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BEHAVIORAL ENGINEERING LABORATORY
Department of Psychology
New Mexico State University



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# LOCUS OF THE STIMULUS TO VISUAL ACCOMMODATION: WHERE IN THE WORLD, OR WHERE IN THE EYE?


JAN CHRISTOPHER HULL
RICHARD T. GILL
STANLEY N. ROSCOE


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In two experiments, observers judged the apparent size of a collimated disk of light (a simulated moon) projected just above the horizon of real and virtual scenes by means of a stimulus presentation device, the "moon machine." As these judgments were registered, masks obscured various bands of the lower half of the visual field. Immediately following these judgments measurements of the observers' visual accommodation were made using a laser optometer. Results showed a strong correlation between mean apparent size

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and mean accommodation shift. Major conclusions were (1) viewing a virtual (collimated) image of a real scene is not the same as viewing the real scene, (2) for natural (real) scenes the retinal locus of scenic texture is the primary determinant of apparent size, whereas for virtual images it has a more reliable effect on visual accommodation, and (3) whatever the relationship between apparent size and visual accommodation is, their mean correlation is in excess of 0.90. These findings agree well with, and extend, those of Iavecchia, Iavecchia, and Roscoe (1978) and Simonelli and Roscoe (1979).

BEHAVIORAL ENGINEERING LABORATORY

New Mexico State University
Box 5095
Las Cruces, New Mexico
88003

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# LOCUS OF THE STIMULUS TO VISUAL ACCOMMODATION: WHERE IN THE WORLD, OR WHERE IN THE EYE?

Jan Christopher Hull
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Stanley N. Roscoe

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... If a point be fixed and an object beyond be moved farther away from the eye, the object will appear more distant and smaller. If the fixed point be moved instead of the object, the object appears more distant and smaller. It is the relation of the object to the fixation point and not to the eye which determines the apparent size and distance. ... It may be objected that this explanation is little more than a restatement of the facts of the case. It is however a restatement which emphasises the importance of the fixation point as the centre of the visual space and as the determining factor of the apparent relations within that space.

W. H. R. Rivers
Mind, 1896, p. 77

## INTRODUCTION

Since the early 1970s, Roscoe and his colleagues and students have been studying certain evidently related misperceptions experienced by pilots (Roscoe 1979a; 1979b). Objects such as airport runways appear smaller and farther away when projected as real or virtual images than they do when viewed directly. As one consequence of this, pilots making landing approaches tend to come in too high and land long and hard. Misjudgments of this nature can be viewed as manifestations of violations of the size-distance invariance hypothesis.

Experiments to investigate these misjudgments at NASA's Ames Research Center (Roscoe, Olzak, and Randle 1976; Roscoe 1977; Roscoe and Benel 1978; Roscoe 1979b; Randle, Roscoe, and Petitt 1980) have shown a strong correlation between judgments of apparent size and visual accommodation. However, since pilots flying airplanes by contact visual reference view objects at distances much greater than those tested, these findings needed to be extended and refined. This extension was undertaken by Iavecchia, Iavecchia, and Roscoe (1978).

A convenient method to study perceptual misjudgments is to put an illusion to work for you. The illusion chosen by Iavecchia et al. was the moon illusion. In it the horizon moon is judged larger than the celestial moon, even though for all practical purposes their distances from a terrestrial observer are equal. Note that the size-distance invariance hypothesis does not explain this illusion. Observers not only report that the horizon moon appears larger but that it appears nearer, <u>not</u> farther as the size-distance invariance hypothesis requires.

To study this phenomenon effectively, the Iavecchias used a device known colloquially as the "moon machine," to be described and illustrated later. This apparatus allows one to superpose a collimated disk of light (the moon) on a natural outdoor scene or an artifical laboratory scene. An adjustable-diameter comparison disk nearby allows surprisingly reliable estimates of the size of this simulated moon for any given background scene. This technique, originally employed by Kaufman and Rock (1962; Rock & Kaufman 1962) was used by the Iavecchias in two experiments.

In the first, subjects viewed the simulated moon against scenes from corresponding windows of the third through eighth floors of the psychology building in Champaign looking eastward across the University of Illinois' Urbana campus. They found that the apparent size of the moon increased as viewed from the third through the sixth floors and decreased thereafter. Although visual accommodation was not measured, the background texture visible from the various elevations appeared at distances ranging from approximately 30 m to more than 1000 m.

In a second experiment done only from the sixth-floor elevation, the distance and angular depression of visible texture were systematically manipulated by a series of masks. These masks revealed all of the view above the horizon and obscured different bands of texture below the horizon. In this experiment, visual accommodation was measured via a laser optometer. Once again (as at Ames Research Center) a strong correlation ($r$ = 0.9) between apparent size and accommodation was obtained.

In the Iavecchia experiments, the distance to background textural stimuli and their retinal locus were confounded. In the first experiment the distance to visible textural stimuli increased as the views progressed from the third through sixth floors, and the apparent size of the moon increased accordingly. From the sixth through eighth floors the texture appeared farther and farther below the foveally presented collimated disk, which decreased in apparent size accordingly. In the second experiment masks were used to obscure or reveal horizontal bands of texture whose absolute distance and angular depression from the collimated moon covaried inversely.

To untangle this confounding, the present two experiments were conducted. In the first, visual distance to a scene was held constant at optical infinity while the nature and retinal locus of the scenic content were varied. In the second, the nature and retinal locus of the scenic content were held nearly constant while the distance to the visible scene was varied. To accomplish the first set of manipulations, the second Iavecchia experiment was partially replicated using masks to reveal horizontal bands at various depression angles below the horizontal line of sight. For the second type of manipulation, subjects viewed the campus scene from various floors of the psychology building through a single mask revealing a textural band depressed between 6 and 12 degrees below horizontal.

## METHOD

### Subjects

Subjects were seven women and one man whose ages ranged from 17 to 24 years.

### Apparatus

The basic moon machine was the same as that used in the Iavecchia et al. (1978) and the Simonelli and Roscoe (1979) investigations. As illustrated in Figure 1, the moon machine projects a collimated simulated moon subtending a 0.67-degree visual angle (approximating the 0.5 degree angle of the real moon) onto a combining glass through which a subject can view any 45 x 45-degree natural or artificial scene.

A subject is instructed to focus on the simulated moon and to register a judgment of its size by adjusting the diameter of an uncollimated comparison disk projected from a distance of one meter. The comparison moon is brought into view by means of a sliding mirror assembly that simultaneously obscures the collimated moon and surrounding scene. A subject's visual accommodation to each view is measured by means of a laser optometer (Hennessy & Leibowitz 1972; Iavecchia et al. 1978).

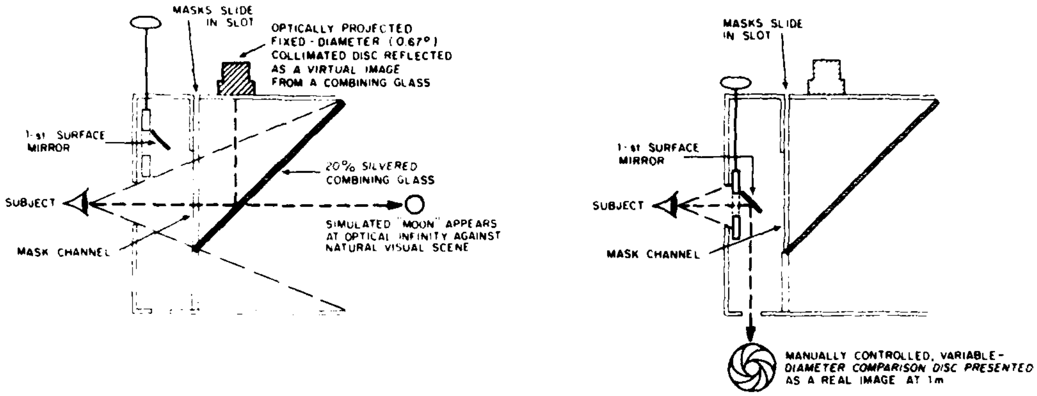


Figure 1. Cutaway schematic diagrams of the "moon machine" showing the presentation of the collimated lunar disc (left) and the variable-diameter uncollimated *comparison disc (right).*

## Procedure

In the first experiment, masks occluded parts of the lower half of the visual scene only. Three were used to reveal, respectively, the Near/Low, Intermediate, or Far/High portion of the lower half of the visual field and all of the upper half, as illustrated in Figure 2. In a fourth condition no mask was present, thereby revealing an unobstructed view of the entire 45 x 45-degree visual scene.

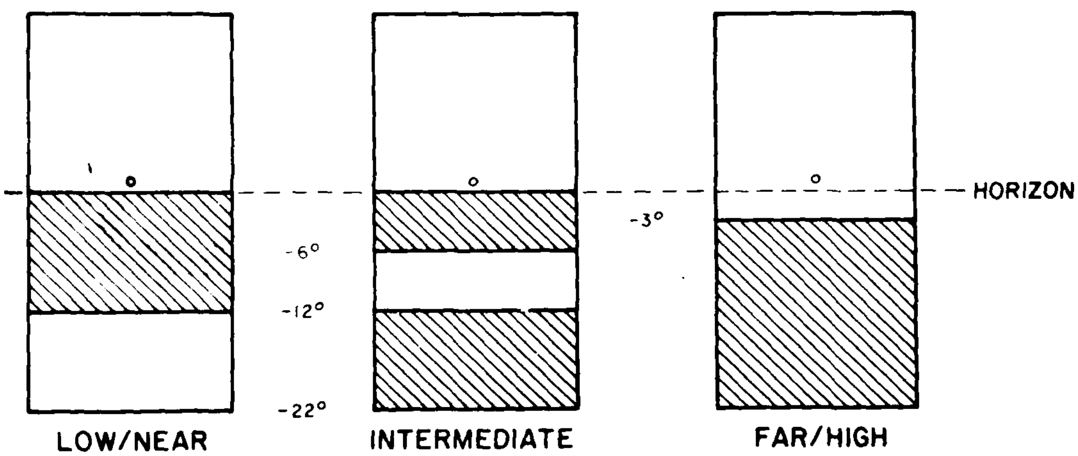


Figure 2. Masks that revealed entire upper half of visual scene and, repectively, Near/Low, Intermediate, and Far/High horizontal bands of texture.

In this experiment, the scenic content was also manipulated. The first scene was a backlighted projection screen with resolvable texture. This screen was viewed through the moon machine with a large (25-inch diameter, 25-inch focal length) collimating field lens in between, as diagrammed in Figure 3. The second scene was a photographic slide of the vista across the Urbana campus from the sixth floor of the psychology building in Champaign. This was backprojected onto the screen. The third view was the natural vista from the sixth floor of the psychology building. Use of the collimating lens in the first two conditions thus equated the vergence of the light from the screen, slide, and actual vista, all appearing to emanate from optical infinity.

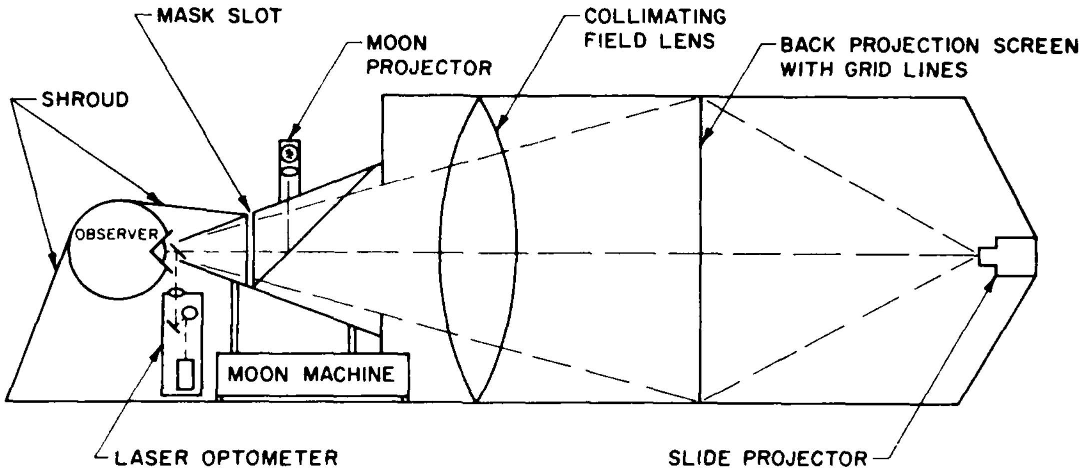


Figure 3. Experimental viewing system showing observer, moon machine with mask slot, collimating field lens, viewing screen, and slide projector.

In a repeated-measures design with masks and scenes as factors, each subject, on successive days, viewed the three scenes. On each day the viewing sequences of the four masking conditions were counterbalanced for the eight subjects.

In a second experiment subjects viewed the natural vista through corresponding windows of the fifth through eighth floors of the psychology building. In this case only the intermediate mask was used. It exposed a horizontal band depressed between 6 and 12 degrees below the line of sight to the moon. Once again the sequences of viewing from the floors were counterbalanced for the eight subjects. The purpose of this manipulation was to vary the absolute distance to visible texture while holding its depressed angular position (retinal locus) constant.

For each condition in each experiment, each subject made two judgments of the size of the simulated moon after which accommodation was measured. This sequence was repeated once resulting in four size judgments and two measures of accommodation for each subject, the average values of which were taken as raw data. Independently of these measurements, accommodation responses in the dark (dark focus) and to the comparison moon viewed against a black backdrop were measured. Here, the comparison moon was adjusted by the experimenter to subtend the same visual angle as the simulated moon.

## RESULTS

In these experiments, the subjects' measured dark focus values were subtracted from their raw accommodation scores to produce measures of accommodation shift. In Figure 4a are plotted the mean accommodation shift scores and the mean apparent size scores for the Near/Low, Intermediate, and Far/High masks for the Backlighted Screen with Grid viewing condition. Both apparent size and accommodation shift bear a strong but slightly J-shaped relationship to the retinal locus of visible texture.

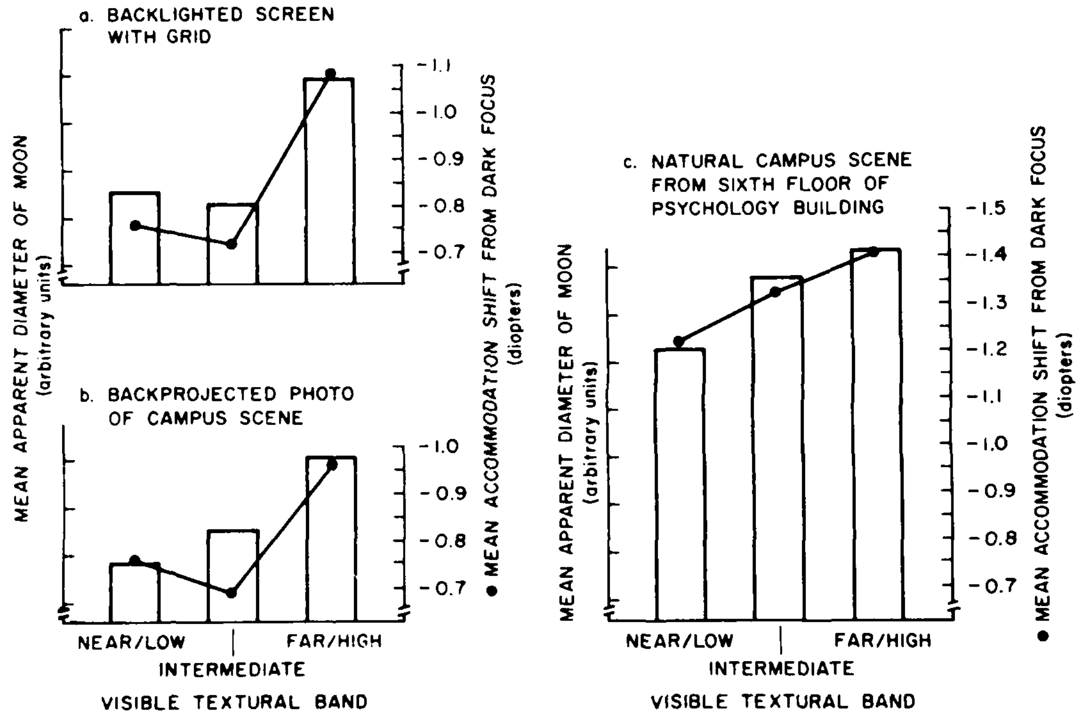


Figure 4. Accommodation shifts (bullets) and apparent size judgments (bars) of subjects viewing simulated moon through Near/Low, Intermediate, and Far/High masks in (a) Backlighted Screen, (b) Backprojected Photograph, and (c) Natural Campus Scene viewing conditions.

Specifically, the lowest values for both apparent size and accommodation are with the Intermediate mask and not the Near/Low one. Note, also, that the value for the Far/High Mask is quite different from the values for the Near/Low and Intermediate masks (which are quite close to each other). This finding holds for both apparent size and accommodation shift. Figure 4b is an analogous graph for the Backprojected Photograph of Campus scene. Both the relative and absolute numerical results are similar to those obtained without the photograph.

In Figure 4c are the corresponding data for the Natural Campus Scene from the Sixth Floor condition. These data are unlike those of the first two viewing conditions in that the accommodation shift responses are systematically more distant. Also, the apparent size judgments are larger than those obtained in either of the first two viewing conditions.

Given three masking conditions and measures for apparent size and accommodation shift, if means are plotted in a scatterplot, there will be three points for each of the above viewing conditions. If these nine points are plotted on the same graph, Figure 5 is obtained. The correlation describing this swarm of points is 0.97.

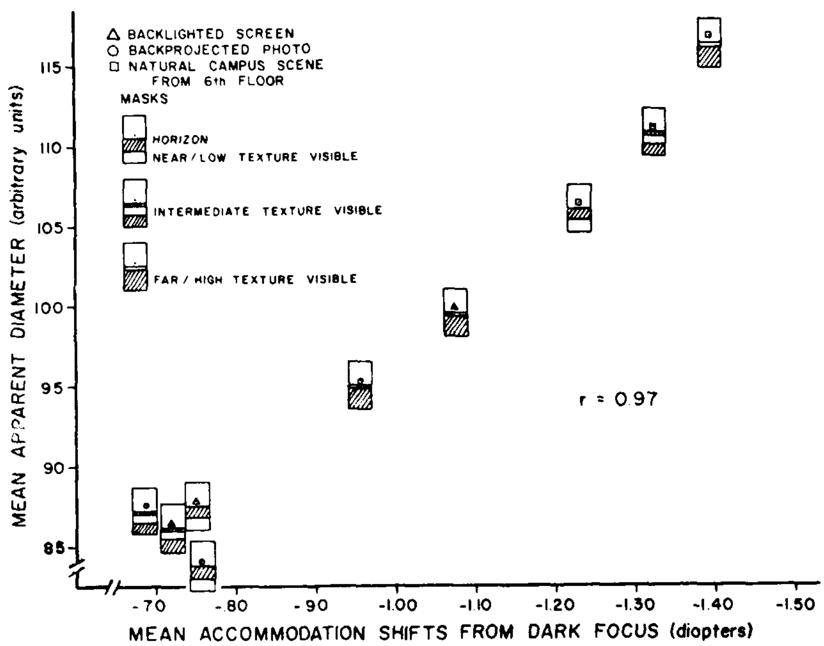


Figure 5. Mean apparent diameter of the simulated moon as a function of mean accommodation shift from individual dark-focus levels for eight subjects viewing three textural bands (masks) for each of three scenes (views).

Separate repeated-measures ANOVAs were conducted for each viewing condition. These results are shown in Table 1. As one progresses from the Screen to the Photograph to the Natural Scene the F-ratios for accommodation shift, though consistent in direction, decrease in strength, with responses to the three horizontal bands of texture in the Natural Campus Scene not differing reliably. An opposite pattern is found for the apparent size analyses, the more reliable differences being associated with manipulation of the natural vista.

Table 1

Summary of ANOVAs for Experiment 1

ACCOMMODATION SHIFT

| Viewing Condition | Mask Means | F-Ratio | p |
|---|---|---|---|
| Backlighted Screen | N/L -0.750 | 7.08 | > .01 |
| | I -0.719 | | |
| | F/H -1.075 | | |
| Backprojected Photo | N/L -0.756 | 4.08 | > .05 |
| | I -0.688 | | |
| | F/H -0.956 | | |
| Natural Campus cene | N/L -1.231 | 1.04 | |
| | I -1.325 | | |
| | F/H -1.394 | | |

APPARENT DIAMETER OF MOON

| Viewing Condition | Mask Means | F-Ratio | p |
|---|---|---|---|
| Backlighted Screen | N/L 87.78 | 3.01 | > .10 |
| | I 86.50 | | |
| | F/H 99.94 | | |
| Backprojected Photo | N/L 84.09 | 2.37 | > .15 |
| | I 87.59 | | |
| | F/H 95.28 | | |
| Natural Campus Scene | N/L 106.41 | 3.75 | > .05 |
| | I 111.09 | | |
| | F/H 116.75 | | |

Data from the second experiment in which subjects viewed the natural campus scene through the intermediate mask from the fifth through eighth floors of the psychology building were analyzed separately. If a plot of the mean accommodation shifts and apparent sizes for these four floors is made, an inverted V results. This plot was superposed on Figure 5 so that these results could be compared with the results of the first experiment. This is Figure 6.

The data for this second experiment are depicted in Figure 7 in a manner analogous to Figure 4. While the accommodation measures follow a pattern similar to those obtained in the first experiment, apparent size follows the pattern found by Iavecchia et al. (1978). However, the accommodation measures do not differ reliably from one floor to another. Additionally, the apparent size scores from one floor to the next do not differ reliably.

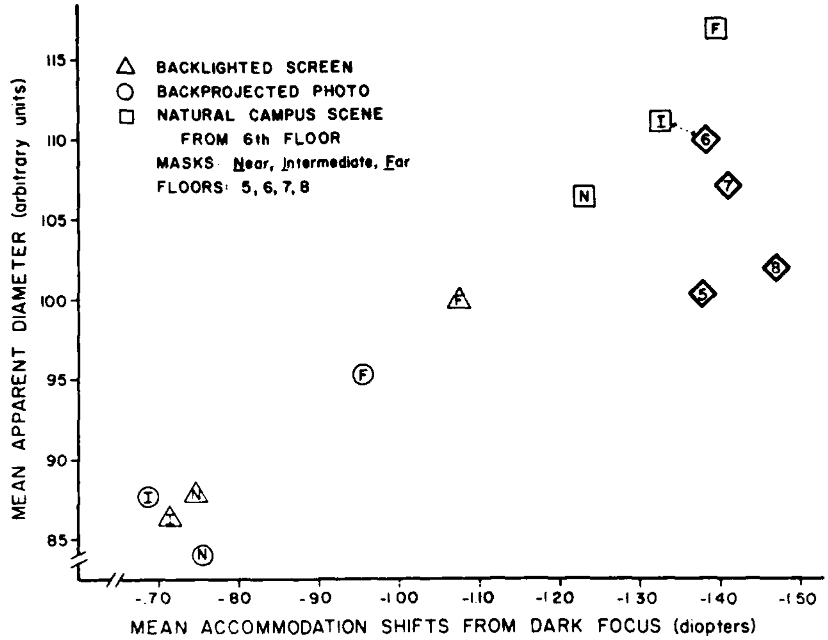


Figure 6. Mean apparent diameter of the simulated moon versus mean accommodation shifts for eight subjects viewing the campus vista through the Intermediate mask from various floors of the psychology building. (Means from Figure 5 are repeated for comparison.)

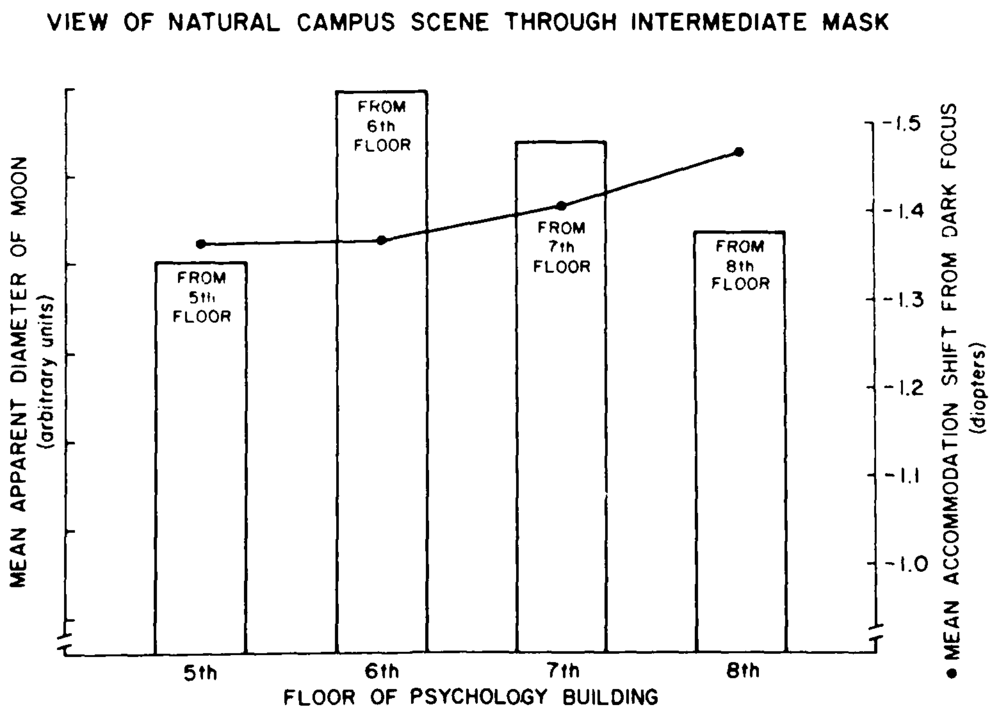


Figure 7. Accommodation shifts (bullets) and apparent size judgments (bars) of subjects viewing simulated moon through Intermediate mask from fifth, sixth, seventh, and eighth floors of the psychology building.

Two additional results may be noted. First, the correlation of each subject's dark focus with his/her accommodation shift to a black backdropped comparison moon (experimenter adjusted to be the same objective size as the simulated moon) was 0.96. Second, the correlation of the reciprocal of apparent diameter squared and accommodation shift was approximately 0.71, the highest obtained in any correlational analysis of transformed raw data (see discussion of scaling problems).

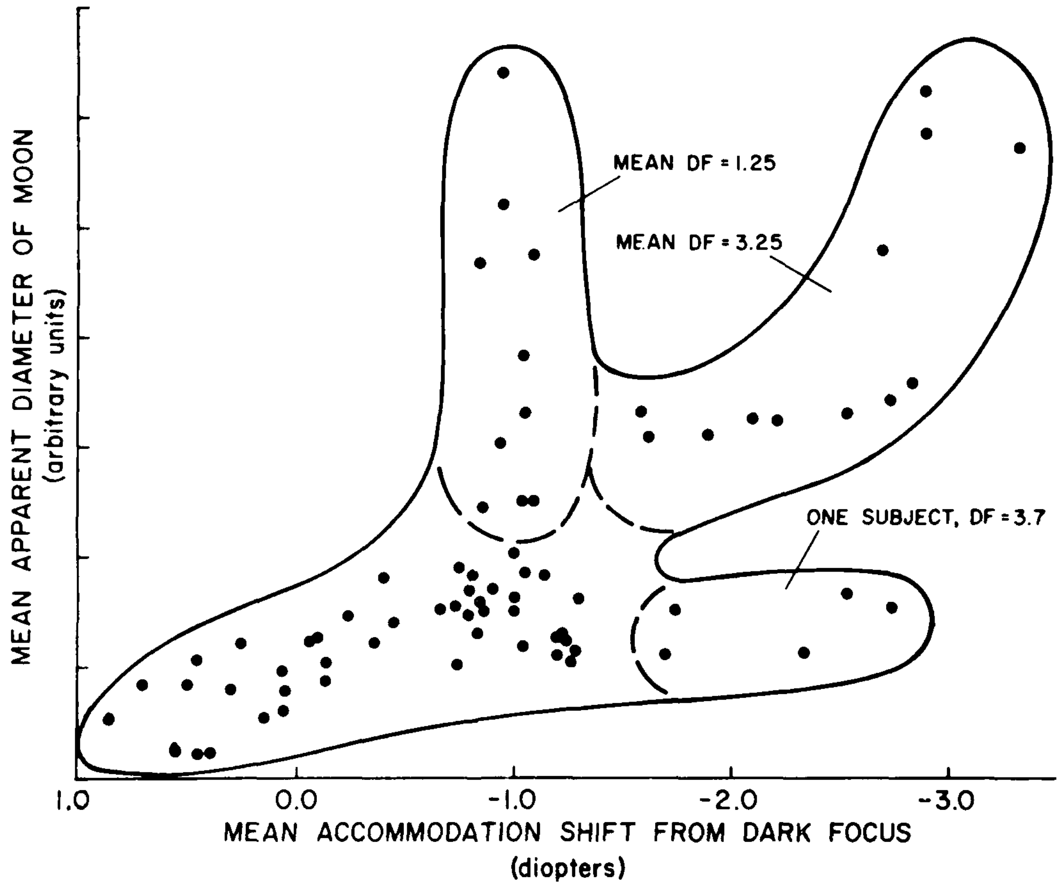


Figure 8. Scatterplot of 72 individual judgments of size and associated accommodation shifts of eight subjects viewing each of three scenes through each of three masks.

Finally, when all 72 data points (8 subjects x 3 masks x 3 viewing conditions) for apparent size judgments are plotted against accommmodation shifts, the graph takes on the appearance of a diverging fan (Figure 8). Thus it can be seen that while mean apparent size and accommodation responses for a group of subjects correlate almost perfectly, only about half the total variance is accounted for when individual differences in subject responses are not eliminated by averaging.

# DISCUSSION

The mean accommodation for all corresponding masks for the Backlighted Screen and Backprojected Photograph conditions are very similar. This indicates that a two-dimensional image of a real-world scene does not differ greatly in stimulus value from a textured surface without meaningful scenic content. The ANOVAs for these two conditions showed reliable differences due to the subjects' more distant accommodative responses to the Far/High mask (the one that revealed only texture immediately below the horizon). Seemingly, for accommodation to move outward toward an untextured target it is only necessary for some texture to be visible just below or near this target.

A different pattern of statistical reliablility was found between the Natural Campus Scene and either of the two optically collimated viewing conditions (Screen or Photograph). For the former, differences in the apparent size of the moon with the differently masked backgrounds were highly reliable; for the the latter, they were marginally reliable. Conversely, differences in measured accommodation to the differently masked views were less relaible for the Natural Campus Scene than for the two optically collimated conditions. Despite these converse statistical trends, the basic relationships between apparent size and accommodation were consistent for the three viewing conditions.

From these results we can conclude the following. The differential shifts in accommodation must be attributed to the experimental manipulations in view of the fact that the collimated moon when viewed against the black backdrop exerted an average outward accommodative shift of approximately 0.8 D that was almost uniform from subject-to-subject. The correlation between dark focus values and accommodation to the black backdropped collimated moon was 0.96.

Drawing on the results of the two collimated viewing conditions, changing the retinal locus of the stimulus results in changes in accommodation, accompanied by small and unreliable changes in apparent size of a collimated image, and the converse is true when we speak of real scenes. Apparent size judgments change as the retinal locus of real texture changes, but accommodation changes relatively little. Here, however, as in the study by Iavecchia et al. (1978), retinal locus of the accommodation stimulus and the actual distance to visible texture are confounded.

This confounding was examined in the second experiment. Here, accommodation changed little if any as subjects viewed the real scene at various distances with the retinal locus of the visible texture held constant. Changes in apparent size judgments, although also unreliable, followed the pattern found by the Iavecchias, increasing from the fifth to sixth floors and decreasing thereafter.

This lack of reliable effect of distance is hard to fathom, until one recalls the exact experimental manipulation made in this instance. Subjects viewed the real campus scene from four different floors of the psychology building through the Intermediate mask in every case. However, the results of our first experiment indicated that the texture revealed by the Intermediate mask had the weakest pull from the dark focus. Thus, it can be seen that the choice of the Intermediate mask was coincidentally inappropriate.

Main Findings

1. Viewing a collimated image of a real scene is not the same as viewing the actual scene, even when the real scene extends well beyond the nominal distance of optical infinity. Most likely the difference arises because all of the collimated image is at the same optical distance, infinity. In the real situation, however, different objects in the scene, in addition to being beyond the nominal distance of optical infinity, are at different real distances from the observer.

2. The combined results of these two experiments imply that for natural vistas the retinal locus of resolvable texture is the primary determinant of apparent size, and for collimated images it has a strong effect on accommodation.

3. Whatever the nature of the relationship may eventually turn out to be, the overall correlation between apparent size and accommodation averaged across subjects is in excess of 0.9.

Possible Relationships

Consider now the possible functional relationship between apparent size and accommodation shift. Although a plot of the mean apparent size versus mean accommodation shift (from dark focus) is linear with a high correlation (see Figure 5), a plot of the 72 individual data points leading to these means is not (see Figure 8). This plot of accommodation shift versus apparent size is in the form of a diverging fan, and each of the two major and one minor vanes of this fan represents a different level of dark focus for the particular subjects in this limited sample of eight.

One interpretation of this strange finding might be that the relationship between apparent size and accommodation shift is different, yet still linear, for persons with substantially different dark focuses. That is, the slope of the relationship between apparent size and accommodation depends in some complicated way on the individual's dark focus. Since neither accommodation shift nor apparent size was manipulated independently, any statement concerning a possible causal relationship would be speculative.

Still considering the possible functional relationship between apparent size and accommodation shift, recall that a second-degree inverse transformation of apparent sizes produced the largest correlation with individual (as opposed to group) accommodation shifts. This suggests that the function describing apparent size judgments of a lighted disk (the simulated moon) may be a second-degree polynomial or higher. Thus any linear regression equation would leave the variance associated with differential individual responses unaccounted for.

Scaling Problems

Another observation relevant to this experimental approach concerns the dioptric scale. The dioptric (D) scale implies that human eyes are relatively insensitive to changes in real distance from optical infinity to one meter in comparison to changes in distance within one meter. That is, large changes in the actual distance (optical infinity to 1 m) are translated into small changes on the dioptric scale (0 D to 1 D). Conversely, at the near end of the dioptric scale, substantial dioptric changes (10 D to 15 D) are representative of small changes in actual distance (0.1 m to 0.067 m).

The dioptric scale does not seem appropriate to reflect the actual accommodative dynamics of the human visual system. Perhaps this should not be tremendously surprising since the use of the dioptric scale here represents the convenient though not entirely appropriate imposition of a physical relationship (the lens maker's formula) onto a human system.

## FURTHER RESEARCH

These results are provocative and, in conjunction with the results of Iavecchia et al. (1978) and Simonelli and Roscoe (1979), strongly suggest that there is a systematic relationship involving size judgments and visual accommodation. The point is that there is obviously a system of variables operating to produce the phenomenon of misjudgments of size. This system most likely contains visual accommodation, the nature of the textural stimuli impinging on the periphery of the retina as well as the fovea or parafovea, perhaps individual differences in dark focus, and other visual and environmental factors.

Although some systematic relationships evidently exist among such variables and judgments of size, these relationships are clouded by the limitations of the dioptric scale. An effective approach should be capable of dealing with systems of variables in a formal and coherent manner. It should not be constrained by reliance on existing potentially inappropriate scaling of relevant physical and psychological factors. The question posed is not a physical one. The interest is in the human psychophysiology of misperceptions of size and distance. The appropriate and most fruitful approach will be one that defines the functional relationship of this system of environmental and visual factors to judgments of size and distance.

## ACKNOWLEDGMENT

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