Apparent Movement in Depth

in a Phenomenal Three-dimensional Space

by

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Approved by:

_____

Major Professor

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Introduction

A well known phenomenal effect of intermittent stimulation is apparent movement. Apparent movement arises from the successive exposure to two stationary points of light which are both spatially and temporally separated. Keeping the spatial separation constant, as the temporal alternation varies from slow to fast three distinct observations are reported. With a relatively slow temporal alternation, one stimulus appears and then the other; there is a clear impression of the <u>successive</u> occurrence of two stimuli. With a slightly faster temporal alternation, there is an impression of movement from the position of the first member of the stimulus pair to that of the second, i.e., <u>apparent</u> <u>movement</u>. And finally, with the fastest temporal alternation, one sees each stimulus <u>simultaneously</u> with no apparent motion across the visual field, even though each of the two stimuli continue to flicker (cf. Koffka, 1935; Wertheimer, 1961).

The most widely used measures of apparent movement are (a) the threshold between apparent succession and apparent movement and (b) the threshold between apparent movement and apparent simultaneity. These thresholds have been called the "succession threshold" and the "simultaneity threshold," respectively, and both have been found to increase as the distance separating the stimuli increases (Corbin, 1942; Orlansky, 1940). The relation between spatial separation and rate of successive stimulation has been formally referred to as Korte's third law; an increase in the distance separating two successive stimuli must be accompanied by an increase in the temporal successive presentations for optimal apparent movement (cf. Koffka, 1935). The kind of spatial separation which applies to Korte's law, however, is uncertain; it may be physical (distal) separation, retinal (proximal) separation, or phenomenal[1] separation.

Corbin (1942) conducted a study which examined whether apparent movement is a matter of retinal or physical separation. The simultaneity threshold for apparent movement was determined for several spatial separations between two lights under conditions in which (a) the lights appeared in the frontal parallel plane, and (b) the two-dimensional stimulus plane was slanted away from the observer. In the second condition retinal separation decreased, while physical separation remained constant, as the slant of the stimulus plane increased. Dissociating retinal from physical separation in this manner seemed to have no effect on apparent movement, suggesting that retinal separation in itself is not the effective factor. However, the threshold for apparent movement did vary with different physical separations. Apparent movement was found to increase in proportion to the perceived increase in separation, but not to the physical (objective) separation. These results suggest constancy of apparent movement where constancy is defined as the perception of the distal (physical) rather than the proximal (retinal) features of the stimulus. However, this interpretation of Corbin's findings may be equivocal, because factors such as convergence, accommodation, and retinal size varied as a function of slant and were not controlled. These variables are known to affect apparent movement and perceptual constancies (Epstein, 1977; Koffka, 1935; Orlansky, 1940; Rock, 1975).

Attneave and Block (1973) further examined whether apparent movement is a matter of retinal or perceived separation. The threshold for apparent movement was determined under two conditions: (a) when two lights appeared in the frontal plane with perspective information for slant, and (b) when two lights appeared in the frontal plane without perspective information for slant. The physical separation of the lights between conditions was kept constant. In this study factors such as convergence,

accommodation, and retinal size were kept constant because the perceived separation of the lights between conditions was varied by two-dimensional depth cues. Furthermore, retinal disparity was controlled by having observers monocularly view the stimulus plane. The simultaneity threshold was found to be greater with perspective information for slant than without perspective information for slant, even though the physical and the retinal separation between conditions were the same. However, the threshold for apparent movement with perspective information for slant was found to be less than that required if the two lights were separated by the actual physical separation corresponding to the projected perspective separation. These differences suggest that apparent movement depends upon the phenomenal separation or phenomenal location[2] of two stimuli which falls short of perfect constancy.

Shepard and Judd (1976) reported evidence that pairs of stimuli need not be retinally separated nor spatially separated in the frontal plane in order to achieve the experience of apparent movement. In their rotational extension of apparent movement, perspective views of the same three-dimensional shape in two orientations were presented in the same spatial location in the frontal plane. The orientations portrayed (a) rotations in the picture plane corresponding to a rotation about an axis through the line of sight, or (b) rotations in depth about an axis orthogonal to the line of sight. The succussive presentations of the perspective views appeared phenomenally to be either a three-dimensional object rotating around a circle in the picture plane or a three-dimensional object rotating in depth. Shepard and Judd also found that the succession threshold for apparent rotational movement increased linearly with increasing three-dimensional angular differences between the two

perspective (two-dimensional) views. In other words, the greater the "three-dimensional" angle of rotation portrayed in two-dimensions, the larger the phenomenal angle through which one object was rotated to coincide with the other. The linear function suggests that the phenomenal angular separation of the portrayed perspective views may correspond in a "one-to-one" relation to the distal rotation (Cooper, 1976; Cooper and Shepard, 1973; Robins and Shepard, 1977; Shepard, in press; Shepard and Podgorny, 1978).

The evidence reviewed above suggests that if two stimuli are separated by a constant distance in three-dimensional space, or in pictorial representations of depth, apparent movement remains approximately the same regardless of stimulus distance from the observer and stimulus orientation relative to the observer. However, it is the phenomenal location, or phenomenal identity, of the stimulus pair that is the effective variable regarding the separation of two stimuli for apparent movement. Therefore, the kind of spatial separation which Korte's law implies can be made dependent on phenomenal separation that is more akin to the three-dimensional separation, rather than separation in the purely two-dimensional retinal image. This view implies that apparent movement is not bound[3] to stimulus parameters, but governed by the same variables that underlie perceptual constancies (Attneave, 1972; Attneave and Block, 1973).

Size constancy is defined as the perception of the distal (physical) size rather than the proximal size of the stimulus. It has been previously demonstrated that relatively accurate size constancy and distance perception is maintained in two-dimensional pictorial representations of depth (Smith and Gruber, 1958; Smith, Smith, and Hubbard; 1958; Uhlarik, Pringle, Jordan, and Misceo, 1980). A goal of the present research was

to further examine the role of phenomenal separation on apparent movement. Specifically, the present experiment examined the possibility that size constancy in pictorial depth can influence the perception of apparent movement by demonstrating changes in apparent movement contingent on changes in the phenomenal location and phenomenal size of two stimuli. To this end, a two-dimensional perspective representation of two same distal sized squares in different pictorial depth planes was used to examine (a) the possibility of apparent movement in a phenomenal three-dimensional space[4], (b) whether apparent movement varies in proportion to phenomenal separation or two-dimensional picture plane (retinal) separation, and (c) if the phenomenal "three-dimensional" movement varies in proportion to the distal representation of pictorial depth.

A two-dimensional perspective representation of a square of a fixed distal size in different pictorial depth planes is shown in Figure 1. If size constancy maintains for this square during apparent movement, the successive alternations of any two squares should appear as the same invariant sized square moving back and forth in pictorial (perceived) depth. Pictorial depth separation was dissociated from two-dimensional retinal separation by utilizing conditions in which there was no perspective depth context. In these latter conditions size constancy might not maintain, and if so, the successive alternations of any two squares would appear as a single square changing in size while moving in the vertical dimension of the frontal (picture) plane.

The distance between the horizontal lines of the perspective context (Figure 1) decreases in a hyperbolic manner. The reason for this decrease is that the longitudinal (distance) dimension of three-dimensional space is projected as an altitude (A) which is a negatively accelerated function

Figure Caption

Figure 1. A two-dimensional perspective representation of

the same distal sized square in six different

pictorial depth planes.
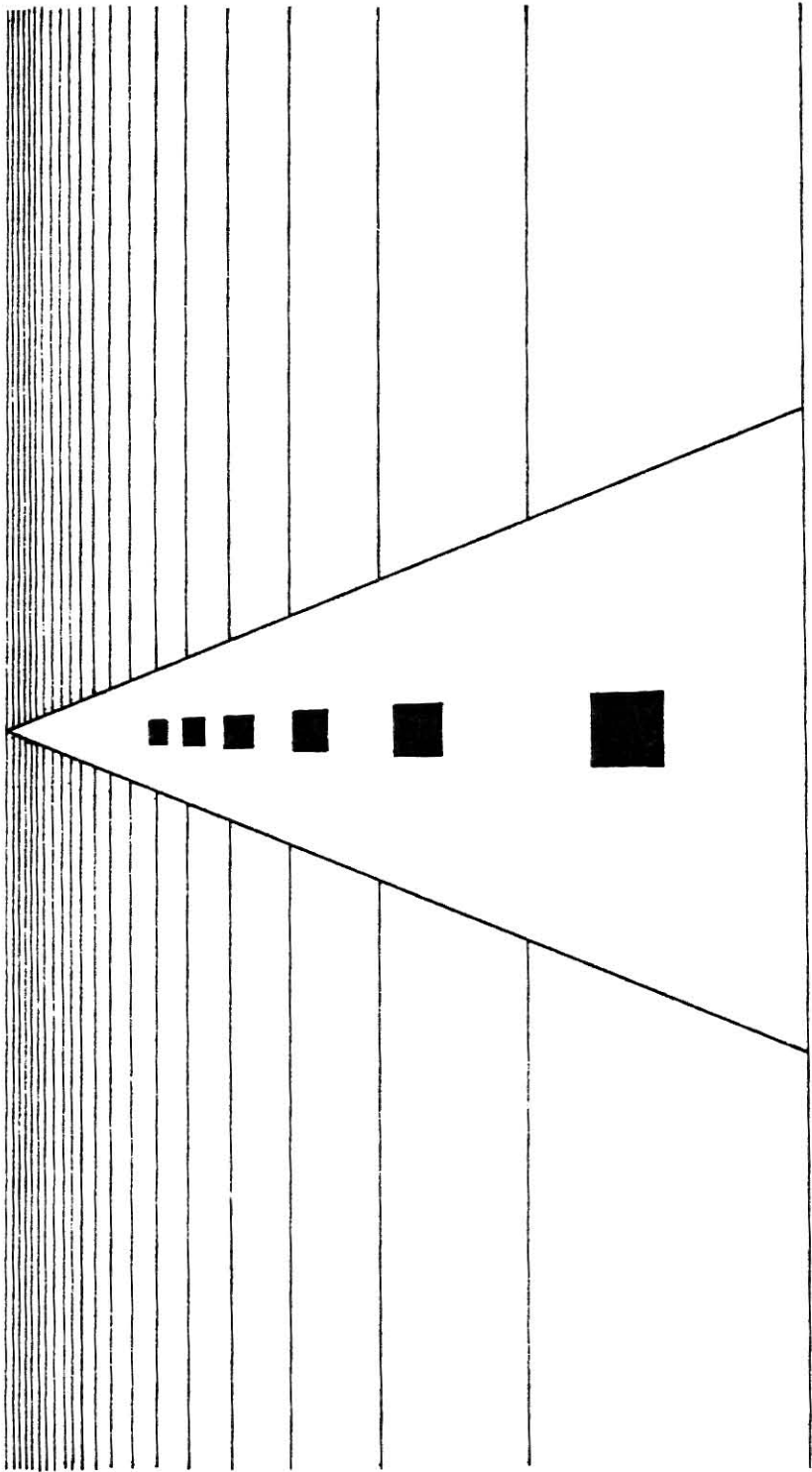
of distance (D). Algebraically, A is proportional to $1/D^2$. If apparent

movement is not directly proportional to frontal projection plane sepa-

ration, but rather to apparent distance in pictorial depth, then appar-

ent movement might be positively accelerated as a function of frontal

plane separation. In other words, apparent movement in pictorial depth

should increase as an inverse function of the perspective transformation

in the picture plane. This is because size constancy in apparent move-

ment would correspond to the phenomenal depth location of pairs of squares

and not to the actual separation in the picture plane. However, in the

absence of the perspective context and with the perception of size change

in apparent movement, apparent movement should increase in proportion to

picture plane separation.

The correspondence of "three-dimensional" apparent movement to the

three-dimensional representation of two-dimensional pictorial depth was

determined by scaling the apparent movement thresholds as a function of

hypothetical equal intervalled separations between pairs of sizes. The

equally spaced separations were used (a) because the inverse function

of pictorial depth is equal intervalled, and (b) to approximate the phe-

nomenal extent of the perceived movement. A linear increase in apparent

movement as a function of equal intervalled separations would suggest

that movement in pictorial depth is more akin to the three-dimensional

representation of depth than to picture plane separation. In addition,

the present study also examined the role of pictorial depth size on size

constancy in apparent movement. That is, the role of perceived size on

apparent movement was examined by changing the size differences between

pairs of squares, so that pictorial depth size became incongruent with

pictorial depth. This was achieved (a) by reversing the linear

perspective size changes in Figure 1, so that pictorial size became larger with increasing vertical separation, and (b) by keeping the size of the pairs of squares the same.

Method

Experimental Design

Figure 2 shows an example of the six experimental conditions used in the present study. Condition I was designed to examine the effects of pictorial depth size on apparent movement. Here, pairs of squares differed in size according to linear perspective, so as to be congruent with the perspective context to depth. Since the only difference between Condition I and Condition II was the type of context, Condition II controlled for the effects of pictorial depth separation between pairs of squares on apparent movement. Conditions III and IV differed from Conditions I and II in that the linear perpsective change in size of the squares was reversed. Condition III examined whether pictorial depth size (Condition I) was necessary for apparent movement in pictorial depth and Condition IV examined whether the effects of Condition II on apparent movement could be replicated regardless of the orientation of the squares. Condition V further examined the role of pictorial depth size (Condition I) on apparent movement by keeping the size difference between pairs of squares the same. Condition VI served to assess the effects of different sized squares (Conditions II and IV) on apparent movement by keeping the size difference between pairs of squares the same.

Observers

The observers were 38 introductory psychology students fulfilling a course requirement, all with normal or corrected vision. Training and screening of these students consisted of preliminary tests to familiarize observers with the perception of apparent movement. Preliminary training and screening sessions never included any of the critical experimental conditions. Five observers were rejected because their judgments showed

Figure Caption

Figure 2. An example of the same separation between pairs

of squares for the six experimental conditions

used in the present study.

I
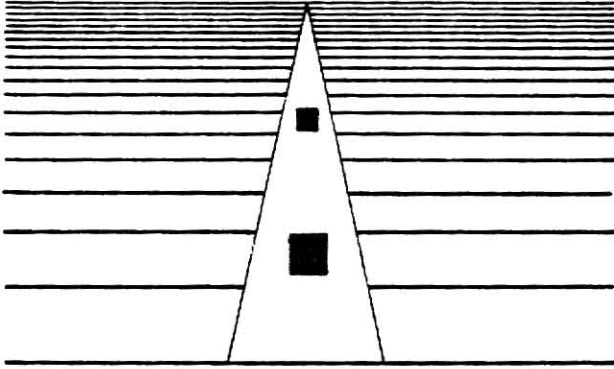
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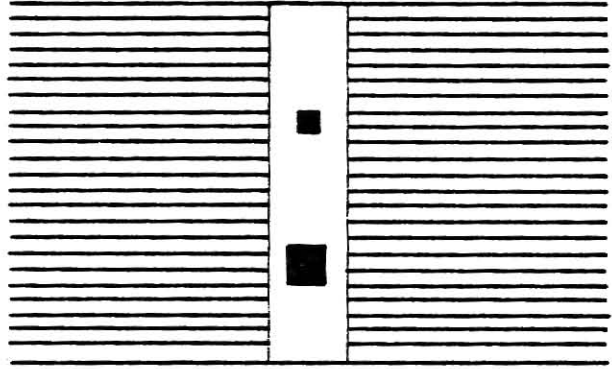
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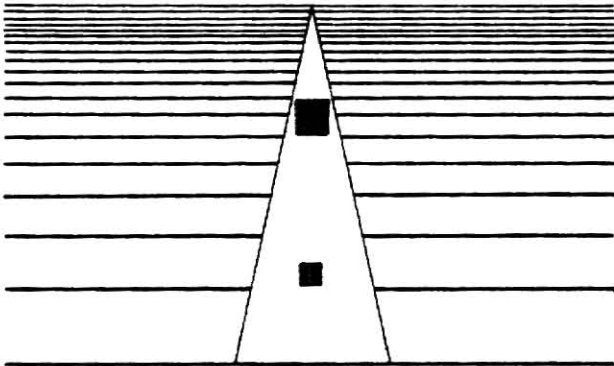
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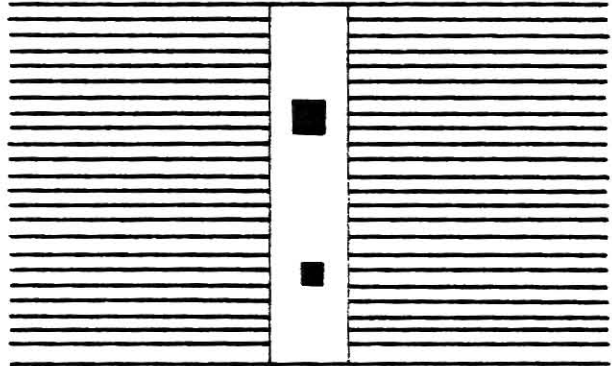
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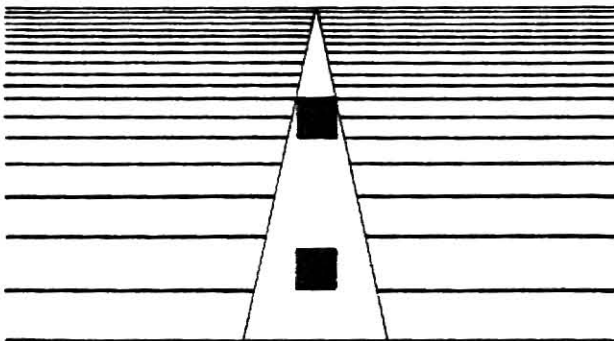
VI
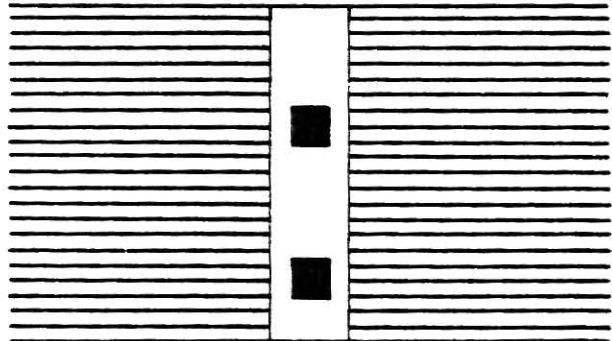
excessive perseverance of apparent movement and apparent simultaneity. Another three were rejected because they reported an inability to perceive apparent movement.

Apparatus

Each pair of stimulus squares was continuously alternated in two fields of a three field Iconix tachistoscope (Model 6191). The contextual background was presented in the third field and was always visible. The termination of one stimulus field always coincided with the onset of the other stimulus field. However, the duration of each stimulus field, always the same for both, was varied by the experimenter. Each decrement or increment in the duration of the fields containing the squares varied in 10 msec steps.

Previous work on apparent movement has usually kept the duration of each stimulus constant and varied the offset-to-onset time (interstimulus interval) required for the perception of apparent movement. Sgro (1963) has shown that with a duration above 32 msec and interstimulus interval above 60 msec the simultaneity threshold for apparent movement approached an asymptote. In the present experiment the duration of each stimulus field was well above 32 msec. Therefore, the findings of this experiment should be comparable to findings which have kept the duration constant and varied the interstimulus interval.

Stimuli

A standard black square (23 min and 45 sec in visual angle) was always paired with a comparison which belonged to one of three different sets. The comparisons were: (Set A-Conditions I and II) above the standard and always smaller in size relative to the standard, (Set B-Conditions III and IV) below the standard and always smaller in size relative

to the standard, and (Set C—Conditions V and VI) above the standard and always the same in size as the standard. The comparisons in Set A consisted of a two-dimensional perspective projection of the standard at five different equal three-dimensional depth planes. From the largest to the smallest comparison size, the visual angles were: 16 min and 37 sec, 11 min and 52 sec, 9 min and 30 sec, 7 min and 7 sec, and 5 min and 21 sec, and their respective height in the picture plane were: 29.5-, 45.0-, 55.0, 61.5- and 66.0-mm.

The vertical heights represent separations of the comparison from the standard and were measured from the position of the standard's bottom edge to the position of the comparison's bottom edge in the picture plane[5]. The comparison sizes and separations of Set B were the same as the comparisons of Set A, but differed from Set A by a 180 deg plane rotation (the standard inclusive). Finally, the separations of Set C were also the same as of Set A and Set B. The 15 black comparisons were drawn on separate white backgrounds.

The three comparison sets were used in two variations in the type of context: Pairs of sizes appeared on a background that contained either (a) perspective information for depth (Column 1, Figure 2) or (b) no perspective information for depth (Column 2, Figure 2). The context consisted of 20 lines for both conditions. However, in the perspective context condition, the distance between the lines varied hyperbolically to create a foreshortened depth gradient and the thickness of the lines decreased with increasing height in the picture plane. In the no perspective context condition, the distance between the lines and the thickness of each line was constant. The thickness of the lines in the former condition did not vary with each line, but with every four lines.

Procedure

Each observer was tested individually. The stimulus field was viewed binocularly with the room lights off. All participants were encouraged to maintain a head position near or touching the viewing scope of the tachistoscope. There was no fixation point because (a) in preliminary pilot work observers reported that it was easier to perceive movement without a fixation point and (b) previous research has demonstrated that overt eye movements and foveal fixation are not correlated with the occurrence of apparent movement (Guilford and Helson, 1929; Hulin and Katz, 1934).

The simultaneity threshold was estimated with the use of an ascending (A) and descending (D) method of limits (cf. Attneave and Block, 1973; Corbin, 1942; Orlansky, 1940; Sgro, 1963). There were three A and three D series in the form of ADADAD. The beginning stimulus duration for each A and D series was randomized and terminated when the observer made the first reversal in his/her judgment. For example, using the A series the procedure was as follows: The experimenter presented the observer with a duration of the alternating stimulus fields below the simultaneity threshold. The observer then responded either that he/she did or did not experience apparent movement. If the observer responded "No," the alternating fields were stopped, the field duration was increased by 10 msec and presented to the observer again. This procedure was continued until the observer made the first "Yes" judgment.

Pretraining. Before beginning the experiment all observers were familiarized with the perception of apparent movement. In this preliminary session, a horizontal and a vertical line (both were 1.5 deg high and 3.5 min wide in visual angle) were presented in succession. In the preliminary session the third field of the tachistoscope contained a blank

white background. Each observer was instructed that, when looking in the
viewing hood of the tachistoscope, a single object may appear to be moving
from one position to another and back again. Here one object may appear
continuously visible, but move in some direction even though there is
no real movement of the object. On the other hand, there may be two ob-
jects that appear to be visible at about the same time. Under this con-
dition, the two objects will appear simultaneously with no motion between
them. In addition, each observer was read the following instructions:

> If you look in the viewing scope you will see a vertical
> and horizontal line which meet at their ends, forming a 90 deg
> angle between them. Although the vertical and horizontal lines
> are actually flickering (i.e., they come on and off one after
> the other), the two lines appear simultaneously (i.e., at the
> same time) and neither seem to move. What you see can be
> changed, however, by decreasing the rate of alternation from
> very fast to very slow. For example, with decreasing rate of
> alternation a point is reached where there may appear to be
> only one line visible, which moves from a vertical to a hori-
> zontal position and back again [the experimenter demonstrated
> this by varying the duration of the stimulus fields, in 10 msec
> steps, until the observer reported that he/she experienced one
> object in apparent motion]. Take care to note that this single
> line appears to move like the second hand of a clock from 12 to
> 3 and then from 3 counterclockwise back to 12. Your experience
> of one line sweeping a 90 deg rotation is called apparent move-
> ment.

> Your task is to report whether you see one object in ap-
> parent motion by saying "Yes," or whether you see two objects
> that seem to flicker by saying "No." The purpose of this pro-
> cedure is to determine the alternation rate which you are con-
> fident that any alternation below it will not produce apparent
> movement and any alternation rate above it will produce appar-
> ent movement.

Observers were further instructed not to report "Yes" (I see apparent movement) if only one object of the pair was seen to move part way in the direction of the second and back to its original position (part-movement), or if two objects appeared to move toward each other and back to their original positions (dual-movement). They were told to report "Yes" only if one object was perceived to move throughout its entire path.

Posttraining. After six preliminary series with the vertical and the horizontal lines, each observer was randomly assigned to view one of the six experimental conditions (five stimulus pairs) in a 1-hour session. In addition, the presentation order of the comparisons was also randomized. Each observer was assigned to view only one experimental condition since preliminary work suggested transfer effects from viewing more than one experimental condition. For each stimulus pair, the first two method of limits series served as practice series and were not included in the final data analysis. At the end of the experimental session, the observers were asked to describe, with words or pencil, their experience and where they had looked while reporting "Yes" and "No."

Results

The data obtained from the five observers in Condition I were very different from those obtained in all other conditions. Therefore, five additional observers were used to determine if such pattern of results initially obtained for Condition I could be replicated. The results reported herein consist of a random selection of five observers from the ten possible for Condition I in order to perform equal n analyses of variance using all the experimental conditions. The overall analysis of variance showed no main effect of ascending and descending series nor did this factor interact with other factors. Therefore, the data were pooled over these conditions.

Subjective Reports

The results reported are general descriptions of the kind of movement the observers experienced. It should be noted that drawings were used when observers occasionally experienced difficulties as they attempted to verbally describe what they had seen. All but one observer (in Condition IV) reported seeing one square in apparent motion. Some observers were more confident that others of having seen one square continuously visible while in apparent motion. Further, under specific context conditions and comparison type, some observers reported more than one type of movement with the same stimulus pair. More is said about the types of movement perceived below.

There seemed to be no systematic differences between groups of observers under each experimental condition with regard to where they had looked while responding "Yes" or "No". There were a variety of "looking" strategies employed but none were consistently used. The most commonly

reported strategy was to inspect the general area in between the squares and/or in the vicinity of one of the squares while keeping the whole field in view. Eight observers reported the visual pursuit of a square in motion. This seemed not to be related to any of the specific experimental conditions. A fixation of either side of the median plane of the squares was reported by only one observer.

For descriptive purposes, the types of movement reported to have been perceived were grouped according to the most salient characteristics. The general categories describing all the types of movement perceived are:

1. Three-dimensional movement: one square seems to move out of the stimulus plane, behind and/or in front of the stimulus plane. The square appears rigid and seems to approach and recede in depth from the observer, without size changes.

2. Movement with figural (size) change: one square moves up and down in the stimulus plane, with its size getting smaller and larger at the same time. The square in apparent movement appears plastic and not rigid.

3. Plane movement: one square moves up and down in the stimulus plane, without any change in size (i.e., beta-movement).

4. Unidirectional movement: one square maintains its size and moves in the stimulus plane to the position of the second square. Movement in the opposite direction does not occur.

5. Fused movement: squares quite different in size from each other move together and fuse, becoming one joint figure moving in the stimulus plane (cf. Orlansky, 1940).

The first three types of movement describe the most salient movement effect observed under each experimental condition. The last two types of

movement describe the effects observed in specific experimental conditions when the comparison was quite different in size from the standard. The interesting fact in connection with the above types of movement is that they did not appear fortuitous. That is to say, the various experimental conditions favored certain types of movement over others. For example, the above types of movement correspond to each experimental condition as follows:

Condition I. All five observers reported three-dimensional movement with perspective context when the standard was paired with comparisons that decreased in size according to linear perspective (Set A). Two observers in this condition reported that three-dimensional movement was less convincing with the largest sized comparison than with the other four smaller sized comparisons.

Condition II. Figural change was reported by all five observers when the standard was paired with linear perspective sized comparisons (Set A) in the absence of perspective context to depth. However, when the comparison was quite different in size from the standard a combination of figural change, unidirectional movement, and/or fused movement was reported. For example, with the two smallest sized comparisons, two observers reported unidirectional movement and another reported a combination of unidirectional movement and fused movement. The unidirectional movement usually consisted of the standard moving to the position of the comparison. Once the standard reached the position of the comparison, the comparison was reported to reappear, but not to move to the position of the standard.

Condition III. Figural change was most frequently reported with the reversed linear perspective sized comparisons (Set B) in the presence of perspective context to depth. One observer, however, reported a combination

of plane movement and unidirectional movement, usually of the standard
when it was paired with the two smallest sized comparisons.

Condition IV. Figural change was also reported with the reversed
linear perspective sized comparisons (Set B) in the absence of perspec-
tive context to depth. Two observers in this condition reported a com-
bination of figural change, plane movement and/or unidirectional movement
with the two smallest sized comparisons. One observer was unable to ver-
balize what was seen in apparent motion with the three smallest comparisons.
This observer reported that something moved up and down in the picture plane,
but was uncertain as to what it looked like. The description seemed to be
consistent with the perception of the phi-phenomenon (cf. Wertheimer, 1961).

Condition V. Three observers reported a plane movement with perspec-
tive context when the standard and comparison were the same in size (Set
C). Two other observers reported a combination of plane movement and
three-dimensional movement. The three-dimensional movement was usually
reported with the greatest two or three comparison separations from the
standard. That is, as the comparison approached the apex of the conver-
ging lines present in the perspective context, three-dimensional movement
was likely to be perceived.

Condition VI. Plane movement was unanimously reported with the ab-
sence of perspective context when the standard and comparison were the
same in size (Set C).

Statistical Analyses

The minimum field duration required for apparent movement was sub-
jected to a three-way analysis of variance of the effects of type of context
(with and without perspective) by comparison set (perspective sizes, re-
versed perspective sizes, and same sizes) by separation (29.5, 45.0, 55.0,
61.5, and 66.0 mm). The measures obtained for each unique combination

of context type and comparison set were treated as between observers effects and those obtained from all observers for all separations were treated as within observers effects.

Analysis of the Complete Experimental Design. The first analysis was an analysis of variance comparing the effects of all variables in the experimental design. The purpose of this was (a) to determine if the type of context and comparison set affected the simultaneity threshold, and (b) to determine if the effects of increasing separation on the simultaneity threshold were the same for each context type and comparison set condition.

The summary table for the complete mixed design analysis is presented in Table 1. The main effects of Context type and Comparison set, and the Context type by Comparison set interaction were statistically significant. The between group cell means for the Context type by Comparison set interaction are presented in Table 2. This table shows that the greatest difference between type of context occured with comparisons that decreased in size according to linear perspective ($F(1,24) \geq 124.80$, $p < .01$). When the same perspective sizes were inverted 180 deg, however, the effects of the type of context were negligible ($F(1,24) < 1$). Furthermore, the type of context also had a differential effect when the comparisons were identical in size ($F(1,24) \geq 6.99$, $p < .05$), but this difference was less than that obtained with the perspective sizes (Set A).

Table 2 also shows that the type of comparison set had a systematic influence in the presence of contextual depth information ($F(2,24) \geq 111.80$, $p < .01$). The contrast between Set A and Set B ($F(1,24) \geq 125.20$, $p < .01$) and the contrast between Set B and Set C ($F(1,24) \geq 8.96$, $p < .01$) were statistically significant. However, the orientation of the perspective

Table 1

Summary of the Overall Analysis of Variance

Source	df	MS	F
Between Group			
Context type (P)	1	28704.16	69.53*
Comparison Set (S)	2	41116.63	99.60*
P X S	2	12933.13	31.33*
Observers wt. P X S	24	412.13	
Within Group			
Separation (D)	4	26577.30	232.87*
D X P	4	1173.29	10.28*
D X S	8	1799.54	15.77*
D X P X S	8	401.00	3.51*
D X Observers wt. P X S	96	114.13	

*$p < .01$

Table 2

Mean Minimum Field Duration (in msec) Required for Apparent Movement

for Each Context Type and Comparison Set Condition and their Row and

Column Marginal Means

Comparison Size

|	Perspective (Set A)	Reversed Perspective (Set B)	Identical (Set C)	Context Mean
Perspective Context	211.0	146.7	129.5	162.4
Frontal Plane Context	146.8	143.1	114.3	134.7
Comparison Set Mean	178.9	144.9	121.9	

sizes showed no between group differences in the absence of perspective context ($F(1,24) < 1$). But the effect of these different sized comparisons was different from that of the same sized comparisons. The contrast between Set B and Set C ($F(1,24) \geq 25.11$, $p < .01$) was statistically significant.

Table 1 shows that the main effect of Separation was statistically significant. Separation interacted with the type of context. In addition, Separation also interacted with Comparison set. Figure 3 presents the mean simultaneity threshold for each comparison set as a function of separation for both context conditions. For all comparison sets regardless of context type, the simultaneity threshold increased systematically with separation. The bilinear fanning of the comparison set functions was greater with perspective context ($F(8,96) \geq 15.61$, $p < .01$) than without perspective context ($F(8,96) \geq 3.67$, $p < .01$). These different patterns in the comparison set by separation functions across the context conditions produced a significant three-way Separation by Context type by Comparison set interaction. The simple two-way separation by context type interactions indicated that the functions were divergent only for the perspective sizes ($F(4,96) \geq 15.31$, $p < .01$). For the reversed perspective sizes the functions were almost the same ($F(4,96) < 1$) and for the identical sizes the functions were parallel ($F(4,96) \geq 1.11$, $p > .05$).

Figure 3 suggests a curvilinear function for the perspective sizes in the presence of contextual information for depth and a linear function for the perspective sizes in the absence of contextual information for depth. Because retinal separation and physical separation between context conditions were kept the same, the curvilinear function suggests that the effective separation for apparent movement might have been perceived

Figure Caption

Figure 3. Mean minimum field duration (in msec) required for
apparent movement as a function of picture plane
separation for each comparison set for both context
conditions. Bars indicate ± 1 standard error.
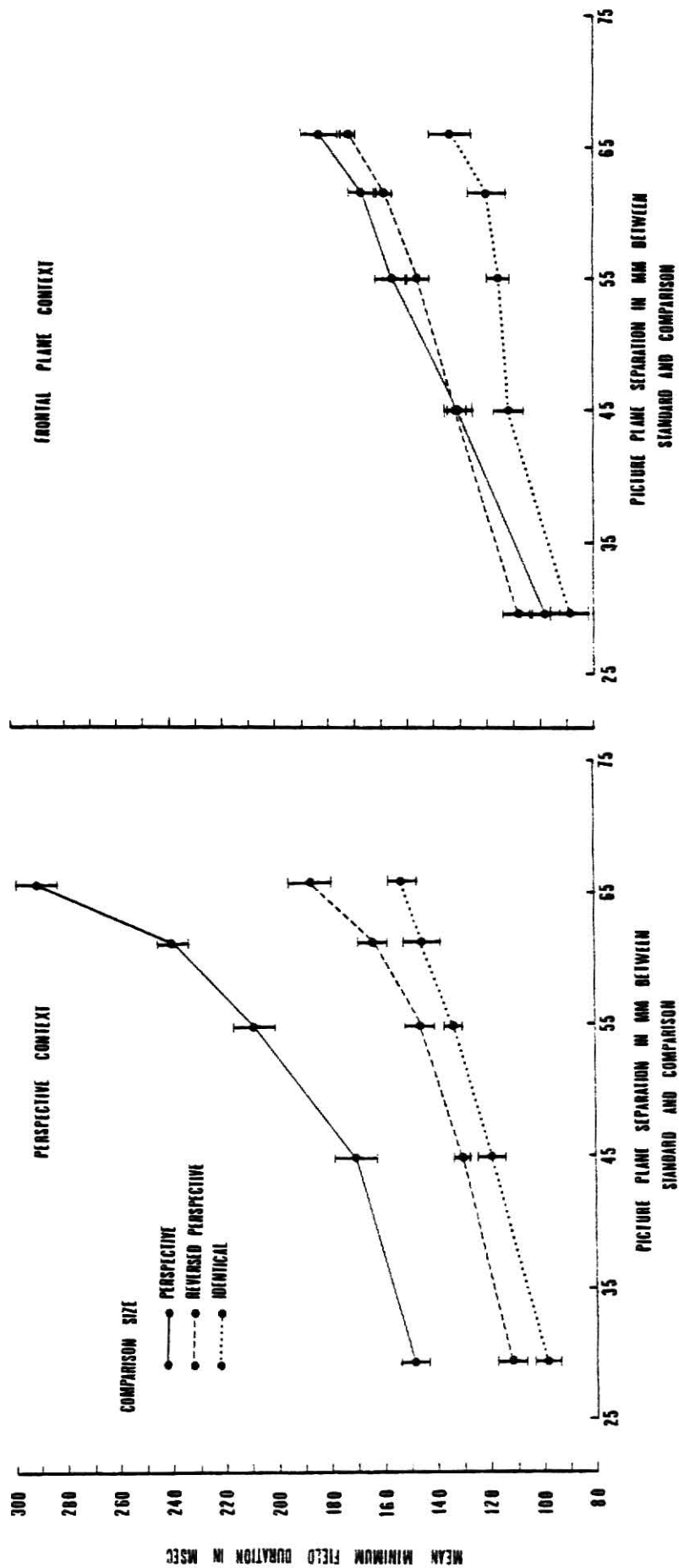
pictorial separation. Therefore, one may expect apparent movement to be proportional to the three-dimensional depth representation of pictorial depth.

The above possibilities were examined with statistical analyses on the shape (trend) of the simultaneity threshold as a function of separation. Specifically, two trend analyses of variance were performed; one employed hypothetical polynomial trend coefficients that preserved the interval spacing of the separations used in the experiment; and the other employed hypothetical polynomial coefficients that assumed equal intervalled separations (cf. Robson, 1959; Winer, 1971). The trend analysis with equal intervalled separations examined (a) whether the threshold increased linearly if it increased curvilinearly with picture plane separation, and (b) whether the threshold increased curvilinearly if it increased linearly with picture plane separation. Each trend analysis is discussed separately. Furthermore, in order to simplify the presentation of the results, the components of the complete orthogonal trend analysis were separated into three groups: (a) linear trends, (b) quadratic trends, and (c) higher order (cubic and quartic) trends.

Trend Analyses with Unequally Spaced Separations. The purpose of this analysis was to determine whether the simultaneity threshold for each comparison set increased (a) curvilinearly with perspective context and (b) linearly without perspective context. The summary table for the complete orthogonal trend analysis is presented in Table 3.

Linear Trends. Figure 3 shows that the simultaneity threshold increases with increasing picture plane separation. The linear trend analysis of each experimental condition were all statistically significant ($p < .01$). Table 3 shows that the linear trends of Separation by Context

Table 3

Summary of the Trend Analyses on the Within Sources

of Variance for Unequally Spaced Separations

Source	df	MS	F
Linear trends			
Separation (D)	1	102146.46	402.71*
D X Context type (P)	1	2585.91	10.19*
D X Comparison set (S)	2	6189.68	24.40*
D X P X S	2	717.29	2.83
D X Observers wt. P X S	24	253.65	
Quadratic trends			
D	1	3192.91	46.25*
D X P	1	2078.59	30.11*
D X S	2	927.64	13.44*
D X P X S	2	702.93	10.18*
D X Observers wt. P X S	24	69.04	
Cubic trends			
D	1	712.52	10.03*
D X P	1	16.03	<1
D X S	2	4.37	<1
D X P X S	2	155.54	2.05
D X Observers wt. P X S	24	75.89	
Quartic trends			
D	1	179.57	3.11
D X P	1	8.28	<1
D X S	2	78.12	1.35
D X P X S	2	34.58	<1
D X Observers wt. P X S	24	57.73	

*$p < .01$

type interaction and Separation by Comparison set interaction were statistically significant. However, the divergent slopes of the Separation by Context type interaction were parallel to those of the Separation by Comparison set interaction.

Quadratic Trends. An inspection of Figure 3 suggests a nonlinear function for (a) the perspective sizes in the presence of perspective context ($F(1,24) \geq 103.75$, $p < .01$) and (b) the reversed perspective sizes in the presence of perspective context ($F(1,24) \geq 17.01$, $p < .01$). It should be noted that the departure from linearity with the reversed perspective sizes appears localized at the last two separations. Perhaps this departure from linearity may have been due to three observers who showed inflections in their simultaneity threshold at the last two separations.

Table 3 shows a statistically significant quadratic trend of Separation by Context type by Comparison set interaction. This three-way interaction indicated a quadratic Separation by Comparison set interaction with perspective context ($F(1,24) \geq 45.82$, $p < .01$), but not with perspective context missing ($F(1,24) \geq 1.41$, $p > .05$). Furthermore, the quadratic trend of Separation by Context type interaction for the perspective sizes was statistically significant ($F(1,24) \geq 46.05$, $p < .01$), but for the reversed perspective sizes ($F(1,24) \geq 3.85$, $p > .05$) and for the identical sizes ($F(1,24) < 1$) was not statistically significant.

Table 3 also shows that the quadratic trends of Separation by Context type interaction and of Separation by Comparison set interaction were statistically significant. The former two-way interaction indicated a quadratic change with perspective context ($F(1,24) \geq 75.49$, $p < .01$). The latter two-way interaction indicated a quadratic change with perspective sizes ($F(1,24) \geq 58.05$, $p < .01$) and with reversed perspective

sizes ($\underline{F}$(1,24) $\geq$ 14.98, $\underline{p}$ < .01). The quadratic trend of the main effect of Separation was also statistically significant.

$\underline{Higher}$ $\underline{Order}$ $\underline{Trends}$. Trends of each experimental condition with third ($\underline{F}$(1,24) $\geq$ 6.04, $\underline{p}$ < .05) and with fourth ($\underline{F}$(1,24) $\geq$ 5.44, $\underline{p}$ < .05) order polynomial coefficients were statistically significant only for the perspective sizes in the presence of the perspective context (Condition I). Table 3 shows that trend interactions with polynomial coefficients greater than second degree were not statistically significant. However, a cubic trend main effect of Separation was statistically significant.

$\underline{Trend}$ $\underline{Analyses}$ $\underline{with}$ $\underline{Equally}$ $\underline{Spaced}$ $\underline{Separations}$. Since apparent movement may have been directly proportional to perceived separation and not picture plane separation, equally spaced trend coefficients were used to approximate perceived pictorial separation. The purpose of this analysis was to determine if the results obtained with picture plane separation (unequally spaced separations) could be reversed. That is, if curvilinear relations found with picture plane separation would grow linearly with equally spaced separations and if linear relations found with picture plane separations would grow curvilinear with equally spaced separations. The summary table for the complete orthogonal trend analysis is presented in Table 4.

$\underline{Linear}$ $\underline{Trends}$. Figure 4 presents the simultaneity threshold as a function of equally spaced separations for each comparison set for both context conditions. The linear trend analysis of each experimental condition were all statistically significant ($\underline{p}$ < .01). Table 4 shows that the linear trend of Separation by Context type interaction and of Separation by Comparison set interaction were statistically significant. The divergent slopes of the two-way interactions were parallel. The linear trend of the main effect of Separation was also statistically significant.

Table 4

Summary of the Trend Analyses on the Within Sources

of Variance for Equally Spaced Separations

Source	df	MS	F
Linear trends			
Separation (D)	1	105750.19	413.10*
D X Context type (P)	1	3622.69	14.15*
D X Comparison set (S)	2	6967.19	27.21*
D X P X S	2	1945.19	4.08
D X Observers wt. P X S	24	256.01	
Quadratic trends			
D	1	164.06	2.29
D X P	1	937.51	13.12*
D X S	2	125.93	1.76
D X P X S	2	514.57	7.20*
D X Observers wt. P X S	24	71.47	
Cubic trends			
D	1	374.08	5.22**
D X P	1	114.08	1.59
D X S	2	16.15	<1
D X P X S	2	38.15	<1
D X Observers wt. P X S	24	71.69	
Quartic trends			
D	1	21.00	<1
D X P	1	19.08	<1
D X S	2	89.06	1.55
D X P X S	2	6.42	<1
D X Observers wt. P X S	24	57.47	

*$p < .01$, **$p < .05$

Figure Caption

Figure 4. Mean minimum field duration (in msec) required for

apparent movement as a function of equally spaced

separations for each comparison set for both

context conditions. The size of the interval (X)

was arbitrary. Bars indicate ± 1 standard error.
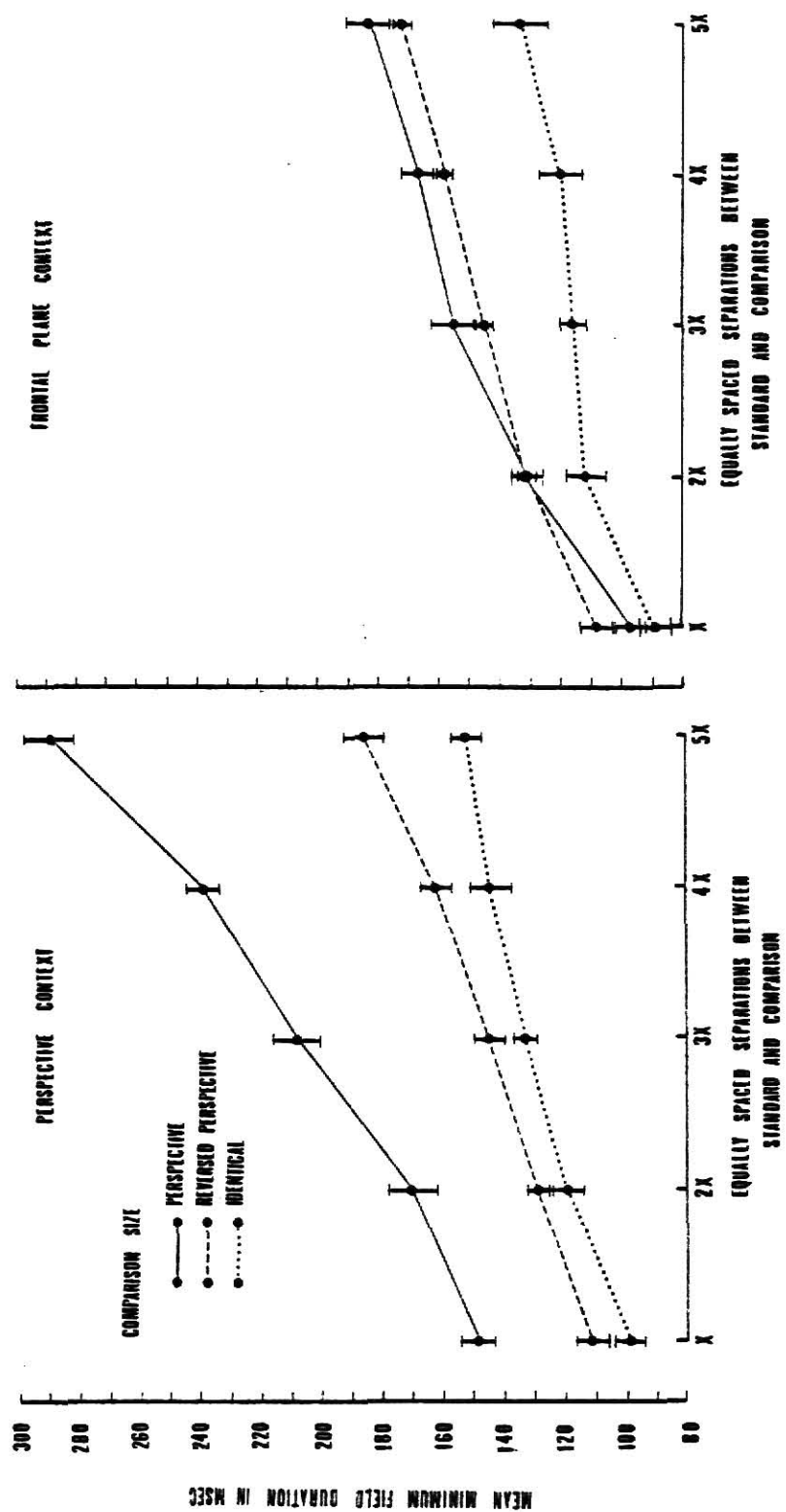
Quadratic Trends. The quadratic trend of separation of the perspective sizes with perspective context ($F(1,24) \geq 12.99$, $p < .01$) and of the perspective sizes without perspective context ($F(1,24) \geq 11.50$, $p < .01$) were statistically significant. Figure 4 suggests that the former function increases at a nonconstant rate with separation and that the latter function increases negatively with separation. The quadratic trend of Separation by Context type interaction was statistically significant for the perspective sizes ($F(1,24) \geq 24.51$, $p < .01$), but for the reversed perspective sizes ($F(1,24) \geq 2.89$, $p > .05$) and for the identical sizes ($F(1,24) < 1$) was not statistically significant. These different quadratic patterns in the separation by context type functions across the comparison set conditions produced a significant quadratic trend of Separation by Context type by Comparison set interaction. Table 4 shows that the quadratic trend of Separation by Context type interaction was statistically significant. This two-way interaction indicated a quadratic change without perspective context ($F(1,24) \geq 12.94$, $p < .01$), but not with perspective context ($F(1,24) \geq 2.22$, $p > .05$).

Higher Order Trends. A cubic trend of separation of identical sizes without perspective context was statistically significant ($F(1,24) \geq 5.66$, $p < .05$). Figure 4 indicates that this function has inflections at the second and at the fifth separation. Table 4 shows that trend interactions with polynomial coefficients greater than second degree were not statistically significant. The cubic trend of the main effect of Separation was statistically significant.

Discussion

Apparent Movement in Phenomenal Depth

Orlansky (1940) investigated the effects of identical and nonidentical sizes on apparent movement and found that (a) identical pairs were frequently reported in motion over a wide range of time intervals, (b) the frequency of perceiving movement and the range of time intervals required to perceive movement decreased with increasing size differences between members of the stimulus pair, and (c) mirror-image pairs, having the smallest range of time intervals, were less frequently perceived in motion. Kolers and Pomerantz (1971) confirmed these results and presented data which indicated that three-dimensional movement with mirror-image pairs required longer interstimulus intervals than changes of shape in the stimulus plane with different shaped pairs (e.g., circle and square). The conclusion drawn by Orlansky (1940) was that movement occurs preferably with regard to equals (identical members), and less preferably with regard to unequals (disparate members), suggesting that the Gestalt principle of similarity is a relatively "potent" determinant for the apprehension of movement (cf. Wertheimer, 1961).

The above findings were generally confirmed by the present experiment. Figure 3 shows that (a) three-dimensional movement (Condition I) required the greatest field durations, (b) figural change with different sized pairs (Conditions II, III, and IV) required shorter field durations, and (c) plane movement with identical pairs (Conditions V and VI) required the least field durations. The present study also shows that the type of movement perceived was more consistent if an unchanging square was perceived in motion (Conditions I, V, and VI) than if a square was perceived to undergo plastic size changes while in motion (Conditions II,

III, and IV). In the latter conditions more than one type of movement was reported, especially with pairs of squares which were very different in size.

In the present experiment, however, three-dimensional movement occured with different sized pairs of squares which were congruent with a foreshortened depth gradient context (Condtion I). Here, the effects reported were of a single square which remained the same in size, but moved in phenomenal depth. That is, the size disparity of the squares were resolved with the perception of movement in phenomenal depth. Because the phenomenal size of the square in apparent movement remained the same, it appears that the physical (retinal) similarity of the stimulus pair was not necessary for apparent movement without size changes. This result demonstrates that the relative potency of the principle of figural similarity for the apprehension of movement also occurs with perceived size similarity.

The Role of Pictorial Depth on Apparent Movement

Apparent movement with the linear perspective size changes was found (a) to increase positively with picture plane separation in the presence of perspective context (Condition I) and (b) to increase linearly with picture plane separation in the absence of perspective context (Condition II). This difference suggests that the contextual information for depth influenced the effective separation required for apparent movement, since retinal separation and physical separation between context conditions were kept constant. That is, apparent movement increased positively because the phenomenal extent of the perceived motion was greater than that actually present in the picture plane. Hence, while retinal separation and physical separation between context conditions were kept

constant, apparent movement was found to vary with the phenomenal separation.

The possibility that the pictorial representation of distal size (Condition I) influenced the perceived separation was corroborated by the subjective reports. The subjective reports indicate that three-dimensional movement occured predominantly in Condition I. Furthermore, two observers reported a change in the phenomenal extent perceived with three-dimensional movement[6]. In addition, changes in pictorial depth size produced changes in the type of movement reported. For example, figural change occured with the reversed perspective sizes in the presence of perspective context (Condition III), and plane movement occured with the identical sizes in the presence of perspective context (Condition V). These results suggest that apparent movement in a phenomenal three-dimensional space is dependent on perceived size and not actual size.

However, the effects of context type were found not to be ubiquitous nor the same whenever they existed. For example, the type of context had similar effects on apparent movement with the reversed perspective size changes (Conditions III and IV). Figure 3 shows that both functions increase systematically with separation, but without slope or ordinate differences. On the other hand, context type systematically increased the simultaneity threshold with the identical sized pairs (Conditions V and VI). Figure 3 shows that the function for perspective context is systematically above the function without perspective context. These different influences of context type suggest that the correct perspective size changes in the presence of perspective context together induced the observed changes in apparent movement.

The differences found by varying context type while keeping the size of squares the same confirmed the results reported by Attneave and Block (1973). However, the present study extended Attneave and Block's results by showing that apparent movement increased linearly with picture plane separation regardless of context type. The linear function with perspective context suggests that apparent movement increased in proportion to picture plane separation rather than to the perceived representation of pictorial depth. This is consistent with the subjective reports of plane movement, rather than three-dimensional movement. The implication of these effects is that apparent movement is dependent more on the retinal parameters of the stimulus configuration than on the perceived representation of depth. This retinal dependence was further confirmed with the lack of contextual depth effects found when size differences changed according to reversed linear perspective. Therefore, the incongruences between pictorial size and pictorial depth appear to make apparent movement dependent on picture plane separation. However, size changes consistent with pictorial depth were found to induce changes in apparent movement in the direction of the perceived pictorial representation of depth. The implication of this is that, as the stimulus configuration becomes congruent with pictorial depth, apparent movement corresponds more to the perceived properties of stimulation than to the retinal properties.

The Congruity of Apparent Movement with Pictorial Depth

Kolers and Pomerantz (1971) presented data which suggested that the visual system needs more time to construct a rigid change in depth than a coplanar change of shape. However, a more concise explanation suggested by the present study is that more time is needed to construct a rigid

change in depth because the path of the perceived movement transverses
a greater distance than that perceived when the two stimuli appear simul-
taneously in the picture plane. It follows that perceived three-dimen-
sional movement increases in proportion to increases in three-dimensional
pictorial representation of depth and not picture plane (retinal) sepa-
ration. The possibility that three-dimensional movement is congruous to
the pictorial representation of depth was examined by scaling the simul-
taneity thresholds as a function of equally spaced separations. Although
the results were suggestive of this expectation, quantitative coincidence
between the hypothesis and the experimental data was not entirely satis-
factory.

For example, Figure 3 shows that in the presence of perspective con-
text the function for the perspective sizes (Condition I) and for the re-
versed perspective sizes (Condition III) depart from linearity. The de-
parture from linearity was found to be greater for Condition I than for
Condition III. For all the other conditions (Conditions II, IV, V, and
VI), the functions increase linearly with picture plane separation. On
the other hand, Figure 4 shows that in the presence of perspective con-
text the comparison size functions increase approximately linear with
equally spaced separations. Here, it was expected that the function for
Condition I should have increased linearly and that the functions for Con-
ditions III and V should have increased negatively. However, some tend-
ency towards the negative increase is present with Condition V. But only
Condition I was found to depart from linearity. Figure 4 also shows
that in the absence of perspective context, with the exception of Condi-
tion IV, the comparison size functions increase negatively with equally
spaced separations. Here, all three functions were expected to increase

negatively, but only Conditions II and VI were found to depart from linearity.

The violations between the expectations and the experimental data that need attention are the functions for the reversed perspective sizes (Conditions III and IV), since these functions were found to increase approximately linear regardless of the scale of the separations. The causes of these violations do not immediately present themeselves, but in Condition III three observers did show inflections in their simultaneity threshold at the last two separations. In a more general sense, however, the violations could have been due to the impoverished two-dimensional representation of depth used in the present study. Perhaps with more depth cue-laden stimulus configurations a better coincidence between the expectations and the experimental data would have occured. Nevertheless, the general import of the results is that apparent movement in the stimulus plane is directly related to separation in the stimulus plane. That is, figural change (Conditions II, III, and IV) and plane movement (Conditions V and VI) increase approximately linear with picture plane separation. On the other hand, apparent movement in a phenomenal three-dimensional space (Condition I) increases approximately linear with the pictorial representation of depth, rather than picture plane (retinal) separation.

Conclusions

The pictorial representation of distal size was found to influence apparent movement in the direction of the perceived objective properties of pictorial depth, rather than the two-dimensional retinal properties of the stimuli. This was evidenced in that an invariant sized square was perceived to move in depth and in that this "three-dimensional" movement increased positively with separation in the frontal plane. Both of these results are consistent with the perception of pictorial size constancy in apparent movement. Therefore, the spatial separation Korte's law implies was made dependent on the perceived depth size separation and not actual (retinal) size and separation. The implication of this is that apparent movement is governed by the same variables that underlie perceptual constancies in pictorial depth. This constancy of apparent movement complied with the psychophysical function relating the thresholds of three-dimensional movement to the pictorial representation of depth. However, apparent movement did not correspond in a "one-to-one" relation to distal distance. Specifically, apparent movement was found to increase at a faster rate than distal distance, suggesting that the effective separation might have been the perceived extent of the three-dimensional movement. In fact, a varied experimental literature suggests a nonlinear correspondence between perceived distance and distal distance (Galanter and Galenter, 1973; Smith and Gruber, 1958; Smith, et al., 1958; Wohlwill, 1965). Perhaps a "one-to-one" psychophysical correspondence would have obtained if the thresholds were related to the perceived distance of the movement in depth. This problem will be undertaken by the present author in the near future.

Footnotes

[1]In the present paper phenomenal and perceived are used synonymously to refer to our experience of depth in three-dimensional space or in two-dimensional representations of three-dimensional space. The geometry that is adequate to describe the structure of our space in perception has often been assumed to be Euclidean (e.g., Cook, 1978; Baird and Biersdorf, 1967; Epstein, Park, and Casey, 1961). However, it is not self-evident at all that our visual space is Euclidean. The assumption is explicit in the size-distance invariance hypothesis; perceived size-distance ratio equals the physical size-distance ratio. The usual way of stating the hypothesis is to say that the two ratios are proportional. The Euclidean formulation of the hypothesis assumses that the constant of proportionality is equal to unity. This assumption has been shown to be grossly incorrect and non-Euclidean theories of space perception have been advanced (cf. Foley, 1972; Indow, 1967; Indow, Inoue, and Matsushima, 1962).

[2]Rock and Ebenholtz (1962) have also shown that apparent movement is primarily a function of change in three-dimensional phenomenal location of the sources of stimulation and not a function of change in the anatomical locus of stimulation. This was evidence in that apparent movement was achieved even though the two sources of stimulation had the same anatomical locus of excitation, but different phenomenal locations. Hence, disparate anatomical loci of excitation and, consequently, their neural interaction is not necessary for the perception of apparent movement.

[3]The term "stimulus bound" as used in this paper is best defined as a perceptual process that is dependent on stimulus parameters that have

their effects at a peripheral (e.g., retinal) level and not at a central or cognitive level (cf. Howard, 1974).

[4]Apparent movement in an illusory three-dimensional space has been cited extensively (e.g., Bartley and Miller, 1954; Kolers, 1963; Smith, 1951, 1952, 1955). Under appropriate conditions, the present experiment demonstrated that it can occur with sufficient regularity. It is proposed that such movement effects be distinguished from other types of apparent movement (e.g., alpha-movement, beta-movement, gamma-movement, delta-move-ment, and the phi-phenomenon, cf. Aarons, 1964; Bartley, 1963; Hovland, 1935; Wertheimer, 1961). Keeping with previous nomenclature of visual apparent movement, this type of apparent movement should perhaps be called epsilon-movement.

[5]Another criterion that could have been used to measure the separations between the standard and the comparisons was their center-to-center distance. Orlansky (1940) has shown that if the center-to-center distance, or if the distance between the nearest points of two figures, is kept constant the pattern of results were not changed. The choice made in the present study, however, was not entirely without meaning; it was thought that the measure from the standard's bottom edge to the comparison's bottom edge best represented their projected separation in the picture plane.

[6]It is believed that the change in the phenomenal extent perceived with three-dimensional movement has not yet been reported in the litera-ture.

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Apparent Movement in Depth

in a Phenomenal Three-dimensional Space

by

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AN ABSTRACT OF A MASTER'S THESIS

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Abstract

The successive exposure to two stationary lights in the frontal plane can invoke the perception of apparent movement. This perception of apparent movement is known to be dependent on the rate of the successive exposure and on the distance separating the two lights. However, there is some question as to whether apparent movement varies with retinal (proximal) separation or perceived separation. The present experiment examined the relationship between perceived separation and the time (threshold) required for apparent movement. The purpose was to determine whether apparent movement varies with perceived separation, and if so, what is the nature of the psychophysical function.

Perceived separation was varied by two-dimensional representations of three-dimensional depth. For example, the threshold for apparent movement was determined under conditions in which two squares (a) appeared on a plane with perspective information for depth, and (b) on the same plane without perspective information for depth. The frontal plane (objective) separation between stimuli was varied for each context condition. The stimuli were pairs of different sized squares, such that the size differences between the squares increased with increasing separation, so as to be consistent with a foreshortened density depth gradient. In other words, in the presence of perspective context information for depth, the static stimulus field was a two-dimensional perspective representation of the same distal sized square in different pictorial depth planes.

The movement perceived when pairs of squares that differed in size according to linear perspective were successively presented in the static perspective context was of an invariant sized square moving in pictorial

(perceived) depth. However, in the absence of perspective context, the movement perceived was of a square that changed in size while moving in the vertical dimension of the stimulus plane. In addition, the threshold for apparent movement (a) increased positively with separation in the presence of perspective context and (b) increased linearly with separation in the absence of perspective context. This difference suggests that the perspective context influenced the effective separation required for apparent movement, since retinal separation and physical separation between context conditions were kept the same. That is, apparent movement in pictorial depth varied with the perceived separation, rather than retinal separation. The possibility that "three-dimensional" movement is congruous to the pictorial representation of depth was examined by scaling the thresholds as a function of equally spaced separations. This psychophysical function was found to increase approximately linear, suggesting that apparent movement is governed by the same variables that underlie perceptual constancies in pictorial depth.

When the perspective size changes between pairs of squares was reversed, so that the larger square always appeared above the smaller one, the type of context did not affect the threshold. However, the threshold did increase with frontal plane separation regardless of context. In these conditions, the perceived movement and the threshold functions were not different from the nonreversed perspective sizes without perspective context. When pairs of squares that were identical in size were used, the threshold also increased linearly with frontal plane separation. The type of context, however, systematically increased the threshold for apparent movement. In the latter conditions, the type of movement perceived was of a square that remained the same in size while moving in the stimulus plane. These results

suggest that apparent movement in a phenomenal three-dimensional space is dependent on perceived size and not actual size.