment variables:

Stimulus shape. The triangle figures of Experiment 1, and semicircles, 2-3/4 in. in diameter (see Fig. 5B) were used. The semicircles subtended the same  $1-1/2^{\circ}$  horizontal retinal angle as did the triangles.

Retinal stimulation. N and T modes of presentation, as described in Experiment 1, were used for each of the two stimulus shapes.

Fixation group. The 40 Ss were divided into two groups of 20. For the Cross Group, the continuously visible binocular fixation cross of Experiment 1 was used. For the No-Cross Group, the cross was not presented and the central vertical line of the combined stimulus pattern was used for fixation. Stimuli for each of the four conditions (N and T for each shape) were presented to each group.

#### Procedure

Ss of the Cross Group were instructed to fixate on the binocular fixation cross. When each trial was begun, the alternating figures

were presented immediately. This was not the case for the No-Cross Group. When the combined visual field was presented during the instruction period, Ss of this group were instructed to fixate on the middle vertical line. Prior to each motion trial, the combined visual field was again presented continuously. Alternation was introduced and a report obtained only after S indicated that proper fusion had been achieved. This procedure rarely took more than one or two sec. and insured that there was proper fusion and fixation at the start of each trial.

### Results

#### N vs. T

The results for the N and T conditions differed significantly ( $F=59.49$ ,  $df=1/38$ ,  $p < .001$ ), and the difference between means occurred regardless of stimulus shape or fixation group (see Table 2). Overall N and T frequency ahead means were 2.42 and 5.41 respectively. Thus, more than half of the T reports were ahead, whereas more than three-fourths of the N reports were behind.

#### Triangles vs. Semicircles

The results for the two shapes differed significantly ( $F=15.45$ ,  $df=1/38$ ,  $p < .001$ ). Regardless of retinal stimulation or fixation group, the mean number of aheads was lower for the semicircle conditions than for the triangle conditions. The overall semicircle mean was 3.28 as compared to the triangle mean of 4.46.

#### Cross vs. No-Cross

The results for the two fixation groups also differed significantly ( $F=4.64$ ,  $df=1/38$ ,  $p < .05$ ). There were lower ahead means for the No-Cross Group, regardless of retinal stimulation or stimulus shape. Over-

TABLE 2

Experiment 2: Mean "Ahead" as a Function of  
Retinal Stimulation, Stimulus Shape  
and Fixation (Cross vs. No-Cross)

Stimulus condition	Mean "ahead"	S. D.
Cross Group		
Triangle		
N	3.45	2.78
T	6.45	2.73
Semicircle		
N	2.65	2.67
T	5.85	3.20
No-Cross Group		
Triangle		
N	2.10	2.14
T	5.85	3.18
Semicircle		
N	1.10	1.48
T	3.50	3.09

all Cross and No-Cross Group means were 4.64 and 3.14 respectively. Inspection of the data also indicates that there was a smaller relative difference between N and T conditions when the cross was used.

#### Individual Differences

Some Ss preferred motion ahead and others motion behind, with some showing no particular preference. A few perceived the motion one way, regardless of stimulus condition. However, 33 Ss reported more aheads for T stimulation than for N, and in 26 cases this difference exceeded two for at least one of the shapes. The difference exceeded four for 19 Ss.

#### Discussion

The data further substantiate the generality of the TIAM predominance effect. The result of Experiment 1, that the effect occurs when a tachistoscope and binocular fixation are used, has been duplicated. Furthermore, the difference between N and T conditions occurred for semicircles as well as for triangles, although the two figures elicited different frequencies of ahead reports. In general, however, temporal stimulation resulted in more than twice as many ahead reports as compared with nasal stimulation. Furthermore, the predominance effect occurred for each of a majority of Ss and is not merely a statistical artifact.

The presence of the binocular fixation cross was not necessary for the occurrence of the TIAM predominance effect. However, the cross did affect the frequencies of ahead reports.

### Experiment 3: Stereoscopic Presentation

The TIAM predominance effect was first demonstrated using an original model of the Brewster stereoscope and subsequently using a tachistoscope fitted with polarizing filters for interocular presentation. The tachistoscope, however, was judged impractical for use in further experiments because changing stimulus conditions was relatively difficult. Since continuously presented binocular fixation was found to be unnecessary in Experiment 2, use of a modified telebinocular stereoscope was considered to be a good alternative. The present experiment was essentially a replication of Experiment 2 (No-Cross Group), this time using the stereoscope.

#### Method

##### Subjects

Twenty Ss, appearing in their second session, were used. Of these, 17 were members of the Cross Group of Experiment 2.

##### Stimulus Conditions

Stimulus conditions were the same as used in Experiment 2. Triangles were equilateral,  $3/8$  in. on a side. Semicircles were  $5/8$  in. in diameter. As stated in General Method, accurate retinal sizes could not be determined. However, apparent sizes were comparable to those of Experiments 1 and 2. The fused visual fields appeared like those of Experiment 2 (see Fig. 5).

##### Procedure

The procedure for the stereoscope was used, as previously described in General Method.

#### Results

The means for the four stimulus arrangements are given in Table 3.

TABLE 3

Experiment 3: Mean "Ahead" as a Function of  
Retinal Stimulation and Stimulus Shape

Stimulus condition	Mean "ahead"	S.D.
Triangle		
N	2.00	1.84
T	5.60	3.28
Semicircle		
N	1.25	1.51
T	3.80	3.17

They are similar to the corresponding values for the No-Cross Group of Experiment 2 (see Table 2). The data for the four arrangements in the present experiment differed significantly from one another ( $F=19.92$ ,  $df=3/57$ ,  $p < .001$ ). Also, as in Experiment 2, the semicircle resulted in an overall lower level of ahead reports ( $p < .01$ ).

#### Discussion

The Ss of Experiment 2 (No-Cross Group) and Experiment 3 underwent virtually identical procedures. Both groups fixated on the central vertical line, and both viewed the combined visual field prior to each motion trial. Since very similar results were obtained for the two groups, the TIAM predominance effect was not affected by use of the stereoscope. The effect has now been demonstrated using a Brewster stereoscope, a tachistoscope, and a telebinocular stereoscope. Because of its convenience, the telebinocular stereoscope was used in all subsequent experiments.

## Experiment 4: The Role of Relative Position of Stimuli

The TIAM predominance effect has been described as a function of locus of retinal stimulation. However, the difference between nasal and temporal stimulation is not necessarily the crucial factor which gives rise to the difference in perceived movement. Although it has been demonstrated that the predominance effect occurs only with interocular presentation, the N and T conditions are not the only ways in which the two figures can be presented interocularly. This experiment was designed to determine if a predominance effect occurs for interocular stimulus arrangements which do not give rise to stimulation of the two nasal or the two temporal hemiretinas.

### Method

Fifteen Ss, appearing in their second experimental session, viewed four stimulus arrangements (see Fig. 6). For two arrangements there was a fixation line at the left of the figures in the visual field, giving rise to stimulation of the left temporal and right nasal hemiretinas (see Fig. 7). For two arrangements a fixation line was at the right of the figures, giving rise to stimulation of the left nasal and right temporal hemiretinas. The two left temporal-right nasal arrangements differ with respect to the relative position in the visual field of the figure produced by stimulation of the left eye (L) and the figure produced by stimulation of the right eye (R). For one arrangement, L is situated to the left of R, and for the other, L is situated to the right of R. The two left nasal-right temporal arrangements differ in the same way with respect to the relative position of L and R. Arrangements in which L is to the left of R will be referred to as LR, and arrangements in which

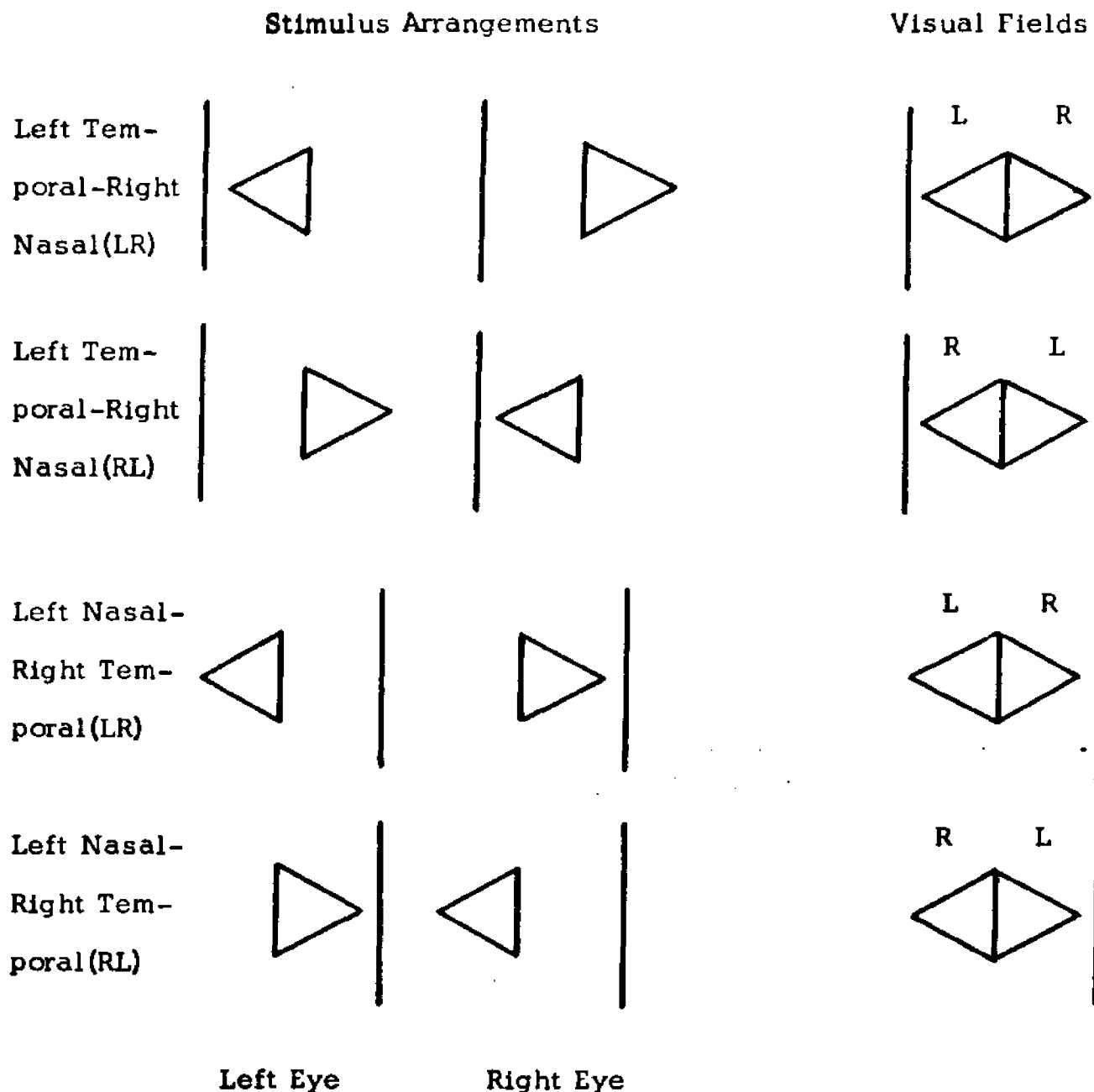
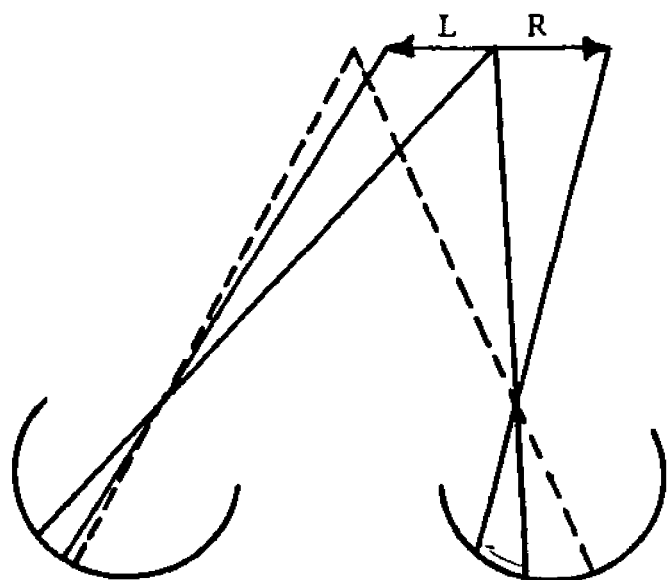
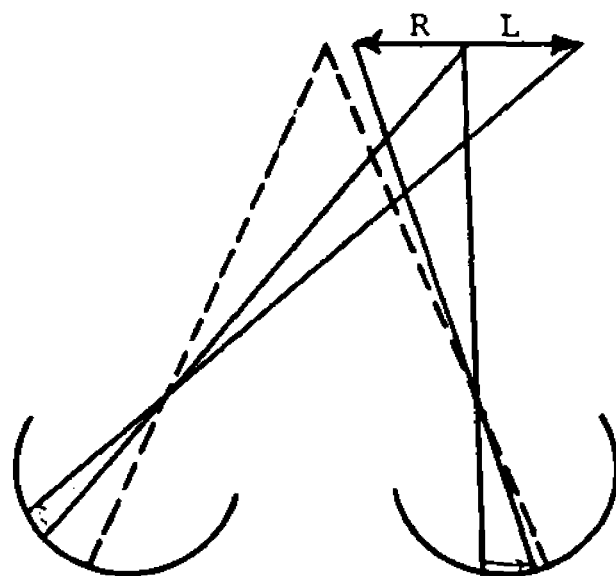


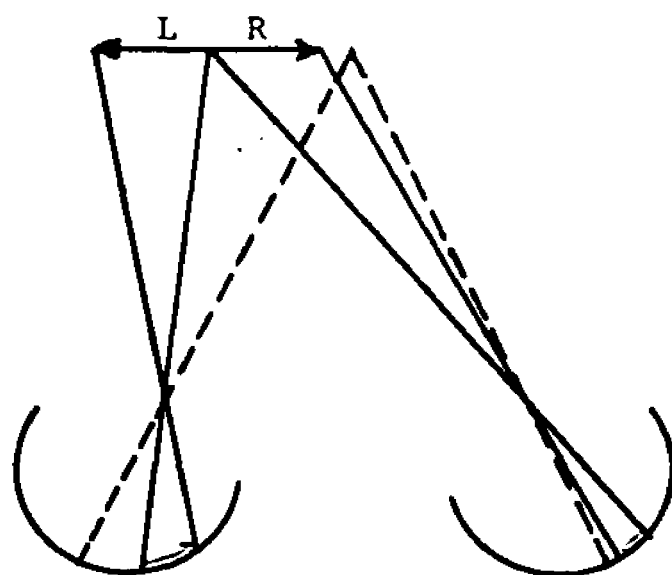
Fig. 6. Stimulus arrangements leading to left temporal and right nasal stimulation and to left nasal and right temporal stimulation when fixation is maintained on the fused vertical line. With respect to the relative position of the R and L figures in the visual field, for two of the arrangements L is to the left of R (RL), and for two of the arrangements R is to the left of L (RL).



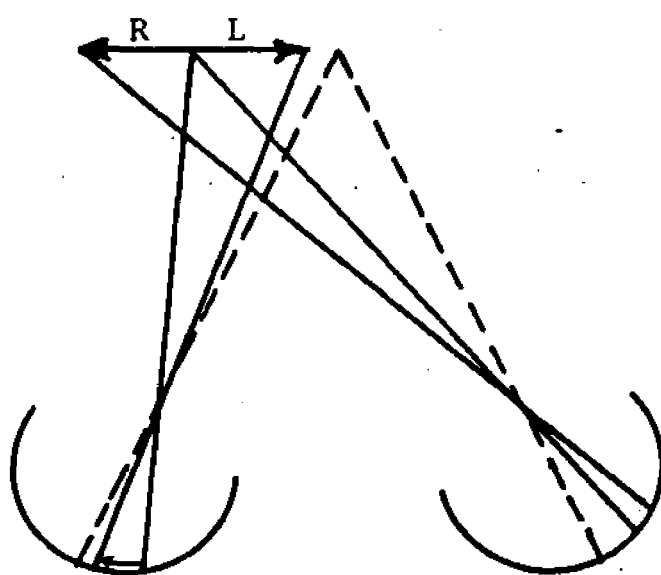
Left Temporal-Right Nasal



Left Temporal-Right Nasal



Left Nasal-Right Temporal



Left Nasal-Right Temporal

Fig. 7. Schematic diagrams of retinal stimulation resulting from the stimulus arrangements of Fig. 6. Horizontal arrows represent the stimulus figures and dotted lines represent lines of sight. Fixation at left gives rise to stimulation of the left temporal and right nasal hemiretinas, and fixation at right gives rise to stimulation of left nasal and right temporal hemiretinas.

L is to the right of R will be referred to as RL.

### Results

The results are summarized in Table 4. The mean "aheads" for the four arrangements differed significantly ( $F=35.13$ ,  $df=3/42$ ,  $p < .001$ ): For both types of retinal stimulation, the RL arrangement gave rise to significantly more ahead reports than the LR arrangement ( $p$ 's  $< .01$ ), results consistent with the TIAM predominance effect. Overall, the results for left temporal-right nasal stimulation did not differ significantly from the results for left nasal-right temporal stimulation ( $p > .05$ ).

### Discussion

The experiment demonstrated that a TIAM predominance effect occurs when the left temporal and right nasal hemiretinas, or the left nasal and right temporal hemiretinas are stimulated. Therefore, the effect does not depend upon stimulation of the two nasal hemiretinas versus stimulation of the two temporal hemiretinas. In the present experiment, a difference between arrangements in the relative position in the visual field of the L and R figures (LR vs. RL) was sufficient to produce a predominance effect. Inspection of Fig. 2 (p.16) indicates that the nasal arrangement is an LR arrangement and the temporal arrangement is an RL arrangement. Thus, the TIAM predominance effect may now be reformulated in terms of relative position rather than in terms of retinal areas stimulated: LR elicits motion behind and RL motion ahead. Since the 'direction of rotation rule' formulated by Pastore is an alternate way of describing the TIAM predominance effect (see p.15), the rule can be broadened as follows: For all RL and LR conditions, a single cycle beginning with stimulation of the left eye gives rise to perception of clockwise rotation, and a cycle beginning with stimulation of the right eye gives rise to counterclockwise rotation.

TABLE 4

Experiment 4: Mean "Ahead" as a Function of Retinal  
Locus and Relative Position in the Visual Field

Stimulus condition	Mean "ahead"	S.D.
Left temporal-right		
nasal		
LR	2.27	1.84
RL	7.07	2.64
Left nasal-right		
temporal		
LR	2.33	2.50
RL	7.13	2.54

## Experiment 5: Two Arrangements

### Simultaneously Presented

The data for an individual are interpreted as consistent with the TIAM predominance effect when the number of ahead reports for RL exceeds the number for LR. Furthermore, when the magnitude of this particular RL-LR difference increases, the greater would be the degree of individual consistency with the predominance effect. In terms of group data, a result in which the mean for RL is significantly larger than the mean for LR is interpreted as consistent with the predominance effect. The strength of the predominance effect would increase as the magnitude of this mean difference increases.

In Experiments 1-4, each stimulus condition was presented individually in separate trials. Consequently, there was a period of 10 sec. or more between each observation. Inspection of the individual data from these experiments indicates that, for many Ss, the TIAM predominance effect was small, and for a few it did not occur. In the present series of experiments, two arrangements were presented simultaneously so that immediate motion comparisons could be made. The hypothesis was that simultaneous presentation would give rise to a stronger predominance effect, relative to the strength of the predominance effect that would be produced by separate presentation.

### Experiment 5A

#### Method

Subjects and stimulus conditions. Twenty-seven Ss, appearing in their second experimental session, were used. Two stimulus cards, each containing an LR and RL arrangement with central fixation, were presented. For one card, an LR arrangement was above and an RL ar-

arrangement was below (Fig. 8). The separation between the centers of the upper and lower triangles was 1 in. The space between each triangle and the vertical fixation line was 1/16 in. The second card was identical except that an RL arrangement was above and an LR arrangement was below. The inversion of the above and below arrangements served as a control for the possible effect of upper versus lower position on the card.

Procedure. The single vertical line in the visual field insured proper pretrial fusion. Ss were instructed always to fixate along the line between the triangles. In making motion judgments, Ss reported first on the figure in the upper position and then on the lower figure. Two separate reports were thus recorded for each presentation.

### Results

When compared with the data for triangles in Experiment 3 (Table 3), the results of the present experiment (Table 5) indicate that the strength of the predominance effect increased when LR and RL arrangements were presented simultaneously. Individual analysis indicated that with the exception of two Ss who perceived ahead motion for all conditions, the data of every S showed a strong predominance effect for at least one stimulus card. Results for the four arrangements (two for each card) differed significantly ( $F=43.23$ ,  $df=3/78$ ,  $p<.001$ ), and the means were consistent with the TIAM predominance effect. However, an unexpected difference was found between the two stimulus cards.

LR above and RL below. RL resulted in significantly more ahead reports than LR ( $p<.01$ ). The relative difference was more than 5:1, as compared to 2:1 or 3:1 in previous experiments. Omitting the two

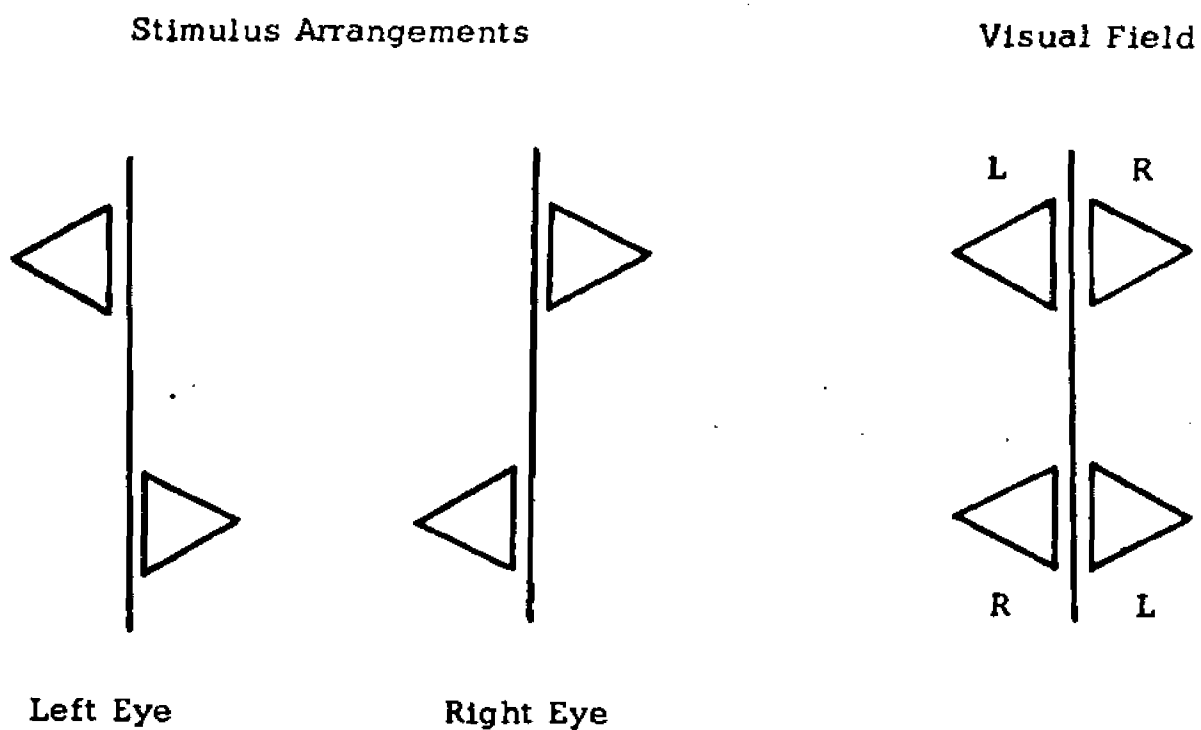


Fig. 8. Stimulus arrangements for Experiment 5A, with an LR condition above and an RL condition below.

TABLE 5

Experiment 5: Mean "Ahead" with Two Arrangements  
Presented Simultaneously

Stimulus condition	Mean "ahead"	S.D.
Experiment 5A		
Above: LR	1.74	2.52
Below: RL	9.48	0.75
Above: RL	7.15	3.39
Below: LR	4.70	3.24
Experiment 5B		
Above: LR	2.81	2.74
Below: RL	7.89	2.26
Above: RL	6.56	2.52
Below: LR	4.04	3.38
Above: LR	2.85	2.94
Below: LR	3.04	2.78
Above: RL	7.04	2.52
Below: RL	7.26	2.36
Experiment 5C		
Semicircles		
Above: LR	1.10	2.00
Below: RL	8.55	1.20
Above: RL	6.10	3.30
Below: LR	3.25	3.08
Left fixation		
Above: LR	3.20	2.36
Below: RL	6.50	2.18
Above: RL	6.60	2.80
Below: LR	4.35	2.48

Ss who always perceived the motion as ahead, the mean number of ahead reports for LR and RL were respectively 1.08 and 9.45. Values of 0.0 and 10.0 would indicate perfect consistency with the predominance effect. Furthermore, for each of 23 Ss the difference between arrangements in number of aheads exceeded five, and differences of nine or ten were not unusual. Thus, LR almost always elicited motion behind and RL motion ahead.

RL above and LR below. RL again elicited significantly more ahead reports than LR ( $p < .05$ ), but the difference was much less than for the first card. The RL arrangement produced significantly fewer ahead reports when above than when below ( $p < .05$ ), and the LR arrangement produced significantly more ahead reports when below than when above ( $p < .01$ ). In fact, the RL-LR difference which occurred when RL was above LR was actually less than had previously been found without simultaneous presentation. Thus, while simultaneous presentation strengthened the predominance effect for the first card, the reversing of upper and lower positions led to an attenuation of the effect for the second card. However, examination of the individual data indicated that this attenuation occurred only for about a third of the Ss. The data of each of 15 Ss were consistent with the predominance effect. The mean numbers of ahead reports for these Ss were 2.60 and 9.20 for LR and RL respectively. On the other hand, for 10 Ss there was either a partial or complete reversal of the predominance effect. The LR and RL means for these 10 Ss were 6.8 and 3.5, a result opposite to the expected one. It may be tentatively concluded that simultaneous presentation of conditions strengthens the TIAM predominance effect, but that for some Ss, simultaneous presentation may lead to a loss or reversal of the effect when RL is above LR.

### Experiment 5B

The difference found between the two stimulus cards in the preceding Experiment 5A may have been due to an effect of upper and lower position on the perceived movement. Thus regardless of whether the arrangement is LR or RL, the upper position may favor behind movement and the lower position may favor ahead movement. When RL is above and LR below, this position effect would lead to an attenuation in the number of aheads for RL and an increase in the number of aheads for LR. An attenuation for RL and an increase in LR did in fact occur for some Ss in the preceding experiment. However, it is not clear whether this position effect is a general phenomenon or whether it occurs only when RL is above LR. In order to distinguish between these possibilities, two stimulus cards were added to those of the previous experiment, one card having LR and the other having RL in both upper and lower positions. If the position effect is a general phenomenon, upper and lower positions should elicit different results when the two positions contain the same stimulus arrangement.

### Method

Twenty-seven Ss were used, of whom twenty-two were being used for the first time. The remaining five Ss had been used previously, but did not take part in Experiment 5A. The procedure was identical to that of Experiment 5A, except that four stimulus cards were presented for a total of eight arrangements. Two cards were the same as those used in Experiment 5A. The third card had an LR arrangement in both upper and lower positions, and the fourth had two RL arrangements.

### Results

The results (see Table 5) substantiate those of the preceding

Experiment 5A. The data for the eight arrangements differed significantly ( $F=20.19$ ,  $df=7.82$ ,  $p<.001$ ) and for each arrangement the ahead mean was consistent with the TIAM predominance effect.

LR above and RL below. Results for RL and LR differed significantly ( $p<.01$ ) and there was again a strong predominance effect, although the relative LR-RL difference was not as large as in the previous experiment. For each of 23 Ss, there were more ahead reports for RL than for LR. The LR-RL difference exceeded four for 16 Ss.

RL above and LR below. The attenuation in the RL-LR difference with reversal in upper-lower positions was replicated, and there were again two types of Ss. For each of 17 Ss the results were consistent with the predominance effect. LR and RL means for this group were 1.65 and 7.47. For each of 9 Ss the predominance effect was either reduced or reversed, and LR and RL means were 7.89 and 4.44.

LR in both positions and RL in both positions. For these stimulus cards, the top and bottom conditions elicited nearly identical results ( $p's>.05$ ). Most Ss reported similar ahead frequencies for both positions. Also, mean ahead values for the RL and LR arrangements were comparable to the values obtained when LR was above RL. The data thus suggests that upper-lower position affects the motion reports of some Ss only when RL is above LR.

#### Experiment 5C

The purpose of this experiment was to determine if the results of the two previous experiments can be generalized to other stimulus shapes and stimulus arrangements. The effect of simultaneous presentation was tested using semicircles, and triangles with fixation to the

left of the figures. In view of the results for the control arrangements of the previous experiment, similar controls were not considered necessary in the present experiment.

### Method

Twenty Ss, of whom 17 had previously taken part in at least one other experiment, were used. The procedure was identical to that of Experiment 5B. Four stimulus cards were used which were similar to those of Experiment 5A. For two cards, semicircles having the same dimensions as those used in Experiment 3 replaced the triangles. For two cards the fixation line was placed to the left of the triangles (see Experiment 4). LR was situated above RL for one semicircle card and one left-fixation card, and RL was above LR for the other card of each type.

### Results

The results (see Table 5) were generally consistent with those of the two previous experiments. The data for semicircles and triangles with left fixation were analysed separately.

Semicircles. The results were similar to the results found for triangles in Experiment 5A. The data for the four arrangements involving the semicircle differed significantly ( $F=29.44$ ,  $df=3/57$ ,  $p < .001$ ) and when LR was above RL the LR-RL difference ( $p < .01$ ) was much larger than the corresponding difference in Experiment 3 which did not involve simultaneous presentation (Table 3). The LR-RL difference exceeded three for 19 of the 20 Ss and the difference exceeded five for 14 Ss. When RL was above LR, the results for the two arrangements differed significantly ( $p < .05$ ), and, as in Experiment 5A, the difference was small and there were two subject types.

The data for each of thirteen Ss were consistent with the predominance effect. LR and RL means for these Ss were 1.54 and 8.00. The data for each of seven Ss indicated a loss or reversal of the predominance effect. LR and RL means for these Ss were 6.43 and 2.57.

Triangles with fixation at left. A strengthening of the predominance effect did not occur for these cards. The data for the four arrangements differed significantly ( $F=11.60$ ,  $df=3/57$ ,  $p < .001$ ), and when LR was above RL the LR-RL difference was significant ( $p < .01$ ). Although the number of aheads for RL exceeded the number for LR for 17 of the Ss, the predominance effect for the group was less than found without simultaneous presentation in Experiment 4 (Table 4). For the second card, however, results were similar to those found previously for simultaneous comparison when RL was above LR. The overall RL-LR difference was small, and there were two types of Ss. The data for each of fourteen Ss were consistent with the predominance effect. Their group means were 3.36 and 7.50 for LR and RL, respectively. For each of six Ss there was a loss or reversal of the effect. LR and RL means for these Ss were 6.67 and 4.50.

#### Discussion

The results of Experiments 5A, 5B and 5C indicate that when LR and RL are simultaneously presented, LR being above RL, there is greater subject consistency and a stronger group predominance effect in comparison to the results obtained by the presentation of LR and RL separately. A strengthening of the effect also occurs for about two-thirds of the Ss when the relative position of the arrangements is changed so that RL is above LR. For this particular arrangement, however, there is an attenuation or reversal of the predominance

effect, rather than an enhancement, for about one-third of these Ss. In short, the results for these Ss are influenced by the placement of RL above LR.

### Experiment 6: Test for the Role of Eyemovement

This experiment was designed to examine the hypothesis that differential eyemovements associated with viewing LR and RL arrangements are related to the predominance effect. When viewing TIAM, it is difficult for an S to maintain perfect fusion. During each alternation cycle there is a 50 msec. interstimulus interval when neither eye is stimulated and a 500 msec. interval when only one eye is stimulated. As a result, there is a tendency for proper convergence for fusion to be lost. If the eyemovements which result differ for LR and RL stimulus conditions, this difference may be related to the TIAM predominance effect.

The testing for the role of eyemovement was based on the fact that the eye only moves in one direction at a given time. If the two stimulus arrangements are viewed simultaneously with a common point of fixation, differential eyemovement for each arrangement could not occur. Thus, there should be no predominance effect on the hypothesis that eyemovement is a critical factor. But if the effect occurs, eyemovement is excluded.

### Method

#### Subjects and Stimulus Conditions

Twenty Ss with prior experience viewed two stimulus cards. One card (see Fig. 9) was similar in arrangement to the cards previously used for simultaneous presentation, except that the upper and lower triangles were closer together ( $3/4$  in. between centers) and there was a long horizontal line between upper and lower arrangements. With fixation maintained on the intersection of the two lines, Ss could simultaneously perceive the upper and lower triangles. The second card was identical to the first except for the position reversal of upper and

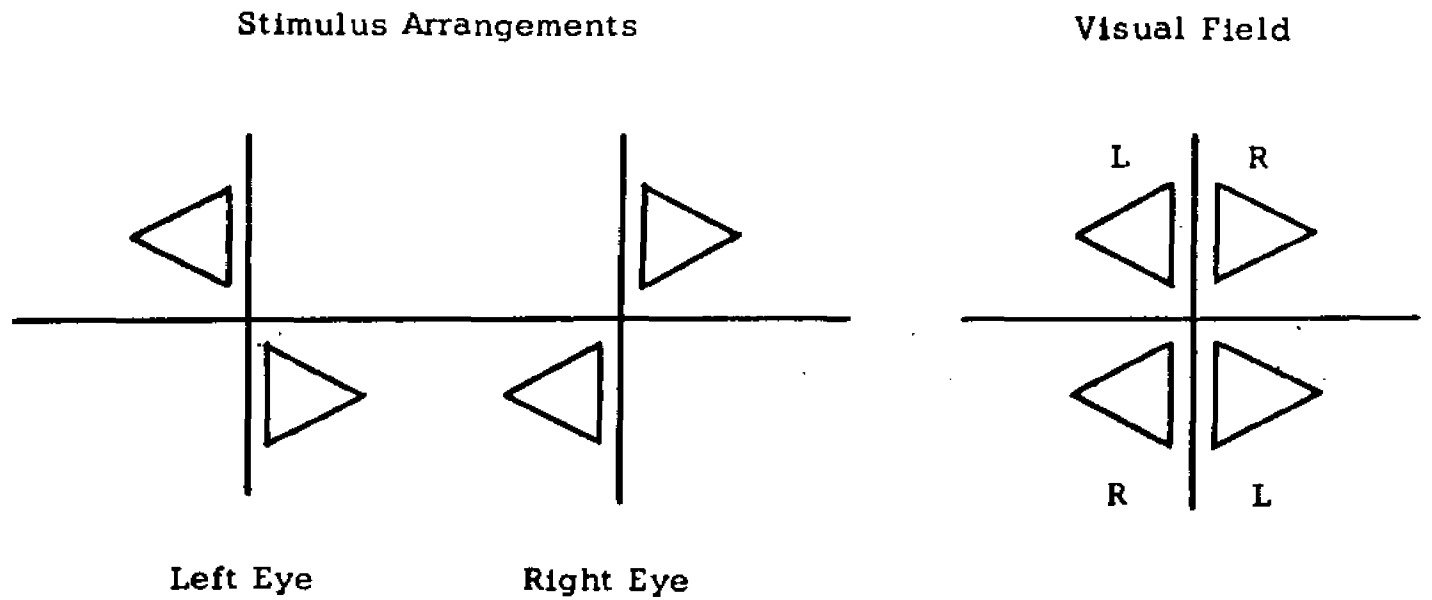


Fig. 9. Stimulus arrangement for Experiment 6 in which LR is above RL. The second card was identical, but with RL above LR.

lower arrangements .

### Procedure

Ss were instructed not to look separately at the upper and lower arrangements, but always to fixate on the central intersection of lines. Although they were told to observe the upper and lower motions simultaneously, they always reported first on the upper and then on the lower arrangement. During the series of trials, Ss were occasionally reminded of the need to maintain central fixation.

### Results

The results (see Table 6) are not consistent with the hypothesis pertaining to the role of eyemovements. The data for the four arrangements differed significantly ( $F=31.15$ ,  $df=3/57$ ,  $p < .001$ ) and means for the four stimulus arrangements were consistent with the predominance effect and comparable to the simultaneous presentation results of Experiment 5 (Table 5). When LR was above RL, the LR-RL difference was significant ( $p < .01$ ) and large, and there was a strong predominance effect for all but two of the Ss. When RL was above LR, the LR-RL difference was significant ( $p < .01$ ) but relatively small, and there were again two types of Ss. For twelve consistent Ss the LR and RL means were 3.25 and 8.23, whereas for eight inconsistent Ss the corresponding values were 7.13 and 6.50.

### Discussion

The results of this experiment are consistent with the view that eyemovements are not related to the TIAM predominance effect since the effect occurred even when the possibility of differential eyemovements for the two conditions was eliminated. Eyemovements may still have occurred, but since the Ss were instructed to maintain central

TABLE 6

Experiment 6: Mean "Ahead" with Control  
for Eyemovement

Stimulus condition	Mean "ahead"	S.D.
Above: LR	1.80	2.27
Below: RL	8.55	2.27
Above: RL	7.60	2.44
Below: LR	4.80	3.36

fixation and to observe both stimulus arrangements simultaneously, such movements were presumably the same for both arrangements. It is possible that some Ss did not follow instructions. However, when questioned during the experiment, Ss reported that the upper and lower triangles could be perceived in oscillation at the same time, and that one moved ahead and the other behind.

### Experiment 7: Vertical TIAM

In the TIAM studies which have been reported, the two stimulus figures were situated to the right and left of each other in the visual field. The movement perceived was therefore horizontal. However, AM in depth also occurs when the stimuli are above and below each other and the movement is vertical (Steinig, 1929). The purpose of this experiment was to determine if the predominance effect occurs for vertical TIAM.

#### Experiment 7A

##### Method

Eighteen Ss in their second experimental session viewed two stimulus arrangements. The triangle figures were drawn pointing up and down, giving rise to perception of the visual fields shown in Fig. 10. Fixation was maintained on the common horizontal line. For one arrangement the R triangle was situated above the L triangle, and for the other, L was above R. These two arrangements for vertical motion are analogous to the RL and LR conditions for horizontal motion.

##### Results

The results (see Table 7) indicate the absence of a predominance effect. The data for the two arrangements did not differ significantly ( $t < 1$ ). Some Ss tended to prefer motion ahead and some motion behind, but ahead frequencies were generally similar for both arrangements.

#### Experiment 7B

In this experiment, four additional stimulus arrangements which give rise to vertical TIAM were presented. The aim was again to determine if a predominance effect occurs.

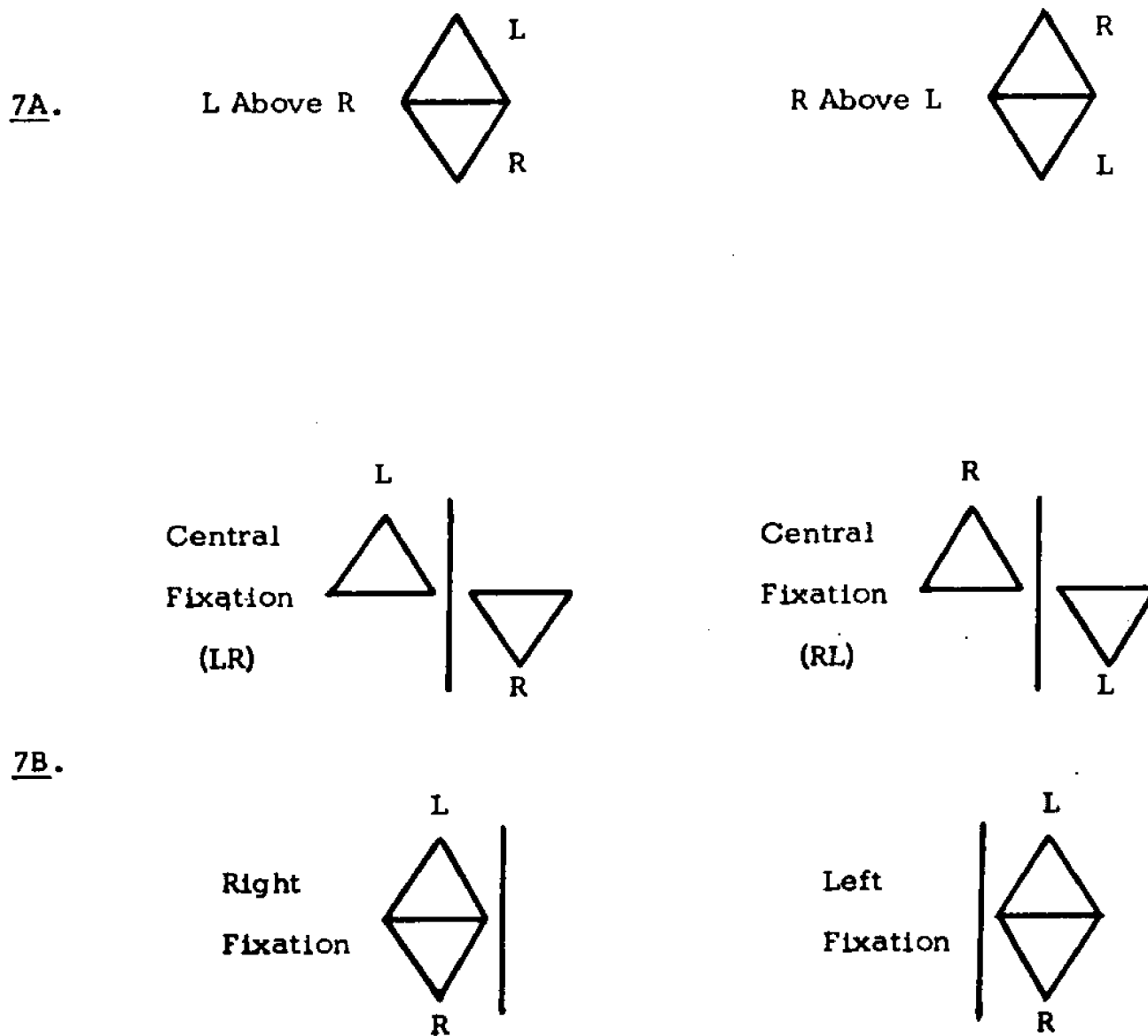


Fig. 10. Combined visual fields for stimulus arrangements of Experiment 7A and 7B.

TABLE 7

Experiment 7: Mean "Ahead" for Vertical TIAM

Stimulus condition	Mean "ahead"	S.D.
Experiment 7A		
R above L	4.67	3.69
L above R	4.72	3.29
Experiment 7B		
Central fixation		
LR	5.27	3.64
RL	8.07	1.90
Right fixation	5.80	3.66
Left fixation	6.00	3.62

### Method

Fifteen Ss in their second experimental session viewed four stimulus arrangements. Combined visual fields for the four arrangements are shown in Fig. 10. There was an LR and RL arrangement with central fixation, and one arrangement with left fixation and one with right fixation. In each case, fixation was maintained on the vertical line.

### Results

The results are summarized in Table 7. The data for the four arrangements differed significantly ( $F=3.58$ ,  $df=3/42$ ,  $p < .05$ ). Paired comparisons indicated that only LR and RL arrangements differed significantly ( $p < .05$ ). Although movement ahead predominated for both arrangements, the RL arrangement elicited more ahead reports than the LR arrangement, a result consistent with the TIAM predominance effect. However, the relative difference was less than previously found for horizontal motion, and the difference occurred for only seven Ss. The means for these Ss for LR and RL were, respectively, 1.59 and 8.14, whereas for the remaining eight Ss the corresponding means were 8.13 and 8.50.

### Discussion

Except for the LR and RL arrangements, vertical movement did not produce a predominance effect. The effect which occurred for LR and RL was weak in comparison to the effect usually found for horizontal TIAM, and the effect occurred for less than half of the Ss. Since only 15 Ss were tested, and since the significance level (.05) of the LR-RL difference may be considered marginal, the experiment should be replicated. Furthermore, for the LR and RL arrangements the figures were in different horizontal positions as well as in different vertical positions in the visual field. Consequently, there was a horizontal as well as a vertical com-

ponent to the perceived motion. The triangle appeared to swing up and down in depth, but simultaneously moved from side to side. Since the only arrangements producing results at all consistent with the predominance effect were those involving some horizontal motion, the predominance effect which occurred for some Ss may have been due to the horizontal motion component. It is concluded that the predominance effect does not occur for completely vertical TIAM, and that further study is required to verify the occurrence of the effect when the vertical movement includes a horizontal component.

### Experiment 8: Separation Between Figure and Fixation Line

Experiments 1-3, in which the two figures had a common vertical side, verified the TIAM predominance effect; similarly, Experiments 5 and 6 also verified the effect even though there was a separation of  $1/16$  in. between the vertical side of each figure and the fixation line. The purpose of the present experiment was to ascertain further the influence of the distance between the vertical side of a triangle and the fixation line.

#### Method

Twenty Ss with prior experience in a TIAM experiment viewed four stimulus cards. For two cards (an LR arrangement on one card and an RL arrangement on the other) there was a  $1/16$  in. separation between the vertical side of each triangle and the fixation line.<sup>5</sup> The separation for the other two cards (an LR arrangement on one card and an RL arrangement on the other) was  $3/8$  in.

#### Results and Discussion

The results are summarized in Table 8. The data for the four arrangements differed significantly ( $F=26.08$ ,  $df=2/57$ ,  $p<.001$ ), and for both separations there was a significant LR-RL difference ( $p's<.01$ ) which was consistent with the TIAM predominance effect. Although the size of the difference was larger and the overall number of ahead reports was slightly less for  $3/8$  in. as compared to  $1/16$  in., the difference in separation did not significantly influence the predom-

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<sup>5</sup>The two arrangements were identical to the upper and lower arrangements of Fig. 8 (p.48), except that each arrangement was on a separate card.

TABLE 8

Experiment 8: Mean "Ahead" as a Function of Separation  
Between Figure and Fixation Line

Stimulus condition	Mean "ahead"	S.D.
1/16 in. separation		
LR	2.75	2.49
RL	7.10	2.00
3/8 in. separation		
LR	1.90	1.45
RL	6.40	2.62

inance effect ( $p > .05$ ). Thus, for separations of  $3/8$  in. or less, the degree of separation between the triangle and the fixation line does not affect the TIAM predominance effect.

### Summary of Part I

The experiments reported have demonstrated the following:

1. A predominance effect occurs for oscillation in depth only when the stimuli are presented interocularly.

2. The effect occurs for semicircles as well as for triangles, although the overall number of ahead reports is lower for semicircles.

In general, there are at least twice as many ahead reports for temporal stimulation than for nasal stimulation.

3. Three different instruments, an original model of the Brewster stereoscope, a tachistoscope with polarizing filters, and a telebinocular stereoscope have been used to produce the predominance effect.

4. The effect occurs with or without continuous binocular fixation. Furthermore, the effect does not depend on differential eyemovements.

5. The effect does not depend on nasal versus temporal stimulation, but depends on a difference in the relative position of the two stimuli in the visual field. Thus, LR gives rise to movement behind and RL gives rise to movement ahead.

6. There are substantial individual differences in the strength of the predominance effect. For the particular simultaneous presentation in which arrangement LR is above arrangement RL, individual differences are minimized and there is an improvement in individual consistency with the predominance effect. For the contrasting simultaneous presentation (arrangement RL above arrangement LR) individual consistency is also improved for a majority of Ss. For this latter presentation, however, there is an unexplained attenuation or reversal of the predominance effect for the remaining Ss.

7. The predominance effect does not occur for TIAM in a vertical direction, but it may occur when the vertical movement involves a horizontal component.

8. The separation between each figure and the fixation line (at least up to 3/8 in.) does not influence the predominance effect.

**Part II**

**Proposed Explanation for the TIAM Predominance Effect**

The 'direction of rotation rule' formulated by Pastore (p.15) is a relatively simple description of the TIAM predominance effect, but the rule does not explain why the effect occurs. The following tentative explanation was proposed: The TIAM stimuli give rise to percepts which are equivalent to double images,<sup>6</sup> and stereoscopic depth produced by these double images is related to the nature of the perceived TIAM. In the TIAM procedure, the right and left figures stimulate noncorresponding or disparate retinal points, and two separate figures or double images are perceived when the figures are viewed simultaneously. In binocular viewing, double images which are perceived are the unfused half-images of a single object in space. In the TIAM situation, no single physical object produces the two images. However, the retinal stimulation is equivalent to the stimulation produced in the normal double image situation.

There are two types of double images, crossed and uncrossed. In binocular viewing, an observer may perceive uncrossed double images of an object by fixating on a nearer object. The double images of the farther object are said to be uncrossed because the percept resulting from stimulation of the left retina is perceived on the left and the percept resulting from stimulation of the right retina is perceived on the right. If the observer fixates on the farther object, the double images of the nearer object are said to be crossed since the percept corresponding to the image produced on the left retina is perceived on the right and the percept corresponding to the image produced on the right retina is perceived on the left. In terms of retinal stimulation, the LR stimulus

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<sup>6</sup>This idea was suggested by Dr. Eric Heinemann.

arrangement is equivalent to presentation of uncrossed double images and the RL arrangement is equivalent to presentation of crossed double images. Thus, the TIAM predominance effect may be alternately stated as follows: Alternate presentation of uncrossed double images gives rise to movement behind and alternate presentation of crossed double images gives rise to movement ahead. Fig. 11 illustrates the three uncrossed (LR) and the three crossed (RL) stimulus arrangements which have been used to produce TIAM. The solid dots represent the stimulus figures (the double images) drawn on the stimulus cards. The small circles represent the nearer or farther locations in space of the single object which would give rise to the double images.

It has long been known that fusion of disparate images is not a requirement for stereopsis and that double images are perceived in stereoscopic depth (see Ogle, 1952, for a review of early studies). Uncrossed double images are localized behind the point of fixation and crossed double images are localized ahead of the point of fixation. For small disparities (small separations between images), the images are localized as distant as the position in space of the object giving rise to the images (Ogle, 1953). In Fig. 11, the solid dots (the stimulus figures) would presumably be localized at the position of the small x's. For larger disparities, there is no longer a direct correspondence between amount of disparity and amount of depth. However, there remains a qualitative sense of depth in which the images are distinctly perceived ahead or behind the fixation point (Ogle, 1952). With further increase in disparity, the ability to discriminate between ahead and behind localization becomes less certain, and eventually the images are indefinitely localized.

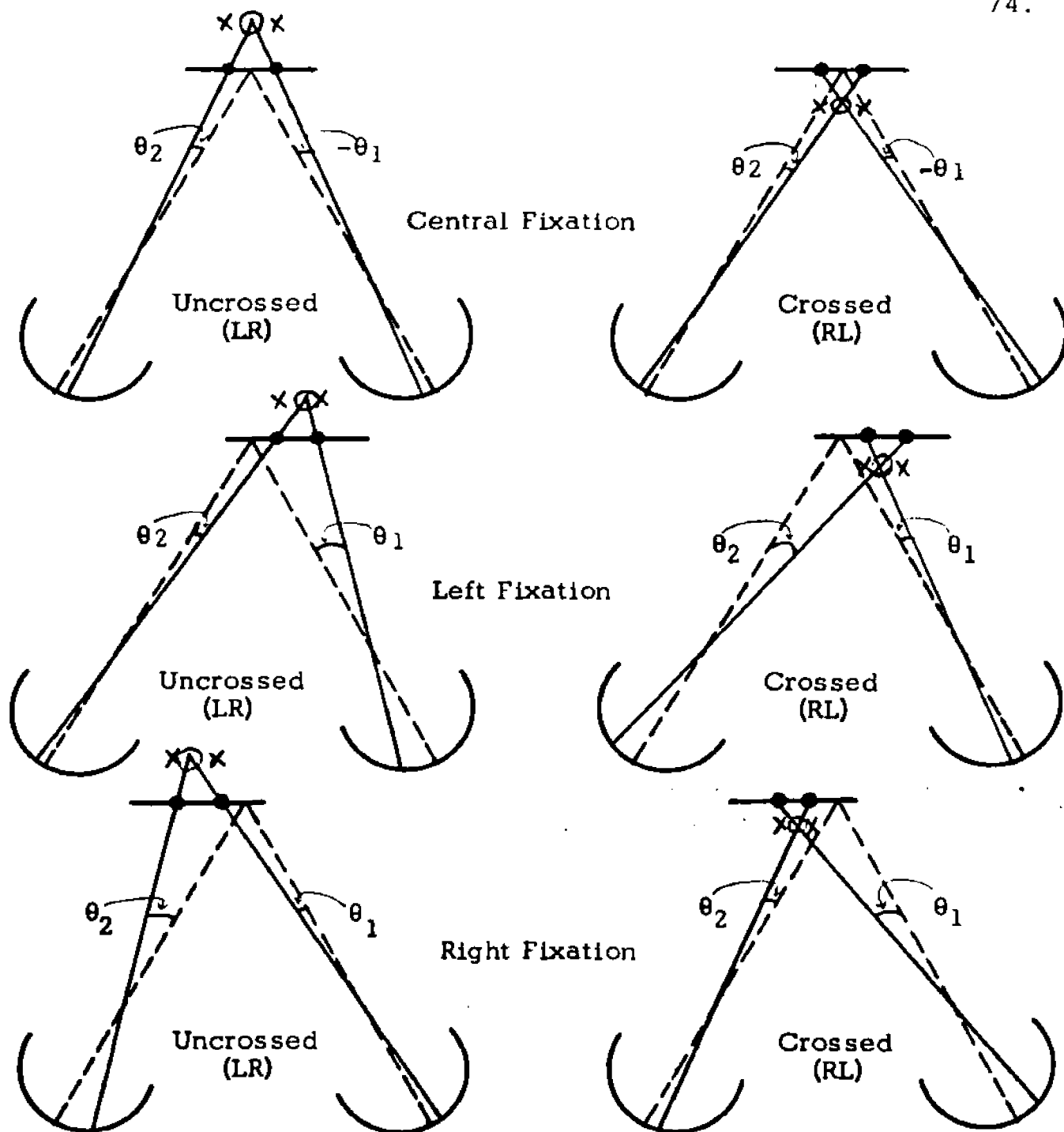


Fig. 11. The six TIAM stimulus arrangements which produce uncrossed (LR) and crossed (RL) double images. Horizontal lines represent the plane of the stimulus cards and the solid dots represent the L and R figures. Dotted lines represent the lines of sight and  $\theta_2 - \theta_1$  is the measure of retinal disparity. The location of the object that would give rise to the double images is indicated by the small circles. The small crosses correspond to the presumed depth localizations of the double images.

The range of disparities for which depth from double images is perceived varies with retinal area stimulated and with the experimental situation. However, accurate qualitative depth localization has been demonstrated for disparities as large as  $10^\circ$  with central fixation (Westheimer and Tanzman, 1956). Since the retinal separations for the TIAM stimuli were well within this range (the disparity between vertices was  $3^\circ$  in Experiment 1), there is a direct correspondence between the nature of the depth localization presumed to occur and the nature of the TIAM perceived when the double images are alternately presented. Uncrossed images (LR) are localized behind and give rise to behind TIAM and crossed images (RL) are localized ahead and give rise to ahead TIAM. This correspondence between depth localization and perceived TIAM is the basis for the hypothesis pertaining to the relationship of stereopsis to the TIAM predominance effect. This hypothesis will be referred to as the double image hypothesis.

Interocular presentation of stimuli has been shown to be a necessary condition for the occurrence of a predominance effect (Experiment 1). Since only interocular stimulation produces retinal disparity, this result is consistent with the double image hypothesis. In Experiment 4, the predominance effect was found to occur for all RL and LR arrangements, and not only for N and T arrangements. This result is consistent with the double image hypothesis since nasal or temporal stimulation of the two retinas is not necessary for producing double images. In Experiment 7, a predominance effect did not occur for vertical TIAM when there was no horizontal separation between stimuli. These stimulus arrangements produce vertical rather than horizontal disparity, and vertical disparity does not produce stereopsis (Ogle, 1955). Thus,

no predominance effect occurred in the absence of the necessary condition for stereopsis, a result consistent with the double image hypothesis.

In order to obtain additional evidence pertaining to the validity of the double image hypothesis, a second series of experiments was carried out. Experiments were designed to verify the assumption that the TIAM stimuli are perceived in stereoscopic depth and to determine if these depth effects are related to the TIAM which is perceived.

### Experiment 9: Dot Stimuli

If stereopsis is related to TIAM being perceived ahead or behind, then it should affect interocular AM even when the AM is planar. For example, if two small dots are presented alternately, a single dot is perceived moving horizontally to and fro within the plane of fixation. If the dots are presented interocularly, the double image hypothesis leads to the prediction that although the movement may still be planar, the path of the dot will be perceived in a plane closer to or farther from the observer than the plane of fixation. Thus for LR stimulation the dot should be perceived to move in a plane behind the fixation plane, and for RL stimulation the dot should be perceived to move in a plane ahead of the fixation plane. This experiment was designed to test these predictions.

#### Method

Twenty-six Ss were used. Four stimulus arrangements were presented to 15 Ss and four additional arrangements were presented to a second group of 15 Ss. The second group included 4 Ss of the first group. Only six of the stimulus arrangements were relevant to the present experiment. Two of the arrangements presented to the second group will be discussed as part of Experiment 11.

The six stimulus arrangements are illustrated in Fig. 12. The dots were  $3/32$  in. in diameter. For two arrangements (LR and RL), there was a central fixation line, with the dots  $3/16$  in. from the line. For two arrangements (LR and RL) the fixation line was to the left of the dots, with a  $1/8$  in. separation between the line and the closer dot. For all arrangements, the separation between the centers of the two dots in the visual field was  $3/8$  in. The two stimulus arrangements

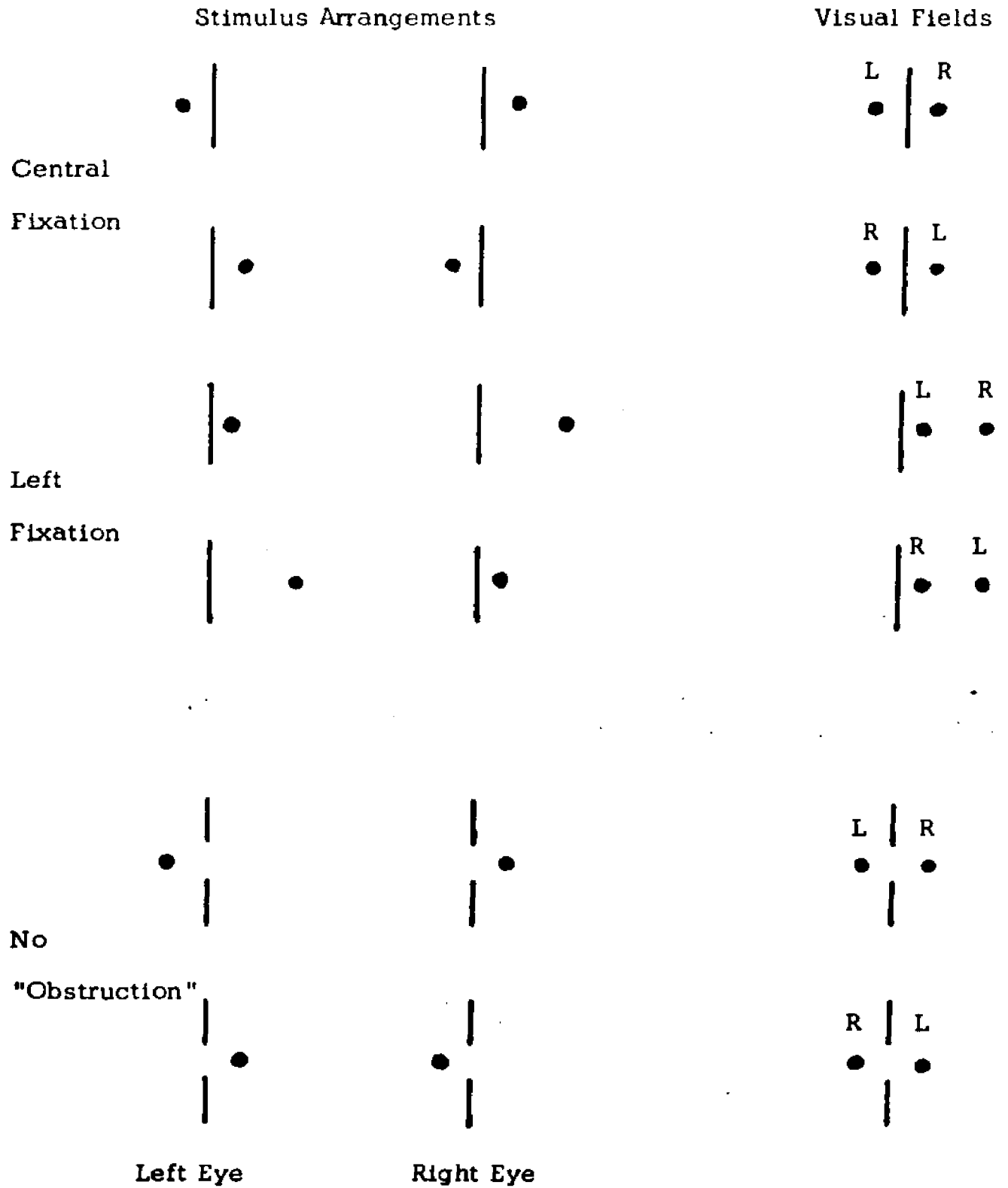


Fig. 12. The three stimulus arrangements of Experiment 9.  
There was an LR and RL condition for each.

presented to the second subject group were similar to the central fixation arrangements except that there was a 1/4 in. gap in the middle of the fixation line. When the line is continuous, it may act as an "obstruction" to the path of movement of the dot. As a result, some Ss perceive AM in depth rather than planar AM.

### Results

The results (see Table 9) were as predicted. The data for the four arrangements presented to the first group differed significantly ( $F=14.44$ ,  $df=3/42$ ,  $p<.001$ ) and the mean for each condition was consistent with the predominance effect. LR and RL means differed significantly for both central and left fixation ( $p's<.01$ ). Central fixation produced significantly fewer ahead reports, overall, than did left fixation ( $p<.05$ ). The presence of the central line sometimes gave rise to reports of AM in depth rather than planar AM. The dot was perceived to oscillate in an arc ahead or behind the line. For central fixation with no "obstruction," only planar movement was perceived and the results were consistent with the predominance effect. LR and RL means differed significantly ( $t=5.55$ ,  $df=14$ ,  $p<.001$ ), and motion behind predominated for LR and motion ahead predominated for RL. Comparison with the data for central fixation indicated that the presence of the "obstruction" led to significantly fewer ahead reports ( $F=9.04$ ,  $df=1/28$ ,  $p<.01$ ).

### Discussion

The experiment demonstrated that there is a differential effect of LR and RL stimulation on interocular AM when the perceived movement is not tridimensional. The predominance effect is therefore not limited to TIAM, but occurs for bidimensional interocular AM as well.

TABLE 9

Experiment 9: Mean "Ahead" for Planar AM of Dots

Stimulus condition	Mean "ahead"	S.D.
Central fixation		
LR	1.00	1.63
RL	5.67	3.66
Left fixation		
LR	3.07	3.06
RL	7.33	2.90
Central fixation, no "obstruction"		
LR	3.13	2.99
RL	8.13	2.04

This result is consistent with the double image hypothesis since stereoscopic depth in double images should be present regardless of whether the perceived movement is planar or tridimensional. In this experiment the behind and ahead depth localization produced by LR and RL arrangements were directly observed.

A second result of the experiment was that the presence of an "obstruction" to the path of movement affected the movement perceived. Besides the fact that oscillation in depth rather than planar movement was sometimes perceived, there was an increase in the overall frequency of behind reports. There was apparently a greater natural preference for perceiving the dot pass behind the line than ahead of the line, and this preference affected both LR and RL conditions. The greater number of behind reports for central as compared to left fixation may also have been due to the presence of the "obstruction" for central fixation.

Experiment 10: Static Depth Localization  
of Stimuli Presented Interocularly

One basis for the double image hypothesis is the assumption that the TIAM figures are equivalent to double images and are localized in stereoscopic depth. This experiment was designed to test the prediction that LR figures are localized behind the fixation line and that RL figures are localized ahead of the fixation line.

Experiment 10A: Triangles

Method

Subjects and stimulus conditions. Twenty Ss in their second experimental session viewed four stimulus arrangements which had been used in previous experiments. There was an RL and LR arrangement for triangles with a central fixation line (from Experiment 8) and for triangles with a left fixation line (from Experiment 4).

Procedure. Only continuously presented visual fields were viewed. For each trial, S turned the switches on and obtained proper fusion. With fixation maintained on the vertical line, S then reported, in a forced choice situation, whether the two triangles appeared ahead of the line (relatively closer) or behind the line (relatively farther).

Results

The results (see Table 10) indicate that at least for central fixation, there was a tendency to localize LR triangles behind the fixation line and RL triangles ahead of the line. The data for the four arrangements differed significantly ( $F=14.31$ ,  $df=3/57$ ,  $p < .001$ ) and there was a significant difference between LR and RL for central fixation ( $p < .01$ ). There were also more ahead reports for RL than LR for left fixation, but the difference was not significant ( $p > .05$ ).

TABLE 10

Experiment 10: Depth Localization "Ahead" as a Function  
of LR and RL Stimulus Arrangements

Stimulus condition	Mean "ahead"	S.D.
Experiment 10A: Triangles		
Central fixation		
LR	2.05	2.31
RL	7.70	2.41
Left fixation		
LR	4.45	3.09
RL	5.15	3.07
Experiment 10B: Dots		
Central fixation		
LR	2.20	2.79
RL	5.50	3.15
Left fixation		
LR	3.05	3.31
RL	6.90	3.11
Experiment 10C: Control for convergence		
Above: LR	1.72	2.36
Below: RL	7.28	2.38
Above: RL	5.32	2.72
Below: LR	3.12	2.72
Above: LR	1.68	1.69
Below: LR	3.00	2.06
Above: RL	4.80	2.80
Below: RL	6.60	2.77

With central fixation, Ss usually found it easy to make depth judgments and most reported perceiving distinct differences in the relative depth localization of the triangles and the line. Judgments with left fixation were generally more difficult to make, due at least in part to the fact that the figures were peripheral and less distinct. This may partly account for the lack of a significant difference between LR and RL.

Two additional observations were occasionally reported. A few Ss reported perceiving reversals in depth localization. Thus, if the triangles first were localized ahead, there was a reversal to behind localization after prolonged viewing. Also, the R and L triangles sometimes appeared to be oppositely localized, with one ahead and the other behind.

#### Experiment 10B: Dots

The preceding Experiment 10A demonstrated stationary depth effects for triangles. The present study repeated the same procedure for dots.

#### Method

Twenty Ss having no prior experience with the dot stimuli were used. The four dot arrangements presented to the first group in Experiment 9 (LR and RL for central and left fixation) were presented using the same procedure as used in the preceding experiment.

#### Results

The results (see Table 10) confirmed the existence of stationary depth effects. The data for the four arrangements differed significantly ( $F=12.97$ ,  $df=3/57$ ,  $p < .001$ ), and for both central and left fixation, RL led to significantly more ahead reports than did LR ( $p$ 's  $< .01$ ). The ahead depth means were comparable to the ahead

motion means obtained previously with the same stimulus cards in Experiment 9 (Table 9). Also, as occurred with triangles in the preceding experiment 10A, a few Ss observed depth reversals or opposite depth localization for R and L figures.

#### Experiment 10C: Control for Convergence

The two preceding experiments confirmed the existence of depth effects associated with RL and LR stimulation. There is a depth localization predominance effect which corresponds to the TIAM predominance effect. However, the ahead or behind depth localization is not necessarily due to stereopsis, for it is possible that differential convergence might be involved. Evidence has been reported which suggests that convergence can serve as a useful depth cue (Cf. Richards and Miller, 1969). Although the convergence angle should theoretically be identical for LR and RL arrangements, it is likely that in practice there are slight differences.<sup>7</sup> Consequently, the present experiment was designed to control for the possible role of convergence differences.

#### Method

Subjects and stimulus conditions. Twenty-five Ss were used. The four stimulus cards, each having an upper and lower arrangement, are

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<sup>7</sup>For both LR and RL stimulus conditions, the two lines to be fused (the vertical fixation lines or the vertical sides of the two figures) were always drawn on the stimulus card with exactly the same 3 in. separation. Therefore, when an S slides the box to adjust the distance between the stimulus card and the viewer in order to obtain proper fusion, the optimal position should be the same for LR and RL. However, in practice there are usually slight differences, and for some Ss the position difference is substantial. Furthermore, the differences occur in a consistent manner, with LR requiring a closer position than RL. This is equivalent to the apparent distance between lines being closer for LR than for RL. The result is a slight difference in convergence angle between the two conditions.

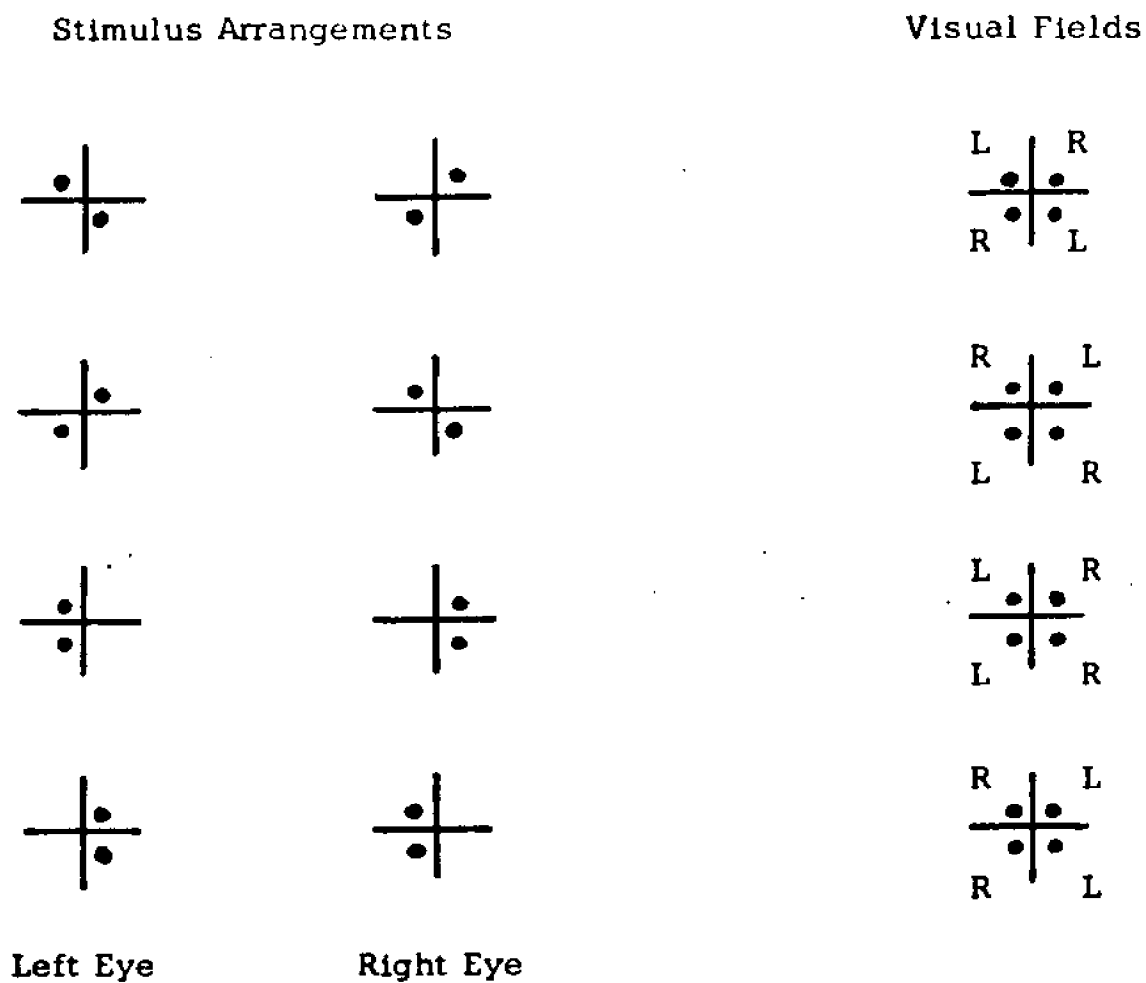


Fig. 13. Stimulus arrangements of Experiment 10C.

illustrated in Fig. 13. The dots were  $3/16$  in. from the vertical and horizontal lines. The first card had an LR arrangement above and an RL arrangement below, and the second card was identical, except that upper and lower arrangements were reversed. The third card had two LR arrangements and the fourth had two RL arrangements. The visual fields for all arrangements appeared identical.

Procedure. As in Experiments 10A and 10B, only the continuously presented visual fields were viewed. Ss were instructed to fixate on the intersection of the horizontal and vertical lines and to view all four dots simultaneously. They were specifically told not to look separately at the upper and lower dots. This procedure was assumed to have eliminated differential convergence for the two arrangements since two different convergence angles cannot occur simultaneously. Ss were instructed to make separate depth judgments (whether the pair of dots appeared ahead or behind the vertical line) for the upper and lower pairs. A report was first made for the upper pair, immediately followed by a report for the lower pair. Ss were reminded several times during the series of trials to view both pairs of dots simultaneously.

### Results

The results are summarized in Table 10. The control for convergence had no apparent effect on the depth predominance effect demonstrated in Experiments 10A and 10B. Also, an above-below position effect occurred which is similar to the position effect found for TIAM in Experiment 5. The data for the eight arrangements differed significantly ( $F=15.68$ ,  $df=7/168$ ,  $p<.001$ ), and the differences between means were consistent with the predominance effect.

LR and RL on same stimulus card. When LR was above and RL below, there was a very strong depth predominance effect. The LR-RL difference was significant ( $p < .01$ ), and the difference was larger than found with separate viewing of each arrangement in Experiment 10B. The number of ahead reports for RL was greater than the number for LR for each of 19 Ss, and the RL-LR difference exceeded five for 18 Ss. On the other hand, when RL was above and LR was below the LR-RL difference was attenuated in comparison with the difference found in Experiment 10B. Also, as occurred in the analogous TIAM studies (Experiment 5), there were two types of Ss. Each of 15 Ss was consistent, and means for this group for LR and RL, respectively, were 1.13 and 6.73. The data for each of 10 Ss showed a loss or reversal of the effect. LR and RL means for these Ss were 6.10 and 3.20.

Two LR arrangements and two RL arrangements. The results for these stimulus cards suggest the occurrence of an upper-lower position effect. When there were two LR arrangements, both upper and lower arrangements gave rise to a behind predominance. However, there were more ahead reports for the upper arrangement than for the lower arrangement. A similar upper-lower difference occurred when there were two RL arrangements. Thus, omitting the effects of LR versus RL stimulation, there was a consistent tendency toward perceiving localization behind for upper position and toward perceiving localization ahead for lower position. These position effects could account for the relative increase in the LR-RL difference which occurred when LR was above RL and the relative decrease in the LR-RL difference which occurred when RL was above LR. Inspection of the

individual data indicated that the Ss who showed a position effect for these two stimulus cards were not necessarily the ones who showed a position effect when RL was above LR. The differences between above and below which occurred when the upper and lower positions contained the same arrangement did not occur for the analogous TIAM stimulus cards of Experiment 5B. However, the two experiments are not perfectly comparable since there was a larger vertical separation between arrangements and the two observations were not simultaneous in the TIAM experiment.

### Discussion

These three experiments have provided evidence which is consistent with the hypothesis that the TIAM predominance effect is related to stereoscopic depth in double images. The LR figures (uncrossed double images) tended to be localized behind the fixation line and the RL figures (crossed double images) tended to be localized ahead of the fixation line. For a given S, the depth effects were not perfectly consistent, and for some Ss there was no difference between the data for LR and RL. However, the same variability in degree of consistency occurred for the TIAM predominance effect. There are thus ahead and behind depth localization effects which correspond to the ahead and behind motion effects. Since control for differential convergence did not eliminate the depth localization predominance effect, it can be assumed that the depth effects were due to stereopsis.

Stereoscopic depth effects resulting from presentation of double images have previously been reported by Westheimer and Tanzman (1956). Polarizing filters and a central binocular fixation spot were

used rather than a stereoscope. Ss judged whether a pair of interocularly presented crossed (RL) or uncrossed (LR) spots appeared ahead or behind the fixation spot. Differential eyemovement was controlled by a very short exposure duration. Westheimer and Tanzman reported, as in the present experiment, that localization ahead prevailed for crossed images whereas localization behind prevailed for uncrossed images. Also as in the present experiment, individual differences in the degree of differential localization were reported.

The upper-lower position effect which occurred for depth localization in Experiment 10C also occurred for oscillation in depth when two TIAM arrangements were presented simultaneously in Experiment 5. This result provides further evidence that the depth and TIAM effects are related. No explanation for the position effect can currently be offered, although the effect may be related to an asymmetry in the visual field.

### Experiment 11: Trapezoids and Foreshortened Triangles

The results of Experiment 9 ("obstruction" versus no "obstruction") suggest that the nature of the stimulus pattern can lead to a greater preference for perceiving a particular type of movement, regardless of whether the condition is LR or RL. It should therefore be possible to design stimulus patterns which specifically favor perception of oscillation in depth either ahead or behind. If the stimulus pattern is such that motion behind requires a shorter path of movement than motion ahead, then movement behind should be the preferred percept. This experiment was designed to test this prediction.

#### Method

##### Subjects

A total of 18 Ss in their second experimental session were used. Four stimulus arrangements were viewed by 15 Ss. A second group of 15 Ss, 12 of whom were part of the first group, viewed four additional arrangements, two of which were part of Experiment 9. Thus, only six of the arrangements were relevant to the present experiment.

##### Stimulus Conditions

There were three stimulus patterns, with a card having an LR arrangement and a card having an RL arrangement for each (see Fig. 14). The patterns were designed to produce depth effects independent of oscillatory AM in depth. For one pattern there was a small equilateral triangle (5/16 in. on a side) and a large equilateral triangle (1/2 in. on a side). The small triangle tends to be perceived in a plane (not tilted) which is more distant than the plane of the large triangle. Consequently, when alternation is introduced, a single triangle is perceived which moves closer and further away as it oscillates in depth. The specific

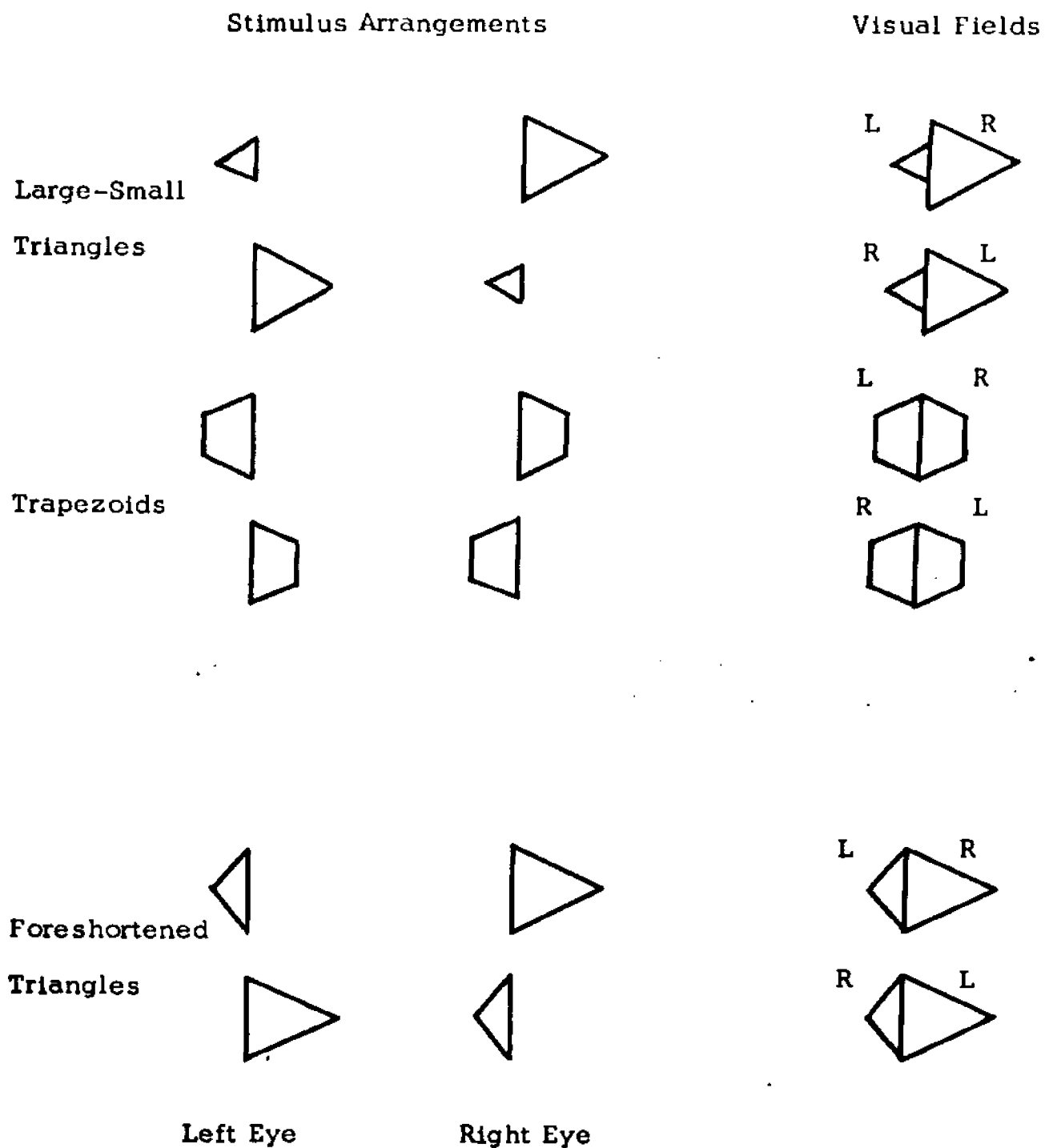


Fig. 14. Stimulus arrangements for Experiment 11. There was an LR and RL arrangement for each type of pattern.

effect which this added depth effect might have on TIAM reports cannot be predicted.

Trapezoids were used for the second pattern. There is a tendency to perceive a trapezoid as a rectangle tilted in space. The short edge (1/4 in.) of these isosceles trapezoids is generally perceived to be further away than the long edge (1/2 in.). When the R and L figures appear tilted, the motion path required for movement behind is shorter than the path required for movement ahead. Consequently, movement behind should be the preferred percept.

The third stimulus pattern (presented to the second group) consisted of a foreshortened triangle and a larger triangle. The vertical edge of both triangles was 3/8 in., but the two other sides were 1/4 in. for the foreshortened triangle and 7/16 in. for the larger triangle. The foreshortened triangle tends to be perceived as a large triangle tilted in space, with the vertex more distant than the vertical side. As a result, the motion path should be shorter for motion behind than for motion ahead, and motion behind should be the preferred percept.

### Results

The results are summarized in Table 11. Although an LR-RL difference occurred in each case, comparison with previous data for equilateral triangles indicates that there was a decrease in the overall frequency of ahead reports for two of the three stimulus patterns. The means for the four arrangements presented to the first group differed significantly ( $F=13.43$ ,  $df=3/42$ ,  $p<.001$ ), as did the means for the two arrangements presented to the second group ( $t=3.31$ ,  $df=14$ ,  $p<.01$ ).

TABLE 11

Experiment 11: Mean "Ahead" for Large-Small Triangles,  
Trapezoids, and Foreshortened Triangles

Stimulus condition	Mean "ahead"	S.D.
Large-small triangle		
LR	2.27	2.45
RL	6.07	3.17
Trapezoids		
LR	1.47	2.27
RL	3.73	2.80
Foreshortened triangles		
LR	0.60	1.20
RL	3.87	3.22

### Large and Small Triangles

Comparison with the triangle data of Experiment 3 indicates that the backward-forward movement in depth produced by this pattern (and verified by Ss' reports) had no apparent effect upon the oscillatory movement. Means for RL and LR differed significantly ( $p < .01$ ) and the values were comparable to the means previously obtained for triangles of equal size (Table 3).

### Trapezoids

For both LR and RL there was a marked reduction in the number of ahead reports. Although the means for the LR and RL arrangements differed significantly ( $p < .05$ ) and there were more than twice as many ahead reports for RL than for LR, the apparent backward tilt of the figures (verified by Ss' reports) resulted in a preference for motion behind for both stimulus arrangements.

### Foreshortened Triangles

For this pattern there was also a marked decrease in the number of ahead reports. There were significantly more ahead reports for RL than for LR ( $p < .01$ ), but in both cases, the apparent backward tilt of the foreshortened triangle (verified by Ss' reports) resulted in a behind preference.

### Discussion

The experiment demonstrated that depth effects related to the nature of the stimulus pattern can affect the perceived oscillation in depth. When two identical equilateral triangles are presented, the lengths of the paths of motion for oscillation ahead and behind are equivalent. Omitting the effects of LR versus RL stimulation, there should presumably be an equal likelihood of perceiving move-

ment ahead or behind. Since the trapezoids and foreshortened triangles appeared tilted backward in depth, oscillation behind required rotations of less than  $180^\circ$ , whereas oscillation ahead required rotations through more than  $180^\circ$ . As a result, a shorter movement path was required for movement behind, and movement behind was the preferred percept. Similarly, apparent tilt ahead in depth, such as ought to occur when trapezoids with a common shorter base are viewed, would be expected to elicit a preference for movement ahead. On the other hand, tilt in depth was not perceived for the large-small triangles, and the lengths of the motion paths were equal for oscillation ahead and behind. Thus, even though there was a backward-forward movement, the oscillation in depth reports were unaffected.

The results of this experiment are indirectly related to the double-image hypothesis. Depth which was perceived as a result of the nature of the pattern (independent of oscillation in depth) affected the oscillation in depth which was perceived. In a similar way, depth effects related to stereopsis in double images could also influence the nature of the perceived movement.

Experiment 12: Tilt in Depth of  
Stimuli Presented Interocularly

Can the depth localization of TIAM stimuli demonstrated in Experiment 10 account for the TIAM predominance effect? For the case of dots in planar movement, the basis for a relationship between depth and movement is obvious. Thus if the dots are localized ahead of the line, the horizontal motion may be expected to occur in a plane ahead of the line. This explanation assumes that there is a maintenance of the depth localization during the alternating exposure of the two figures.

For the case of oscillatory TIAM, the basis for a relation between depth localization and oscillation ahead or behind is more difficult to specify. TIAM does not involve localization in depth of a moving figure, rather it involves oscillatory movement in depth. A particular localization of figures would not necessarily lead to a particular type of oscillation. For example, the triangle might appear localized ahead of the fixation line, but the vertex of the moving triangle could still oscillate behind. However, the triangle is an extended figure, and all points on the "surface" of the figure are not uniformly disparate. Points more distant from the fixation line (the point of fusion) are more disparate than points near the line. Consequently, there is a gradual increase in degree of disparity from the vertical side of the triangle outward to the vertex. Assuming some degree of correspondence between amount of disparity in double images and amount of relative depth, the vertex of the triangle should be seen in greater depth relative to the fixation line than the vertical side of the triangle. As a result, the triangles should appear tilted in space. For RL stimulation (crossed images) the vertices should tilt closer than the vertical sides (ahead), and for LR stimulation (uncrossed

images) the vertices should tilt further away than the vertical sides (behind). If these predictions are correct, it would suggest a basis for the relationship between stereopsis from double images and the TIAM predominance effect. If the vertices were tilted behind, the path of movement for behind oscillation would be shorter than the path required for ahead oscillation. Consequently, as occurred for tilted figures in Experiment 11, behind movement would be the more likely percept. Similarly, if the vertices were tilted ahead, the ahead motion path would be shorter and ahead motion would be the more likely percept. The present experiment was designed to test the prediction that TIAM figures appear tilted in space.

### Method

#### Subjects and Stimulus Conditions

Twenty Ss in their second experimental session viewed four stimulus arrangements. Two arrangements (LR and RL) involved a pair of 3/8 in. horizontal lines, each extending from the middle of a vertical fixation line (Fig. 15). The visual field appeared as a single vertical line intersected by a horizontal line. The two triangle arrangements (LR and RL) of Experiment 3 were also used. A particular visual field was perceived as two triangles having a common vertical side.

#### Procedure

As in Experiment 10, only the continuously presented visual fields were viewed. Ss were instructed to fixate on the vertical line for the line figures, and on the vertical common side for the triangle figures. Depth reports involved determining, in a forced choice situation, whether either the outer ends of the horizontal lines or the vertices of the triangles were tilted ahead or behind with respect to either the central vertical line or the vertical side of the triangles.

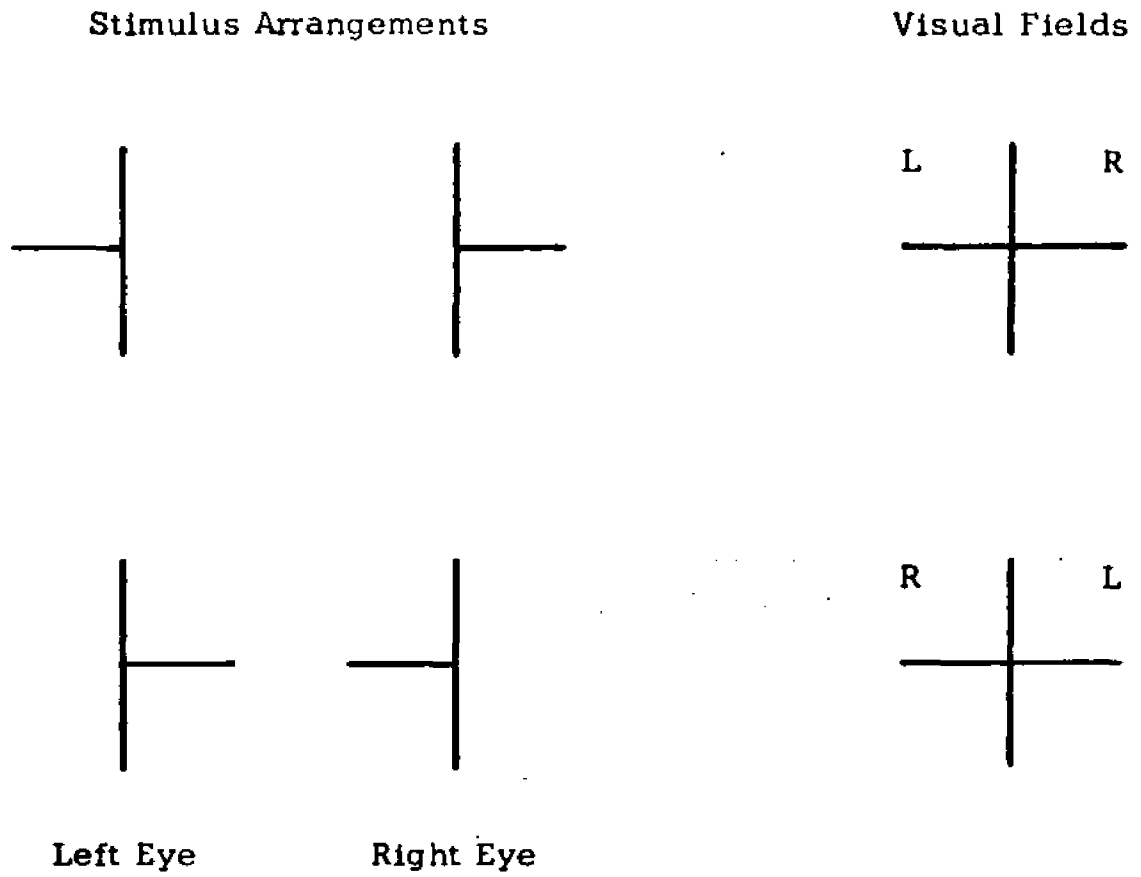


Fig. 15. The horizontal line stimulus arrangements (LR and RL) of Experiment 12.

### Results

The results (see Table 12) were consistent with the predictions. The data for the four arrangements differed significantly ( $F=15.63$ ,  $df=3/57$ ,  $p<.001$ ), and for both lines and triangles there were significantly more ahead tilts reported for RL than for LR ( $p$ 's  $<.05$ ). However, the relative LR-RL differences were not as large as previously found for depth localization or for TIAM. In general, the tilt in depth effects were not as strong or sharply defined as the ahead-behind depth localization of Experiment 10. Although each  $S$  was able to discriminate between ahead and behind tilt, inaccurate judgments may have diminished the LR-RL differences which were obtained.

### Discussion

The experiment demonstrated that TIAM figures appear tilted ahead or behind, although the degree of tilt, and the magnitude of the "tilt" predominance effect was relatively small. These tilt effects are apparently related to stereoscopic depth from double images. By shortening the required motion path for either ahead or behind oscillation, the apparent tilt could account for the TIAM predominance effect.

Several factors in this experiment may have diminished the degree of tilt perceived and the accuracy of tilt discriminations. There was a tendency to perceive the two lines as a single unit, and to perceive the triangles in the frontoparallel plane due to their equilateral dimensions. Also, as Ogle (1952) has pointed out, the texture of the paper on which the figures are drawn has an inhibiting effect on the perception of depth. It is possible that these depth reducing factors are overcome to a greater extent by stereopsis when the figures are perceived in AM.  $E$  and others have observed that the oscillating triangle often does not

TABLE 12

Experiment 12: Mean "Ahead" Tilt as a Function  
of Relative Position for Lines and Triangles

Stimulus condition	Mean "ahead"	S.D.
<b>Lines</b>		
LR	4.85	3.31
RL	7.30	2.85
<b>Triangles</b>		
LR	2.50	2.38
RL	4.60	3.04

appear to return to the frontoparallel plane at the end of each alternation cycle. This is especially noticeable if the exposure interval for each eye is reduced to produce a very rapid AM. The triangle remains tilted when in its extreme positions and oscillates either ahead or behind through less than  $180^\circ$ .

## Experiment 13: Relation Between either Tilt or Depth

### Reports and Subsequent TIAM Reports

This experiment was designed to determine if depth localization and tilt are related to subsequent TIAM reports. Ss made motion reports immediately after making depth reports, and the degree of correspondence between the two reports was examined.

#### Method

##### Subjects and Stimulus Conditions

Twenty Ss, each of whom also took part in Experiment 12, viewed four stimulus arrangements. The two arrangements (LR and RL) involving triangles with a common side (from Experiment 12) and the two arrangements (LR and RL) involving triangles with a separate central fixation line (from Experiment 10A) were used.

##### Procedure

For each card, Ss first turned the switches to the continuously on position. Reports of ahead or behind tilt were obtained for the triangles with a common side, and reports of ahead or behind depth localization were obtained for the triangles with a separate central fixation line. Immediately following each depth judgment, Ss moved the switches to the alternation position and reported on the nature of the TIAM. Ss were specifically informed that the two judgments were not related and that they would not necessarily correspond.

#### Results

The results (see Table 13) indicate that there was a significant relationship between depth reports and subsequent motion reports.

##### Stationary Depth Reports

The results for the four arrangements differed significantly ( $F=11.65$ ,

TABLE 13

Experiment 13: Relation Between Mean "Aheads" for Depth and TIAM

Stimulus condition	Static depth		TIAM		Depth-TIAM relation	
	Mean "ahead"	S.D.	Mean "ahead"	S.D.	% matches	r
Common						
side						
LR	2.35	2.50	2.50	2.87	62.5*	.39*
RL	6.05	3.19	5.40	2.91	61.0*	
Fixation						
line						
LR	3.10	2.93	2.65	2.24	63.0*	.62*
RL	7.05	2.75	6.30	2.70	68.0*	

\* $p < .01$

$df=3/57$ ,  $p < .001$ ), and for both figures there were significantly more ahead depth or tilt reports for RL than for LR ( $p$ 's  $< .01$ ). The depth localization means for the separate fixation line figures were comparable to the values obtained with different  $S$ s in Experiment 10A. Some  $S$ s spontaneously reported that the triangles appeared tilted as well as being localized ahead and behind, with the type of tilt corresponding to the type of localization.

For the common side figures, the strength of the predominance effect for tilt was greater than obtained previously in Experiment 12. Since the same  $S$ s were used in the two experiments, it is possible that in the present experiment the  $S$ s were better able to make accurate tilt discriminations.

#### Motion Reports

The data for the four arrangements differed significantly ( $F=23.43$ ,  $df=3/57$ ,  $p < .001$ ) and for both stimulus figures there was a significant RL-LR difference in accordance with the TIAM predominance effect ( $p$ 's  $< .01$ ). The mean values obtained were comparable to the values obtained previously for the same stimulus cards (see Experiments 3 and 8).

#### Relationship Between Depth and Motion

Two measures of depth-motion relationship were computed. These were the percentage of individual pairs of reports in which the motion report matched the depth report, and the correlation between  $S$ s' depth scores and motion scores.

Depth-motion correspondence. For each arrangement more than 60% of the depth reports matched the subsequent motion reports, with an average of 61.8% for the common side figures and 65.5% for the separate

fixation line figures. In each case the number of matches was significantly greater than the chance level of 50% (binomial distribution,  $p = 1/2$ ,  $N=200$ ,  $p$ 's  $< .01$ ). Thus there was a significant tendency for the reports to correspond, but in more than a third of the trials they did not.

Correlation between depth and motion scores. For both stimulus figures the Pearson product moment correlation was significantly greater than zero ( $df=38$ ,  $p$ 's  $< .01$ ). A larger correlation was obtained for the separate fixation line figure than for the common side figure, but the difference was not significant ( $Z=1.35$ ,  $p > .05$ ). The sizes of the  $r$ 's obtained indicate that a relatively small percentage of the variability in the motion scores can be accounted for by variability in the depth scores.

### Discussion

The results are consistent with the double image hypothesis. Perception of ahead tilt and ahead depth localization tended to be followed by perception of ahead motion, and behind tilt and depth tended to be followed by behind motion. It may be that ahead depth localization also involves ahead tilt, and that behind depth localization also involves behind tilt. However, except for the observations of a few  $S$ s, this possibility has not been verified.

The degree of depth-motion relationship, as measured by both percentage of report correspondence and correlation between scores, is less than might have been expected. However, since neither the depth nor motion effects are perfectly consistent, and since there was a time delay between the two observations, the lack of a stronger degree of relationship is not surprising.

## Summary of Part II

The following results were obtained which relate to the validity of double image hypothesis:

1. Dots perceived in planar AM are localized behind the fixation line for LR and ahead of the line for RL. An "obstruction" to the path of movement produces a general preference for movement behind.

2. A depth localization predominance effect occurs which is analogous to the TIAM predominance effect. LR stimuli (uncrossed double images) are localized behind the fixation line, and RL stimuli (crossed double images) are localized ahead of the fixation line. The depth effects do not depend upon differential eye convergence, and an upper-lower position effect occurs which is analogous to the position effect previously found for TIAM.

3. Figures which appear tilted behind in depth give rise to predominantly behind TIAM, apparently as a result of the shorter motion path required for movement behind.

4. TIAM stimuli appear tilted ahead or behind in depth, presumably as a result of greater disparity between figures at the vertices. These tilt effects could influence the TIAM which is perceived, since tilt ahead or behind would lead to a shorter path of movement for oscillation ahead or behind.

5. When either depth or tilt reports are immediately followed by TIAM reports, there tends to be a correspondence between the type of depth or tilt perceived and the type of TIAM perceived.

## General Discussion

This research has demonstrated the existence of a TIAM predominance effect which transcends a specific apparatus and occurs for a variety of stimuli: LR stimulus arrangements give rise to oscillation behind the plane and RL arrangements give rise to oscillation ahead of the plane. Evidence has been presented which suggests that the occurrence of the effect is related to stereopsis in double images. Several difficulties with this explanation will now be discussed.

One possible problem involves the fact that simultaneity of disparate images is a requirement for stereopsis (Ogle, 1962). The assertion that stereopsis influences TIAM requires the assumption that stereopsis occurs despite the alternate presentation of stimuli. Ogle's (1963) research on the effect of time delay on stereopsis is related to this problem. Defining the delay period as the time between onset of the stimulus to one eye and the onset of the stimulus to the other eye, Ogle found that there is a decrease in stereoscopic acuity with increase in delay, up to a limiting delay beyond which there is no stereoscopic depth. For short, single exposures, the limiting delay was about 100 msec., but the limit increased with both increase in exposure time and introduction of repetitive alternation between the two images. In the present research, the delay was 550 msec., but the exposure duration was 500 msec., and the stimulus presentation was repetitive. Although the conditions were not directly comparable to those of Ogle, his data do not rule out the possibility that stereopsis could have been maintained in the present research. Furthermore, the perception of AM tends to unify the two images into a single event, and this could prevent a loss of stereopsis due to lack of simultaneity. Another factor which might be relevant is the possible role of after-

images in linking the temporally separate events. Ogle and Reiher (1962) found that stereopsis can occur in afterimages produced both simultaneously and successively. In future research it would be of interest to determine if variation in temporal conditions has an effect on the TIAM predominance effect. However, extremely long inter-stimulus intervals could not be tested since AM would no longer be perceived.

A second problem concerns the fact that neither the depth nor the TIAM predominance effects were perfectly consistent. Stereopsis is generally considered to be perfectly consistent in the sense that if stereopsis occurs, uncrossed disparity always produces localization behind the fixation plane and crossed disparity always produces localization ahead of the fixation plane. However, there is a disparity range for which double images are "qualitatively" perceived in depth (Ogle, 1952), and the accuracy of depth localization gradually decreases with further increase in disparity (Westheimer & Tanzman, 1956). Thus, for relatively large disparities, depth localization is not perfectly consistent, and the results of the present depth experiments are not unexpected.

Assuming that stereopsis influences the TIAM which is perceived, the inconsistency in the TIAM reports can be accounted for by the less than perfect consistency in the perception of depth in double images. The fact that Ss sometimes have natural preferences for perceiving TIAM in a particular way, and the fact that spontaneous motion reversals are often perceived, may also contribute to the lack of consistency in the motion reports.

In experiment 8, variation in the separation between TIAM stimuli

and the central fixation line did not influence the TIAM predominance effect. This result may be regarded as presenting a problem for the double image hypothesis since degree of disparity is an important variable for stereopsis. However, if the range of separations tested was within the disparity range for which there is qualitative rather than precise depth localization, little change would be expected in the degree of ahead-behind depth effects. Consequently, there would be no change in the strength of the TIAM predominance effect. On the other hand, since stereopsis does not occur at all for very large disparities, it should be possible in future research to demonstrate a loss of the predominance effect for very large separations. However, this demonstration may prove impractical since AM may no longer be perceived for very wide separations.

In addition to study of the effects of variation in temporal conditions and separation, several suggestions for further research may be offered. The upper-lower position effects found for both TIAM and depth localization should be studied in greater detail. Vertical separation between arrangements could be manipulated, and results for observation of single arrangements could be compared, in the same experiment, with results for simultaneous presentation of two arrangements. The study of TIAM as an "ambiguous figure" is another possible research area. Reversal frequencies with prolonged viewing could be obtained and compared with results for other well known reversal phenomena. Finally, it would be of interest to determine whether a predominance effect occurs when a figure in actual physical movement is viewed interocularly.

## Appendixes

## Appendix I

### Review of Interocular and Tridimensional Apparent Movement

The phenomenon of apparent movement (AM) was known before the turn of the century, but it was not until publication of Wertheimer's (1912) classic paper that it was studied in detail. Wertheimer made it clear that the problem of apparent motion is of great theoretical significance for psychology and physiology. In succeeding years there has been much discussion concerning the mechanisms underlying the phenomenon, and a substantial amount of research has been carried out to analyse the various factors which influence it (Aarons, 1964). However, two aspects of the phenomenon have been relatively neglected, interocular AM and tridimensional AM.

#### Interocular AM

Exner (1875) was the first to report interocular AM and others have since verified it (Münsterberg, 1894; Wertheimer, 1912; Langfeld, 1927). As Wertheimer (1912) emphasized, interocular AM is important because it casts doubt upon an explanation of AM solely in terms of a retinal interaction mechanism. Interocular AM thus points to a central involvement in the process underlying AM.

Further studies of interocular AM have made even a central locus for the AM mechanism difficult to specify. Wertheimer's (1912) original "short-circuit" theory placed the process in the cerebral cortex, and this was later elaborated and emphasized in the field theory of Gestalt psychologists. Deatherage and Bitterman (1952) have reported that the path of interocular AM can be influenced by presumed changes in the cortical field. Alternate central explanations, such as that of Osgood (1953, p. 245) have also placed the process in the cortex. However,

the cortex is bilateral and the interocular procedure permits the production of the neural activity independently in the two hemispheres. Fibers from the nasal portion of the right retina and the temporal portion of the left retina project to the left visual cortex, thereby giving rise to the cortical representation of the right half of the visual field. Similarly, the left nasal and right temporal retinas project to the right half of the cortex, giving rise to the cortical representation of the left visual field. But the nasal portions of the two retinas project to opposite sides of the cortex, as do the two temporal retinas, and the temporal and nasal portions of the same retina. Piéron (1933) alternately stimulated both nasal retinas and Smith (1948) extreme nasal retinas, and both reported AM. Gengerelli (1948) produced AM by alternately stimulating opposite halves of the same retina. Thus, AM can occur even though the retinal stimulation is conveyed to opposite hemispheres. It is possible that the corpus callosum, which provides for information transfer between hemispheres (Cf. Mountcastle, 1962; Berlucchi, Gazzaniga and Rizzolatti, 1967), could serve to integrate the two separate neural processes. However, Bridgman and Smith (1945) demonstrated AM, produced by stimulation of widely separated nasal and temporal portions of the same retina, in human patients with a complete section of the corpus callosum. This result does not necessarily mean that the corpus callosum (or some other commissure or subcortical structure) is not normally involved in interocular AM, but it may mean that AM can occur without a direct interaction of the two neural processes. A study by Verhoeff (1940) may bear on this matter. Patients having anomalous projection due to an inability to fixate properly were found able to perceive interocular AM. These patients were said to lack a

fixed relationship between retinal fixation area and cortical projection area. The results were taken to suggest that the AM mechanism involves cortical areas which do not bear a fixed functional relationship to retinal locus. In other words, specific spatial relations of cortical events may not be crucial. There thus may not be a specific brain locus involved in the AM mechanism. Further evidence which appears to support this view comes from the demonstration that AM can apparently take place across acquired scotomata (blind regions) of the visual field (Teuber and Bender, 1950). Results have also been reported which are said to indicate that phenomenal rather than retinal separation of the two stimuli is sufficient (and necessary) to produce AM (Rock and Ebenholtz, 1962; Brosgole, 1966).

In addition, AM, produced interocularly, has been compared to other methods of presentation. It has been found that the time interval for optimal movement is considerably longer for interocular AM than for monocular or binocular AM (Allers, 1935); that for fixed temporal conditions interocular AM is a "real looking" as monocular AM but not as good as binocular AM (Shipley, Kenney and King, 1945); and that with monocular viewing, AM produced by stimulating one hemisphere predominates over AM produced by stimulating opposite hemispheres (Gengerelli, 1948). In a more complete analysis, Ammons and Weitz (1951) found that with fixed temporal conditions, monocular AM is reported more frequently than interocular AM, and stimulation of the same hemisphere (monocular or interocular viewing) results in AM more often than stimulation of opposite hemispheres. Ammons and Weitz interpret these results as suggestive of a subcortical involvement in AM. However, different stimulation methods involve different conduction pathways,

and with constant temporal conditions, differences found for different viewing conditions may be due solely to differences in optimal temporal relations. In any event, the interocular situation, with its separate stimulation of the two retinas and the possibility of separately stimulating the two halves of the cortex, should certainly be studied in greater detail.

### AM In Depth

Most AM studies have dealt with planar forms of motion. It has been known for some time, however, that tridimensional AM may often be perceived. Wertheimer (1912) successively presented two parallel vertical lines with a third fixed line placed between them. A single line was perceived to move across the middle line, moving in an arc behind it. Similar effects, in which one figure appears to swing back and forth in front of or behind another figure, have been reported by Langfeld (1927), Fernberger (1934) and Rock and Ebenholtz (1962). Benussi (1916) demonstrated a change from two to three-dimensional movement by simply presenting a pair of separated dots in succession. After a while, the planar AM initially perceived changed to a circular motion in the third dimension (in a plane of  $90^\circ$  to the frontoparallel). Mibai (1931) noticed a similar effect using parallel lines.

The easiest way to produce immediate tridimensional AM is by proper manipulation of stimulus shape.<sup>8</sup> Higginson (1926) alternately presented two triangular shapes, one pointing to the left and the other to the right. A single triangle was perceived to swing from one orientation to the other with the vertex rotating ahead of the plane, toward

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<sup>8</sup>AM in depth can also be produced by changes in brightness or size (Bartley, 1969, p. 252). These effects will not be considered.

the observer. Similar forms of tridimensional AM have been reported by others, using triangular figures oppositely oriented above and below each other (Steinig, 1929), and arrow shapes (Orlansky, 1940; Broscole, 1966) and semicircles (Orlansky, 1940) pointing in opposite directions.

Koffka (1930) has argued that motion in depth is often favored over motion in the plane in accordance with classical principles of perceptual organization. Thus, tridimensional AM is often the form which is shortest in tack without distortion of form. According to Orlansky (1940), Schiller's investigation (1933) supported Koffka's contention by showing that the path followed in tridimensional AM is actually the shortest, best patterned and smoothest of all alternatives. Vernon (1937), after reviewing tridimensional AM studies, concluded that "the attraction through similarity of the two parts of the configuration operates in agreement with the tendency towards the easiest motion without distortion of the configuration....and this may quite frequently produce a rotary three-dimensional movement... [p. 173]."

Another issue concerns the perception of tridimensional AM either ahead or behind the plane. It has been reported (Cf. Fernberger, 1934; Rock & Ebenholtz, 1962) that Ss may perceive either type of movement. However, these investigators were not concerned with controlling the type of movement which is perceived, and furthermore, they did not present their stimuli interocularly.

## APPENDIX II

Individual Data and Statistical Analyses<sup>9</sup>A. Experiment 1

Subj.	Stimulus Condition				
	B	R	L	N	T
1	8	5	4	3	3
2	4	3	3	5	9
3	8	8	9	2	8
4	8	6	7	4	4
5	3	5	3	3	4
6	0	3	3	1	4
7	6	5	5	4	6
8	5	5	3	2	7
9	10	10	10	10	10
10	10	10	10	10	10
11	9	2	1	1	7
12	3	4	3	1	5
13	2	4	3	1	5
14	4	2	4	0	3
15	2	5	1	1	1
16	9	5	3	0	3
17	5	6	6	4	6
18	2	4	1	3	4
19	8	6	7	3	9
20	4	4	4	4	6

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	22.4	
Condition	14	21.84	7.97***
Error		2.74	

Paired Comparisons

	T	B	R	L	N
T					**
B					**
R					**
L					

<sup>9</sup>Significance levels:

\* $p < .05$

\*\* $p < .01$

\*\*\* $p < .001$

B. Experiment 2

Subject	Fixation-Cross Group				No-Cross Group			
	Triangle		Semicircle		Triangle		Semicircle	
	N	T	N	T	N	T	N	T
1	0	0	0	0	0	9	1	9
2	4	7	2	10	3	8	0	5
3	2	5	0	1	0	1	0	0
4	5	7	2	5	0	0	0	0
5	6	7	7	10	0	9	0	0
6	4	8	2	7	0	0	0	0
7	1	9	0	7	4	4	1	1
8	5	6	3	9	2	3	1	1
9	0	6	4	5	3	7	5	9
10	8	10	7	9	5	6	1	3
11	3	7	4	8	2	9	0	1
12	6	7	3	3	1	5	2	6
13	0	4	0	3	2	8	4	5
14	0	4	2	5	2	10	1	2
15	2	10	1	7	1	4	0	5
16	4	4	4	4	7	9	0	8
17	10	10	10	10	1	7	1	5
18	6	1	1	10	0	2	0	0
19	1	9	0	5	7	9	4	3
20	2	8	1	9	2	7	1	7

B. Experiment 2 (cont.)Analysis of Variance

Source	DF	MS	F
Between <u>S</u> s	39	20.15	
Fixation (A)	1	85.55	4.64*
<u>S</u> s WG	38	18.43	
Within <u>S</u> s	120	7.80	
Shape (B)	1	56.40	15.45***
AB	1	9.52	2.61
B x <u>S</u> s WG	38	3.65	
Stimulus cond. (C)	1	381.30	56.49***
AC	1	.02	< 1
C x <u>S</u> s WG	38	6.75	
BC	1	3.32	1.49
ABC	1	5.98	2.69
BC x <u>S</u> s WG	38	2.22	

C. Experiment 3

Subject	Triangle		Semicircle	
	N	T	N	T
1	3	9	1	5
2	0	0	0	0
3	0	5	0	0
4	3	8	3	4
5	7	10	5	10
6	2	5	1	3
7	2	10	0	2
8	0	5	0	5
9	3	5	0	2
10	2	6	0	3
11	1	7	1	8
12	0	0	0	0
13	4	2	2	1
14	3	9	3	3
15	2	3	3	6
16	1	3	1	1
17	0	9	0	9
18	5	8	4	5
19	0	0	0	0
20	2	8	1	9

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	16.69	
Condition	3	75.71	19.92***
Error	57	3.80	

Paired Comparisons

	T <sub>tri</sub>	T <sub>sem</sub>	N <sub>tri</sub>	N <sub>sem</sub>
T <sub>tri</sub>		*	**	**
T <sub>sem</sub>			*	**
N <sub>tri</sub>				

D. Experiment 4

Subject	Left		Right	
	Fixation		Fixation	
	LR	RL	LR	RL
1	3	10	8	8
2	3	7	2	9
3	3	9	2	7
4	1	3	3	4
5	4	10	0	9
6	3	8	6	9
7	0	0	0	0
8	6	10	6	8
9	0	8	0	8
10	2	7	2	10
11	1	8	1	7
12	0	6	1	6
13	0	8	0	7
14	5	5	0	5
15	3	7	4	10

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	14	14.79	
Condition	3	115.22	35.13***
Error	42	3.28	

Paired Comparisons

	RL <sub>rf</sub>	RL <sub>lf</sub>	LR <sub>rf</sub>	LR <sub>lf</sub>
RL <sub>rf</sub>			**	**
RL <sub>lf</sub>			**	**
LR <sub>rf</sub>				

E. Experiment 5A

Subj.	LR above RL		RL above LR	
	LR <sub>a</sub>	RL <sub>b</sub>	LR <sub>b</sub>	RL <sub>a</sub>
1	10	10	10	10
2	2	10	5	10
3	1	9	4	7
4	2	9	5	10
5	1	10	3	10
6	0	10	10	0
7	1	9	6	6
8	0	9	5	5
9	2	8	3	10
10	0	10	10	0
11	2	10	0	9
12	3	10	3	10
13	1	7	2	0
14	0	10	3	8

Subj.	LR above RL		RL above LR	
	LR <sub>a</sub>	RL <sub>b</sub>	LR <sub>b</sub>	RL <sub>a</sub>
15	1	10	3	8
16	2	9	10	7
17	0	9	5	0
18	0	10	0	10
19	1	10	5	10
20	2	10	9	2
21	0	10	2	8
22	2	9	5	5
23	10	10	10	10
24	1	9	6	8
25	0	10	0	10
26	3	9	3	8
27	0	10	0	10

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	26	9.40	
Condition	3	279.42	43.23***
Error	78	6.88	

Paired Comparisons

	RL <sub>b</sub>	RL <sub>a</sub>	LR <sub>b</sub>	LR <sub>a</sub>
RL <sub>b</sub>		*	**	**
RL <sub>a</sub>			*	**
LR <sub>b</sub>				**

F. Experiment 5B

Subj.	LR above RL		RL above LR		Both LR		Both RL	
	LR <sub>a</sub> (1)	RL <sub>b</sub>	LR <sub>b</sub> (2)	RL <sub>a</sub>	LR <sub>a</sub> (3)	LR <sub>b</sub>	RL <sub>a</sub> (4)	RL <sub>b</sub>
1	0	10	0	10	1	0	8	8
2	2	7	0	7	2	2	7	7
3	1	2	1	5	9	8	9	9
4	0	9	1	10	0	0	9	9
5	4	6	6	5	7	8	9	9
6	6	5	2	6	1	1	5	5
7	5	8	4	8	6	6	5	9
8	2	7	3	9	2	6	9	7
9	0	10	8	3	0	0	6	6
10	0	7	3	6	1	2	6	7
11	10	10	10	10	10	10	10	10
12	5	5	2	8	8	7	8	7
13	0	10	9	8	0	0	7	7
14	3	7	3	6	6	4	5	7
15	3	8	7	6	4	4	6	6
16	6	7	2	4	4	4	10	10
17	0	10	1	9	0	0	5	5
18	2	10	3	8	4	4	8	8
19	0	10	10	0	0	0	0	0
20	2	9	0	9	2	3	7	8
21	0	10	0	7	1	1	10	10
22	2	8	1	10	3	3	10	10



G. Experiment 5C: Semicircles

Subject	LR above RL		RL above LR	
	LR <sub>a</sub>	RL <sub>b</sub>	LR <sub>b</sub>	RL <sub>a</sub>
1	0	10	6	2
2	2	7	0	6
3	1	8	6	2
4	9	9	9	9
5	0	10	1	6
6	0	10	1	9
7	1	6	6	3
8	0	9	3	7
9	3	7	1	1
10	1	9	7	0
11	1	7	0	9
12	0	8	1	6
13	2	7	0	10
14	1	9	3	9
15	1	9	4	8
16	0	9	0	10
17	0	9	4	7
18	0	8	3	7
19	0	10	0	10
20	0	10	10	1

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	5.55	
Condition	3	212.23	29.44***
Error	57	7.21	

Paired Comparisons

	RL <sub>b</sub>	RL <sub>a</sub>	LR <sub>b</sub>	LR <sub>a</sub>
RL <sub>b</sub>		*	**	**
RL <sub>a</sub>			*	**
LR <sub>b</sub>				

H. Experiment 5C: Left Fixation

Subject	LR above RL		RL above LR	
	LR <sub>a</sub>	RL <sub>b</sub>	LR <sub>b</sub>	RL <sub>a</sub>
1	1	3	4	6
2	4	10	7	4
3	5	8	7	7
4	8	4	2	9
5	4	5	4	8
6	3	8	5	5
7	2	7	7	2
8	4	6	4	10
9	5	8	5	7
10	4	4	4	2
11	0	6	1	3
12	0	8	2	5
13	0	9	7	10
14	8	4	7	10
15	1	2	0	2
16	3	7	3	8
17	3	7	4	10
18	4	7	2	10
19	0	7	2	7
20	5	10	10	7

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	11.14	
Condition	3	55.78	11.60***
Error	57	4.81	

Paired Comparisons

	RL <sub>a</sub>	RL <sub>b</sub>	LR <sub>b</sub>	LR <sub>a</sub>
RL <sub>a</sub>			*	**
RL <sub>b</sub>			*	**
LR <sub>b</sub>				

I. Experiment 6

Subject	LR above RL		RL above LR	
	LR <sub>a</sub>	RL <sub>b</sub>	LR <sub>b</sub>	RL <sub>a</sub>
1	0	10	2	8
2	0	10	10	6
3	4	7	4	6
4	0	9	8	9
5	1	9	4	10
6	2	9	7	8
7	3	0	0	3
8	0	7	0	0
9	0	10	10	10
10	0	9	9	7
11	0	10	0	10
12	1	7	3	8
13	2	9	9	8
14	6	10	7	9
15	8	7	2	9
16	1	8	7	9
17	4	10	9	8
18	0	10	5	6
19	0	10	3	10
20	4	10	7	8

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	11.13	
Condition	3	185.01	31.15***
Error	57	5.94	

Paired Comparisons

	RL <sub>b</sub>	RL <sub>a</sub>	LR <sub>b</sub>	LR <sub>a</sub>
RL <sub>b</sub>			**	**
RL <sub>a</sub>			**	**
LR <sub>b</sub>				**

J. Experiment 7

Subject	Experiment 7A	
	R above L	L above R
1	5	5
2	0	0
3	2	3
4	8	8
5	10	8
6	2	5
7	6	6
8	6	7
9	0	0
10	10	10
11	10	10
12	7	2
13	2	2
14	8	4
15	0	1
16	0	0
17	2	6
18	6	8

Subject	Experiment 7B			
	LR	RL	R Fix.	L Fix.
1	6	5	6	7
2	8	10	0	6
3	2	10	10	10
4	2	10	3	3
5	0	7	1	1
6	1	9	3	0
7	9	9	10	8
8	2	7	7	10
9	8	5	0	0
10	2	6	6	4
11	7	6	7	6
12	10	10	10	10
13	10	10	10	10
14	10	10	10	10
15	2	7	4	5

Source	DF	MS	F
<u>Ss</u>	14	27.50	
Condition	3	22.64	3.58*
Error	42	6.32	

	RL	L Fix.	R Fix.	LR
RL				*
L Fix				
R Fix				

K. Experiment 8

Subject	1/16 in.		3/8 in.	
	LR	RL	LR	RL
1	3	8	2	6
2	0	8	4	9
3	4	10	0	10
4	1	7	0	0
5	2	7	3	9
6	4	9	0	7
7	1	5	2	8
8	5	9	2	4
9	0	6	0	8
10	3	10	1	9
11	2	3	3	4
12	1	7	1	5
13	3	5	1	7
14	9	9	2	2
15	3	4	4	7
16	9	9	4	4
17	2	5	4	5
18	2	5	3	6
19	1	8	2	8
20	0	8	0	10

Analysis of Variance

Source	DF	MS	F
Ss	19	4.90	
Condition	3	134.58	26.08***
Error	57	5.16	

Paired Comparisons

	RL <sub>1/16</sub>	RL <sub>3/8</sub>	LR <sub>1/16</sub>	LR <sub>3/8</sub>
RL <sub>1/16</sub>			**	**
RL <sub>3/8</sub>			**	**
LR <sub>1/16</sub>				

L. Experiment 9

Subj.	First Group			
	Central Fix.		Left Fix.	
	LR	RL	LR	RL
1	0	5	0	10
2	1	2	0	0
3	1	10	0	9
4	0	1	7	7
5	3	10	2	9
6	0	6	2	8
7	2	3	2	2
8	6	7	4	6
9	0	1	10	10
10	0	7	2	6
11	0	10	4	9
12	0	0	0	0
13	0	3	0	10
14	0	10	7	10
15	2	10	6	6

Subj.	Second Group	
	LR	RL
1	1	10
2	0	3
3	4	10
4	4	5
5	3	8
6	9	8
7	4	6
8	5	9
9	0	9
10	3	10
11	0	10
12	2	7
13	0	9
14	2	8
15	10	10

Source	DF	MS	F
<u>Ss</u>	14	11.86	
Condition	3	117.38	14.44***
Error	42	8.13	

	RL <sub>lf</sub>	RL <sub>rf</sub>	LR <sub>lf</sub>	LR <sub>rf</sub>
RL <sub>lf</sub>			**	**
RL <sub>rf</sub>				**
LR <sub>lf</sub>				

M. Experiment 10A

Subject	Central Fix.		Left Fix.	
	LR	RL	LR	RL
1	3	10	10	7
2	1	7	2	2
3	2	10	10	0
4	3	5	4	6
5	0	10	7	3
6	2	10	2	10
7	0	6	2	5
8	1	8	7	7
9	6	7	3	1
10	0	9	9	9
11	8	10	0	0
12	0	3	0	4
13	0	10	2	5
14	1	10	5	7
15	4	10	6	10
16	3	7	5	5
17	0	9	6	1
18	1	5	3	6
19	0	5	0	8
20	6	3	6	7

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	8.95	
Condition	3	108.08	14.31***
Error	57	7.59	

Paired Comparisons

	RL <sub>cf</sub>	RL <sub>lf</sub>	LR <sub>lf</sub>	LR <sub>cf</sub>
RL <sub>cf</sub>			**	**
RL <sub>lf</sub>				**
LR <sub>lf</sub>				

N. Experiment 10B

Subject	Central Fix.		Left Fix.	
	LR	RL	LR	RL
1	0	9	0	4
2	8	2	8	8
3	1	6	0	6
4	1	7	1	9
5	0	10	2	6
6	1	0	0	0
7	0	5	8	9
8	3	8	0	8
9	0	7	0	7
10	0	4	1	0
11	2	1	1	3
12	0	1	0	7
13	3	6	6	4
14	4	9	3	10
15	1	8	3	9
16	1	2	8	9
17	10	5	10	10
18	3	8	6	10
19	0	2	0	10
20	6	10	4	8

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	18.59	
Condition	3	94.15	12.97***
Error	57	7.26	

Paired Comparisons

	RL <sub>lf</sub>	RL <sub>cf</sub>	LR <sub>lf</sub>	LR <sub>cf</sub>
RL <sub>lf</sub>			**	**
RL <sub>cf</sub>			*	**
LR <sub>lf</sub>				

O. Experiment 10C

Subject	LR above RL		RL above LR		Both LR		Both RL	
	LR <sub>1a</sub>	RL <sub>1b</sub>	LR <sub>2b</sub>	RL <sub>2a</sub>	LR <sub>3a</sub>	LR <sub>3b</sub>	RL <sub>4a</sub>	RL <sub>4b</sub>
1	6	4	4	5	2	2	1	1
2	5	4	7	2	4	6	4	3
3	0	10	2	8	0	7	3	7
4	1	7	2	7	0	3	2	6
5	6	2	6	4	4	3	6	6
6	1	8	1	6	0	0	4	5
7	0	10	2	5	0	1	9	10
8	2	8	1	5	1	4	4	7
9	0	10	0	9	0	10	10	10
10	0	10	1	7	0	2	2	8
11	0	10	2	8	3	7	4	9
12	1	10	5	4	1	1	7	9
13	0	10	1	8	2	5	6	10
14	1	7	5	4	3	4	4	4
15	2	8	9	0	0	2	2	3
16	9	1	6	6	4	4	2	2
17	0	0	0	2	0	0	0	3
18	0	10	0	2	0	2	9	10
19	1	10	1	8	1	1	7	9
20	1	9	5	5	3	4	6	7
21	1	7	7	4	1	1	5	5



P. Experiment 11

Subj.	First Group			
	Triangles		Trapezoids	
	LR	RL	LR	RL
1	2	7	1	6
2	6	8	7	3
3	1	3	2	3
4	0	1	0	0
5	8	9	7	8
6	0	5	1	7
7	3	8	2	2
8	2	3	0	5
9	1	3	0	0
10	3	9	1	6
11	0	10	0	2
12	6	9	1	1
13	2	7	0	5
14	0	9	0	8
15	0	0	0	0

Subj.	Second Group	
	LR	RL
1	0	10
2	0	1
3	0	1
4	3	8
5	0	1
6	1	6
7	0	5
8	4	1
9	0	1
10	0	5
11	0	9
12	0	2
13	0	6
14	1	8
15	0	0

	RL <sub>tri</sub>	RL <sub>trap</sub>	LR <sub>tri</sub>	LR <sub>trap</sub>
RL <sub>tri</sub>		*	**	**
RL <sub>trap</sub>				*
LR <sub>tri</sub>				

Source	DF	MS	F
<u>Ss</u>	14	17.50	
Condition	3	61.22	13.43***
Error	42	4.56	

Q. Experiment 12

Subject	Lines		Triangles	
	LR	RL	LR	RL
1	9	2	5	2
2	5	10	2	2
3	8	10	0	5
4	9	10	4	8
5	4	7	0	0
6	0	9	2	9
7	5	7	1	6
8	9	5	0	2
9	4	2	1	7
10	1	9	2	0
11	5	5	3	1
12	0	1	0	0
13	9	8	6	4
14	0	10	1	6
15	1	6	3	5
16	3	8	1	4
17	7	10	1	9
18	7	8	3	6
19	9	10	9	10
20	2	9	6	5

Analysis of Variance

Source	DF	MS	F
<u>Ss</u>	19	16.15	
Condition	3	77.21	15.63***
Error	57	4.94	

Paired Comparisons

	RL <sub>line</sub>	LR <sub>line</sub>	RL <sub>tri</sub>	LR <sub>tri</sub>
RL <sub>line</sub>		*	*	**
LR <sub>line</sub>				*
RL <sub>tri</sub>				*

R. Experiment 13

Subject	Depth				Motion			
	Com. Side		Fix. Line		Com. Side		Fix. Line	
	LR	RL	LR	RL	LR	RL	LR	RL
1	3	5	4	3	4	8	5	9
2	3	6	4	7	2	3	2	5
3	0	7	3	5	0	3	0	8
4	4	4	9	10	1	5	4	8
5	0	0	0	10	0	1	3	8
6	2	10	2	2	0	2	0	2
7	0	10	0	8	9	9	2	5
8	0	5	0	8	1	7	2	5
9	5	8	3	9	4	5	1	6
10	0	3	5	1	0	0	0	0
11	3	5	4	5	0	1	0	4
12	0	0	8	10	9	9	8	10
13	2	1	10	8	5	5	5	5
14	0	7	1	5	1	9	1	10
15	0	9	0	10	0	7	3	6
16	1	5	3	8	1	5	2	5
17	5	10	1	8	1	6	1	5
18	6	7	2	5	2	5	3	5
19	9	10	3	9	3	9	4	10
20	4	9	0	10	7	9	7	10

R. Experiment 13 (cont.)Analysis of Variance: Depth

Source	DF	MS	F
<u>Ss</u>	19	7.78	
Condition	3	102.75	11.65***
Error	57	8.82	

Analysis of Variance: Motion

Source	DF	MS	F
<u>Ss</u>	19	21.03	
Condition	3	74.28	23.45***
Error	57	3.17	

Paired Comparisons

	RL <sub>fl</sub>	RL <sub>cs</sub>	LR <sub>fl</sub>	LR <sub>cs</sub>
RL <sub>fl</sub>			**	**
RL <sub>cs</sub>			*	**
LR <sub>fl</sub>				

Paired Comparisons

	RL <sub>fl</sub>	RL <sub>cs</sub>	LR <sub>fl</sub>	LR <sub>cs</sub>
RL <sub>fl</sub>			**	**
RL <sub>cs</sub>			**	**
LR <sub>fl</sub>				

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