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The Effect of Multiple Depth Cues in the Perception of Occlusion

James William Rhodes
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by James William Rhodes entitled "The Effect of Multiple Depth Cues in the Perception of Occlusion." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Psychology.

Stephen Handel, Major Professor

We have read this dissertation and recommend its acceptance:

Michael G. Johnson, Howard Pollio, Gordon Burghardt, Michael Moshell, Donald Bouldin

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

THE EFFECT OF MULTIPLE DEPTH CUES IN THE PERCEPTION OF OCCLUSION

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

James William Rhodes

August 1980

DEDICATION

To my parents, Dr. and Mrs. James E. Rhodes

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ABSTRACT

The perception of depth in visual displays containing multiple sources of depth information was investigated. A computer graphics system generated randomly textured visual patterns that were presented on a television screen. One half of each pattern moved continuously toward the remaining stationary half. The texture elements of the moving half of the pattern were deleted from view as they contacted the stationary pattern area. This kinetic occlusion of texture elements tended to be perceived as one surface passing behind another. Two experiments were performed in which the depth cues of brightness, texture density, and relative velocity were systematically added to kinetic occlusion patterns.

The first experiment explored the effect of a single depth cue, brightness or texture density, when combined with kinetic occlusion. The moving half of each pattern consisted of adjacent horizontal sections. A moving section could contrast in brightness or texture density with the other moving sections or with the stationary area. Subjects reported the moving sections as passing behind the stationary area regardless of prevailing brightness or texture density differences. The effect of brightness or texture density was to vary the perceived depth ordering of the moving sections passing behind the stationary area.

In the second experiment, brightness, texture density, and relative velocity were simultaneously combined with kinetic occlusion. The moving horizontal sections of a visual pattern could differ in relative

velocity, and both the moving sections and stationary area could differ in brightness and/or texture density. The perceived depth ordering of the moving sections was determined by brightness and texture density; relative velocity did not exert a systematic effect. Subjects agreed in their judgments of the moving sections, but individual differences emerged in the judged depth of the stationary area relative to the moving sections. Occlusion was the most frequently occurring perceptual organization (i.e., all moving sections passing behind the stationary area), but other organizations occurred as well. The stationary area could be perceived as: 1) at a greater depth than all the moving sections; 2) at an intermediate depth between two moving sections; and 3) at the same depth as one of the moving sections. Some subjects used only one organization, whereas others used two or more organizations. These perceptual organizations represented different ways of resolving conflicts between kinetic occlusion and brightness/texture density combinations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Visual perception of the three-dimensional structure of the environment is dependent on the pattern of light reflected to the observer's eyes. The patterning of light is a consequence of the physical properties of surfaces in the environment. When illuminated, differences in pigmentation and reflectance of surfaces modify the light (the optic array) reflected to a point of observation. The optic array can be motionless or it can be dynamically changing, but in each case optical structure or patterning is lawfully related to the physical structure of the environment.

Gibson (1961, 1966, 1979) has studied how the physical environment structures the optic array and how these properties of optical structure are related to perception. In this work, he has detailed a number of general properties of the environment that are important for an organism to perceive. For example, terrestrial animals must perceive the ground plane which provides a surface of support and differentiate the plane from the surrounding physical medium of air. In particular, an abrupt ending of the ground plane in the form of a precipice must be detected and avoided. Objects lying on the ground plane must also be perceived so as to avoid injurious collisions during locomotion.

A second goal has been to discover the properties of the optic array that give rise to perception. A fixed gaze in a motionless environment can provide effective stimulus patterns, such as texture density gradients. However, motion of the organism and/or parts of the environment produces a much larger class of optical patterns that can, at least in principle, give perceptual information about events in that environment. For example, as an object approaches, its boundaries and its surface texture expand radially. Preliminary studies with humans and some other animals have shown that an optical expansion pattern produces an avoidance reaction such as flinching or ducking. Other optical patterns such as motion perspective and kinetic occlusion have also been shown to result in the perception of ecologically important events.

Gibson's program of ecological optics is important not only as a general methodological approach to the study of visual perception, but also because it encompasses some of the more critical empirical issues in visual perception. One of the most important of these issues is the determination of the visual stimuli for the observer's perception of depth.

Depth perception is a basic component of our perception of the environment. One of the first and most authoritative attempts to specify systematically the stimuli for depth perception was made by Helmholtz in his *Treatise on Physiological Optics* (1962). Chief among the visual stimuli for depth were binocular disparity and the pictorial depth cues, such as linear perspective and interposition. A significant characteristic of these depth cues was that they were static in nature. The only dynamic or motion dependent stimulus discussed by Helmholtz was motion parallax, although he was astute in his recognition of its potential for determining depth relationships. Even Helmholtz, however, spoke of motion parallax in terms of comparing the different positions of fixed retinal images at successive intervals (Helmholtz, 1962, p. 295). This greater emphasis on static cues was in part due to a lack of sufficiently sophisticated apparatus to isolate and present dynamic stimuli, but it was also due to a general conception of depth perception that was based on a model of the observer as stationary with respect to the surroundings.

Since Helmholtz's Treatise, there has been an increasing recognition of dynamic visual stimuli as a primary rather than a derived source of information about depth. Wallach and O'Connell (1953), Johansson (1976), Gibson (1979), and others have shown that continuous spatio-temporal transformations of simple stimulus elements can produce the perception of form and motion in three-dimensional space. In general, these experiments demonstrate that depth is readily perceived in dynamically transformed stimulus arrays but is absent when the same stimulus arrays are motionless. The conceptual framework of this newer approach modifies the notion of a motionless observer by proposing that motion in the environment or of the observer is indispensible for a complete account of depth perception.

The topic of this dissertation concerns one form of optical change known as kinetic occlusion. The typical condition for kinetic occlusion is the progressive covering or uncovering from view of distant objects by nearby objects. Unless the surfaces of these objects are perfectly smooth and have no differences in reflectance or pigmentation, they will reflect a pattern of optical texture formed by numerous adjacent areas of contrasting intensity or wavelength. The optical change critical to kinetic occlusion is the deletion or accretion of optical texture. Figure 1 illustrates the role of optical texture in kinetic occlusion. If area A in Figure 1 moves behind area B (or if B moves in front of A), the optical consequences will be the progressive removal of texture from A at the border or junction of the two areas. Opposite motion of area A results in the addition rather than deletion of optical texture.

Kinetic occlusion is not a simple extension of the static depth cue of interposition. The border defining the separation of two surfaces in depth is formed by the locus of accretion or deletion of optical texture. The shape of this border is not related to the effectiveness of kinetic occlusion. An irregularly shaped border, such as one that delimits a random polygon, is determined by kinetic occlusion in the same way as a straight line border (Kaplan, 1969). By contrast, the geometric properties of the border, and in fact, the gestalt properties of the occluding and occluded figures, have been shown to be critical in the perception of interposition (Ratoosh, 1949; Dinnerstein and Wertheimer, 1957). One such illustration of interposition is presented in Figure 2. Kinetic occlusion is an instance of a dynamic stimulus whose formal properties are simpler than those of the analogous static cue. Potentially, kinetic occlusion may be a source of information about relative depth which is effective across a wide variety of environmental conditions. What evidence supports this possibility?

Kaplan (1969) proposed that the systematic accretion or deletion of optical texture along a border would be sufficient to produce the perception of one surface moving behind another. To test his

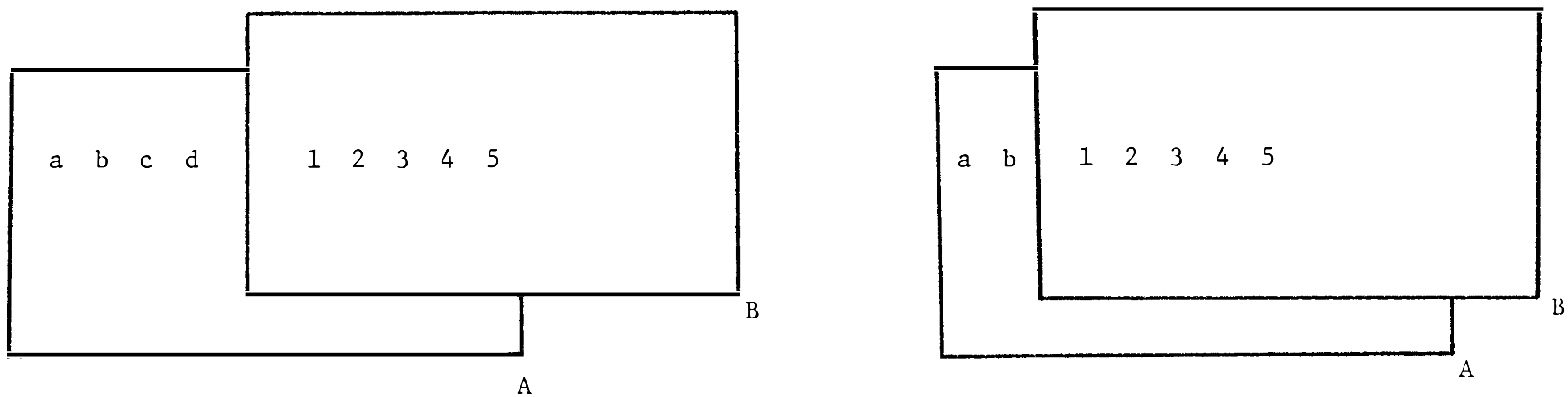


Figure 1. The deletion or accretion of optical texture in kinetic occlusion.

Optical texture elements are deleted from surface A as it slides behind surface B, whose texture elements are unmodified. The letters and numbers represent texture elements.

A B

Figure 2. The effect of figural properties on the perception of interposition.

The boundary of the lower square is intersected by the boundary of the upper shape in both A and B. However, subjects typically reported interposition only in A. Both parts of B were described as "touching but not overlapping."

Source: Dinnerstein and Wertheimer, 1957, p. 23.

hypothesis about kinetic occlusion, Kaplan employed adjacent areas of homogeneous random texture so that the perceptible boundary between the textured areas was eliminated when they were motionless. When one of these areas moved, however, optical texture elements were added or deleted from that area at the border of the two areas. An immediate and clear separation of the two areas in depth was reported. The area undergoing accretion or deletion was seen as a surface moving behind the area whose texture was preserved.

In other stimulus displays used by Kaplan (1969), accretion or deletion took place in both areas, and the relative rate of accretion/deletion was varied. The perception of occlusion was lost when accretion or deletion occurred simultaneously on both sides of the display. Subjects typically described these displays as consisting of two textured surfaces attached to abutted rollers so that the texture moved into or out of a margin or crack. Furthermore, if the texture of one of the areas was deleted at a faster rate than the other, subjects saw the faster region as the more distant.

Taken together, Kaplan's (1969) experiments demonstrated that kinetic occlusion was sufficient for the perception of surfaces separated in depth. Homogeneous texture and uniform brightness ensured that there were no other depth cues besides kinetic occlusion.

Nonetheless, most environments contain a multiplicity of cues for perceived depth. When two or more depth cues are present, they may cooperate or compete in determining perceived depth. The effect of a single depth cue, such as kinetic occlusion, could be altered by the brightness or texture density of the areas undergoing kinetic occlusion.

A first step in the investigation of interaction among multiple depth cues is to consider the effect of each cue when presented singly. Three depth cues are discussed: brightness, texture density and relative velocity.

Brightness. A demonstration reported by Kilpatrick (1961) shows that relative brightness can serve as a depth cue. Two balloons at equal physical distances from the observer were viewed in a dark room. Continuously increasing the illumination intensity of one balloon made it appear to move toward the observer; the other balloon appeared to be stationary. Decreasing the illumination of one balloon produced the opposite effect of motion away from the observer. Gibson (1950) has argued that brightness of illuminated surfaces is not a reliable cue to depth, and that an experiment like the one reported by Kilpatrick represented a highly atypical viewing condition. Gibson (1950) stated that the intensity of light reflected to the eye does not diminish with increasing physical distance from the point of observation. Nonetheless, relative brightness can contribute to perceived depth, even if in an anomolous or unreliable way. Therefore, the conditions under which relative brightness results in perceived depth and how it interacts with other, more reliable depth cues is of interest.

Texture Density. Most physical surfaces are not perfectly uniform in composition. They usually have small, local variations in pigmentation or reflectance that gives them a characteristic texture. Light reflected from a surface to the observer's eyes is described by Gibson (1979) as optical texture or an array of adjacent differences in luminous intensity and wavelength. If a surface oriented perpendicularly to the line of sight is tilted away from the observer, the optical texture will be systematically changed. The angular separation of optical texture elements corresponding to the distant part of the surface will be decreased, and the optical texture corresponding to the nearer end will be expanded. The steepness of this texture density gradient will be proportional to the inclination of the surface relative to the observer. Similarly, the distance of any point along the surface will be proportional to the average density of texture elements at that point.

Gibson (1950) maintained that texture density gradients are invariant over a wide range of environmental conditions, within broad limits. Variation in the number, shape, or regularity of spacing of physical texture elements will result in an invariant optical texture density gradient for a surface at a fixed position relative to the observer. However, a number of recent studies have shown that texture properties alter the perception of a surface. Newman, Whinham, and MacRae (1973) found that texture density gradients with a regular element spacing led to more accurate judgments of surface slant than texture density gradients containing irregularly spaced elements. This occurred even though both gradients contained the same total number of elements. Newman et al. (1973) suggested that linear perspective, which accompanied the regular spacing of texture elements, was necessary to render the texture density gradient useable by the observer. Wohlwill (1966) has also found that judgments of distance based on a texture density gradient improved when the number and regularity of spacing of texture elements was increased. Moreover, a visual pattern containing foreshortening of elements and a gradient of diminishing element size in addition to a density gradient resulted in judgments of surface slant that were more accurate than with a density gradient alone (Rosinski and Levine, 1976). These studies force a modification of Gibson's original formulation of his texture density gradient hypothesis. Although a texture density gradient may contain information about distance and slant, other variables determine whether a texture density gradient is useable by the observer.

Relative Velocity. Helmholtz observed that the angular displacement of objects in the visual field was proportional to their physical distances from the observer. For example, when a person looks out the window of a moving automobile, nearby objects are displaced across the visual field at a greater velocity than more distant objects. This relationship between angular velocity and physical distance is known as motion parallax. Gibson, Gibson, Smith, and Flock (1959) have shown that the relative velocity difference that accompanies motion parallax results in the perception of surfaces at different depths. They projected two sets of randomly distributed texture elements onto a screen. The two sets of elements were superimposed and were seen as a single randomly textured surface when they were stationary. If one set was moved laterally across the screen at a faster rate than the other, the two sets were perceptually segregated in depth. Subjects reported seeing two surfaces at different depth levels, but the depth relationship between the two surfaces was ambiguous. The faster moving surface was not consistently seen as closest, contrary to what the law of motion parallax predicts.

Although motion parallax involving two levels of relative velocity gives the observer ambiguous information about relative depth, Gibson (1979) has proposed that a larger gradient of velocities may provide more accurate information about depth. When an observer moves through the environment, the entire visual field undergoes a continuous change known as motion perspective. The visual field expands radially in front of the observer, and the focus of this expansion pattern corresponds to the direction of locomotion. There is also a continuous gradient of angular velocities which decrease in magnitude with increasing distances from the observer.

A mathematical analysis of motion perspective by Lee (1974) has shown that, potentially, the expanding optic array can inform the observer of his or her direction of movement as well as the relative distance of objects in the environment. Research by Warren (1976) and Schiff and Detwiler (in press) has demonstrated the ability of the observer to make use of this information in the optical expansion pattern. In these experiments, artificial motion perspective displays simulated locomotion parallel to the ground plane or motion toward an object. Warren's (1976) observers could use the focus of expansion to determine their direction of travel. Similarly, Schiff and Detwiler (in press) showed that the rate of optical expansion was critical in judgments of "time to collision" with an object. Thus, the optical expansion pattern contains useable information about the observer's motion relative to the environment.

Purpose

The foregoing sections have considered the effect of brightness, texture density, relative velocity, and kinetic occlusion when they occur singly. The present work concerned the perceptual effect of these cues when they occur in combination. Two experiments were performed. The first examined kinetic occlusion in combination with one additional depth cue, brightness or texture density. The second experiment extended this investigation by combining three cues (brightness, texture density, and relative velocity) with kinetic occlusion. The methods and results of these experiments are reported in the following chapters.

CHAPTER II

GENERAL METHODOLOGY

This section will detail the experimental apparatus as well as those aspects common to both experiments. Methodology specific to each experiment will be detailed at a later time.

Subjects

All subjects were undergraduates at the University of Tennessee who received class credit or payment at the rate of $2.00 per hour for their participation in an experiment. Two experiments were performed, and a different set of subjects was used in each experiment.

Experimental Task

The task given to subjects was to judge the relative depth of different sections within a stimulus display. A schematic diagram corresponding to each display was provided, and subjects labeled the diagram to indicate perceived ordering of display sections in depth. A simple numerical code was used in which "1" stood for the closest display section, and progressively larger whole numbers were used to label increasingly more distant sections of a display. Two or more display sections seen at the same depth were all coded with the number appropriate to that depth level. For example, if two sections were both seen as the second closest parts of the display, they were each coded as "2."

Apparatus

A computer graphics system provided by the Department of Computer Science was used to generate the stimulus displays. The system consisted of an IMSAI 8080 microcomputer, a video-converter unit (Cromemco TV Dazzler), and a television monitor. The video-converter created a visual display by mapping sections of computer memory (the video buffer) onto the television screen. Each byte of memory contained a code specifying the brightness of the corresponding picture element. The 64×64 stimulus array required 2048 bytes of computer memory in the video buffer. Motion in the stimulus display was produced on-line by the use of two video buffers. While one video buffer was being displayed, the computer program systematically shifted the content of memory locations in the second video buffer to the left or right. By alternately displaying the two video buffers, a continuous pattern of motion was produced.

Stimulus Displays

A schematic illustration of a stimulus display is presented in Figure 3. The entire area of the display was composed of texture formed by the random spacing of small, luminous picture elements on a dark background; one half of the display was always stationary. The other, moving half of a display was composed of three adjacent and equal sized horizontal sections that could be independently controlled. The texture composing each of the horizontal sections was uniformly and continuously translated in a lateral direction toward the stationary

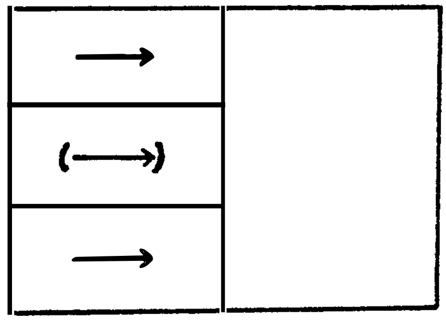


Figure 3. The general format of stimulus displays.

The arrows indicate the moving sections of the display; the remaining area is stationary. The section with the arrow in parentheses was moving in some displays and stationary in others. Each part of the display could independently vary in brightness or texture density.

area. The texture in each section was continuously added at its trailing border and was continuously deleted at its leading border which coincided with one border of the stationary area. Figure 3 shows the moving sections and their direction of motion relative to the stationary area. In some displays, all three horizontal sections moved, but in others, the middle section was stationary.

The three principal stimulus parameters manipulated in the displays were brightness, texture density, and relative motion. There were two levels of brightness intensity, two levels of texture density, and three possible magnitudes of relative velocity. The values of all three parameters could be independently varied for each of the three moving sections of the display, and the values of brightness and density could be varied independently for the stationary section. This allowed a wide variety of possible stimulus displays.

Testing Conditions

In both experiments, subjects viewed the stimulus displays while seated at a desk. The stimulus displays were presented by a television monitor (screen size 26 cm × 36 cm) positioned in front of the subject at a distance of about 150 cm. The room was illuminated by overhead florescent lights, and the room temperature was maintained at about 20°C. Background noise resulted from the air conditioning unit and computer equipment in the room. Individuals entered and left the room while the experiments were taking place, but no subject complained or otherwise gave any indication of being disturbed by these occurrences.

CHAPTER III

EXPERIMENT I

The perception of the three-dimensional structure of the environment seems immediate. However, it is unclear what aspects of the visual stimulus are critical for providing this information and how multiple visual cues for depth are perceptually integrated. Since the pioneering work of Helmholtz, a number of stimulus cues have been shown to convey information about the relative depth of objects. Some of these stimulus patterns or cues are static, such as linear perspective, whereas others are motion-determined or dynamic, such as motion parallax and kinetic occlusion. The unfortunate tendency in psychology has been to study depth cues one at a time in isolation. Yet, outside the laboratory, the observer is usually confronted with multiple cues for depth. One unanswered question, then, is how does the observer make use of this multiplicity of information?

Stimulus cues can combine their effects: the perceptual outcome is dependent on the compatibility of cues and the relative weight of each. A demonstration reported by Kilpatrick (1961) illustrates some of the ways perceptual stimulus cues can be integrated. Two balloons at equal physical distances from the observer were viewed against a dark background. When the balloons had the same brightness and size, they appeared equal in depth. By increasing size while holding brightness constant, the larger balloon was made to appear closer. Likewise, the brighter of two equal sized balloons appeared closer. Moreover, if both brightness and size were varied in the same direction, the apparent separation in depth was enhanced compared to the effects of either variable alone. By varying brightness and size in opposite directions (e.g. a larger but dimmer balloon), perceived separation in depth was minimized, but the larger sized balloon was still seen as closest. Thus, compatible cues can combine to produce a greater separation in depth than a single cue, and incompatible cues tend to cancel their effects, although one cue can be predominant and yield the consequences of that cue.

In more general theorizing, Brunswik (1943) has proposed a framework for the relative importance of stimulus cues in perception. Brunswik emphasized the observer's attempt to arrive at a veridical perception of the environment on the basis of multiple stimulus cues. The relative depth of objects, for example, is known to the observer only through the pattern of light focused on the retina (the proximal stimulus). The proximal depth cues, such as interposition and relative size, vary in the degree to which they give the observer ecologically valid information about depth. On the basis of the observer's experience with a particular environmental setting, the available depth cues are ranked in a hierarchy of accuracy or usefulness to the observer in that environment. Multiple depth cues combine their effects, but those depth cues occupying the highest position in the observer's "cue hierarchy" exert the strongest influence on perceived depth.

The first experiment in the present work was a beginning study of one depth cue, kinetic occlusion, in combination with a single additional depth cue, brightness or texture density. A previous investigation of kinetic occlusion by Kaplan (1969) employed random-dot patterns of homogeneous texture density and brightness so as to eliminate other depth cues. Under these conditions, kinetic occlusion produced a compelling perception of two surfaces separated in depth. In naturalistic settings, however, kinetic occlusion is likely to be accompanied by differences in brightness or texture density. The brighter parts of the visual field are typically closer to the observer than those parts with lesser brightness intensity, although this relationship is not invariant in all or even most environments. Similarly, increasing texture density is usually associated with increasing physical distances from the observer. In some instances kinetic occlusion will be compatible with brightness and texture density, although variations in the observer's environment make this positive relationship only probable rather than certain. Thus, at times depth cues will be in conflict. The purpose of Experiment I was to determine how kinetic occlusion interacts with brightness or texture density when these cues are combined in compatible and conflicting ways.

Method

Stimulus Displays

The two principal variables manipulated in the stimulus displays were brightness and texture density. Correspondingly, two sets of 36 displays were used, one incorporating brightness variations and the other, texture density variations. Both of the principal stimulus variables had two levels of intensity. The brightnesses of the texture elements were 4 ft. cd. and 8 ft. cd. The two levels of texture density were 1.4 texture elements per cm^2 and 0.5 texture elements per cm^2. Unlike brightness, however, the control of texture density was not precise. The computer program used for the stimulus displays was not designed to generate variations in texture density. The primary limitation of the texture density variable was that brightness covaried with texture density levels. Consequently, the low level of texture density was darker than the high level. This difference in brightness applied to the background as well as the texture elements. As a result of brightness confounding, interpretation of the effect of texture density was problematic.

The visual displays varied in a number of other ways, and are illustrated in Figure 4. First, the brightness or texture density of the moving sections could be symmetrically placed on either side of a middle section of contrasting brightness or texture density. The alternate spatial arrangement placed moving sections of identical brightness or texture density in adjacent positions (see Figure 4, A). Secondly, the middle horizontal section of a stimulus display could move with rate and direction of the other moving sections or it could be stationary (see Figure 4, B). Finally, the overall size of the stimulus displays could vary between those with two horizontal sections (27.0 × 11.2 cm) and those with three horizontal sections (27.0 × 17.5 cm) (see Figure 4, C). All displays were viewed at a distance of 150 cm.

Counterbalancing

The sequence of 72 stimulus displays was counterbalanced across subjects. The procedure consisted of dividing displays into equal sized

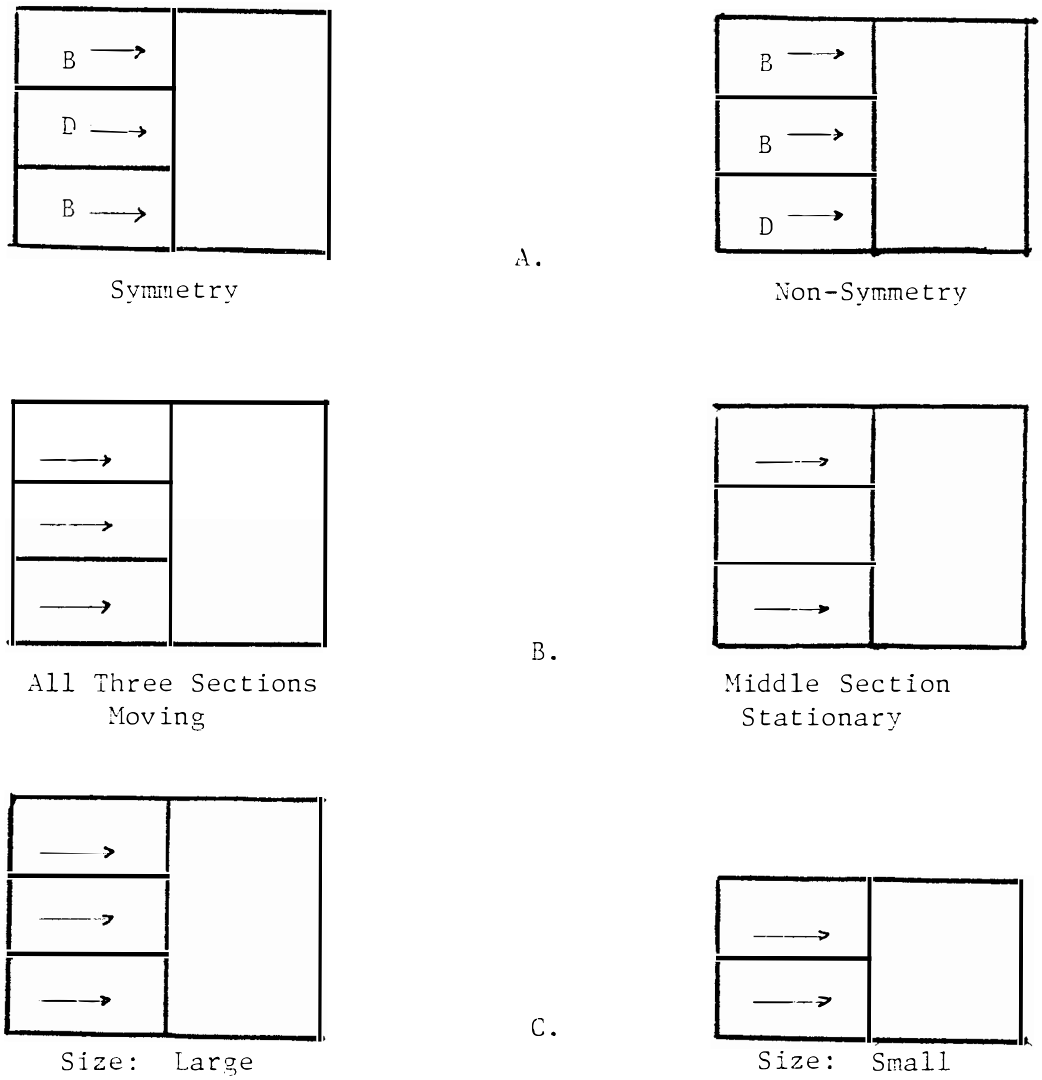


Figure 4. Schematic illustration of three types of stimulus displays used in Experiment I.

These were: (A) symmetry vs. nonsymmetry; (B) number of moving sections; (c) size of display. Arrows indicate the moving sections of the displays. Brightness is coded as: B = Bright: D = Dark.

blocks, randomizing the sequence within blocks, and then presenting the blocks of displays in counterbalanced order. The number of blocks was chosen to match the number of subjects (16) in the experiment. Thus, each subject received a different ordering of stimulus displays. Counterbalancing ensured that all blocks appeared in all sequential positions and that each block was followed by every other block one time.

Results

The stimulus displays in Experiment I were divided among those having relative brightness differences and those having texture density differences. However, the effect of texture density on perceived depth was virtually identical to that of brightness. Because of this similarity and the confounding of brightness with texture density, the effects of brightness will be discussed first, and the data on texture density will be discussed in terms of these results.

Fifteen of the 16 subjects reported depth in nearly all of the stimulus displays. The remaining subject failed to perceive depth in almost all of the displays. The data for this subject was excluded from further analysis, and the results reported below represent the data for the remaining 15 subjects.

The dominant perceptual organization in all stimulus displays was occlusion: moving sections were seen as passing behind the stationary area in 96.4% of the total number of responses. Occlusion was perceived regardless of the prevailing brightness differences within displays. Brightness contrasts produced differences in perceived depth among the moving sections as well as differences among stationary parts. On the basis of these findings, the stimulus displays could be arranged into four groups illustrating how movement and relative brightness affected perceptual organization. Examples of displays from each group are shown schematically in Figure 5, and the types of perceptual organizations are described:

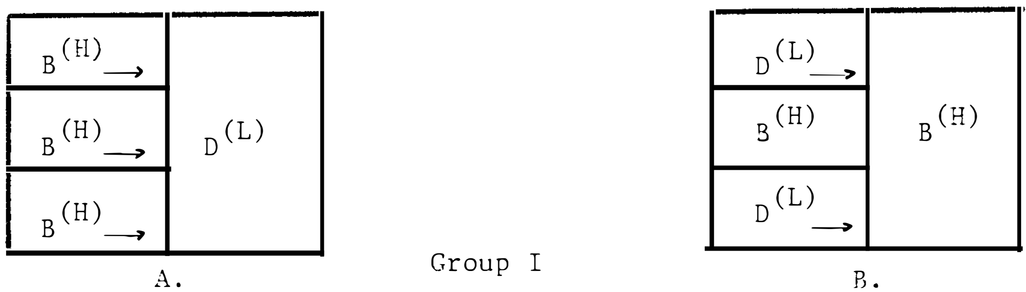
Group I: Brightness Contrast Between Moving and Stationary Sections

In the first group of displays (Figure 5) all moving sections were identical in brightness. The brightness of the moving sections could be either identical to the stationary area or contrasting to it. In both cases, however, the moving sections were seen at the identical depth level behind the stationary area in 100% of the responses. This outcome held for displays with a single, large stationary area (Group I, A) and for displays which had a horizontal stationary section placed between the moving sections (Group I, B).

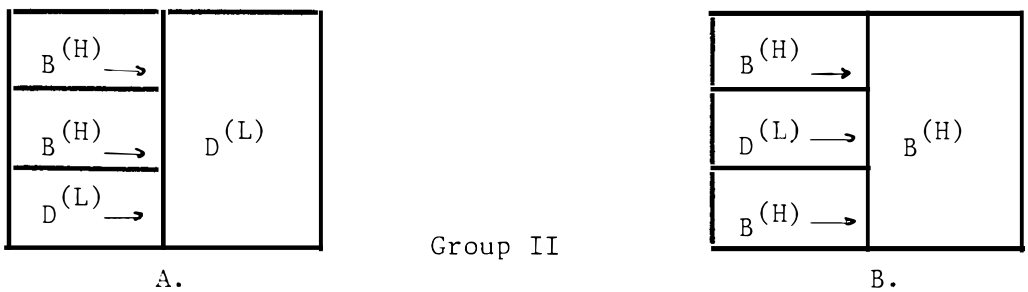
Group II: Brightness Contrast Between Moving Sections

The displays in the second grouping contained two sources of information about depth: relative brightness and kinetic occlusion. All moving sections shared the common factor of kinetic occlusion, but one of the moving sections contrasted in brightness with the others. As a result, one of the moving sections was the same brightness as the stationary area (see Figure 5, Group II).

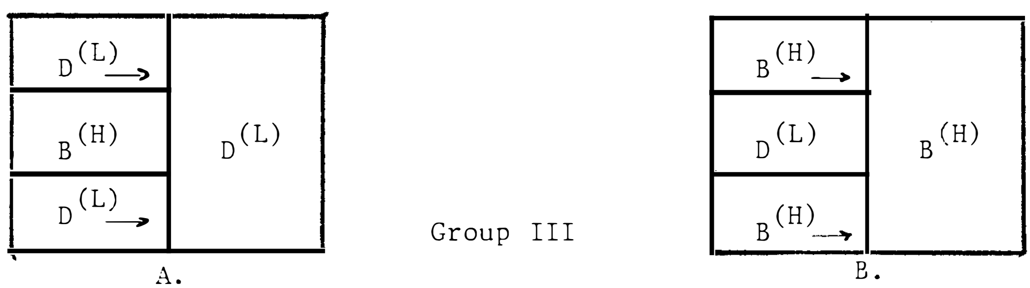
In nearly all instances (93%) the moving sections as a group were seen as more distant than the stationary area. Within this group, moving sections of contrasting brightness were seen at different



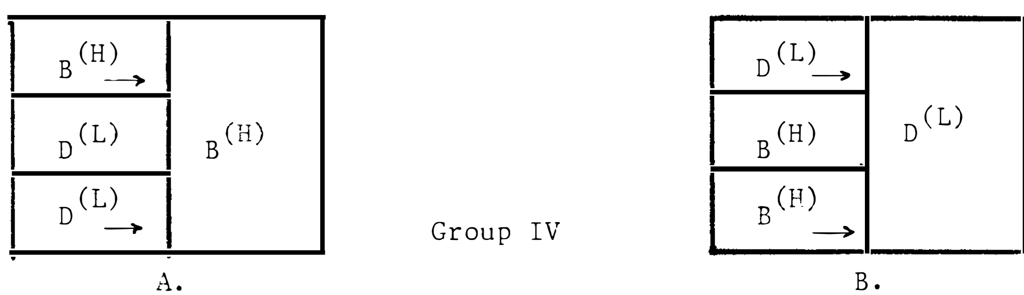
Brightness (Texture Density) Contrast Between Moving & Stationary Sections



Brightness (Texture Density) Contrast Between Moving Sections



Brightness (Texture Density) Contrast Between Stationary Sections



Brightness (Texture Density) Contrast Between Moving Sections & Between Stationary Sections

Figure 5. Schematic illustrations of the four groupings of stimulus displays in Experiment I.

depth levels in 78% of the responses. Thus, kinetic occlusion was the dominant source of information about depth (i.e., all moving sections were seen behind the stationary area), and brightness differences affected only the depth of moving sections relative to each other.

The perceived depth among contrasting moving sections was weakly related to the brightness of the stationary area. There was a tendency for moving sections whose brightness equalled that of the stationary area to be seen as closer (57%) than moving sections whose brightness differed (43%). Using subjects as the sampling variable, this difference failed to reach statistical significance ($t_{14} = 1.64$, $p > .05$). Thus, brightness differences between moving sections did not produce consistent judgments of depth.

Another possible determinant of perceived depth in displays with moving sections of contrasting brightness concerned the spatial pattern of brightness. Examples A and B in Group II of Figure 5 illustrate the two spatial patterns of brightness, viz., symmetry and non-symmetry. The spatial distribution of brightnesses did not affect the subject's response. For example, moving sections of the same brightness were located in depth together regardless of whether they were spatially adjacent (82%) or separated by a moving section of contrasting brightness (80%). Furthermore, the larger non-symmetric brightness area was seen as closer slightly more often than the small area (52% vs. 48%). This equal distribution was consistent across all subjects.

Group III: Brightness Contrast Between Stationary Sections

The third group of displays introduced a brightness difference between a large and a small stationary area (see Figure 5). The moving sections were identical in brightness and were located together in depth behind both stationary areas in 93% of the responses. The large stationary area tended to be judged as closer than the small area (69% vs. 31%), regardless of the brightness values of the two regions. This difference reached statistical significance ($t_{14} = 2.91$, $p < .05$). These results demonstrated that perceived occlusion of moving sections was not disrupted by variations in perceived depth of the stationary areas.

Group IV: Brightness Contrast Between Moving Sections and Between Stationary Sections

The stimulus displays in the fourth group combined brightness differences between stationary and between moving sections. There were only two displays in this group, both of which are presented in Figure 5, Group IV. These displays produced the widest range of responses, although occlusion was perceived by all subjects.

Perhaps the most important finding was that brightness affected perceived depth in the same way observed with previous displays. First, the moving sections of contrasting brightness were perceived at different depth locations in 76% of the responses. Secondly, the larger stationary area was seen as closer than the smaller area (72% vs. 28%), and this difference was statistically significant ($t_{14} = 3.19$, $p < .05$). Furthermore, brightness differences did not affect this outcome. Third, the bright moving section was not consistently seen as closer than the dark moving section (58% vs. 42%). These findings are parallel to those obtained in the previous two groups of displays. The displays in the fourth group demonstrated that perceptual effects of relative brightness for both moving and stationary areas did not interact in combination.

Texture Density Displays

The results for stimulus displays having texture density differenced closely paralleled those obtained with brightness differences. Occlusion was the most frequently occurring response (91.8%), i.e., the moving sections were seen behind the stationary parts of a display. Differences in the texture density of either moving sections or stationary areas altered their relative depth consistent with perceived occlusion. Texture density displays followed the same pattern of grouping obtained with brightness displays. Within each grouping, the effect of texture density was also similar to the effect of brightness.

The perceived depth of moving display sections that were either identical or contrasting in texture density is described in Table 1. Moving sections with identical texture density tended to be located at the same depth, and moving sections contrasting in texture density were seen at different depth levels. In both cases the moving sections were seen as passing behind the stationary display area. Furthermore, there was no tendency for moving sections of high texture density to be seen as closer than moving sections of low texture density (50% vs. 50%).

TABLE 1

The Relative Depth of Moving Sections of Contrasting and Identical Texture Density for Stimulus Display Groupings in Experiment I[1]

Display Groupings	Moving Sections of Contrasting Texture Density Seen at Different Depth Levels	Moving Sections of Identical Texture Density Seen at the Same Depth Level
Group I	*	93%
Group II	83%	82%
Group III	*	98%
Group IV	82%	*

[1]An asterisk indicates that there were no displays in this category.

For stationary display areas contrasting in texture density, the larger area was seen as closer more often than the smaller area (63% to 37%). This difference approached, but did not reach statistical significance ($t_{14} = 2.11$, $p > .05$). In addition, some of the stimulus displays contained moving sections of differing size. These size differences were the result of two moving sections of identical texture density occupying adjacent positions in a display (see Figure 1A, page 5, for an example). The larger moving areas tended to be seen as closer than the smaller moving areas (56% vs. 44%), but this tendency was not statistically significant ($t_{14} = 2.0$, $p > .05$). These results follow those obtained with brightness displays.

In summary, the effect of texture density on depth judgments was similar to the effect of relative brightness. This outcome appears to be the result of the covariation of brightness with texture density. Hence, brightness and kinetic occlusion were the primary determining factors in all displays. No conclusions about the effect of texture density seem possible from this data. In Experiment II, however, the brightness of texture elements was independent of density. The results from Experiment II concerning the role of texture density in perceived depth will be discussed in the following chapter.

Discussion

With few exceptions, stimulus displays were perceived as three-dimensional organizations of moving and stationary surfaces. There were two sources of information for perceived depth in these displays: a) kinetic occlusion and b) relative brightness or texture density.

Kinetic occlusion led to the perception of depth: the continuously occluded moving sections were seen as passing behind the stationary display areas, irrespective of the brightness or texture density of either the stationary or moving areas. These results generalize the findings of Kaplan (1969), who investigated kinetic occlusion with stimulus displays of homogeneous brightness and texture density, to displays with nonhomogeneous brightness and texture density. In both instances, depth was constantly seen.

The effect of relative brightness or texture density was to modify the perceived depth of moving and stationary display areas consistent with the perceived occlusion. Although moving sections as a group were perceived in depth behind the stationary area, their depth relative to each other was affected by brightness or texture density differences. Moving sections of the same brightness or texture density were localized at the same depth, but moving sections of contrasting brightness or texture density were not consistently ordered in depth relative to each other.

The interaction of relative brightness or texture density with kinetic occlusion raises a number of questions. One effect of brightness or texture density was to modulate the relative depth of moving sections which shared the common factor of kinetic occlusion. One question that remains to be determined is whether depth would continue to be consistent with the perception of occlusion if multiple depth cues, such as brightness, texture density, and relative velocity, were simultaneously combined with kinetic occlusion. A second question would be to determine if texture density or relative velocity in combination with brightness make the relative depth of moving sections less ambiguous. The second experiment (Experiment II) explored these sorts of questions.

CHAPTER IV

EXPERIMENT II

In the first experiment, kinetic occlusion was combined with one other depth cue, brightness or texture density. Although occlusion was the dominant perceptual organization, brightness or texture density altered perceived depth within the framework of occlusion. The purpose of Experiment II was to extend this investigation by simultaneously combining kinetic occlusion with three other cues: brightness, texture density, and relative velocity. The resulting stimulus displays were more complex than those in the previous experiment in that there were more possible combinations of depth cues, and these cues could be either compatible or conflicting with each other and with occlusion. One goal was to discover what combinations of depth cues would yield the most stable perceptual organization, and whether occlusion would remain the dominant perceptual organization. A second goal was to investigate further the integration of conflicting perceptual cues. A third goal was to gain a more complete understanding of critical features of kinetic occlusion, as discussed below.

Previous work by Kaplan (1969) has suggested that the rate at which occlusion takes place is related to perceived depth. Both texture density and relative velocity of moving sections of a kinetic occlusion display can alter occlusion rate, i.e., the number of texture units deleted per unit of time. On the basis of Kaplan's findings, the moving area of a display with the highest texture density and relative velocity would be predicted to be seen in the greatest relative depth.

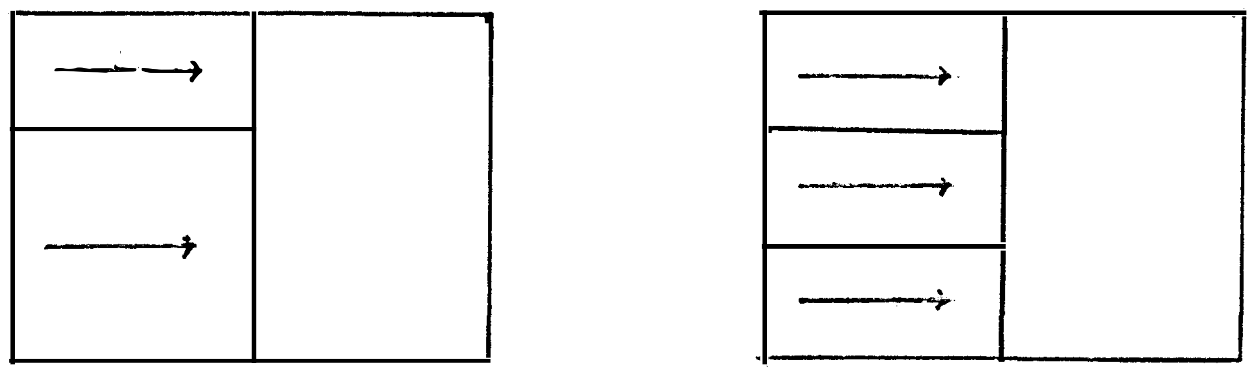
Gibson's (1950) analysis of texture density gradients supports this prediction with respect to texture density since the most distant part of the visual field is associated with the greatest texture density. The perception of relative velocity in terms of motion parallax would place the slowest, rather than the fastest of the moving sections at the greatest depth. Thus, the presence of differences in occlusion rate in stimulus displays introduces a conflict, and no predictions can be made on an a priori basis as to how the observer will perceive depth in terms of this factor. The stimulus displays in Experiment II thus allowed the possible role of occlusion rate in the perception of relative depth to be assessed.

Method

Stimulus Displays

All stimulus displays were essentially the same as those used in Experiment I. These displays consisted of a stationary area and two or three moving sections. The displays were 27.0 cm × 17.5 cm in size. A schematic illustration of the displays is provided in Figure 6.

Two parameters of the stimulus regions were used in the displays: brightness and texture density. The two levels of brightness intensity were 4 ft. cd. and 8 ft. cd.; the two levels of texture density were 1.4 texture units per cm^2 and 0.5 units per cm^2. A texture unit subtended a visual angle of 11.3'. The brightness of the texture units was independent of the number of these units (i.e., density) within a given display area, thus overcoming the main difficulty encountered in



A B

Figure 6. Examples of stimulus displays used in Experiment II.

The stimulus displays had (A) two moving sections or (B) three moving sections. The arrows indicate the moving sections of a display. The remaining sections were stationary.

Experiment I in which the texture units of low texture density level were darker than units of the high texture density level.

There were three levels of velocity of the three moving sections. These velocity values were: Fast (27 cm/sec); Medium (9.6 cm/sec); Slow (5.4 cm/sec). These velocities were chosen so as to be easily discriminable. There was also a fourth condition in which all moving sections moved at 9.6 cm/sec. In stimulus displays with two moving sections, the fast velocity was 33.8 cm/sec, while the slow velocity was 6.8 cm/sec. In the equal velocity condition both sections moved at 6.8 cm/sec.

The two levels of brightness and of texture density resulted in four unique combinations. Brightness was denoted as "B" and texture density as "D," and the two possible levels of each parameter were coded as "1" and "2" for the low and high levels, respectively. Hence, the four combinations of brightness and texture density were: D2B2, D2B1, D1B2, and D1B1. The relative velocity levels are coded as "F," "M," "S" for the fast, medium, and slow velocities. As a result, there were twelve unique combinations of brightness, texture density, and relative velocity levels.

Although the stimulus displays differed in terms of brightness, texture density, and relative velocity, they also differed in two other ways, as illustrated in Figure 7 . The stimulus displays could have either two horizontal sections (Total = 108 displays) or three moving sections (Total = 84 displays). This is shown in Part A of Figure 7. Within the set of displays having three horizontal sections, 12 of the displays contained no motion. The horizontal sections in the

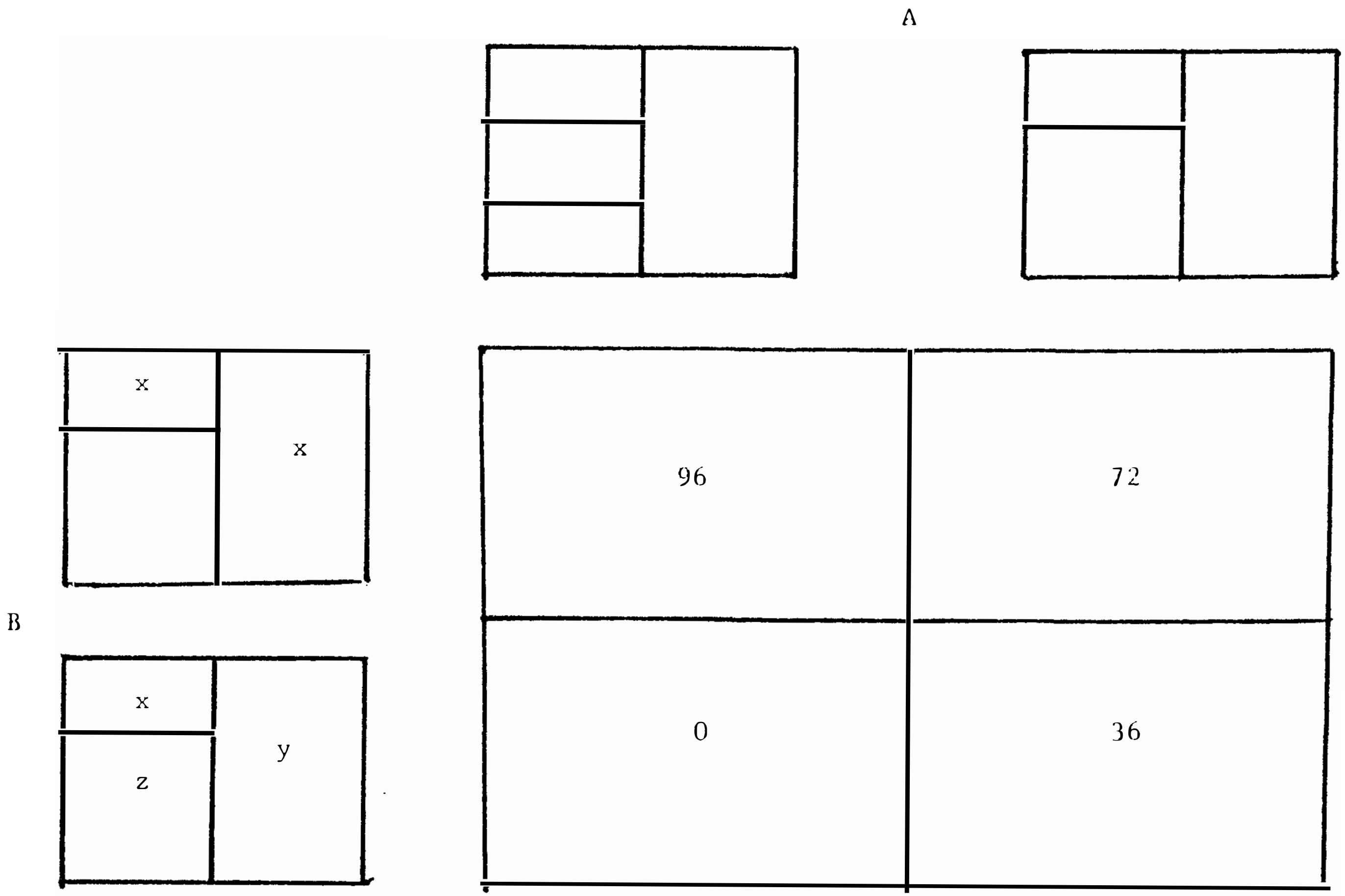


Figure 7. Classification of stimulus displays used in Experiment II.

A. The stimulus display could have either two or three horizontal sections. B. Stimulus displays could have one horizontal section that matched the stationary area in brightness and texture density (X-X), or all parts of the display could have different brightness/texture density combinations (X-Y-Z). The number of displays in each classification is presented.

remaining displays of both groups were continuously moving, as previously illustrated in Figure 6. The second way stimulus displays could differ was in terms of whether one of the horizontal sections matched the stationary area in brightness and/or texture density (see Part B, Figure 7). Most of the displays (168) had one horizontal section with a brightness and texture density combination identical to that of the stationary area. In the remaining displays (36), the brightness and texture density combination for each part of the display was different.

For all displays, the brightness, texture density, and relative velocity levels for the horizontal sections were counterbalanced with respect to vertical position. That is, the vertical position of each horizontal section in a display received each combination of brightness, texture density and relative velocity equally often. In displays in which there was a large and a small moving area, the vertical positions of these two areas was also counterbalanced.

Counterbalancing

There was a total of 204 stimulus displays. Each of the 16 subjects viewed all displays over the course of three experimental sessions of approximately 50 minutes each. The experimental sessions took place on separate days, and subjects viewed about 68 displays at each session. The order of presentation of displays was counterbalanced so that each subject was presented with a different ordering of displays. The counterbalancing scheme was essentially the same as used in Experiment I. The total set of displays was broken into 16 blocks to correspond to the number of subjects. The order of displays within blocks was randomized, and the sequence of blocks was determined by a Greco-Latin Square.

Results

Results of Experiment II will be presented in three parts. The first part will discuss the relative depth of stationary sections. These sections contained brightness and texture density differences, but clearly relative velocity and kinetic occlusion cues were absent. The second part will discuss the perceived depth of moving sections. The third part will discuss the judged depth of the stationary areas relative to the moving sections.

Brightness and Texture Density Differences in Stationary Display Areas

There were twelve stimulus displays in which the three horizontal sections were stationary but contained brightness and texture density differences. These stimulus differences were systematically related to the ordering of the display sections in depth as shown in Table 2. The D2B2 section was perceived as closest and the D1B1 section was seen as the most distant. D1B2 and D2B1 sections were most frequently seen at the intermediate position. To determine whether this spatial ordering of brightness/texture density combinations was consistent across subjects (N = 16), a Friedman two-way analysis of variance was performed. The analysis revealed that subjects consistently rank ordered the brightness/texture density combinations ($X_r^2 = 275.7$, $p < .001$). Hence, these displays showed that brightness and texture density could be effective depth cues independently of relative velocity or kinetic occlusion for all subjects.

TABLE 2

The Perceived Depth of Stationary Display Sections as a Function of Brightness and Texture Density[1]

Brightness and Texture Density	Perceived Depth of Stationary Sections			Total
	Closest	Intermediate	Most Distant	
D1B1	18%	27%	55%	100%
D1B2	32%	35%	33%	100%
D2B1	40%	49%	11%	100%
D2B2	74%	23%	3%	100%

[1]These data represent the grouped responses for 16 subjects who viewed each of the 12 stimulus displays having no moving sections. Total responses = 192.

The Perceived Depth of Moving Display Sections

Moving display sections could differ in brightness, texture density, and relative velocity. The effect of brightness and texture density on judged depth of the moving sections will be presented first. An analysis of the effect of relative velocity will follow.

Displays with three moving sections. Table 3 presents the empirical relationship between values of brightness, texture density, and the perceived ordering of moving display sections in depth. The data in Table 3 apply to displays with three moving sections, allowing three possible depth positions. The D2B2 moving section was placed at the closest depth position, whereas the D1B1 moving section was placed at the most distant depth position. The D1B2 and D2B1 moving sections were typically perceived at the intermediate depth level.

TABLE 3

The Perceived Depth of Moving Display Sections as a Function of Brightness and Texture Density: Displays with Three Moving Sections[1]

Brightness and Texture Density	Perceived Depth of Moving Sections: Closest	Intermediate	Most Distant	Total
D1B1	6%	10%	84%	100%
D1B2	17%	52%	31%	100%
D2B1	30%	58%	12%	100%
D2B2	80%	15%	5%	100%

[1]The data represent the grouped responses for 16 subjects who viewed each of the 84 stimulus displays having three moving sections. Total responses = 1344.

Displays with two moving sections. The same effect of brightness and texture density across response categories could be observed with displays having two moving sections, as shown in Table 4. The D2B2 moving section was perceived as closest, and the D1B1 moving section was perceived as the most distant. The D1B2 and D2B1 moving sections occurred with nearly equal frequency at the closest and most distant depth positions, since an intermediate depth level was not possible with displays having only two moving sections. There was, however, a tendency for the D2B1 moving section to be seen as closest and the D1B2 moving section to be seen as the most distant, but these effects were not strong.

A rank ordering for the perceived depth of the four brightness/texture density combinations was determined for each subject (N = 16).

TABLE 4

The Perceived Depth of Moving Display Sections as a Function of Brightness and Texture Density: Displays with Two Moving Sections[1]

Brightness and Texture Density	Perceived Depth of Moving Sections: Closest	Perceived Depth of Moving Sections: Most Distant	Total
D1B1	14%	86%	100%
D1B2	44%	56%	100%
D2B1	57%	43%	100%
D2B2	85%	15%	100%

[1]These data represent the grouped responses for 16 subjects who viewed each of the 108 stimulus displays having two moving sections. Total responses = 1728.

These rankings were obtained from displays with two and three moving sections (i.e., those represented in Tables 3 and 4). A Friedman two-way analysis of variance showed that subjects consistently ordered the brightness/texture density combinations in depth for both sets of displays ($X_r^2 = 274.7$, $p < .001$).

Relative velocity. The relationship between judged depth of moving display sections and relative velocity is shown in Tables 5 and 6. The data in these tables represent the same set of responses reported in Tables 3 and 4, but reordered in terms of relative velocity.

Unlike brightness and texture density, differences in relative velocity did not consistently affect perceived depth. Reference to Table 5 shows that relative velocity was not systematically related to depth ordering in displays with three moving sections. In displays

TABLE 5

The Perceived Depth of Moving Sections as a Function of Relative Velocity: Displays with Three Moving Sections[1]

Relative Velocity	Perceived Depth of Moving Sections			Total
	Closest	Intermediate	Most Distant	
Fast	32%	35%	34%	100%
Medium	31%	34%	35%	100%
Slow	37%	31%	32%	100%

[1]These data represent the grouped responses for 16 subjects who viewed each of the 84 stimulus displays having three moving sections. Total responses = 1344.

TABLE 6

The Perceived Depth of Moving Sections as a Function of Relative Velocity: Displays with Two Moving Sections[1]

Relative Velocity	Perceived Depth of Moving Sections		Total
	Closest	Most Distant	
Fast	45%	55%	100%
Slow	55%	45%	100%

[1]These data represent the grouped responses for 16 subjects who viewed each of the 108 stimulus displays having two moving sections. Total responses = 1728.

with two moving sections (see Table 6), the slow velocity tended to be perceived as closer and the fast velocity as more distant, but this difference failed to reach statistical significance ($t_{14} = 1.71$, $p > .05$).

Size of Moving Sections

The perceived depth of moving display sections was related to their relative size. In those stimulus displays which contained a size difference between moving sections (size ratio of 2:1), the smaller area was typically seen as closer (53.2%) than the larger area (46.6%). This equal distribution was obtained for all subjects.

Equal Depth

Responses which placed two or more parts of a display at the same depth level were analyzed separately and not included in the data presented thus far. Out of the total number of responses, 13.9% involved equal depth. All three stimulus parameters influenced the perception of the moving sections at the same depth level. The majority of equal judgments were between moving sections of equal velocity (63%). The effect of equal velocity was to localize moving sections at the same depth level in spite of brightness and texture density differences which generally tended to separate the moving sections in depth. In these cases equality of density among the moving sections was critical to judgments of depth. Regions with values of D2B2 and D2B1 were judged at the same depth. Typically, these equal depth regions were seen as passing directly behind the stationary area.

Summary: Perceived Depth of Moving Display Sections

To summarize these results, relative depth among moving sections was based on brightness and texture density values. The D2B2 moving sections were associated with the closest depth position, while the D1B1 moving sections were associated with the most distant depth position. The D1B2 and D2B1 moving sections were placed at the intermediate depth level in displays with three moving sections, and were divided between the far and close positions, respectively, in displays with two moving sections. These outcomes mirror the depth relationships found with stationary patterns.

Relative velocity and the size of moving sections were only slightly related to the perceived depth of the moving sections. Although brightness and density differences tended to place moving sections at different depth, equal velocity acted in the reverse manner to place the sections at the same depth.

The results presented thus far have represented only one facet of perceptual organization: the relative depth of moving sections. A second perceptual operation in these stimulus displays was to integrate the moving sections with the stationary part of the display. In some displays depth cues (kinetic occlusion, brightness, texture density, and relative velocity) gave the observer consistent information about the spatial relationship of moving sections and stationary area, but in most of the displays there were one or more possible conflicts among cues. The goal in the next step of analysis was to discover how subjects resolved the perceptual conflicts inherent in the relationship between the moving and stationary parts of a display.

Individual Differences in Perceptual Organization

The strategy used in the present analysis was to search for response patterns or perceptual strategies which were used for a class of stimulus configurations. Four response categories were found. Each perceptual organization defined the relationship between stationary and moving sections. For example, the property of all moving sections seen in depth behind the stationary area defined occlusion. Responses of this category could differ in terms of the relative ordering of moving sections, but all moving sections were seen as passing behind the stationary display area. Each possible ordering of moving sections defined a particular response within this category. The remaining response categories described other possible depth relationships between the moving sections and stationary area of a display. Like the occlusion category, they defined the common characteristics of a varied set of responses.

The four response categories are illustrated in Figure 8. As previously discussed, the essential feature of occlusion (Category A) was that all moving sections were seen behind the stationary area. The matching response (Category B) placed one of the moving sections at the same depth as the stationary area, while the other moving sections in the matching category were seen in front or behind the stationary area. The moving sections in the reverse occlusion category (Category C) were all located in front of the stationary area, i.e., the exact opposite spatial ordering obtained with occlusion. Intermediate occlusion (Category D) represented a compromise between occlusion and reverse occlusion. At least one moving section was placed in front of the

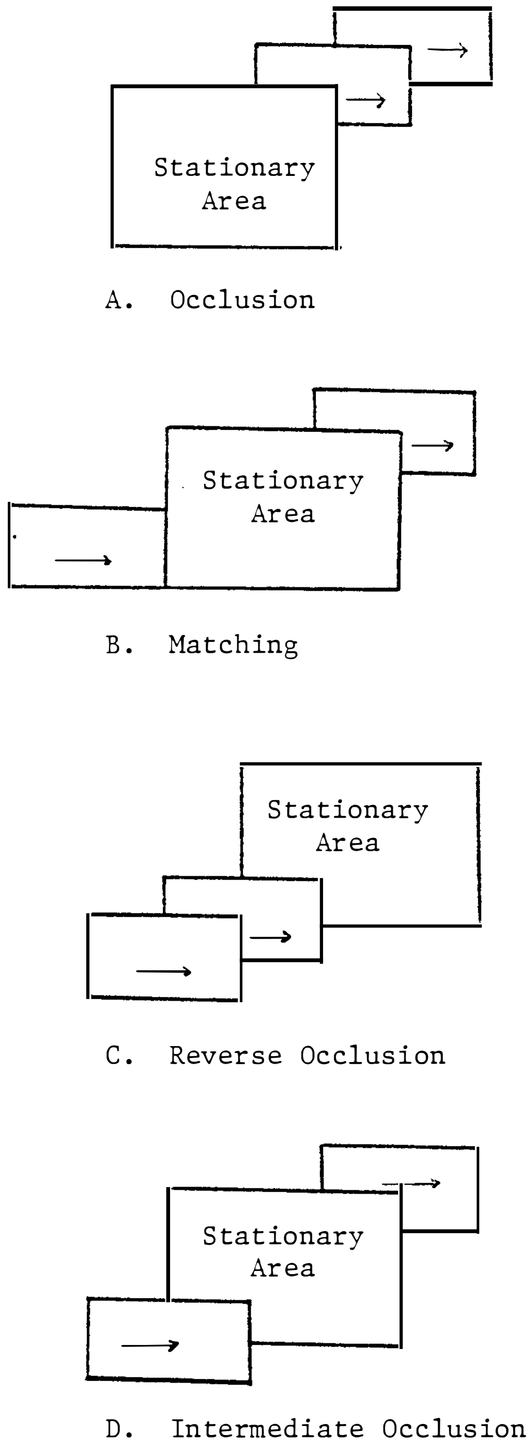


Figure 8. Examples of the response categories used by subjects in Experiment II.

The arrows indicate the moving sections of a display.

stationary area, and at least one moving section was placed behind the stationary area in the intermediate occlusion category. All of the subjects' depth judgments were described by these four response categories.

The subjects were grouped together on the basis of common response patterns. There were five groups of subjects, and they are shown in Table 7 along with the percentage of occlusion, matching, intermediate occlusion, and reverse occlusion for each subject. The numbers in parentheses below each of the response category headings in Table 7 represent the number of different responses possible within each category.

For all but one subject, the highest percentage of responses were in the occlusion category. One group of subjects (Table 7, Group I) used occlusion almost exclusively. Group II, which consisted of a single individual, was characterized by a majority of responses in the matching category. The remaining three groups (Groups III-V) differed in the percentage of matching and intermediate occlusion responses. There were more matching than intermediate occlusion responses in Group III, but in Group IV this relationship was reversed, i.e., intermediate occlusion responses were more frequent than matching responses. The fifth group of subjects used matching and intermediate occlusion with nearly equal frequency. Hence, there was a higher percentage of intermediate occlusion responses in Group V than in Group III, and there was a higher percentage of matching responses in Group V than in Group IV.

TABLE 7

Subject Grouping by the Percentage of Responses Occurring in Each of the Four Major Response Categories[1]

Dominant Response	Group	Subject		Response Category: Occlusion (6)	Matching (18)	Intermediate Occlusion (6)	Reverse Occlusion (6)
Occlusion	I	1		92%	1%	7%	0%
		2		100%	0%	0%	0%
		3		98%	0%	2%	0%
		4		100%	0%	0%	0%
		5		100%	0%	0%	0%
			$\overline{X}$	98%	0%	2%	0%
Matching	II	6		14%	78%	8%	0%
Occlusion and Matching	III	7		58%	27%	12%	3%
		8		41%	38%	15%	6%
		9		74%	25%	1%	0%
			$\overline{X}$	58%	30%	9%	3%
Occlusion and Inter-mediate Occlusion	IV	10		45%	3%	44%	8%
		11		66%	1%	26%	7%
		12		78%	5%	15%	2%
			$\overline{X}$	63%	3%	28%	6%
Occlusion, Matching, and Inter-mediate Occlusion	V	13		60%	20%	16%	4%
		14		39%	32%	23%	6%
		15		47%	23%	24%	6%
		16		52%	22%	23%	3%
			$\overline{X}$	50%	24%	21%	5%

[1]The data represent the responses of 16 subjects who viewed each of 192 stimulus displays. Total response = 3072. The data for stimulus displays containing no motion (12) was not included.

Subjects within each of the groupings were highly similar in their pattern of responding. A Kendall coefficient of concordance was determined for each grouping, and as Table 8 shows, all concordance measures were statistically significant.

TABLE 8

The Kendall Coefficient of Concordance for Each of the Five Subject Groupings

Subject Groups	Kendall Coefficient of Concordance
Group I	.89[1]
Group II	*
Group III	1.0[1]
Group IV	.91[1]
Group V	.92[1]

[1]Significant at $p < .01$

*There was only one subject in this group; thus a measure of concordance is pointless.

Response Categories

Each of the four major response categories specified a unique relationship between the perceived position of the stationary area of a display relative to the moving sections. The response categories represented the joint effect of individual perceptual strategies and the stimulus properties--brightness and texture density--of the stationary area. This interaction will be discussed separately for each response category.

Occlusion. The occlusion response was defined by the stationary part of the display being perceived as closest; the ordering of the moving sections behind the stationary area was not relevant. The brightness and texture density of the stationary area was related to the likelihood that an occlusion response would occur. For displays with two and three moving sections, the percentage of occlusion responses as a function of brightness and texture density was: D2B2 (31.5%), D2B1 (26.4%), D1B2 (22.9%), D1B1 (19.2%). The results corroborated the findings obtained with brightness and texture density of moving sections, viz., the brighter and more dense part of a display tended to be seen as closest.

Matching. Matching responses were defined by one of the moving sections being seen at the same level of depth as the stationary area. The other moving section or sections could be located in front or behind the moving section/stationary area pair (the patching pair). Part A of Figure 9 illustrates the two possible depth orderings in displays with two moving sections; the matching pair could be perceived in front of the other moving section, or behind it. For displays with three moving sections, there were three possible depth levels, and the matching pair could be perceived at any of these positions (see Part B, Figure 9).

Matching occurred when the stationary area matched the brightness and texture density of one of the moving sections (90.8%). Brightness and texture density determined the judged depth. These effects were highly similar to those found for the moving sections in

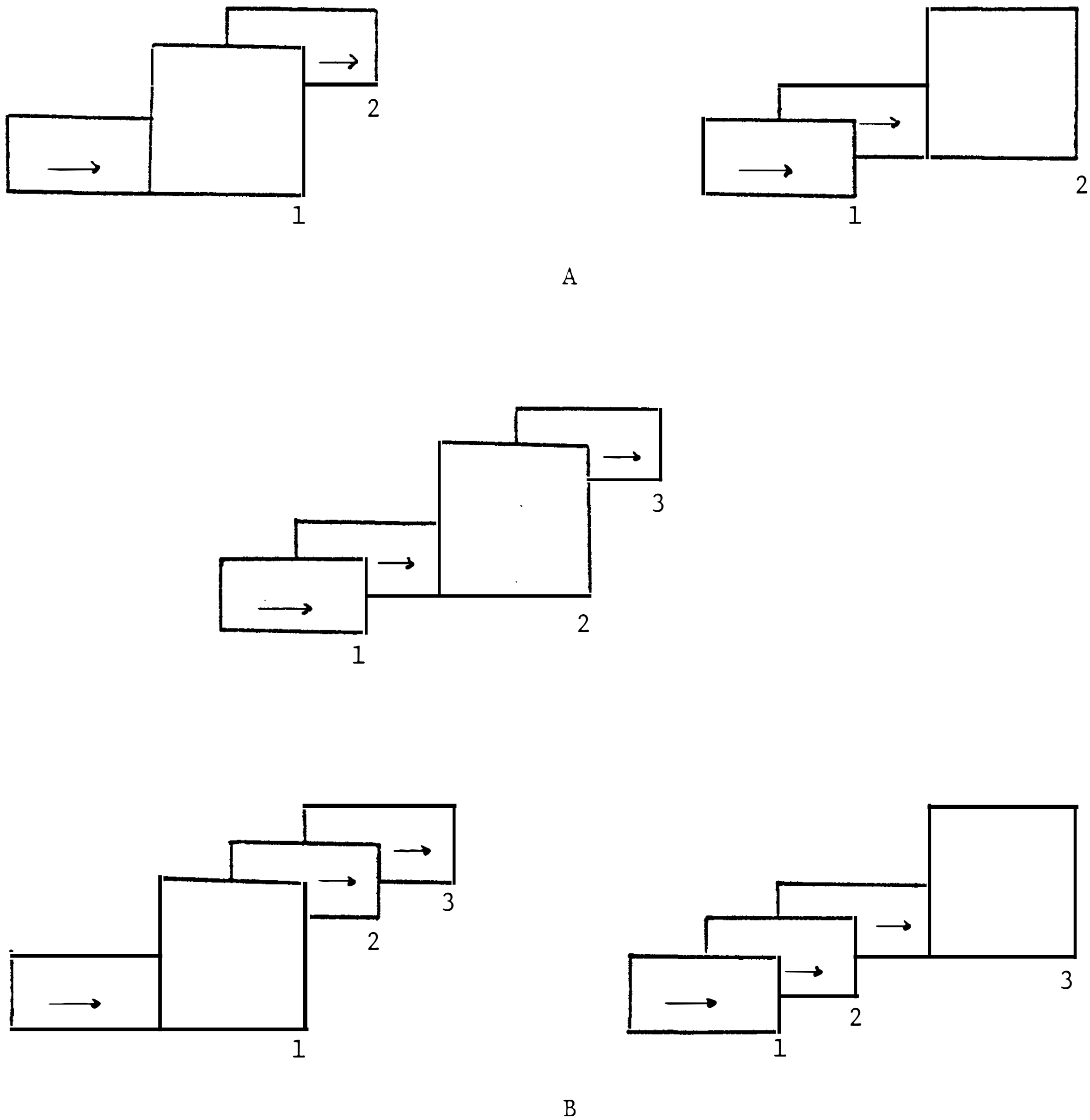


Figure 9. The possible depth positions of the matching pair.

The depth positions are given for displays with (A) two moving sections and (B) three moving sections. Arrows indicate the moving sections of a display. Relative depth is coded as: 1 = closest; 2 = second closest; 3 = third closest.

all response categories. Tables 9 and 10 show that the D2B2 matching pair was seen as closest and the D1B1 matching pair was seen as the most distant. The D1B2 and D2B1 matching pairs were associated with the intermediate depth level of the matching pair displays having three moving sections. In displays having two moving sections, the D1B2 and D2B1 matching pairs were typically seen in the close position.

TABLE 9

The Perceived Depth of the Matching Pair as a Function of Brightness and Texture Density: Displays with Three Moving Sections[1]

Brightness and Texture Density	Percent of Matching Response	Perceived Depth of Matching Pair			Total
		Closest	Intermediate	Most Distant	
D1B1	26%	12%	11%	77%	100%
D1B2	30%	35%	51%	14%	100%
D2B1	21%	33%	56%	11%	100%
D2B2	23%	98%	2%	0%	100%
	$\bar{X}$	44%	30%	26%	

[1]The data represent the grouped responses of 16 subjects. Total responses = 218.

TABLE 10

The Perceived Depth of the Matching Pair as a Function of Brightness and Texture Density: Displays with Two Moving Sections[1]

Brightness and Texture Density	Percent of Matching Responses		Perceived Depth of Matching Pair: Closest	Perceived Depth of Matching Pair: Most Distant	Total
D1B1	27%		15%	85%	100%
D1B2	30%		57%	43%	100%
D2B1	23%		71%	29%	100%
D2B2	20%		100%	0%	100%
		$\bar{X}$	61%	39%	

[1]The data represent the grouped responses of 16 subjects. Total responses = 181.

Relative velocity was important in determining which of the moving sections would be paired with the stationary area in depth (i.e., form the matching pair). Reference to Table 11 shows that the largest proportion of matching responses were formed with the slow moving section in displays with two or three moving sections. However, Table 11 also shows that each level of relative velocity was associated with the possible depth positions of the matching pair in the same way. That is, the matching pair was placed at the closest position in depth most frequently and placed at the most distant position least frequently for all velocity values.

TABLE 11

The Perceived Depth of the Matching Pair as a Function of the Relative Velocity of the Moving Section of the Matching Pair[1]

Displays with Three Moving Sections

Relative Velocity	Percentage of Responses in All Response Categories Except Matching	Depth of Matching Pair: Closest	Depth of Matching Pair: Intermediate	Depth of Matching Pair: Most Distant	Total
Fast	90%	4%	4%	2%	100%
Medium	85%	7%	4%	4%	100%
Slow	82%	8%	6%	4%	100%

Displays with Two Moving Sections

Relative Velocity	All Response Categories Except Matching	Depth of Matching Pair: Closest	Depth of Matching Pair: Most Distant	Total
Fast	93%	5%	2%	100%
Slow	90%	6%	4%	100%

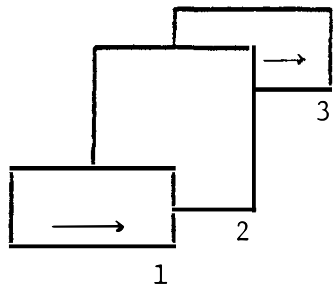
[1]The data represent the grouped responses of 16 subjects. The total number of matching responses for displays with three moving sections was 218; for displays with two moving sections, the total number of matching responses was 181.

Intermediate Occlusion. The intermediate occlusion category was not used exclusively by any subject. Instead, it occurred as an alternate response by subjects who also used occlusion or matching. The displays which elicited intermediate occlusion typically had a D1B1 or D1B2 stationary area.

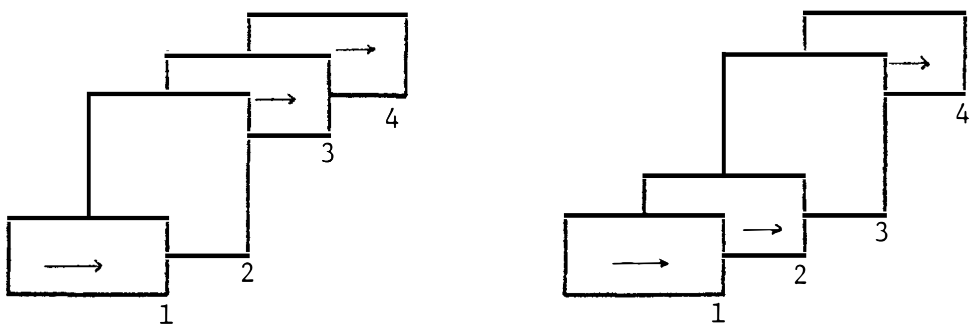
Intermediate occlusion represented a solution to a perceptual conflict. Kinetic occlusion acted to place the stationary area as the closest part of the display, but the D1B1 or D1B2 values acted to place it in the most distant position. Subjects resolved this conflict by placing one of the moving sections (usually D1B1) behind the stationary area and the remaining moving sections (usually D2B2 or D2B1) in front.

There were two major features of intermediate occlusion which distinguished it from matching or occlusion: 1) at least one moving section was localized as closer in depth than the stationary area, and at least one moving section was judged as more distant than the stationary area; 2) none of the moving sections matched the stationary area in depth. As a result, the stationary area in displays with two moving sections was always in the intermediate depth position (i.e., one moving section in front and one in back). This relationship is schematically illustrated in Part A of Figure 10. There are two possible depth locations of the stationary area in displays with three moving sections. The stationary area can be either second closest or third closest out of a total of four depth positions. Part B of Figure 10 schematically illustrates these possibilities.

For displays with two moving sections, the percentage of intermediate occlusion responses as a function of the brightness and texture density of the stationary area was: D1B1 (48.8), D1B2 (29.8), D2B1 (11.9), D2B2 (9.5). This stationary area was always seen at the intermediate depth position. In displays with three moving sections, intermediate occlusion occurred with either a D1B1 or a D1B2



A.



B.

Figure 10. The possible depth positions of the stationary area in the intermediate occlusion category.

The depth positions are given for displays with (A) two moving sections and for displays with (B) three moving sections. Arrows indicate the moving sections of a display. Relative depth is coded as: 1 = closest; 2 = second closest; 3 = third closest; 4 = fourth closest.

stationary area. Here, the D1B2 stationary area was typically seen at a closer position than the D1B1 stationary area (see Table 12).

TABLE 12

The Perceived Depth of the Stationary Area as a Function of Brightness and Texture Density[1]

Brightness and Texture Density	Perceived Depth of the Stationary Area: Second Closest	Third Closest	Total
D1B1	42%	58%	100%
D1B2	78%	22%	100%
D2B1	83%	17%	100%
D2B2	*	*	0%

[1]The data represent the total number of intermediate occlusion responses occurring with displays having three moving sections. Total responses = 121.

*Virtually no responses occurred for this value of brightness and texture density.

Reverse Occlusion. Compared to the other organization categories, reverse occlusion occurred infrequently (Total responses = 51). There were 36 displays in which none of the display sections, moving or stationary, had the same brightness and texture density combination, and reverse occlusion responses were confined to this set of displays. Within this group of displays, only those whose stationary area had a brightness and texture density of D1B1 typically produced reverse occlusion. The percentage of reverse occlusion responses as a function of brightness and texture density of the stationary area was: D1B1 (68.7%), D1B2 (17.6%), D2B1 (9.8%), D2B2 (3.9%).

Discussion

There were two principal features of perceptual organization in the stimulus displays of Experiment II. The first concerned the depth of moving display sections relative to each other. The second feature of perceptual organization was the depth of the stationary area in relation to the moving sections. The perceived depth of the moving sections was systematically related to brightness and texture density, and subjects were generally in agreement as to the depth of the moving sections. In contrast, differences among subjects occurred for the judged depth of the stationary area relative to the moving sections.

The emergence of individual response strategies appeared to depend on multiple sources of information about relative depth that were not entirely compatible. There were four primary conditions relevant to perceived depth: brightness, texture density, relative velocity, and kinetic occlusion. This great number of cues was important, since individual differences were not observed with displays containing only brightness and kinetic occlusion as in Experiment I. A second critical factor was the presence of some ambiguity or incompatibility among stimuli. These conflicts were based on the relationship of kinetic occlusion to the other stimulus parameters. For example, there was a tendency for the moving section and stationary area which both had maximal brightness and texture density values (D2B2) to be placed at the same depth level (i.e., matching). This conflicted with information from kinetic occlusion specifying the stationary area as closer than the moving sections. Another instance of perceptual conflict occurred between kinetic occlusion and the minimal values of brightness and texture density (D1B1). When the stationary area was relatively dim and sparsely textured, this produced a tendency for it to be seen as more distant than the brighter and more densely textured moving sections. Again, a conflict was produced with kinetic occlusion information which specified the stationary area as the closest part of the display.

The data from Experiment II illustrate the economy and flexibility of perceptual organization. Subjects were consistent in their response to stimulus parameters as long as no conflict occurred. When perceptual conflicts did arise, they produced individual differences among subjects only with regard to the area of the display producing the conflict; the remaining, conflict-free areas were not affected. Furthermore, when stimulus conditions of the display changed, individual response strategies also shifted. For example, intermediate occlusion was frequently used in displays having a moving section and stationary area which both had a brightness and texture density of D1B1. In some displays, only the stationary area had a brightness and texture density combination of D1B1; the moving sections had different values of brightness and/or texture density. In these displays, reverse occlusion, rather than intermediate occlusion, emerged as a predominant response strategy.

The results of Experiment II are also pertinent to the role of occlusion rate (accretion or deletion of texture units) in relative depth ordering. Kaplan (1969) has suggested that occlusion rate should be positively related to perceived depth. On the basis of Kaplan's conjecture, the part of a display with the highest occlusion rate would be predicted to be seen in greater depth than an area with a lower occlusion rate. Two means of producing differences in occlusion rate were used in Experiment II: texture density and relative velocity. If perceived depth were solely a function of occlusion rate, the area of display with the fastest relative velocity and the highest texture density would be perceived as the most distant part of the display. This prediction is based on the fact that the faster and more densely textured display area will have its texture units occluded at the fastest rate.

The data did not support the predicted effect of occlusion rate. The high value of texture density was associated with the closest position in depth, rather than the most distant. Furthermore, the fastest velocity was not strongly associated with perceived depth. Hence, occlusion rate, as determined by texture density and relative velocity, did not appear to be a salient factor.

CHAPTER V

CONCLUSIONS

The environment provides the observer with a complex pattern of visual stimulation. This visual pattern contains multiple cues for the perception of the three-dimensional shape of objects and their positions in depth. In some instances the cues will be mutually compatible, but in other instances they will be in conflict. What principles govern the observer's response to multiple depth cues and the conflicts that can occur between them? As an exploration of this question, two experiments were conducted which examined four depth cues: kinetic occlusion, brightness, texture density, and relative velocity.

The first experiment combined kinetic occlusion with brightness or texture density. Here, kinetic occlusion was the dominant cue. Irrespective of the brightness or texture density of the moving or stationary sections of visual displays, moving sections were seen as passing behind, and thus continuously occluded by, the stationary section. The effect of brightness or texture density was to vary the relative depth ordering of the moving sections passing behind the stationary section, although the ordering of moving sections in depth was not strongly consistent. These results showed how a dominant and a nondominant cue can interact. The overall perceptual organization was dominated by kinetic occlusion: the moving sections were seen as more distant than the stationary section. The only part of perceptual organization not specified by kinetic occlusion was the ordering of moving sections relative to each other, and the effect of brightness or texture density, as the nondominant cue, was confined to this part of the perceptual organization.

The second experiment simultaneously combined brightness, texture density, and relative velocity with kinetic occlusion. No single depth cue exclusively determined the perceived depth of all parts of the stimulus displays. The relative depth ordering of moving sections was dependent on brightness and texture density, and relative velocity did not exert a systematic effect on perceived depth. Although subjects were consistent in their judgments of the moving sections, individual differences among subjects emerged in the judged depth of the stationary section. These individual differences represented solutions to perceptual conflicts resulting from the tendency of kinetic occlusion to place the stationary area as closest and brightness/texture density combinations which tended to vary the depth of the stationary section.

Conflicts between depth cues were of two main types. In the first case, one moving section and the stationary section had the highest values of brightness and texture density which acted to place them both at the closest depth position; this conflicted with kinetic occlusion which specifies the stationary section as closest. In the second case, the moving sections had higher values of brightness and texture density than the stationary area. The tendency to place the stationary area as more distant than the moving sections on the basis of brightness and texture density conflicted with kinetic occlusion. Subjects developed perceptual strategies to resolve these conflicts. Some subjects employed the same perceptual strategy throughout all the displays, while others modified their response strategy to resolve the different perceptual conflicts.

Results of Experiment II suggest two principles of perceptual organization. When depth cues were compatible, they systematically influenced perceived depth. This was illustrated in the relative depth ordering of the moving sections. When cues were incompatible and no single cue was dominant, perceived depth was not solely a function of stimuli; individual perceptual strategies emerged as critical. These perceptual strategies were reflected in the judged depth of the stationary area.

The interaction of depth cues is relevant to any theory of depth perception. Constructivist theories such as those of Helmholtz, Brunswik, and Ames have emphasized the observer's role in the integration of depth cues. According to these theories, the distance of objects from the observer is not uniquely specified by visual stimuli. That is, the same visual pattern can be caused by any one of an infinite number of physical objects of varying size, distance, or orientation. In essence, the observer must construct the three-dimensional world by integrating the available depth cues to form a "best guess" about the actual depth of objects. The way in which the observer integrates multiple depth cues is considered to be a function of perceptual strategies that have been successful in the past.

In contrast, Gibson (1979) has proposed an alternate analysis of visual stimuli as invariant patterns which uniquely specify the depth of objects. The invariants include texture density gradients, kinetic occlusion, and motion perspective. Gibson does not emphasize the interaction of depth cues; instead, he proposes that the observer becomes perceptually "attuned" to invariants of visual stimulation. The task of the observer is not to make a best guess on the basis of inherently ambiguous stimuli, but to respond to invariant stimulus patterns that correspond to the three-dimensional layout of the environment.

The results of the present study of multiple depth cues are pertinent to both Gibson's theory and the constructivists' theories. In the first experiment the observers were able to respond to the invariant pattern of kinetic occlusion without competitive interference from brightness or texture density differences. This result was compatible with Gibson's theory and potentially, with constructivist theories, since most observers have had extensive experience with occlusion relationships. When the number of depth cues was increased in the second experiment, more than one possible depth ordering could be perceived. Under these circumstances, the observers relied on perceptual strategies to select among the competing alternative organizations. The appearance of individual response strategies was consistent with constructivist theories of perception, but whether such individual differences would be compatible with Gibson's theory is unclear.

The central tenet of Gibson's theory is that perception is a process of responding to invariant patterns of visual stimulation (e.g., Gibson, 1979). The invariant properties of the environment are systematically related to invariant visual patterns by the laws of projective geometry. The changeable aspects of the environment correspond to various transformations of the stimulus invariances. Hence, the relationships among parts of the environment are preserved in the structure or patterning of the optic array. In this way, an observer can directly and veridically perceive the physical layout of the environment. Furthermore, different perspective views of the environment do not alter the optical information for its layout. Therefore, two or more observers at different physical locations can agree in their perception of the environment.

Since Gibson's theory emphasizes invariant stimulus relationships, how, then, does it account for individual differences in perception? Gibson proposes that individual differences can be understood in terms of 1) the process of differentiation in perceptual learning and 2) the concept of affordances.

All but the simplest environments produce a complex structuring of the optic array. The structure of the optic array contains a vast amount of potential information about the environment. In order to actually use this information the observer must be able to differentiate among the many patterns simultaneously present in the optic array. For example, an experienced hunter can detect a camouflaged animal more often than a novice hunter who has not yet learned to reliably differentiate the animal's form from the surroundings. More generally, observers can differ in what information they have learned to select out of the potential information available. This forms one basis for individual differences in perception within the context of Gibson's theory.

A second way that individual differences enter into Gibson's theory is through the concept of affordances. Just as the size or shape of an object can be specified in the optic array, the potential use of an object can also be specified. The meaning or use specified by an affordance consists of the possibilities of interaction between an individual and the environment. For example, an object is graspable if its size is not too large or small relative to an individual's hand. An object that can be easily held in an adult's hand may not afford this possibility to a small child. Perceiving the affordance of "graspableness" implies that an observer perceive the size of an object in the context of his or her own physical capabilities. Hence, differences in how individuals can interact with the environment are intergally related to differences in the perceived affordances of the environment.

Gibson's theory of visual perception provides a general basis for further study of individual differences. For example, a complex stimulus display may elicit different perceptual judgments because subjects are sensitive to different sources of information in the display. One question to pursue is whether these differences in sensitivity could be altered by selective exposure to one stimulus parameter prior to judgments of a stimulus display containing several parameters in combination. A second question concerns the level of stimulus complexity at which individual differences emerge. The degree of similarity among subject judgments could be measured throughout a series of stimulus displays in which the number of stimulus parameters was varied. In this way, the emergence of individual differences among subjects could be related to a scale of stimulus complexity as measured by the number of parameters in a display.

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APPENDICES

APPENDIX A

JUDGMENTS OF THE CLOSEST MOVING SECTION AS A

FUNCTION OF BRIGHTNESS AND TEXTURE DENSITY[1]

Subjects	Brightness and Texture Density D1B1	D1B2	D2B1	D2B2	Total
1	19	74	108	156	357
2	64	73	117	106	360
3	25	59	127	150	361
4	18	102	79	164	363
5	20	50	130	159	359
6	60	83	102	113	358
7	19	72	104	162	357
8	13	74	111	164	362
9	56	80	104	114	354
10	20	72	114	154	360
11	8	66	115	176	365
12	14	99	93	155	361
13	6	78	110	164	358
14	66	76	108	109	359
15	0	103	78	183	364
16	12	87	94	169	362
TOTAL	420	1248	1694	2398	5760

[1]The data were obtained from a paired comparisons analysis of the judged depth of moving display sections. The judged depth of each moving section was compared to the other moving sections in a display. This resulted in one comparison for displays with two moving sections, and three comparisons for displays with three moving sections. The number of times each brightness/texture density combination was seen as closest in a paired comparison was obtained for each subject and is presented in the body of the table. The data for two and three moving section displays were combined.

APPENDIX B

JUDGMENTS OF THE CLOSEST MOVING SECTION AS A FUNCTION OF RELATIVE VELOCITY: DISPLAYS WITH THREE MOVING SECTIONS[1]

Subjects	Relative Velocity			Total
	Slow	Medium	Fast	
1	70	69	76	215
2	78	64	74	216
3	82	82	61	225
4	75	76	76	227
5	72	72	72	216
6	103	58	66	227
7	76	73	77	226
8	79	70	66	215
9	74	50	100	224
10	66	67	88	221
11	75	70	71	216
12	79	82	61	222
13	80	76	64	220
14	77	59	80	216
15	77	66	72	215
16	74	72	69	215
TOTAL	1237	1106	1173	3516

[1]The data were obtained from a paired comparisons analysis of the judged depth of moving display sections. The judged depth of each moving section was compared to the other moving sections in a display. This resulted in three comparisons for displays having three moving sections. The number of times each relative velocity level was seen as closest in a paired comparison was obtained for each subject and is presented in the body of the table. The data apply to displays with three moving sections.

APPENDIX C

JUDGMENTS OF THE CLOSEST MOVING SECTION AS A FUNCTION OF RELATIVE VELOCITY: DISPLAYS WITH TWO MOVING SECTIONS[1]

Subjects	Relative Velocity Slow	Relative Velocity Fast	Total
1	35	36	71
2	49	23	72
3	43	29	72
4	36	36	72
5	40	32	72
6	44	28	72
7	36	35	71
8	43	28	71
9	35	36	71
10	26	46	72
11	36	36	72
12	50	22	72
13	42	29	71
14	41	31	72
15	37	34	71
16	39	32	71
TOTAL	632	513	1145

[1] The data were obtained from a paired comparisons analysis of the judged depth of moving display sections. The judged depth of each moving section was compared to the other moving sections in a display. This resulted in one comparison for each display having two moving sections. The number of times each relative velocity level was seen as closest in a paired comparison was obtained for each subject and is presented in the body of the table. The data apply to displays with two moving sections.

VITA

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