THE PERCEIVED SIZE OF AFTERIMAGES IN TWO-DIMENSIONAL PICTORIAL ARRAYS

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B.S., Kansas State University, 1984

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Psychology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1987

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The issue of size constancy and the investigation of the relationship between perceived distance and perceived size of an object have been continuing interests in the field of visual perception. Edwards & Boring (1951) define size constancy as operating when "The apparent size of an object is proportional to its physical size and is independent of the distance at which it is seen, provided the physical size of the object does not change with distance" (p.416). In other words, an object of constant distal (physical) size is perceived as being the same size regardless of viewing distance, even though the proximal size of the image on the retina varies with distance.

The perceived size of an object is derived primarily from two factors, the distance to the object and the visual angle subtended by the object. This relationship is often expressed as the Size-Distance Invariance Hypothesis, such that Perceived Size = Visual Angle X Distance (Rock, 1975, p.33). Visual angle (which is the angle subtended by the projection of the object onto the retina, or, the "proximal" size) can be assessed accurately, at least in theory, by the brain in terms of the number of retinal cells that are affected by the object's projection. Distance, on the other hand, is not always assessed accurately by the brain, but is rather deduced from a wide variety of cues for depth, including the observer's own expectations of how far away an object is. Thus it is appropriate to speak of a physical distance of an object and also a perceived distance of an object, because the two are generally not the same. The physical distance of an object can be accurately assessed with objective measurement, but the perceived distance of an object is assessed by the brain's perceptual systems. It is the perceived distance, not necessarily the physical distance, which, when multiplied by the visual angle, would result in the quantity known as perceived size, according to he Size-Distance Invarance Hypothesis. It might also be said that physical distance, when multiplied by visual angle, results in a quantity called physical size.

Algebraically, the Size-Distance Invariance Hypothesis can be expressed two ways: (1) AS=ADxVA, where AS is apparent size resulting from the multiplication of apparent distance (AD) and visual angle (VA); and (2) PS=PDxVA, where PS is physical size resulting from the multiplication of physical distance (PD) and visual angle (VA). For a stationary object viewed by a stationary observer, the visual angle quantity (VA) is a constant. Therefore, so long as the apparent viewing distance remains approximately equal to the physical viewing distance, the apparent size of an object will remain approximately equal to the physical size of the object and size constancy will be maintained. However, if the apparent viewing distance is highly discrepant from the physical viewing distance, the apparent size of the object will also be highly discrepant from the physical size of the object and size constancy will not be maintained. For example, an observer who overestimates the length of a room will judge objects at the end of the room to be larger than they actually are. From this discussion, it can be seen that size constancy is maintained when apparent size approximately matches physical size, which is the same as saying that size constancy is maintained when apparent distance approximately matches physical distance (so long as visual angle remains a constant, that is).

For a moving object or a moving observer, the visual angle of the object varies inversely with its physical distance, which allows the perceived size of an object to remain constant over a wide range of perceived distances. However, the same is not true regarding the perception of the size of afterimages. The proximal size of an afterimage remains fixed on the retina, and therefore the size of the visual angle subtended by the afterimage remains constant regardless of distance. Simple algebraic manipulations of the parameters of the Size-Distance Invariance Hypothesis will show that perceived size must then vary directly with distance when visual angle is held constant. As Crookes (1959) has noted, "for an afterimage to follow size constancy, its perceived size must increase with increasing distance to the projection surface."

Again, differences can be noted between the physical distance and the perceived distance of the projection surface. It follows that size constancy is maintained only when the two distance quantities remain approximately equal, as with "full cue" viewing conditions of real objects. With afterimages, the process involved with size constancy would be operating when perceived distance increases at approximately the same rate as physical distance such that the quantity "perceived size" (visual angle x perceived distance) remains approximately equal to the quantity "physical size" (visual angle x physical distance).

This formulation satisfies the requirements of size constancy, although the "physical size" of an afterimage does not in fact refer to any distal qualities of the afterimage "out there", but rather to the quantity determined by "visual angle x physical distance". The "physical size" of an afterimage can also be thought to refer to the physical size of the afterimage's _projection_ if it were measured in terms of the physical area occluded on the surface on which it is being projected, exactly as if the afterimage were "painted" on that surface. The "physical size" of an afterimage _can_ be measured by having subjects bracket the image with spotlights on the projection surface, and subsequently measuring the distance between the spotlights.

The relationship between physical distance and the physical size of an area occluded by an afterimage is stated as "Euclid's ocular geometry" by Edwards & Boring (1951) in the following terms: "The physical size of an afterimage is proportional to the distance of the surface on which it is projected, provided the size of the retinal image remains constant" (p.417). A parallel formulation of Euclid's ocular geometry is known as Emmert's law, which holds that "The apparent size of an afterimage is proportional to the distance of the surface on which it is projected, provided the size of the retinal image remains constant" (Edwards & Boring, 1951, p.417).

While Emmert's law and Euclid's ocular geometry at first appear to be stating the same thing, we have seen that physical size need not be the same as apparent size when there is a breakdown of size constancy. Various studies have borne out this observation. Helson (1936) used reduction conditions to show that when cues to distance and surroundings are eliminated, the apparent size of an afterimage (measured by comparison to an observer-adjusted standard) remains practically constant over a range of distances. This would be expected, since under the condition of reduced distance cues, apparent distance would remain approximately the same over a range of actual physical distances. And, as we have already mentioned, the Size-Distance Invariance Hypothesis predicts a constant perceived size with a constant apparent distance when the size of the visual angle remains the same as it does for an afterimage. At the same time, Helson found that the physical size of the area occluded by the projected image (measured on the projection surface by a bracketing procedure) tends to obey Euclid's ocular geometry, growing larger at greater distances. Thus there is a separation between the apparent size of the afterimage and its physical size (or the physical size of the area occluded by the afterimage), which can be traced to differences between apparent distance and physical distance. The physical distance to the projection surface increased, producing corresponding increases in the physical size of the area occluded by the afterimage measured on the projection surface, in accordance with Euclid's ocular geometry. But because of the reduction conditions employed, apparent distance did not fluctuate as did physical distance, and so the apparent size of the afterimage did not fluctuate.

The converse of Helson's findings have also been obtained. Frank (1923) found that afterimages projected onto different planes in a perspective drawing of a tunnel changed apparent size in the way that would be expected if the afterimages were projected onto planes of different distances in an actual (3-dimensional) tunnel. Afterimages projected "deep" into the tunnel appeared larger than afterimages projected nearer in the tunnel. Thus, while Helson found that the _physical_ size of an afterimage (the size of the area occluded by he afterimage) could vary with physical distance, even when the apparent size and the apparent distance remained constant, Frank found that the _apparent_ size of an afterimage could vary with apparent distance, even when the physical size of the occluded area and the physical distance to the projection surface remained constant. Both findings represent breakdowns in the operation of size constancy. As we have seen, size constancy is maintained when the apparent size of an object or afterimage remains approximately equal to its physical size. Both Helson and Frank produced conditions in which the apparent size and the physical size of the afterimages did *not* remain approximately equal.

Other attempts have been made to break down size constancy through changing the cues for apparent distance. Ittleson (1952, pp. 32-33) has provided an Ames-like demonstration in which changes in apparent distance are effected by the manipulation of interposition cues, yielding proportional changes in the apparent size of the afterimage.

Young (1952), following the lead of Frank (1923), tried to induce changes in the apparent size of an afterimage by having subjects project the images onto various positions on 2-dimensional slide projections of actual scenes. He compared the subjects' magnitude estimations of the afterimage projected onto the slide to the subjects' previously obtained magnitude estimations of the afterimage projected onto the same region of a blank screen. While he did obtain significant differences in the apparent sizes of the afterimages, the differences did not occur in systematic or predictable ways. In some cases, afterimages projected to "distant" parts of the slide appeared _smaller_ than when projected onto the blank screen, which was contrary to the prediction of Emmert's law. It might be argued, however, that since Young obtained magnitude estimations of the afterimage on the blank screen first, the subjects' cognitive realization of the physical distance to the screen interfered with their being able to perceive differential distances to points on the slide. Another drawback to his study might have been that two subjects, the number used by Young, were simply not enough for reliable effects to become apparent because of the variance caused by individual differences.

The present set of experiments represent an attempt to clarify some of the issues raised by these earlier findings, and explore some of the situations in which the apparent sizes of afterimages do not follow size constancy. The main experimental hypothesis is that pictorial cues for depth, as presented in slides with strong linear perspective, can evoke differences in apparent distance strong enough to produce proportional changes in the apparent size of an afterimage, in accordance with Emmert's law. Secondarily, these experiments are designed to explore the extent to which cognitive expectations about distance may produce changes in apparent distance, and hence, changes in the apparent size of an afterimage.

Hastorf (1950) reported that when subjects knew neither physical size nor physical distance of an object (as in reduced cue viewing conditions), a suggestion of relative size (such as the introduction of a familiar object into the field of view) was enough to fix distance in the minds of the observers. In the present study, it was hoped that the converse would hold true. The present experiments investigated whether a suggestion of distance (as provided by pictorial cues for depth) would be enough to fix a perception of size in the observers' minds.

Finally, the operation of scaling mechanisms in the determination of apparent depth will be explored. Relative size referents will be utilized, in the form of small wooden blocks which appear at different distances in the test slides. As Helson (1936) has said, "...we do not mean to imply that one consciously compares image and surroundings or background. Rather, the image 'covers' an area having a certain apparent size. The apparent size of the image depends upon the apparent area covered." To examine the relationship between the afterimage and the apparent area it covers, the reference blocks which appear in the slides will sometimes cover the same retinal area regardless of their apparent distance in the slide, which is to say that the blocks will have a constant proximal width regardless of distance. An afterimage also maintains a constant proximal width (its fixed size on the retina), and would therefore, in theory, appear to cover the same proportion of these blocks regardless of distance. In other cases, the reference blocks will cover smaller retinal areas at further distances than at closer distances in accordance with the laws of linear perspective. In these cases, the blocks will have a constant distal width, and the afterimage of a fixed size should subtend an area that covers more and more of the block and its surrounding area as distance increases. The blocks of constant distal width should provide additional cues to depth in the pictured scene, accentuating the linear perspective, while the blocks of constant proximal width should provide the opposite, de-emphasizing the depth in the scene. Both sets of blocks will provide a basis for scaling the size of the afterimage on its projection surface.

By manipulating these cues for apparent depth, these experiments are expected to be helpful in delineating some of those situations in which the size constancy of afterimages breaks down because of discrepancies between apparent distance and physical distance. These discrepancies will be manifested in differences between the apparent size of the afterimage, predicted by Emmert's Law and reported by subjects, and the physical size of the afterimage (or the physical size of the area occluded by the afterimage), predicted by Euclid's ocular geometry as the quantity equal to visual angle x physical distance.

Experiment 1

The first experiment, primarily a pilot study, was intended to discover if afterimages do indeed appear larger when projected to a more "distant" area of a two-dimensional array than when projected to a "nearer" area.

Also, Uhlarik, Pringle, Jordan, & Misceo (1980), among others, have found that instructional sets can influence judgments of size. Therefore, two separate instructional conditions were utilized, designed to emphasize either the flatness of the viewing screen or the three-dimensionality of the scene being viewed. The two sets of instructions were basically the same, except for certain key words and phrases that prompted the subject to think in either two dimensions or in three dimensions. In the "2-D" instructional condition, the wording was such that the subject was encouraged to remember that he/she was viewing a flat screen, with no real variation in depth. The wording in the "3-D" condition was directed at having the subject *forget* the flatness of the screen, and pay attention instead to the apparent depth depicted in the slides. Afterimages should appear larger in the "3-D" condition since the subjects' perceptions of apparent depth should be greater than in the "2-D" condition. Appendix A contains copies of the two sets of instructions.

METHOD

Subjects

Subjects were 22 General Psychology students volunteering for course credit. Eleven students were tested under each instructional condition. Normal visual acuity or vision corrected to at least 20/30 based on observer's self-reports was a prerequisite for participation.

Stimuli and Design

The stimuli consisted of a set of seven slides of objects in 3-D arrays, selected from those used by Uhlarik, et.al. (1980).

The three-dimensional array depicted in the slides consisted of two .92m x 7.3m panels of textured cloth joined by a visible seam. Each panel also had a slight crease down its middle. The cloth was dark blue with white polka dots, 6mm in diameter, uniformly distributed with a density of $.6/cm^2$. The array was placed on the floor of an evenly illuminated room.

The stimulus array was photographed with a 35-mm single lens reflex camera with a 50-mm/1.4 macro lens. The camera was mounted with the lens .7m above the textured array. Slides were made from Kodak high-speed Ektachrome (E6) film with a lens opening of f/22, which assured adequate depth of field for the entire array.

Besides the cues for depth inherent in the textured array, additional depth cues were provided by the presence of white blocks placed on the surface gradient at various distances. All blocks had distal heights and depths of 3.8cm. However, the distal widths of the blocks used in the seven slides varied as shown in Table 1. The distance from the camera lens to the surface of the array where each block was placed and the amount of visual angle subtended by each block are also given in Table 1.

	DISTANCE (FROM LENS)			
	1.5m	3.0m	4.5m	6.0m
STANDARD SLIDE	10cm (3.8°)			
CONSTANT DISTAL WIDTH		10cm (1.9°)	10cm (1.3°)	10cm (1.0°)
CONSTANT PROXIMAL WIDTH		20cm (3.8°)	30cm (3.8°)	40cm (3.8°)

Table 1. Distal width and visual angle of the blocks used and the distance to the blocks from the camera lens for the seven stimulus slides. (Proximal size in terms of degrees of visual angle are given in parentheses.)

One slide, considered the "Standard", consisted of a 10cm-wide block placed 1.5m from the camera lens and was used as a standard reference for observers' magnitude estimations. There were two different sets of stimulus slides. Each set consisted of three slides depicting blocks at three different distances (i.e., 3.0m, 4.5m, and 6.0m) in the pictorial array; only one block was presented on any given slide. For one set, Constant Distal Width, all blocks had the same distal width as the block in the standard slide (10cm), and therefore more distant blocks subtended a smaller visual angle on the retina. In the Constant Proximal Width set, all blocks subtended the same visual angle on the retina as the block in the "Standard" slide (3.8°), and therefore the distal widths of the blocks increased with increasing viewing distance.

The lighting in the array as it was photographed came from directly above, and extended uniformly throughout the array, so that no shadows were cast by the blocks. However, the lighting produced differential reflectance from the surface of the blocks, providing additional cues to depth. (Appendix B shows achromatic versions of the seven slides used in this study.) Additionally, four 2mm-square pieces of black tape were affixed to the projection screen as fixation points, corresponding to the four positions at which the blocks appeared when they were projected onto the screen. All four fixation points were continually present on the projection screen as part of the visual array.

These slides were chosen for two reasons. First, they provide several two-dimensional cues for depth, such as the texture gradient of the surface, the increasing height in the visual plane of the more distant blocks, and the strong linear perspective provided by the converging lines of the cloth surface.

The second important rationale for using slides of this particular pictorial array was that data has already been collected regarding the size scaling of "real" objects (the blocks) in these two-dimensional pictorial arrays (Uhlarik, et. al., 1980). The size estimates of the blocks and the size estimates of afterimages would provide a basis for comparison between the size scaling process for real objects and the size scaling of afterimages.

In the Constant Distal Width condition, the 10cm block receded in the array according to the laws of linear perspective with a corresponding reduction in the size of its retinal projection. The images of the blocks in the Constant Proximal Width condition did not diminish with increasing distance, but, like the afterimage, remained a constant size. Therefore, it was expected that magnitude estimations for more "distant" afterimages will be greater in the Constant Distal Width condition than in the Constant Proximal Width condition.

Besides the two sets of test slides, each representing a series of three magnitude judgments, three control conditions were included; each control also representing a series of three judgments. One control condition was used to control for the depth cues and relative size cues provided by the blocks in both test conditions. In this No Block control condition, observers viewed the standard slide and then made judgments of the size of the afterimage as it appeared at each of the three fixation points affixed to the screen. (The fourth fixation point, lowest on the screen and closest in the scene, remained the standard point, at which the afterimage's size was labelled "10 units".)

In the second control condition, no slides were presented so there were neither blocks nor depth cues from the pictorial array. Rather, observers viewed the blank screen, and made judgments of the size of the afterimage as it appeared at each of the three fixation points, as compared to its size at the fourth (standard) fixation point. This No Array condition eliminated all depth cues inherent in the array.

The "Actual 3-D Array" control condition represented a "baseline" condition, which assessed the afterimage's conformity to Emmert's Law under three-dimensional, "real world" viewing conditions. In this condition, subjects were seated in front of the actual three-dimensional array depicted in the slides, with their eyes at approximately the same level as the camera lens had been. Tape marks on the cloth represented fixation points at distances of 1.5m, 3.0m, 4.5m, and 6.0m from the eye of the observer. An afterimage projected to the mark at 1.5m was again assigned a magnitude of "10 units", and size judgments were obtained for the apparent size of the afterimage as it appeared when projected onto each of the other three marks.

Thus there was a factorial combination of three viewing distances (3.0m, 4.5m, and 6.0m) with five viewing conditions (Constant Distal Width, Constant Proximal Width, No Blocks, No Array, and the Actual 3-D Array). Although there was no true variation in "distance" under the No Array condition, or even in the three conditions involving slides (No Blocks, Constant Distal Width, and Constant Proximal Width), judgments were obtained at each of the three fixation points representing different distances in the other conditions.

In the Actual 3-D Array condition, the apparent distance of each of the fixation points should remain approximately equal to the physical distance of the fixation points, assuming that the observer is fairly accurate at judging distance using all of the distance cues available to an observer in the real world. If this assumption is correct, then apparent distance should increase directly with physical distance, yielding size constancy. Size constancy and Emmert's Law dictate that the perceived size of the afterimage must increase proportionately with apparent distance, and therefore this condition should produce progressively larger estimates of the size of the afterimage as distance increases.

In the No Array condition, the observer judged the distance to each of the fixation points on a blank projection screen. The variation in physical distance to each of the fixation points was negligible, so there should be no systematic variation in the observer's judgment of apparent distance to each of the fixation points. Therefore, the afterimage should appear to be the same size regardless of which fixation point it is projected onto, and this condition should also yield the smallest overall estimates of the size of the afterimage at each of the three fixation points.

However, in the other three conditions, pictorial cues for distance, present in the pictured array, will complicate the observer's judgment of apparent distance to the fixation points on the screen. To the extent that the pictorial depth cues override the cues used to judge the distance to the blank screen, judgments of the size of the afterimage will increase with apparent depth, tending toward the judgments obtained in the Actual 3-D Array viewing condition. Conversely, if the pictorial cues are not strong enough to produce variations in apparent depth, judgments of the size of the afterimage will be base on the apparent distance to the projection screen and will tend toward those obtained in the No Array viewing condition.

As we have already established, apparent size results from visual angle x apparent distance (and in the case of afterimages, where visual angle is a constant, apparent size results from apparent distance only) as stated by the Size-Distance Invariance Hypothesis. Therefore, variance in the judgments of the size of the afterimage should be assumed to reflect variations in apparent distance. The extent to which each of the three viewing conditions, Constant Distal Width, Constant Proximal Width, and No Blocks, affect the apparent distance of the fixation points can be assessed by comparison of the judgments of the size of the afterimage that each condition produces over the various fixation points. Information will be provided as to how much the presence of the blocks in the array changes the apparent depth in the array, and in which direction this change occurs, when the size judgments of the afterimage yielded by each condition are compared. Further, comparisons of the judgments obtained in the Constant Distal Width and Constant Proximal Width conditions will indicate whether blocks of constant retinal size increase or decrease the apparent depth in the array, as compared to blocks which have changing retinal size in accordance with the law of linear perspective.

Procedure

Stimuli were presented by a random-access slide projector in conjunction with a rear projection screen 1.27m from the lens of the projector and .65m from the observer. The image of the projected array was 36cm wide x 25cm high. The light from the projector was reduced by a 2.00 neutral density filter attached to the lens. Room light was very low so that the projected image was clearly visible on the screen, and also to facilitate the retention of the afterimage. The projection screen was viewed binocularly through a rectangular enclosure that restricted the field of vision to the screen and the peripheral interior of the enclosure. Head movement was restricted through the use of a Bausch & Lomb forehead and chin rest.

Afterimages were produced by an electronic camera flash (Vivitar #SMS 20D). The flash window was covered by black tape such that the only light escaping came through a 1.7cm diameter circle cut in the tape. This circle was further covered by Micropore tape to diffuse the flash and provide a more even luminance gradient over the area of the circle. The flash was activated .65m from the observer, producing a retinal afterimage subtending a 1.5 deg. solid visual angle. Each observer was tested individually, after an initial five-minute period of dark-adaptation in the dimly lit room.

In previous research, various methods have been used to measure the size of an afterimage. Some researchers have used observer-adjusted spotlights projected on the same surface as the afterimage to bracket the image. Measuring the distance between the spotlights yields a measurement that has been interpreted by some to index the afterimage's apparent size. However, this method is actually a method of measuring the physical size of an afterimage (or the area occluded by an afterimage) on the projection surface. It is no different from an experimenter measuring any other physical object, except that the afterimage is invisible to the researcher who must be shown where it is with the spotlights. It would be inappropriate, for instance, to try to measure the "apparent size" of the experimenter by standing him up against the wall while an observer brackets him with spotlights; the measured distance between the spotlights then being interpreted as indicating the experimenter's apparent width. Any variance in the measurement would obviously indicate error in the observer's bracketing skills. This is also the case with afterimages. Both the afterimage and the bracketing spotlights have distinct retinal sizes. So long as the observer is skillful in his/her ability to adjust the spotlights such that the borders of their retinal images are tangential to the borders of the afterimage's retinal area, the distance between the spotlights (as measured by the experimenter) is the _physical_ size of the area occluded by the afterimage on the projection surface.

If the Size-Distance Invariance Hypothesis provides an accurate formula for the calculation of physical size based on physical distance and visual angle, then the physical size of the area occluded by the afterimage on the projection surface in this experiment should remain constant under the present viewing conditions (constant visual angle and constant distance). The method of bracketing spotlights is therefore not appropriate in the present experiment, since the intent is not to measure the objective size of the afterimage on the screen, which should remain constant, but to measure the _subjective_ size of the afterimage as it appears to the observer.

To measure the apparent size of an afterimage, some researchers have used the method of comparison to an observer-adjusted stimulus. This seems to be an adequate method for obtaining judgments of apparent size in some situations, but, as Teghtsoonian & Teghtsoonian (1970) have pointed out, judgments obtained by adjusting a comparison stimulus involve decisions by the experimenter about the distance to the comparison stimulus and its angular separation from the target stimulus. Thus this method introduces possibly biasing effects associated with the location of the comparison stimulus.

The method of magnitude estimation, on the other hand, involves no special measuring or perceptual skills and introduces no possibly biasing measuring devices external to the subject's own mechanisms for judging apparent size. Since the subject's perception of apparent size is the issue in question, the method of magnitude estimation was deemed to be the most appropriate method for obtaining judgments of apparent size for this experiment.

Observers viewing the standard slide (a 10cm block at the 1.5m distance) were instructed to project the afterimage onto the block. This involved fixating on the lowest black fixation point (affixed to the screen) corresponding to the position of the block. The experimenter assigned a width of "10 units" to the diameter of the afterimage as it appeared at this point. The observer then assigned proportional numbers to the width of the afterimage as it appeared at the fixation points corresponding to the positions of the blocks in the subsequent test slides. If the afterimage appeared twice as wide in a test position as it had appeared in the standard position, it was assigned a "20". If it appeared three times as wide, it was assigned a "30". If it appeared half as wide, it was assigned a "5". Subjects were encouraged to use whole numbers, decimals, or fractions, as long as their judgments were proportional to the 10-unit standard. Subjects could refer to the standard 10-unit position of the afterimage as often as they wished, since the standard fixation point remained affixed to the screen at all times. One judgment per slide was obtained, except in the No Blocks and No Array condition, where judgments for all three "distance" positions were obtained on a single presentation.

The four two-dimensional viewing conditions (Constant Distal Width, Constant Proximal Width, No Blocks, and No Array) were presented in random order. The Actual 3-D Array condition was always presented last.

Subjects were randomly assigned to one of the two instructional conditions described earlier, receiving the "2-D" instructions or the "3-D" instructions (presented in Appendix A).

The design for Experiment 1 was therefore a 3 (viewing distances) X 5 (viewing conditions) X 2 (instructions). Distance and viewing condition were within-subjects factors, while instructions was a between-subjects factor.

RESULTS

The results are depicted in Figure 1, and the cell means are presented in Table 2. An analysis of variance procedure indicated that the effect of the two instructional conditions was non-significant ($F=.43$, $df=1,20$). The results in Fig. 1 and the cell means in Table 2 are therefore collapsed across the two levels of this between-group variable.

The ANOVA showed that both distance ($F=22.85$, $df=2,40$) and viewing condition ($F=22.87$, $df=4,80$) were significant at the $p<.05$ level. In addition, the interaction between these two variables was also significant at the $p<.05$ level ($F=12.91$, $df=8,60$). The interaction is reflected in the fan shape of the data in Fig. 1. All other interactions were not significant.

VIEWING CONDITION	DISTANCE 3.0 m	4.5 m	6.0 m
ACTUAL ARRAY	17.32	25.05	33.09
CONSTANT DISTAL WIDTH	13.73	15.45	18.32
CONSTANT PROXIMAL WIDTH	14.09	14.73	17.23
NO BLOCKS	10.23	12.32	14.64
NO ARRAY	10.32	10.41	10.48

Table 2. Cell means for Experiment 1 collapsed across the non-significant instructional conditions.

In the Actual 3-D Array viewing condition, distance had the greatest effect. This would be predicted by Emmert's Law and size constancy, in that there are true variations in the distances of the fixation points in this condition, and the size of the afterimage would be expected to change accordingly. While the apparent size of the afterimage did not conform completely or perfectly to the predictions of size constancy, the afterimage did appear consistently and proportionately larger at the greater distances. It would probably not be realistic to expect *perfect* size constancy in the light of Crookes' (1959) finding that afterimages normally show less size constancy than do real objects. Crookes demonstrated that an object with the same physical size as a projected afterimage, as well as the same retinal size, will consistently appear larger than the afterimage, even when seen at the same distance and under the same conditions as the afterimage. It was further mentioned that even real objects do not always exhibit 100% size constancy.

The supplemental results depicted in Fig. 1, labelled "Uhlarik, et al", are the judgments of size obtained by Uhlarik, et al (1980) for the blocks pictured in the slides used in the Constant Proximal Width condition of this experiment. These blocks, like the afterimages, subtend a constant retinal angle at the various distances. As can be seen, perfect size constancy was not attained for those objects. Interestingly, however, judgments of the apparent size of the afterimage in the Actual 3-D Array condition nearly match the judgments of the size of the blocks obtained by Uhlarik, et al.

There is a second factor that may account for some of the reduction in magnitude of subjects' estimations from perfect size constancy. Teghtsoonian (1965) found that while judgments of apparent linear extent grow at approximately the same rate as physical linear extent grows, judgments of apparent <u>area</u> grow at a <u>slower</u> rate than the actual physical area grows. Thus estimations of apparent area should be expected to be consistently lower than the actual physical area, with the disparity from perfect size constancy increasing for greater physical areas. The instructions to the subjects used in the present study specified that subjects were to give their magnitude estimations for the apparent <u>width</u> of the afterimage (linear extent), but the fact remains that the afterimage was a circle. Therefore at least some of the subjects may have been affected by the phenomena reported by Teghtsoonian, giving estimations of lesser magnitude than they would have if the afterimage had been simply a horizontal line or bar. Further research may indicate that size constancy would be more nearly attained under these conditions when using linear afterimages than when using two-dimensional afterimages.

In the No Array viewing condition, where subjects judged the size of the afterimage as it appeared at each of the fixation points attached to the blank screen, size constancy was maintained virtually perfectly. Judgments of the size of the afterimage averaged 10.40, not significantly different from the "standard" size of

10 ($z(10) = -.07$), and the judgments did not vary significantly over the three fixation points. This was as expected, since there was no variation in the physical distances of the various fixation points, and no 2-dimensional cues to depth were present to complicate the subjects' judgment of this distance. Therefore, the afterimage appeared to be the same size at each fixation point, as size constancy would predict.

The results of the other three viewing conditions generally support the findings of Frank (1923), who determined that afterimages could be made to change their apparent size by projecting them onto perspective drawings. These experiments show that pictorial cues for depth are strong enough to alter subjects' judgments of distance such that apparent distance no longer matches physical distance, and size constancy fails. In the present experiment, the apparent size of the afterimage in the Constant Proximal Width and Constant Distal Width viewing conditions increased approximately 80% over the apparent size of the afterimage in the No Array condition at the fixation point representing the furthest depicted distance. If size constancy were being maintained, the afterimage should have appeared to be the same size in all viewing conditions (except for the Actual 3-D Array) since the physical distance to the fixation points did not fluctuate. Therefore, pictorial depth cues are interfering with the observers' assessment of distance, inducing a judgment of greater depth than is actually present. This interpretation is given further support by the general positive slope of the plotted data in Fig. 1. Afterimages projected to parts of the two-dimensional array that appear to be further away are judged to be larger than those afterimages projected to parts of the pictured array that appear to be nearer.

Further, the presence of the blocks as size referents in the pictured array for the Constant Proximal Width and Constant Distal Width conditions was found to increase the perceived depth in the array slightly. Magnitude estimations in these two conditions increased over the standard approximately twice as much as the estimations obtained in the No Blocks condition over the various fixation points, and t-tests showed this differential to be significant at the .05 level. However, whether the blocks maintained a constant size on the retina regardless of distance or whether they diminished with increasing distance according to the law of linear perspective was apparently inconsequential, as both conditions produced nearly identical results (see

Fig. 1) and an insignificant t-score was found between their means.

The finding that apparent distance can be manipulated in ways that cause size constancy to fail is intriguing. Further research would be helpful in delineating some of the other factors that may cause apparent distance to become disparate from physical distance. From earlier discussion, it is obvious that judgments of size and the processes underlying size constancy rely heavily on the observer's ability to judge distance correctly. Incorrect judgments of distance result in incorrect judgments of size and a breakdown of size constancy. For persons involved in tasks where accurate judgments of distance and size are essential, such as pilots or drivers, a breakdown of size constancy could be disastrous. An understanding of the operation of constancy mechanisms, and the situations in which they might be expected to fail, is therefore a matter deserving attention.

One of the factors that may influence judgments of size and distance is that of cognitive expectations. Experiment 1 employed different instructional sets in an attempt to change cognition in ways that would be reflected in size judgments. This expectational factor was examined in a different way in Experiment 2.

Experiment 2

A large body of literature on instructional sets and size judgments indicates that beliefs about distance are an important factor in the judgment of apparent size (see Hastorf, 1950, and Carlson, 1977). However, the instructional differences utilized in Experiment 1 were apparently too subtle to effectively influence beliefs about distance.

Afterimages appeared to be the smallest in the No Array viewing condition in Experiment 1, and these judgments remained constant over the three fixation points, demonstrating near-perfect size constancy. (Size constancy predicts a constant apparent size when the physical size of the occluded area remains constant.) Afterimages were judged to be the largest in the Actual 3-D Array condition, and these judgments increased in moderate conformity to size constancy over the three fixation points. Therefore, it was anticipated that these viewing conditions might be used to manipulate an observer's perceptual set concerning distance in the other three conditions, where pictorial cues interfere with real cues in the determination of apparent distance. Viewing the Actual 3-D Array first might influence subsequent judgments of apparent distance, and hence the apparent size of the afterimage in the test conditions. Likewise, subjects viewing the blank projection screen first, as did the subjects of Young (1952), might be influenced in their subsequent magnitude estimations of the size of the afterimage in the test conditions by the knowledge that there is no real variation in distance to any of the fixation points on the screen. Thus, presentation order of the five viewing conditions became a factor in Experiment 2.

METHOD

Subjects

Subjects were 40 General Psychology students volunteering for course credit. Subjects passed brief checks of visual acuity, as well as tests for lateral and vertical phoria, as checked by the Bausch & Lomb Ortho-rater (Model no. 71-21-31). Normal vision or vision corrected to at least 20/30 was needed to qualify for participation.

Stimuli and Design

The findings of Teghtsoonian (1965) that judgments of linear extent are more consistent with size constancy than are judgments of area (discussed in the results section of Experiment 1) suggest that it might be advantageous to use a horizontal, rather than a circular, afterimage for Experiment 2. However, it was decided that the circular afterimage would be used again so that the results of Experiment 2 could be directly compared to those of Experiment 1. The stimuli and design for Experiment 2 were therefore essentially the same as for Experiment 1, with the following exceptions.

First, each of the seven slides involved in the Constant Distal Width, Constant Proximal Width, and No Blocks conditions were presented twice. These two responses were averaged, rather than treating the two stimulus presentations as replications, since it was felt that any one magnitude estimation response might be inexact due to random error on the part of the observer. An analysis involving replications would be inappropriate, since the attempt is not to isolate any "practice" effects, but rather to reduce the amount of error variance associated with a single estimation.

Second, presentation order was introduced in an attempt to affect observers' beliefs about distance. Viewing a blank screen first, as in the No Array condition, may produce a cognitive recognition that there is no variation in distance to any of the fixation points, and therefore cause the afterimage to appear essentially the same size at each of the fixation points. This would be reflected in size estimations obtained in the various test conditions that tend in magnitude towards those obtained in the No Array condition. In the No Array condition, the realization that the afterimage does not change in size when projected onto different regions of a flat screen might make it difficult for the depth cues in the pictorial array to produce any changes in the apparent size of the afterimage that would be due to changes in apparent depth. Likewise, viewing the three-dimensional Actual Array first may increase the amount of apparent depth that the subject would experience in the test slides later. In this case, the cognitive experience of the three-dimensional array and the increase in the apparent size of the afterimage experienced when projecting it to different regions of this array might make the depth cues in the two-dimensional array more salient. Because the depth cues are more salient, it would be expected that there would be greater variations in apparent distance when viewing the various two-dimensional test slides, resulting in estimations of the size of the afterimage that tend toward those obtained in the Actual 3-D Array condition.

Therefore, four presentation orders are planned:

1) 3-D) Three dimensional Actual Array
   2-D) The seven slides involved in the Constant
Distal
        Width, Constant Proximal Width, and No Blocks
        conditions, presented twice in random orders
   No-D) No Array

2) 3-D) Actual 3-D Array
   No-D) No Array
   2-D) The seven test slides presented twice
        in random orders

3) No-D) No Array
   2-D) The seven test slides presented twice
        in random orders
   3-D) Actual 3-D Array

4) No-D) No Array
   3-D) Actual 3-D Array
   2-D) The seven test slides presented twice
        in random orders

These presentation orders are presented graphically in Table 3.

Presentation orders in which the seven 2-D test slides appear first was deemed unnecessary, since Experiment 1 utilized a fixed presentation order of this sort. In Experiment 1, the seven test slides and the No Array condition always preceded the Actual 3-D Array, although the slides and the No Array condition were presented in random order. This approximates the presentation orders in which the seven test slides (the 2-D conditions) would appear first.

	Actual Array (3-D) presented first	No Array (No-D) presented first
Test slides after either 3-D or No-D	Order 1 Test slides (2-D) No Array (No-D)	Order 3 Test slides (2-D) Actual Array (3-D)
Test slides after both 3-D and No-D	Order 2 No Array (No-D) Test slides (2-D)	Order 4 Actual Array (3-D) Test slides (2-D)

Table 3. The four presentation orders used in Experiment 2.

It is expected that, due to the manipulation of beliefs about apparent distance arising from the viewing condition which immediately precedes the seven test slides, the greatest overall judgments of apparent size for the afterimage will occur in the first presentation order, followed by the fourth, the second, and the third, which is expected to yield the smallest overall judgments of apparent size.

It is also expected that there will be an interaction between distance and viewing condition such that the factor of distance will have the least effect in the No Array condition, increase through the No Blocks, Constant Proximal Width, and Constant Distal Width conditions, and have the greatest effect in the Actual 3-D Array condition.

Thus the design for Experiment 2 consisted of 3 distances crossed with 5 viewing conditions presented in 4 orders. Distance and viewing condition are within-subjects factors, while the presentation order is a between-subjects factor. Ten subjects were tested in each of the four presentation order conditions.

Procedure

Subjects were assigned randomly to one of the four presentation order groups. The instructions they received were roughly equivalent to those received by the subjects in the "3-D" instructional group in Experiment 1.

The experimental procedure was otherwise identical to that used in Experiment 1.

RESULTS

Since each of the 40 subjects made a total of 15 judgments of afterimage size (5 viewing conditions x 3 distances), there were 600 observations over all conditions.

An analysis of variance for a mixed three-factor design was done on the data by an SAS computer program. This ANOVA indicated that viewing distance ($F=9.09$, $p=.0003$), viewing condition ($F=17.51$, $p<.0001$), and the interaction between distance and condition ($F=15.02$, $p<.0001$) were all statistically significant, as was also the case in Experiment 1. Figure 2 is a plot of the data collapsed across the four presentation orders showing these significant effects. As in Fig. 1 (Experiment 1), the data form a fan shape, with distance showing the greatest effect in the Actual 3-D Array condition. Again, the afterimage shows conformity to size constancy in the No Array condition, as it appeared to remain at approximately the same size as the standard over the three fixation points.

The Actual Array condition produced less conformity to size constancy than was obtained in Experiment 1. As in Figure 1, the results obtained by Uhlarik, et al (1980) for judgments of the size of the wooden blocks that maintain constant proximal width are presented in Figure 2 for comparison purposes. As can be seen, the real objects showed greater conformity to size constancy than did the afterimages projected onto the Actual Array in this experiment. This decrease in conformity to size constancy of the afterimage in this viewing condition over the two experiments may have to do with the introduction of the presentation order factor, and will be discussed later.

As in Experiment 1, the three conditions involving two-dimensional arrays (slides) produced judgments of the size of the afterimage that were greater than the judgments obtained in the No Array condition but less than the judgments obtained in the Actual Array condition. This indicates that the pictorial depth cues presented in the slides were again strong enough to produce a breakdown of size constancy. The magnitude of the breakdown was about the same as that found in Experiment 1.

The presence of the wooden blocks in the Constant Proximal Width and Constant Distal Width conditions was not as effective at producing changes in apparent depth (reflected in apparent size changes) in this experiment as it was in Experiment 1. The difference between the judgments obtained in those conditions and those obtained in the No Blocks condition was shown to be insignificant at the .05 level by a t-test (see Table 4).

Presentation order was significant ($F=3.98$, $p=.02$), indicating that cognitive expectations influenced subjects' assessments of apparent distance, and hence, apparent size. The effect of presentation order can be seen graphically in Figures 3-6, which depict the distance x viewing condition interactions obtained for each presentation order. The data from each presentation order is roughly the same shape as the overall data in Figure 2. However, differences in the magnitude of the size estimations produced by the various viewing conditions among the four orders are apparent in disparity of vertical placement of the data in the graphs. Figure 3, which is a graph of the results of presentation order #1 (Actual Array-Slides-No Slide), shows the size estimations of greatest magnitude in each of the five viewing conditions. Presentation order #3 (No Array-Slides-Actual Array; Fig. 5) produced size estimations of the least magnitude for all viewing conditions except in the Actual 3-D Array. Orders #2 and #4 (Fig.'s 4 & 6) resulted in intermediate size estimations. These differences between Order #1 and Orders #2 and #4, and between Order #3 and Orders #2 and #4 were both shown to be significant at the .05 level by t-tests (see Table 6).

Figure 7 presents the results obtained in each presentation order collapsed across the three viewing conditions involving slides (Constant Proximal Width, Constant Distal Width, and No Blocks). The data from the other two viewing conditions (Actual 3-D Array and No Array) were removed from this figure to examine the effects that these initial viewing conditions had on the subsequent size estimations obtained in the slide conditions. Again, Order #1 (Actual Array-Slides-No Array) produced the estimations of greatest magnitude in the three slide conditions, while Order #3 (No Array-Slides-Actual Array) produced the estimations of least magnitude in the three slide conditions. However, in considering only the data from the conditions involving slides, t-tests showed that Order #2 (Actual Array-No Array-Slides) was not significantly different from Order #3 at the .05 level (see Table 7). Order #4 (No Array-Actual Array-Slides) resulted in significantly higher estimations in the three slide conditions than did either Order #2 or Order #3, but also resulted in significantly lower estimations than did Order #1 (see Table 7).

None of the interactions with presentation order were significant.

Tables 4-6 present the overall means for each presentation order, viewing condition, and distance. Lines separate those means that were shown to be significantly different at the p=.05 level by t-tests.

Table 4 illustrates the significant differences between the Actual Array condition, the conditions involving slides, and the No Array condition. The slide conditions which included wooden blocks as part of the array were not significantly different from the No Blocks condition, as mentioned above. Therefore, any possible depth cues provided by the presence of blocks in the array are not strong enough to produce significant changes in apparent distance that would be reflected in judgments of the apparent size of the afterimage.

Table 4

VIEWING CONDITION	N	JUDGMENT
Actual 3-D Array	120	20.68
Constant Proximal Width	120	14.72
Constant Distal Width	120	14.71
No Blocks	120	13.20
No Array	120	10.72

Table 5

VIEWING DISTANCE	N	JUDGMENT
6.0 meters	200	16.10
4.5 meters	200	14.81
3.0 meters	200	13.51

The significant differences between distances in Table 5 are probably artificial, due mainly to differences obtained in the Actual Array viewing condition. This difficulty and its implications will be discussed in the next section.

Table 6

PRESENTATION ORDER		N	JUDGMENT
1	Actual Array (3-D) Test Slides (2-D) No Array (No-D)	150	20.14
4	No Array (No-D) Actual Array (3-D) Test Slides (2-D)	150	14.39
2	Actual Array (3-D) No Array (No-D) Test Slides (2-D)	150	13.20
3	No Array (No-D) Test Slides (2-D) Actual Array (3-D)	150	11.49

The significant differences between presentation orders listed in Table 6 were affected by the exclusion of the data from the Actual Array and No Array conditions. Thus, Table 7 below presents the means for the four presentation orders excluding the data from the Actual Array and No Array conditions. Again, lines separate those means that were shown to be significantly different at the p=.05 level by t-tests. This data is the same as that presented graphically in Figure 7.

Table 7

PRESENTATION ORDER		N	JUDGMENT
1	Actual Array (3-D) Test Slides (2-D) No Array (No-D)	90	21.04
4	No Array (No-D) Actual Array (3-D) Test Slides (2-D)	90	14.38
2	Actual Array (3-D) No Array (No-D) Test Slides (2-D)	90	11.32
3	No Array (No-D) Test Slides (2-D) Actual Array (3-D)	90	10.10

DISCUSSION AND CONCLUSIONS

The result of primary interest in this study is the significant main effect of viewing condition indicating that pictorial cues for depth are able to change an observer's judgment of the size of an afterimage. This can be seen in Table 4, where the three conditions involving judgments of the apparent size of the afterimage on slides (the No Blocks, Constant Proximal Width, and Constant Distal Width conditions), all produce judgments significantly different from those produced in the No Array condition. This finding is in agreement with the results obtained by Frank (1923). In both studies, an afterimage changed in apparent size due to changes in apparent depth produced by pictorial depth cues. The fact that there are no corresponding changes in physical distance, or in the algebraically related quantity of physical size, indicates that size constancy is not being maintained.

The finding that the three viewing conditions involving slides are not significantly different from each other indicates that the objects depicted in the slides do not provide strong enough cues to produce changes in apparent depth over and above the apparent distance inherent in the pictured array. Whether the blocks receded in depth according to the law of linear perspective (as in the Constant Distal Width condition), or, like the afterimage, remained a constant width on the retina (as in the Constant Proximal Width condition), or whether the blocks were even there at all made no difference to the judgments of apparent size of the afterimages. It seems that the strong linear and texture perspective provided by the pictured gradient was the main factor producing changes in apparent depth.

The perspective inherent in the array did not, however, produce changes in apparent distance in the way that would be expected. Although the main effect of distance was significant, it appears that this was due to the inclusion of the Actual 3-D Array condition, in which viewing distance was strongly significant. When the data from the Actual 3-D Array and No Array conditions are left out of the analysis, the means for the 3.0m, 4.5m, and 6.0m viewing distances become 13.42, 14.37, and 14.84, respectively ($N = 120$). T-tests showed that these means were not significantly different from each other at the $p<.05$ level. This can be seen graphically in Figures 3-6, where the data from the Constant Distal Width, Constant Proximal Width, and No Blocks conditions exhibit relatively little slope. Apparent distance was therefore not affected pictorially the same way it was under three-dimensional viewing conditions in this experiment. However, it is somewhat interesting that the conditions of this experiment produced afterimages that appeared larger at the various fixation points than they appeared at the standard fixation point, and yet afterimages projected to more "distant" fixation points did not appear significantly larger than afterimages projected to "nearer" fixation points. Perhaps the relatively small range of physical distances used in this study (only 4.5m from the standard point to the most distant point) was not great enough to overcome individual variance present in the judgments of the size of the afterimage.

The significant viewing condition x viewing distance interaction is also apparently due largely to the inclusion of the "inducing" conditions (Actual Array and No Array). This interaction becomes insignificant when the data from the Actual Array and No Array conditions are removed from the analysis. This may also be due to large amounts of individual differences in judging the apparent size of the afterimages.

Near-perfect size constancy was attained in the No Array condition, where subjects made judgments of the size of the afterimage projected onto a blank screen. Here there was no variation in the physical distance of the fixation points. The average judgment of 10.72 obtained in this condition (see Table 4) is statistically equivalent to the 10-unit standard, indicating that there was also no variation in apparent distance. (Remember that the Size-Distance Invariance Hypothesis guarantees that any variations in apparent size reflect differences in apparent distance.) Size constancy was maintained because distance was assessed accurately by the subjects.

Near-perfect size constancy was also attained in the Actual 3-D Array condition in Experiment 1, although less constancy was shown for this condition in Experiment 2. Here, variations in physical distance were approximated by variations in apparent distance, as indicated by judgments that increased over the three viewing distances. The findings reported by Teghtsoonian (1965) and Crookes (1959), which were discussed in the results section of Experiment 1, help explain why perfect size constancy was not exhibited by the afterimage in this condition. Their findings indicate that afterimages should not be expected to show as much size constancy as real objects, and real objects do not always exhibit 100% size constancy anyway. The results of this study and those of Uhlarik, et al (1980) presented in Figures 1 & 2 bear out these assertions, as the data points obtained in this study and by Uhlarik, et al. are of lesser magnitude than would be predicted by Emmert's Law.

The reason for the reduced amount of size constancy exhibited in the Actual Array condition for Experiment 2 is unclear. Perhaps the presentation order was a factor, since judgments obtained in the Actual Array condition when this condition was preceded by the No Array condition (Orders #3 & #4, Fig.'s 5 & 6) were much lower in magnitude than those obtained when the Actual Array was presented first (Orders #1 & #2, Fig.'s 3 & 4). This would indicate that initial exposure to the No Array condition not only decreased the subsequent size judgments obtained in the slide conditions, but also in the Actual Array. However appealing this explanation is, it doesn't account for the fact that the Actual Array was always presented last in Experiment 1, and yet the afterimage showed greater size constancy in that experiment. The only consistent explanation possible at this time is that there is a large amount of statistical fluctuation in the apparent size of the afterimage viewed under normal three-dimensional conditions.

Perhaps the most interesting result obtained in this study is the significant main effect of presentation order. As can be seen in Tables 6 and 7 (and also in Fig's. 3-7), presentation order made a large difference in the apparent size of the afterimage. As predicted, Order #1 (Actual Array-Test Slides-No Array) produced estimations of the size of the afterimage that were of the greatest magnitude. This was presumably because initial exposure to the Actual 3-D Array introduced a suggestion of greater apparent depth in the subsequent slides. This finding is complementary to the finding of Hastorf (1950), who reported that when neither size nor distance was known, a suggestion of size was enough to fix distance in the minds of subjects. The present study shows that a suggestion of distance is also effective at changing observers' perception of size, at least in the case of afterimages. Also as predicted, Order #3 (No Array-Test Slides-Actual 3-D Array) produced the lowest estimations of the size of the afterimage, presumably because the initial exposure to the blank screen introduced the suggestion that there was never any variation in distance when subsequently viewing the test slides.

Order #4 (No Array-Actual Array-Test Slides), while not significantly different from Order #2 (Actual 3-D Array-No Array-Test Slides), still produced consistently greater estimations of the size of the afterimage than did Order 2 throughout the experiment. The fact that the difference is not statistically significant is disappointing, but it shows that these two presentation orders were adequate controls for the other presentation orders. The effect of seeing both the Actual Array and the blank screen before being tested on the slides was to produce moderate judgments, essentially cancelling each other out for "no effect". Averaging all the judgments obtained in Orders #4 and #2 yields a mean of 13.80, which is not significantly different from the overall mean of the judgments, which was 14.81. Conversely, it is still interesting that whichever condition immediately preceded the test slides produced a slight bias in the direction that would be expected, thus Order #4 produces responses of consistently greater magnitude than does Order #2 (compare Fig. 4 with Fig. 6). If the two presentation orders in which the Actual 3-D Array immediately preceded the test slides are averaged (Orders 1 and 4), their average (17.27) is significantly greater than the average of the two presentation orders in which the No Array condition immediately precedes the test slides (Orders 2 and 3 average to 12.35). These findings retain their significance even when the data from the Actual 3-D Array and No Array conditions are removed from the analysis.

These results concerning the presentation order factor are in concurrence with other findings concerning instructional set (Carlson, 1977, and Hastorf, 1950). An instructional set or other means of suggesting apparent size is effective at influencing observer's judgments of apparent size.

In conclusion, then, this study has shown that pictorial cues for depth are sufficient to produce changes in apparent distance to the projection of an afterimage, as evidenced by the increase in apparent size of the afterimage while retinal size remains constant. These cues are apparently not as strong as the depth cues received under normal viewing conditions, however, nor is there a simple relationship between the "depth" portrayed pictorially and the accompanying changes in the construct we call apparent depth. Previous experience also seems to have a strong modulating effect on the amount of discrepancy between apparent and physical distance.

Further research will be necessary to explore the extent to which apparent distance can be separated from physical distance through the use of pictorial cues, resulting in a breakdown of size constancy. Reduction conditions might be employed to further accentuate pictorial cues to distance while de-emphasizing other distance cues present. Representing a greater range of distances than was done in this study might yield a more reliable effect of distance on the apparent size of the afterimage.

While this study dealt with the pictorial representation of monocular cues for depth, it would be interesting to examine how that binocular cues for distance affect an observer's assessment of distance, especially when these cues are presented pictorially. Stereogram images could be used to vary apparent distance through the cue of binocular disparity. Since the stereogram is also a pictorial representation of a strong three-dimensional depth cue, it would be expected that apparent distance could be separated from physical distance under these conditions.

Since size constancy and the related ability to judge distance quickly and accurately is a matter of individual safety in modern life, it is important to understand the processes involved. Once these processes are understood and applied in an intelligent manner, possibly dangerous illusory situations can be avoided. Also, measures of apparent size may someday be used to determine the amount of apparent depth present in a two-dimensional array where two-dimensional arrays are used as three-dimensional analogs, such as in aircraft instrumentation. This study represented an attempt to move forward in these areas, an attempt to increase practical as well as academic knowledge.

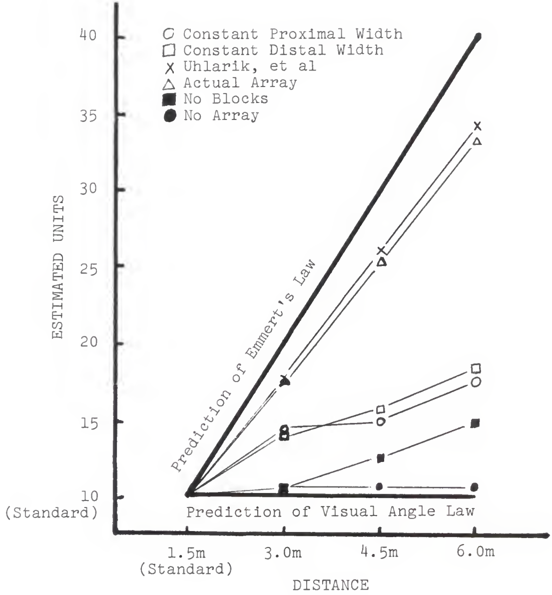

Fig. 1. Results of Experiment 1 collapsed across the non-significant instructional condition showing distance x viewing condition interaction.

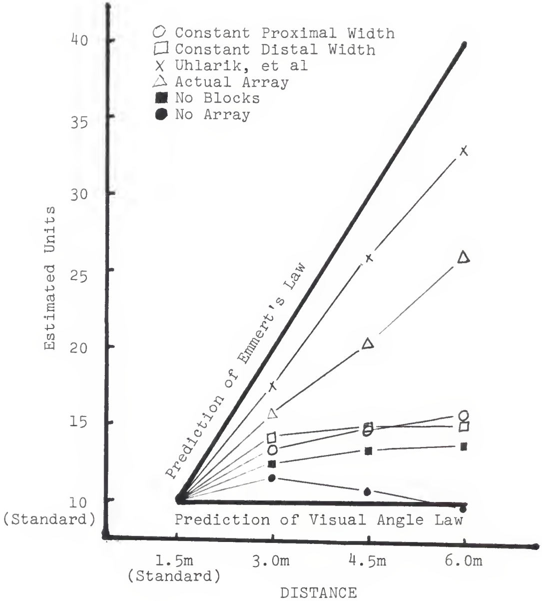

Fig. 2. Results of Experiment 2 collapsed across presentation showing distance x viewing condition interaction.

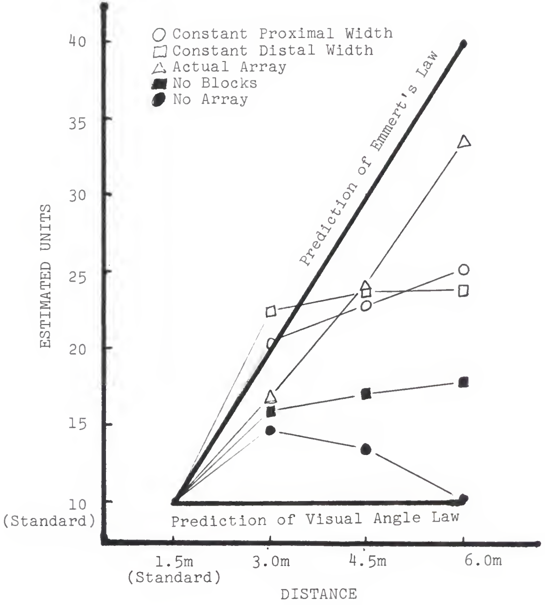

Fig. 3. Distance x viewing condition interaction for presentation order #1 (Actual Array-Test Slides-No Array).

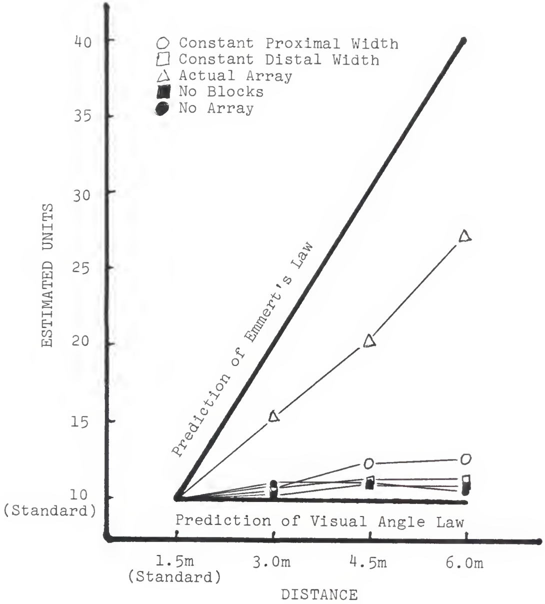

Fig. 4. Distance x viewing condition interaction for presentation order #2 (Actual Array-No Array-Test Slides).

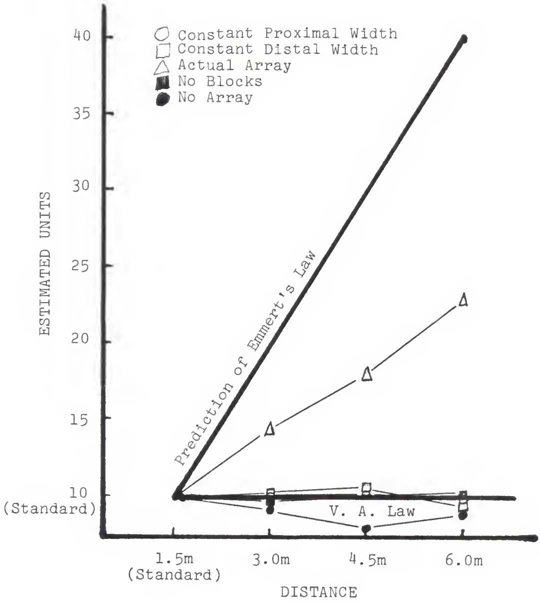

Fig. 5. Distance x viewing condtion interaction for presentation order #3 (No Array-Test Slides-Actual Array).

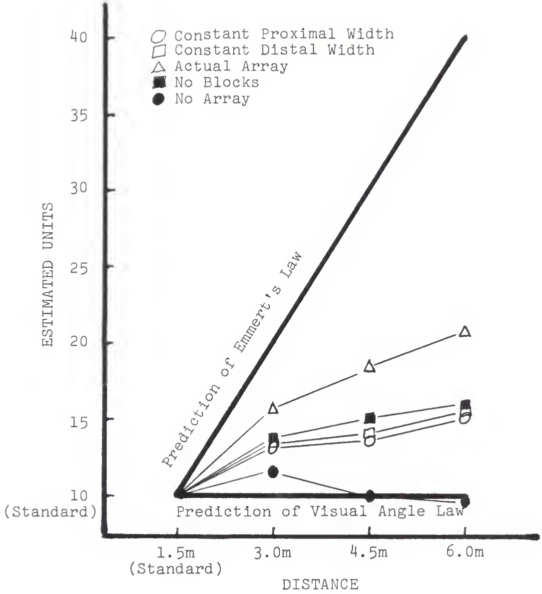

Fig. 6. Distance x viewing condition interaction for presentation order #4 (No Array-Actual Array-Test Slides).

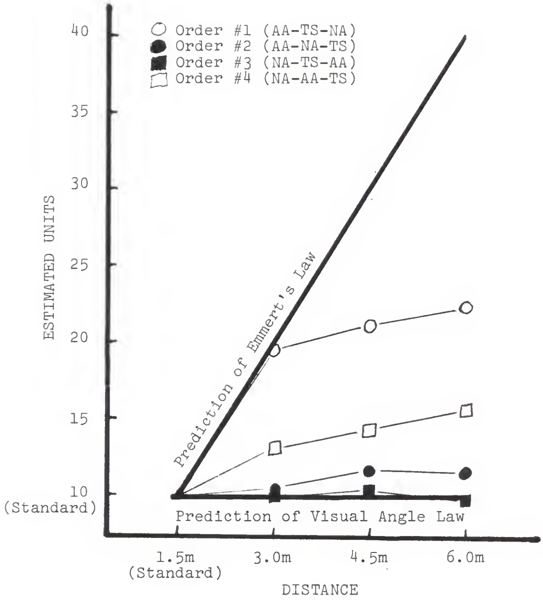

Fig. 7. Results of Experiment 2 collapsed across viewing condition showing presentation order main effect and non-significant interaction with distance.

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APPENDIX A

Instructions Used In Experiment 1

(All subjects were given the following preliminary treatment upon arrival: After the subject was informed that this study involved judging the size of an afterimage on various backgrounds, an afterimage was produced using the electronic flash. The subject was directed to project the afterimage onto the wall of the room and then to project it onto their hand close to their face to demonstrate how an afterimage can change size with various backgrounds. This was followed by the five-minute period of dark adaptation. The subjects were then read one of the two following sets of instructions, depending on which instructional condition they had been assigned to. The difference between the two sets of instructions lies in the variation of a few key words and phrases, underlined here for easy comparison of the two sets.)

2-D INSTRUCTIONS

(A new afterimage was produced, and subjects were presented with the standard slide {see Appendix B}.)

Focus on the black spot on the white block <u>at the lower part of the screen.</u> Note the width of the afterimage. Call this width "10 units". From here on, that black spot will be present _at the bottom of the screen,_ and anytime that you project the afterimage onto that standard point, the width of the afterimage will be called "10 units". Now let your eyes scan _up the screen_ to the second black spot. I want you to give me a number that represents the width of the afterimage at this _upper_ point if its width is "10" at the _lower_ point. If it looks twice as wide, give a "20"; three times as wide, give a "30"; half as wide, give a "5". You can use whole numbers, decimals, or fractions, as long as your response is proportional to the 10-unit standard. Using this scale, how wide would you estimate the afterimage to be at that _upper_ point? (This judgment represented a practice trial, and the response was not recorded.)

From here on, white blocks will be present at different points on _the screen._ With each new slide, fixate first on the black spot _at the bottom of the screen,_ remembering that the width of the afterimage there is "10". Then let your eyes scan _up the screen_ to whichever black spot the white block is near. I will ask you for your judgment of how wide the afterimage appears when it is projected onto the block, compared to the 10-unit standard. In all these slides, I want you to try _not to picture the scene as if you were actually_ standing there in front of it, but instead remember that you are only looking at slides on a flat screen. Try to imagine the afterimage as a "hole" in the screen, and base your judgment on how wide that "hole" appears. If at any time the afterimage becomes so faint that you can no longer judge its width, we will produce a new one.

3-D INSTRUCTIONS

(A new afterimage was produced, and subjects were presented with the standard slide {see Appendix B}.)

Focus on the black spot on the white block in the foreground. Note the width of the afterimage. Call this width "10 units". From here on, that black spot will be present in the foreground, and anytime that you project the afterimage onto that standard point, the width of the afterimage will be called "10 units". Now let your eyes scan down the hallway to the second black spot. I want you to give me a number that represents the width of the afterimage at this further point if its width is "10" at the closer point. If it looks twice as wide, give a "20"; three times as wide, give a "30"; half as wide, give a "5". You can use whole numbers, decimals, or fractions, as long as your response is proportional to the 10-unit standard. Using this scale, how wide would you estimate the afterimage to be at that *further* point? (This judgment represented a practice trial, and the response was not recorded.)

From here on, white blocks will be present at different points on *this hallway.* With each new slide, fixate first on the black spot *in the foreground,* remembering that the width of the afterimage there is "10". Then let your eyes scan *down the hallway* to whichever black spot the white block is near. I will ask you for your judgment of how wide the afterimage appears when it is projected onto the block, compared to the 10-unit standard. In all these slides, I want you to try *to forget the fact that you're watching slides on a screen, and view the scene as if you were actually standing there in front of it.* Try to imagine the afterimage as a "hole" in the *hallway floor,* and base your judgment on how wide that "hole" appears. If at any time the afterimage becomes so faint that you can no longer judge its width, we will produce a new one.

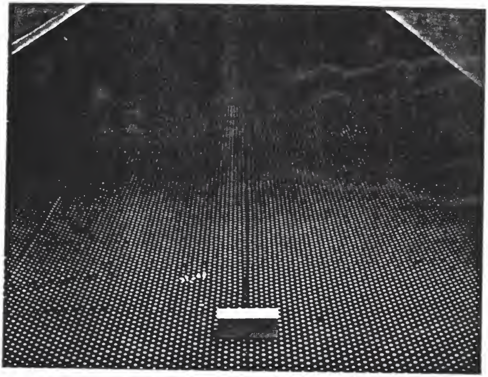
(All subjects in Experiment 2 received the 3-D instructions, with the following three sentences appended at the end: "All of the slides will appear twice. Don't feel that you have to give the same judgment both times. Just try to respond as quickly and accurately as possible.")

APPENDIX B

Stimulus Slides Used
in Experiments 1 & 2

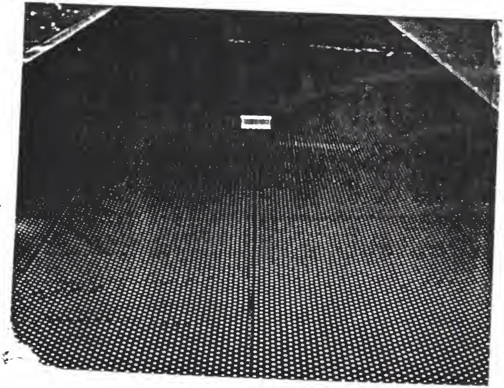
Standard Slide

10 cm block at 1.5 m



Constant Distal Width
Slide 1

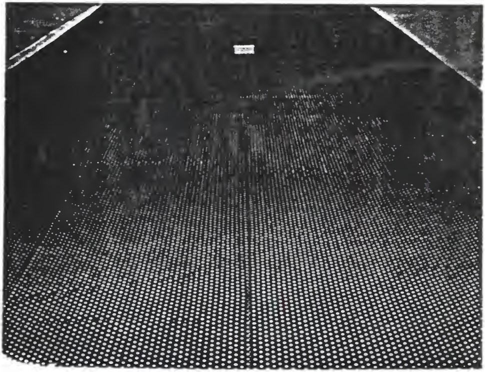
10 cm block at 3.0 m



Constant Distal Width

Slide 2

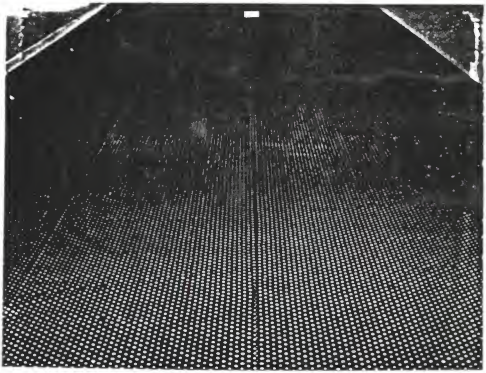
10 cm block at 4.5 m



Constant Distal Width

Slide 3

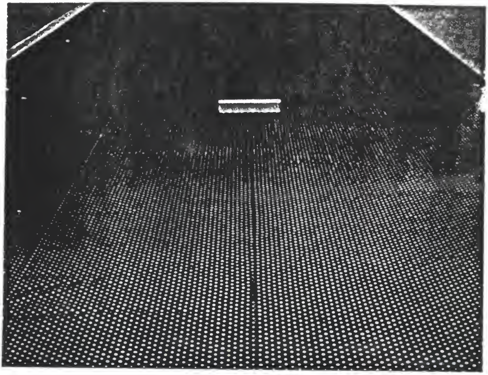
10 cm block at 6.0 m



Constant Proximal Width

Slide 1

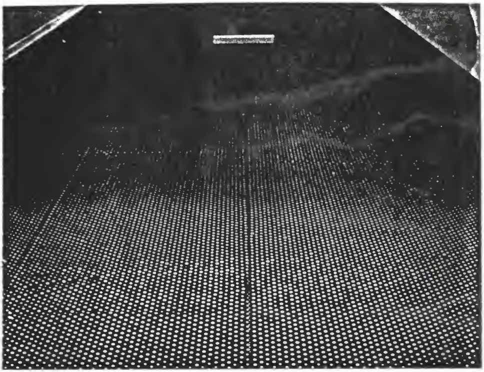
20 cm block at 3.0 m



Constant Proximal Width

Slide 2

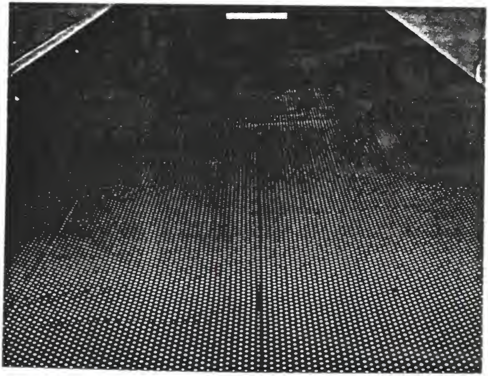
30 cm block at 4.5 m



Constant Proximal Width

Slide 3

40 cm block at 6.0 m



THE PERCEIVED SIZE OF AFTERIMAGES IN TWO-DIMENSIONAL PICTORIAL ARRAYS

by

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B.S., Kansas State University, 1984

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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1987

The two experiments reported dealt with the perceived size of an afterimage as it appeared when projected onto various positions in a two-dimensional pictorial array.

Subjects viewed a two-dimensional array containing strong linear perspective and other pictorial depth cues, presented by a slide projector, as well as the actual three-dimensional array that was depicted in the slides. Subjects gave magnitude estimations of the size of the afterimage as it appeared at three different distances in the three-dimensional array and as it appeared at corresponding positions in the two-dimensional array. Judgments were also obtained for the size of the afterimage as it appeared at the same three points on the blank projection surface.

In Experiment 1, two different instructional sets were employed as a between-subjects factor. One set prompted the subjects to view the two-dimensional array as if it were actually a three-dimensional array and the subject was standing there in front of it. Key words and phrases were changed in the other set, prompting the subjects to remember that they were only watching slides on a flat screen.

While the instructional set factor was found to be non-significant, significant effects were found for the viewing condition factor (blank screen-two dimensional array-three dimensionl array), the position of the afterimage's projection, and the interaction between these two factors. These results indicated that pictorial cues to depth, as presented in the two-dimensional arrays, were strong enough to effect changes in the apparent size of the afterimage in the same direction as three-dimensional depth cues. However, the size of the afterimage did not increase as much in the two-dimensional array as it did in the three-dimensional array.

Experiment two utilized basically the same design as Experiment 1, except that presentation order of the various viewing conditions was controlled as a between-subjects factor instead of instructional set. Presentation order was randomized in Experiment 1.

Significant effects were again found for the viewing condition and positional factors, as well as their interaction. In addition, the presentation order of the various viewing conditions was found to be significant. Subjects viewing the three-dimensional array first gave significantly larger judgments of the size of the afterimage when subsequently viewing the two-dimensional arrays than did subjects who had viewed the blank screen first.

Thus it was concluded that there is an effect of previous experience entering into subject's judgments of the apparent size of an afterimage, having to do with the apparent distance in the array. Also, it was concluded that two-dimensional cues to depth can be effective in altering apparent distance, as reflected in their ability to alter the apparent size of an afterimage in the same way as three-dimensional depth cues.