15 June 1962, Volume 136, Number 3520 SCIENCE

The Moon Illusion, I

Explanation of this phenomenon was sought through the use of artificial moons seen on the sky.

Lloyd Kaufman and Irvin Rock

Since antiquity men have puzzled about the fact that the moon and sun appear larger over the horizon than at the zenith. The distance to the moon is actually somewhat greater at the horizon (because the tangent to the earth is greater than the distance to the earth's surface along the line joining the centers of earth and moon), so the retinal image of the horizon moon is a fraction *smaller* than that of the zenith moon. The phenomenon cannot be explained by differences in refraction based upon differences in the angle of incidence to the earth's atmosphere. Logically, refraction could be thought to displace an image, but enlargement would require refraction in different directions, as is the case with a lens. In point of fact there is a displacement effect, often noticeable in the setting sun, where the vertical diameter is foreshortened so as to yield the impression of an ellipse. But, again, this effect actually produces a *smaller* image of the horizon object. In any case, all lingering doubt about this explanation can be laid to rest with the realization that photographs of the moon in the different positions yield no measurable difference. Hence, the effect has nothing to do with atmospheric optics.

We are, therefore, dealing with an illusion in which retinal images of approximately equal size yield quite different phenomenal impressions of size, based upon differences in perceived direction. There are, however, two ways of understanding the phrase "differences in perceived direction" in this context. In relation to the observer—that is, egocentrically defined—the horizon moon is "straight ahead," whereas, to view the zenith moon, the observer must raise his head or his eyes, or both. When the observer changes his position—as when he is lying supine—the zenith moon, not the horizon moon, is egocentrically "straight ahead." On the basis of the egocentric definition one would have to predict that the zenith moon would appear larger than the horizon moon to an observer lying supine. On the other hand, from an objective standpoint, one can say that the horizon moon is seen at the point where the terrain meets the sky, whereas the zenith moon is seen surrounded by sky on all sides, apart from terrain or horizon. Here the two positions of the moon are distinguished in terms of their geographical location relative to an observer on the earth's surface, and changes in the position of the observer's eye or head are considered irrelevant. The two ways of defining the difference in direction have led to different theories in explanation of the moon illusion.

A theory based on the second approach was put forth by Ptolemy, among others, to the effect that the presence of the terrain creates the impression that the horizon moon is farther away than the zenith moon because the filled space between the observer and the horizon produces an impression of greater extensity than the unfilled space between the observer and the zenith. If this were true it would follow that the horizon moon would look larger than the zenith moon, as shown in Fig. 1. Many people find this point hard to grasp because it seems paradoxical: If something is perceived as farther away shouldn't it appear smaller, not larger? The confusion lies in the fact that in this case the size of the optical image remains unchanged. It would require a *larger* object to yield the same image from a greater distance.

This theory can now be restated in the language of the psychology of size perception. It is a well-known fact that the apparent size of an object depends not only on the size of the retinal image or visual angle but on the distance as well. Within certain limits, objects do not appear to vary substantially in size when viewed from varying distances, despite the fact that the size of the optical image varies inversely with distance. This phenomenon is known as size constancy. It is as if the observer took the distance into account in perceiving the size of the object. In line with this same reasoning, where the visual angle remains constant but where the distances are registered as different, the apparent size will change. In the case of an afterimage projected on surfaces at different distances, the apparent size is a direct function of the distance of the surface, a relation known as Emmert's law. The moon illusion can be considered a special manifestation of Emmert's law, or a manifestation of a similar functional relationship, if it is true that the registered distance to the horizon moon is greater than that to the zenith moon, since the visual angle of the moon remains approximately constant. In fact, on the basis of such a possible difference in registered distance, psychologists would have to pre-

Dr. Kaufman is section head for human factors at the Sperry Gyroscope Company, Great Neck, N.Y. Dr. Rock is a member of the department of experimental and clinical psychology, Graduate School of Education, Yeshiva University, New York.

dict a moon illusion even if one had never been observed (*1*).

But is it true that the horizon moon appears farther away than the zenith moon? Boring concluded not too long ago that quite the contrary is the case (*2*). He asked observers which moon appeared nearer, and they were unanimous in saying that the horizon moon did. We will return later to this point, since we believe there is a fallacy involved in putting the question this way. For the moment it will be worth while to follow Boring's reasoning. If it is the case that the horizon moon does not seem more distant, then theories such as Ptolemy's are invalid. Hence it seemed to Boring that there was little to be gained from sticking to the distinction between "horizon" and "zenith" as objectively defined. He therefore proceeded to examine the implication of the egocentric definition, that the crucial difference for the two moon directions is a difference in the angle of regard.

This, however, is a hypothesis requiring experimental proof, and if one attempts to test it, the question of method arises. It is hardly satisfactory to compare the apparent sizes of the moon in its different celestial positions under natural conditions, for two reasons. First, one must depend on memory in comparing the size of the moon as seen previously in one position with the size of the moon as seen in a different position. Second, no measure of the effect is obtained. Although there have been various attempts to measure the illusion in the past, Boring is to be credited with the first thoroughgoing experiments on the moon illusion. His method was as follows. While viewing either the horizon or the zenith moon, the observer was shown a series of disks projected on a screen 3.5 meters away and off to one side. He was told to select the disk which seemed to match the moon in size. Comparison of the average value for many such determinations made by each subject for the horizon moon with the average for determinations for the zenith moon gave a measure of the moon illusion.

The Angle-of-Regard Hypothesis

Using this method, Holway and Boring (*3*) proceeded to test the hypothesis that the illusion is based on the angle of regard. They first showed that an illusion was obtained. For three observers the average ratio of the diameter of the horizon-moon matching disk to that of the zenith-moon matching disk was 1.67. They next showed that the illusion was reversed (with a ratio of 1.47) when two observers viewed the zenith moon from a supine position, so that from the egocentric viewpoint it was "straight ahead," and viewed the horizon moon by bending their heads backward from the supine position, so that it was "elevated." It should be noted, however, that in spite of these quantitative results, to these observers the zenith moon viewed from a supine position seemed less large than the horizon moon viewed from an upright position. In a second paper (*4*) Holway and Boring reported an attempt to create the illusion by using a reflected image of the moon in a front-surface mirror, so that the observer's response would be independent of the actual position of the moon in the sky. Using a reflected moon as the standard, the investigators compared the illusion obtained with the eyes raised and the head level with that obtained with the head raised and the eyes level. As their own subjects they found an illusion of 2.0 with the eyes raised and a ratio of 1.0, or no illusion, with only the head raised. In further experiments they found that, regardless of the actual position of the moon, they could obtain an illusion if, and only if, the eyes were raised with respect to the head in one case and level in the other. They found a similar effect for eyes lowered with respect to the head. In other words, Holway and Boring analyzed the angle-of-regard hypothesis and, using the method described, found the crucial factor in looking "up" to be the angle of the eyes with respect to the head. In a further experiment Taylor and Boring (*5*) found that the illusion is dependent upon binocular vision and disappears for monocular observation, provided this is not preceded by binocular observation. This fact suggested that the cause of the illusion is certain changes, either in convergence innervation or in torsion, when the eyes are raised. But since such changes would presumably yield cues of nearer distance, they should make the zenith moon appear nearer (and this, it will be recalled, is the opposite of what Boring and his colleagues believed to be the case). Hence, they concluded that there is still no satisfactory theory of the moon illusion.

Grounds for Caution

There are, however, three reasons for caution in accepting the conclusion that the angle of the eyes with respect to the head is crucial for the moon illusion. The first concerns the basis for rejection of the "apparent-distance" hypothesis. Suppose that the moon illusion is based on a difference in the perceived or registered distance of the two moons, and that an observer experiences the illusion. If he is now asked which moon seems the more distant, he is comparing moons which already differ in apparent size. It is natural for him to reason that the larger moon is closer. This is more of a judgmental than a perceptual reaction, and the judgment may dominate when the observer is asked this question. He may not be aware that the horizon moon appears larger to begin with because of the stimulus of the terrain. As noted in (*1*), the observer need not necessarily be aware that a stimulus correlate of distance is registering, and thereby affecting apparent size. When asked about the distances of the two moons, therefore, he may fall back upon what seems an obvious clue—namely, the different apparent sizes of the moons.

We have performed two experiments that support this argument. In the first we sought to demonstrate that subjects will report as farther away whichever moon is smaller. Eight subjects were shown a horizon and a zenith disk or "moon" (by a method described later in more detail), one disk being set so as to yield a much larger impression than the other. The subjects were unanimous in reporting the smaller-appearing disk as farther away, regardless of whether it was seen over the horizon or at the zenith. This finding deprives Boring's argument on the apparent distance of the two moons of its crucial significance. It shows that whichever moon appears larger will be judged nearer, quite apart from any other factors that produce differences in perceived distance.

In the second experiment we sought to show that if one does not use the moon itself (which so readily produces the effect just described) as the object with which to gauge apparent distance, it is possible to obtain direct evidence in support of the assumption that the horizon "sky" seems farther away than the zenith (we are assuming the moon to be coplanar with the sky).

Ten subjects, looking at a sky without moons, were asked to scan the sky and to try to perceive it as a surface. They were then to report whether an imaginary point over the horizon seemed nearer or farther than such a point at the zenith. Nine of the ten reported that the horizon sky seemed farther away. The tenth subject said the horizon sky and the zenith seemed equidistant. This finding corresponds to the belief, which goes back at least to the 11th century, that the sky appears somewhat flat. Smith, in 1738, actually tried to determine the degree of flatness by measuring the half-arc angle (*6*). The observer points to that spot in the sky which is perceived as bisecting the arc of sky connecting the horizon with the zenith. The angle which this direction forms with the ground is the half-arc angle. A hemispherically shaped sky would yield a 45° angle a_0, but a flattened sky would yield a smaller angle a_1 (see Fig. 1). The most recent attempt to determine this angle was made by Miller (*7*), a student of the meteorologist Neuberger (*8*); Miller found its angle to be in the neighborhood of 30° and to vary inversely with the distance of the horizon and directly with the elevation. In other words, his data supported the hypothesis that the apparent flattening is a function of perceived distance along the ground plane.

Thus we have shown that the distance hypothesis is viable, but in the face of the evidence on eye elevation it may seem superfluous—the relevant factor has already been isolated. This leads to the second reason for caution in accepting this evidence as conclusive—namely, the question of methodology. Is it possible meaningfully to compare, in size, an infinitely distant object, whose size is therefore more or less indeterminate, and a nearby object? It would seem that the two are incommensurate. If the observers are comparing lineal size, their matches imply that the distant moon appears to them to be between 5 and 17 inches in diameter. It seems unlikely that many observers would agree that the apparent size of the moon lies within these limits, and even unlikely that the same observer would make a similar judgment under somewhat different conditions of measurement. In fact, Taylor and Boring noted that if the observer moved backward from the screen so as to view from a point farther than 3.5 meters away the disk which he had selected as a match, it was no longer acceptable. Yet we know that the apparent lineal size of this disk would remain fairly constant. This suggests that the observers were attempting to match visual angle (thus, backing away from the screen would cause the disk to appear too small), but the fact is that the visual angle of the disk selected for even the zenith moon was 4 to 10 times that of the moon. Therefore, it appears that the choice was not a match in lineal size or a very accurate match in visual angle. Hence there seem to be serious difficulties connected with such a method. Boring and his associates were well aware of this problem and in one experiment sought to overcome it by requiring the observer to compare a zenith and a horizon moon directly with one another. They accomplished this by using the front-surface mirror to show the moon in a position different from its actual position in the sky. The observer then compared two reflected moons. Boring and his co-workers obtained an estimated illusion ratio by this technique and also again obtained evidence in support of the eye-elevation hypothesis. This technique is clearly preferable to their earlier method because it duplicates the conditions of the moon illusion—that is, the observer is comparing two moons each located in the sky at optical infinity, in different positions. In the method that we

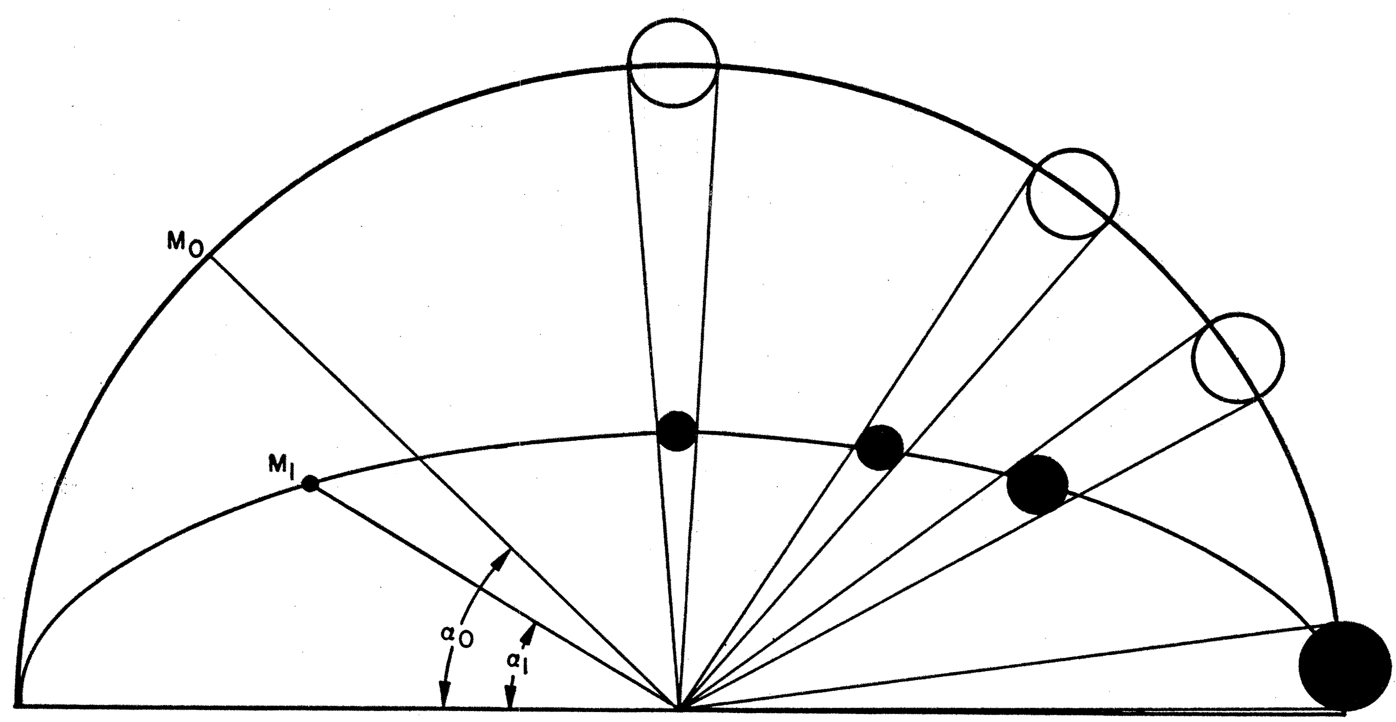

Fig. 1. Effect of the apparent distance of the moon on its apparent. size. Top arc, The true position of the moon; all points on the curve are at the same distance from the observer. Bottom arc, The apparent distance of the moon according to the theory. Solid circles: Resultant differences in perceived size of the moon. The figure also illustrates the effect of apparent shape of the sky on the half-arc angle measure *a*. M_0, Midpoint of actual arc connecting zenith and horizon; M_1, midpoint of perceived arc connecting zenith and horizon. [After Smith (*6*)]

Table 1. Average illusion ratios for the eyes-level and eyes-elevated conditions. Aperture diameter for the standard, 0.093 inch.

Subject	Eyes level			Eyes elevated		
	Horizon standard	Zenith standard	Combined	Horizon standard	Zenith standard	Combined
1	1.72	2.35	2.03	1.72	2.35	2.03
2	1.72	1.74	1.73	1.72	1.57	1.65
3*	1.00	1.11	1.06	1.17	0.84	1.00
4	1.36	1.44	1.40	1.26	1.23	1.25
5	1.05	0.87	0.95	1.14	0.96	1.05
6	1.15	1.12	1.13	1.15	0.93	1.02
7	1.54	1.27	1.41	1.72	1.63	1.67
8*	1.72	1.74	1.73	1.72	2.00	1.86
9*	1.72	1.54	1.63	1.55	1.57	1.56
10	1.72	1.40	1.56	1.46	2.00	1.73
Mean			1.46			1.48
Standard deviation			0.32			0.36

* These subjects were tested after dark.

evolved this feature was therefore preserved, and, in addition, provision was made for actual measurement (Boring's method only allowed for a verbal estimate of the illusion ratio).

The third reason for caution is the observation that, if one tests it directly in daily life, the moon illusion persists in spite of changes in eye or head elevation. The horizon moon remains phenomenally large even if one views it with head tilted forward and eyes raised; the zenith moon remains phenomenally small even if one views it with head tilted back and eyes straight ahead, or if one views it while lying supine. At least this has been our experience, and, as noted above, the observers in the experiments of Holway and Boring were struck by this fact even while yielding quantitative data of a contradictory nature. For all these reasons, we felt it desirable to reexamine this problem with a different method.

The Eye-Evaluation Hypothesis

We sought a technique whereby the observer would compare a horizon object and a zenith object localized on the sky and where, in addition, one object could be varied in size to achieve a subjective match. The device used has two major features. One is a combining glass through which the observer looks out at the sky (see Fig. 2). When the glass is placed at a 45° angle to the line of sight it can reflect into the eye a beam of light which is perpendicular to the line of sight. If a slide containing a small circular aperture is placed between a light source and the combining glass, the observer will see a luminous disk in the direction of the sky. The other feature is a collimator placed in front of the aperture so that the virtual image of the aperture seen through the combining glass will be at optical infinity (*9*). Otherwise the observer might localize the disk somewhere between himself and the distant sky. Two identical units were constructed; one serves as a horizontal moon and the other as a zenith moon. Either can be used as the standard or, by changing the size of the aperture, as the variable. In this way it is possible to measure the illusion. With batteries as the source of power for the light, the apparatus can easily be taken to any desired outdoor location.

In the first series of experiments we sought to determine whether an illusion was obtained with our apparatus and, if so, whether it was based upon elevation of the eyes. In these experiments the collimating lens was 3⅜ inches in diameter; this made binocular viewing possible. The combining glass was 10 by 12 by 1/16 inches. Although the glass was not silvered, it did not produce an objectionable double image. The apertures were drilled into aluminum slides which could be inserted at one end of a box containing a diffuse light source. The slides were placed 6 5/16 inches behind the collimating lens, since this was the focal length of the lens. The distance from the lens to the combining glass was 15 inches. The distance from the observer's eyes to the combining glass was between 10 and 15 inches (*10*) (see Fig. 3). One assembly, for viewing the horizon disk, was placed on a table. The assembly for viewing the zenith disk was mounted on an inclined board behind the observer; it projected an image onto a combining glass placed over his head. In these and other experiments the two assemblies were interchanged occasionally, and thus each was used to produce a horizon disk for some subjects and a zenith disk for other subjects. The apertures varied in size from 0.040 to 0.152 inch in diameter, in steps of from 0.010 to 0.012 inch, and subtended visual angles ranging from 0.34° to 1.38°. The aperture of the standard was 0.093 inch in diameter, subtending a visual angle of 0.80°, somewhat larger than the visual angle subtended by the moon, which is 0.5°.

Eyes raised versus eyes level with respect to the head. Two experiments were performed, with similar procedures and similar results, but we will describe here only the second, inasmuch as certain improvements were incorporated into its design. The apparatus was set up in Freeport, Long Island, in a spot yielding an unobstructed view for more than a mile to the horizon. Ten neighbors of one of us (eight men and two women) served as subjects, and all were naive concerning the point of the experiment. The experiment was conducted in the pre-twilight hours, except for testing of three subjects after dark.

Each subject was tested under two conditions—eyes level with respect to the head and eyes raised with respect to the head. In each case he viewed the horizon disk, or "moon" (hereafter referred to without quotation marks), from an erect position. In the control or eyes-level condition, in viewing the zenith moon, his head was maintained in position by means of a biting board, which he gripped with his teeth. The biting board was adjusted so as to force him to tilt his head to the desired position (so that his eyes were level with respect to his head) for viewing a near-zenith moon at an elevation of about 70°. In the experimental or eyes-elevated condition the biting board was not used for viewing the zenith moon; instead, the subject was required to stand erect and gaze upward naturally. Nor was a biting board or head rest used for viewing the horizon moon. Careful observation attested to the fact that each subject noticeably raised his eyes with respect to his head in viewing the zenith moon.

The subjects were first instructed to view the standard disk and to form an impression of its size. They then shifted their gaze to the variable, which, in the starting position, was much smaller or much larger than the standard. Their task was to indicate when the variable appeared equal in size to the standard. They were permitted to refer back to the standard at any time, and most subjects checked their match by doing so. In this, as in all subsequent experiments reported, the time lapse between viewing the standard and viewing the variable was only the length of time it took the observer to move his head from one unit to the other, no more than a few seconds at most. For viewing the zenith moon, the order of the eyes-raised and the eyes-level trials was balanced for the ten subjects. Under each condition the subject was required to make a setting for the horizon moon as the standard and one for the zenith moon as the standard; again the order of presentation was balanced. For each of these four conditions two determinations were made; in one the experimenter gradually increased the size of the aperture of the variable (ascending method) and in one he gradually decreased the size of the aperture (descending method). Moreover, the order of trials with the ascending and the descending methods were also balanced. The two measures were averaged in computing the results.

The results are given in Table 1 in terms of the average ratio of aperture diameters (illusion ratio) obtained for each subject under the eyes-raised and the eyes-level conditions. It should be made clear that when the horizon moon is the standard the subject must select a zenith moon larger than the standard in order to compensate for the illusion. The illusion is here expressed by the fraction

$$\frac{\text{Variable zenith setting}}{\text{Standard}}$$

When the zenith moon is the standard the subject must select a horizon moon smaller than the standard to compensate for the illusion. The illusion then is expressed by the fraction

$$\frac{\text{Standard}}{\text{Variable horizon setting}}$$

These ratios are given in Table 1, as are the averages for each subject.

The first thing to note is that under both conditions a considerable illusion is obtained. Both of the mean illusion ratios differ significantly from unity at the 0.01 level of confidence. In fact, there is reason to believe the ratio would have been even greater were it not for the fact that six subjects one or more times selected the variable at the end of the available series of apertures. The magnitude of the effect obtained can perhaps best be realized by comparing two circles whose diameters are in the ratio of 1.5:1, as in Fig. 4. This comparison brings out the fact that the ratios pertain to diameters, whereas the observer is comparing areas. The area ratio for the average setting in the experiment is over 2.1:1. Although many authors have estimated the moon illusion to be greater than this, it must be noted that they were depending upon memory, without the opportunity for measurement of any kind. Thus, we cannot be sure what the average magnitude of the true moon illusion is. Undoubtedly it varies for different conditions, as we shall try to

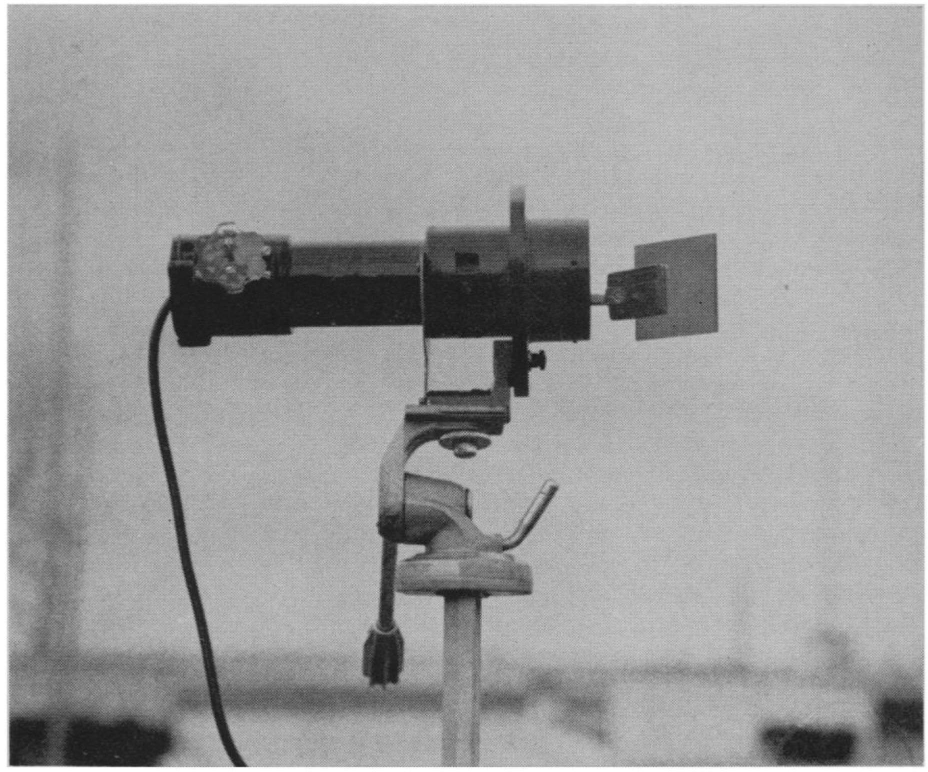

Fig. 2. A close-up of the improved moon illusion instrument, showing the combining glass on the right.

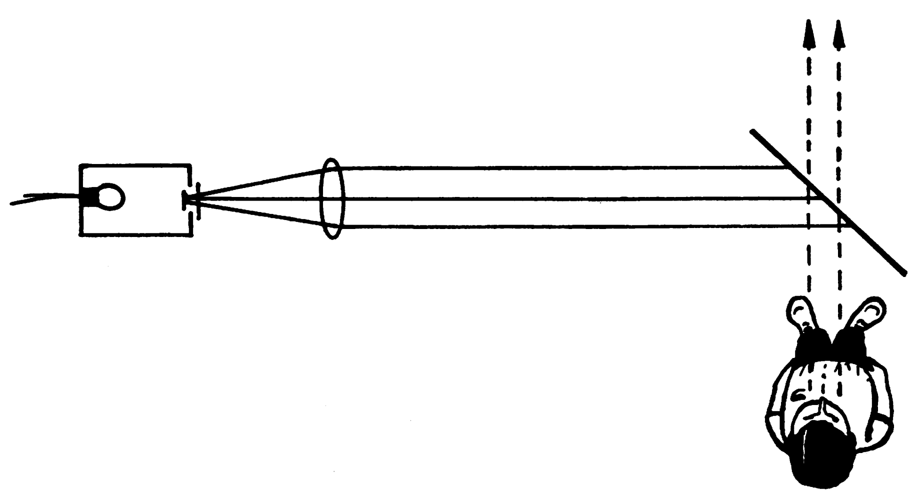

Fig. 3. A schematic diagram, as seen from above, of the apparatus for viewing the horizon moon.

bring out later. Suffice it to say, therefore, that we obtained a considerable illusion, which, incidentally, is not much smaller than that obtained by Boring *et al.*

The second thing to note is that an illusion is obtained without eye elevation—one of the same magnitude, in fact, as that obtained with eye elevation. This finding is in contradiction to the findings discussed earlier, according to which there should be no illusion at all under the eyes-level condition.

Fig. 4. Disks whose diameters are in the ratio of 1.5:1, illustrating the average illusion obtained in the first experiment.

Both moons in the same region of the sky. Because of the importance of this issue, it was decided to examine the eye-elevation hypothesis in an even more direct way. The subject was asked to compare two moons located in exactly the same region of the sky (at an elevation of approximately 20°), viewing one with his eyes level and one with his eyes raised with respect to his head. (The two assemblies were mounted side by side on a table which was tilted upward at a slight angle.) Such a test is independent of other parameters which might conceivably affect the outcome, such as differences in the geographical positions of the two moons and changing cloud conditions.

The subject viewed one moon, the standard, with his eyes raised and the other, the variable, with his eyes level, or he viewed the standard with his eyes level, and the variable with his eyes raised. He made ascending and descending determinations in each case, and thus made four settings in all. The biting board was placed before one unit and mounted in such a way that the observer had to tip his chin downward and raise his eyes approximately 30° with respect to his head to view the moon. The elevation of the eyes was carefully monitored by the experimenter. In viewing through the other unit, the observers were instructed to raise their chins slightly so that their eyes would be level with respect to the head. This elevation too was carefully monitored. Again the subjects (seven men and three women) were neighbors or friends; some of them had served in the first experiment. However, they were all naive with respect to the hypothesis under investigation. The experiment was carried out in the late afternoon (as were all the other experiments reported here, except for those conducted indoors).

In summary, the subjects viewed two moons in the same region of the sky at the same elevation, viewing one with eyes raised and one with eyes level. According to the eye-elevation hypothesis, the moon viewed with eyes level should appear larger. For this reason, the illusion ratios were derived as follows. The average value for settings of the variable when the "eyes-level" moon was the standard were divided by the value for the standard; the average value for settings of the variable when the "eyes-raised" moon was the standard were divided into the value for the standard. In Table 2 these two ratios are shown for each subject (values for the ascending and the descending methods are averaged), together with the combined average.

It is clear that there is no illusion here. We therefore conclude that, under these conditions of measurement, eye elevation does not yield the moon illusion.

Experiments in Darkness

If it is safe to assume that the eye-elevation hypothesis does not explain the moon illusion, there seem to be certain facts that are difficult to understand. Many years ago, Schur (*11*) obtained an artificial moon illusion indoors in large rooms, such as a Zeppelin hangar, in darkness. Holway and Boring report a sun illusion obtained by means of a dense filter which obscures all objects but the sun. This illusion was also found to be a function of eye elevation. More recently, Hermans (*12*) found that an object at a distance of 4 feet in a light-free room appeared to be approximately 6 percent smaller in area when viewed with the eyes raised 30° than when viewed with the eyes straight ahead. An explanation such as Ptolemy's would seem to be ruled out by such findings. Since we had been unable to demonstrate an effect of eye elevation out-of-doors, we decided to examine the hypothesis under conditions of darkness.

An experiment in a planetarium. In one experiment we sought to obtain a moon illusion in the Hayden Planetarium. We used slides with circular apertures in *f*5 projectors, taking care to have the two projectors equally distant from ceiling and horizon wall, respectively. The images were projected from the center platform to the zenith dome and to a horizon screen, each of which was 37.5 feet away. The image of the standard subtended a visual angle of about 1.5°. A series of eight comparison slides was used. The subject stood beside the two projectors so that he was approximately in the center of the planetarium. The room was dark. Even the small red fire lights were put out for a moment, and each projector was covered over, except for the lens. The instructions to the subjects and the measurement procedure were similar to those in the experiments described earlier, except that no attempt was made to control eye position. The average ratio for five male subjects, naive with respect to the experiment, was 1.03.

An experiment in a dark field. We were at a loss to explain why—in the light of Schur's data—we did not obtain an illusion. It can be argued, however, that even if Schur's experiment had also failed to yield an effect, such experiments do not preclude the possibility of obtaining an illusion under conditions of total darkness where the object seen is at optical infinity. The effect might not make its appearance when the objects compared are at a (discriminably) finite distance. Therefore we decided to ascertain whether an illusion is obtainable in total darkness when the objects compared are at optical infinity.

To do this, we simply placed the collimator apparatus in a light-free room and had the subject view one disk straight ahead and the other over his head. In this experiment the apertures were viewed directly through the lens, since there was no need to use the combining glass. In order that the subject should not be prevented from having an impression of great distance through prior perception of the wall and ceiling of the room, he was brought in blindfolded and did not open his eyes until the room was dark. He could not see the apparatus. He was seated on a chair with a head rest at the top that enabled him to rest his head tilted backward at an angle of 60° from the vertical. This meant that he had to raise his eyes 30° to view the overhead disk. The collimator assembly was mounted on a board placed vertically directly over the subject's head. The other assembly was mounted horizontally on a table in front of him, and there was a nose-rest for positioning his head. To minimize any glow from the scattering of light on the surfaces of the lens, the outer surface of each lens was masked with black paper, except for two holes of ¼-inch diameter placed 2.5 inches apart from center to center. By properly positioning the subject's head and having him check with each eye separately, it was possible to guarantee binocular viewing of the disk through the two holes. In other respects the procedure was like that of the experiments already described. Each subject made eight comparison settings, two ascending and two descending with the horizon disk as the standard and two ascending and two descending with the zenith disk as the standard. The order of presentation was balanced, as before. Ten graduate students of Yeshiva University participated; of these, seven were completely naive with respect to the experiment and three were fairly sophisticated concerning the moon illusion problem.

Table 3 gives the average illusion ratios for the horizon standard and the zenith standard. Although the ratio for most of the subjects is greater than 1 and the mean ratio of 1.03 is significantly different from unity, the magnitude of the effect is negligible (note the similarity to the results of the planetarium experiment). Whatever factor is operating here certainly cannot account for the moon illusion, since it leads to a barely discriminable difference in size. The effect is so slight that it could easily be due to an artifact, such as the diminution of the intensity of the image (*13*) through partial coverage of the pupil by the eyelid when the eyes are raised (*4*). Such an effect might show up in a dark-field experiment where other factors are eliminated, in spite of our failure to demonstrate an effect of intensity (as discussed later), or an effect of eye elevation under outdoor conditions. Our finding does confirm that of Hermans concerning eye elevation, and the magnitude of our effect is quite similar to his when the proper conversion from an area comparison to a diameter comparison is made (*14*). But although we confirm his finding, our observation fails to support his prediction that eye elevation would be found to yield a sufficiently large illusion to account for the moon illusion when the objects compared are at distances greater than 4 feet—the distance employed in his experiment.

In view of the negligible effect obtained, we may conclude that we do not substantiate Schur's findings, or the findings of Holway and Boring on a sun illusion with a dense filter. Although we cannot account for the difference, we do feel that our experiment constitutes a crucial test for any effect based on purely egocentric considerations, such as eye or head position. Since the subject tilts his head back 60° in viewing the overhead disk, this experiment is a test of the role of head elevation as well as of eye elevation. The results also can be taken to rule out gravity as a factor in the moon illusion, since it is obvious that two disks do not appear appreciably different in size simply because they are oriented in different directions with respect to gravity.

Table 2. Average illusion ratios for moons in the same region of the sky. Aperture diameter for the standard, 0.093 inch.

Subject	Standard: Eyes elevated	Standard: Eyes level	Values combined
1*	1.27	1.21	1.24
2*	0.96	1.22	1.09
3	1.00	1.28	1.14
4*	0.87	1.00	0.93
5	1.13	0.89	1.01
6	0.96	1.04	1.00
7	1.00	1.07	1.04
8	1.03	0.97	1.00
9	0.96	1.04	1.00
10	0.93	1.00	0.96
Mean			1.04
Standard deviation			0.08

* These were subjects 1, 2, and 4 of experiment 1.

Table 3. Average illusion ratios in dark-field experiment.

Subject	Ratio
1*	1.00
2*	1.02
3	1.06
4	1.01
5	0.98
6	1.07
7	1.00
8	1.03
9*	1.05
10	1.03
Mean	1.03
Standard deviation	0.028

* Subjects with prior knowledge about the moon illusion problem.

Color and Brightness

We have shown that the illusion cannot be understood in terms of an egocentric definition of the different positions of the moon or in terms of the direction of gravity. We have also shown that there is no reason to reject the alternative possibility—namely, that the important factor is the presence or absence of a visible terrain between observer and moon. Before we present additional evidence bearing on this alternative, however, it might be well to consider two other possibly significant differences between the horizon and the zenith moon that have often been noted: (i) the horizon moon occasionally appears reddish in color, whereas the zenith moon does not; and (ii) a full moon rises over the horizon at sunset and therefore appears less luminous than the zenith moon, seen against a dark sky. Although our knowledge about the effects of such differences does not lead to any clear-cut predictions concerning apparent size, these are nevertheless differences which must be examined.

Color. The red color of the horizon moon is a result of selective scattering of light of shorter wavelengths in the atmosphere. That the harvest moon appears large and red is well known, and the setting sun is redder than the zenith sun and seems enormous. To determine the role of color, an experiment was performed in which, for each subject, our artificial horizon moon appeared red during half the measurements and of normal color during the other half. The color was achieved by placing a Minus blue Kodak Wratten Filter No. 29 between the light source and the combining glass. The effect was not unlike that of the setting sun.

The apparatus in this and the subsequent experiments differed slightly from that described previously in that a smaller collimator was used, with a smaller front-surface, half-silvered, 2- by 2-inch combining glass which could be viewed through only one eye (see Fig. 5). The observer placed his eye directly in front of the glass so that the edges of the glass were barely visible in the peripheral field. With the other eye he viewed the sky directly; he was not aware that the artificial moon stimulated only one eye. The artificial moon appeared infinitely distant, as was the case when the binocular apparatus was used. The new apparatus had the advantage of compactness, since each unit was enclosed in a tube 2 inches in diameter and 7 inches long (*15*). Each unit was mounted on a tripod, and this was set at heights which permitted convenient viewing of the horizon moon and the zenith moon, respectively, from a standing position. The apertures in this apparatus varied from 0.015 to 0.132 inch in diameter. There were 16 sizes, which increased as a geometric progression. The aperture of the standard was either 0.047 or (in other experiments) 0.055 inch in diameter, subtending visual angles quite close to the visual angle subtended by the moon. The series of apertures provided a much greater range of sizes for comparison than was available with the earlier apparatus. The extreme values provided for deviation from the standard by a factor of approximately 3. Aside from the difference in apparatus, this experiment was similar to those described earlier. The horizon moon was viewed across Mitchel Air Field from the Hofstra College campus, a visible distance of about 2 miles on a clear day. Each subject was given two trials with the horizon moon red and two trials with the horizon moon of normal color (with the horizon moon as the standard in one of the two trials, the zenith moon as the standard in the other). The order of presentation was balanced. The zenith moon was normal in color for all trials. The results for seven male students were as follows: the mean ratio for horizon moon of normal color was 1.37 (standard deviation, 0.22); the mean ratio for horizon moon red was 1.34 (standard deviation, 0.19). There is thus no evidence that color can even partially explain the moon illusion, and the reddish color which the horizon moon often has must be a coincidental concomitant of the phenomenal size

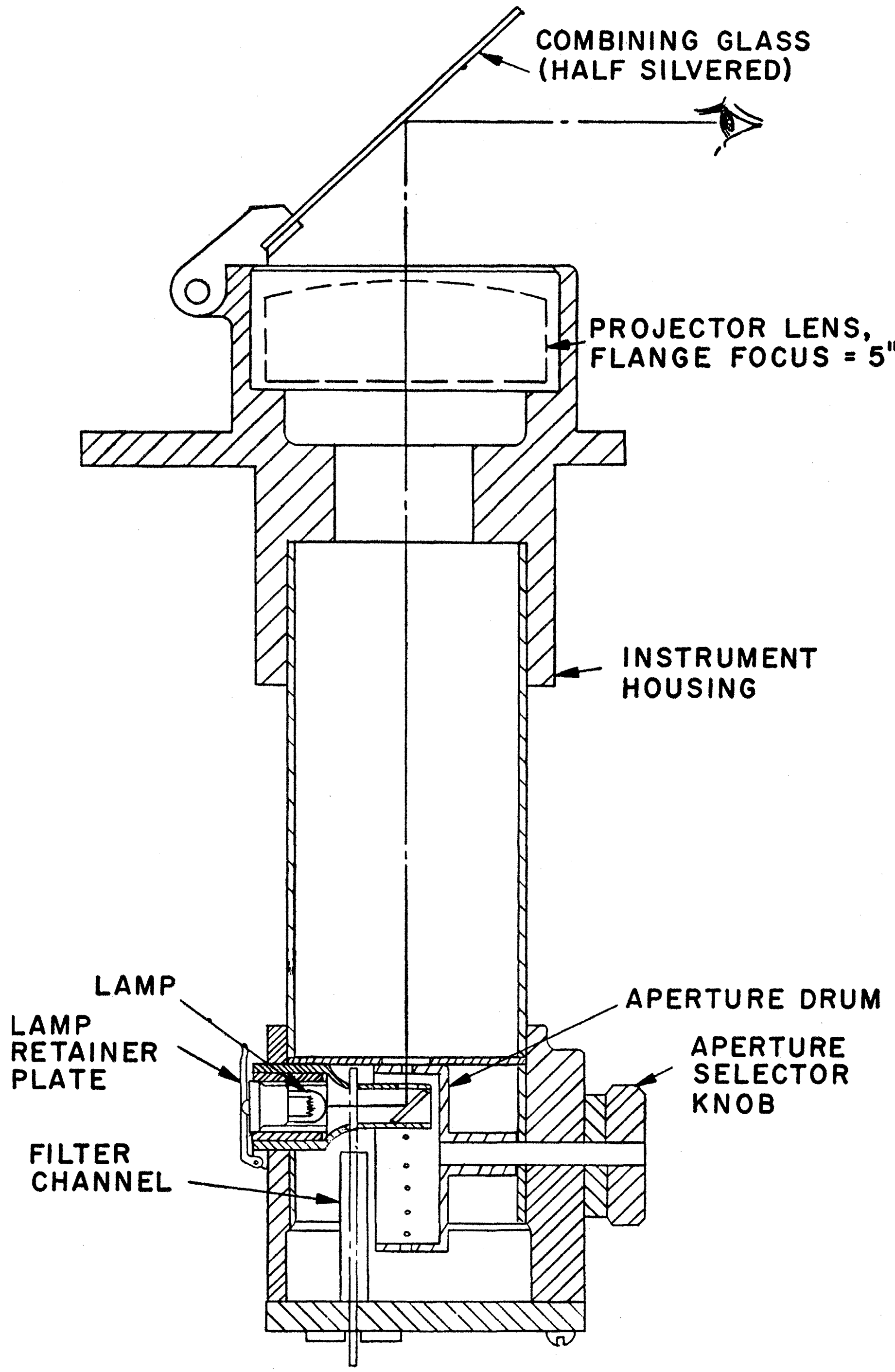

Fig. 5. Cross section of the improved moon-illusion instrument. The combining glass was at a 45° angle to the optical axis. The drum contains apertures of various sizes which can be moved successively in front of the diffusing reflector by turning the selector knob. The aperture selected is indicated by a number engraved on the knob. The collimating lens, 2 inches in diameter, is set at a point approximately 5 inches from the aperture (this distance is its focal length). The filter channel makes it possible to insert a colored or a neutral density filter. The entire instrument can be threaded into a conventional camera tripod.

Brightness. As noted above, there are also certain differences in the appearance of the moon with respect to brightness. It has been reported that brightness affects apparent distance (*16*), and thus there would seem to be some basis for Berkeley's belief (stated in 1709) that the moon illusion is based on the fainter appearance of the horizon moon (*17*). Berkeley reasoned that, through experience, we have come to associate distant visible objects which appear dim with large tangible objects. But there is the contradictory laboratory finding that dimmer objects actually look smaller than brighter objects of the same size (*13*). In fact, we have speculated that this might explain why we obtained a slight illusion in our dark-field experiment. This is an effect opposite to the one Berkeley suggests.

The full zenith moon appears brighter because the sky is darker later at night (that is, it appears brighter by contrast, and the greater brightness is due less than Berkeley thought to greater attenuation of the atmosphere in viewing the horizon moon), but the moon illusion exists whether or not the moon is full, and in general, the moon appears on the horizon at all times of day. Therefore, the horizon moon appears bright and dim equally often. Hence, there is little support for the brightness theory in purely logical considerations. Nevertheless, we performed an experiment analogous to the one on color. There was only one difference: in this case, for half the trials we reduced the brightness of the horizon moon by a factor of 0.5 by placing a half-silvered mirror between light source and combining glass. The horizon moon then appeared about half as bright as the zenith moon. For the other half of the trials the two moons were of equal brightness. The sky characteristics changed during the experiment from heavy cumulus clouds to clear, but the appearance of the sky was always the same for the two conditions of the horizon moon for each subject. The mean illusion ratios for eight Hofstra students (seven male and one female) were as follows: horizon moon of normal brightness, 1.41 (standard deviation, 0.30); horizon moon dim, 1.40 (standard deviation, 0.27).

We performed another experiment in which the difference in appearance approximated somewhat more closely the difference between the luminous zenith moon and the dimmer horizon moon. Both moons were set at the zenith, but one combining glass was placed before a double polaroid filter set in the positions of maximum attenuation (90° out of phase). This caused the sky to appear a dark blue-purple, and caused the artificial moon to seem luminous against it. The filter was 6 inches square; its sides were attached to black cloth which hung down over the observer's head on all sides so that he could see the sky only through the filter. The other moon was viewed against a normal daylight sky. The aperture in each unit was set at 0.047 inch, and the observers were asked to say whether the disks were equal or, if they were not, to say which was larger. Of ten graduate students of Yeshiva University, six said the disks were equal and four said the luminous moon was larger. This experiment therefore tends not to support the explanation of the moon illusion in terms of brightness.

There is thus no evidence that brightness can even partially explain the moon illusion. The dimmer appearance of the full horizon moon is, therefore, also a coincidental concomitant of its phenomenal size (*18*).

(This is part 1 of a 2-part article)

References and Notes

1. Although there has been some controversy as to the exact meaning of Emmert's law, we are interpreting it to mean that the apparent size of an image of constant angular size is a function of *registered* distance. Recently the view that size perception is based on the taking into account of distance has been challenged by various authors [H. E. Gruber, *Am. J. Psychol.* **67**, 411 (1954); W. Epstein, J. Park, A. Casey, *Psychol. Bull.* **58**, 491 (1961)]. It has been found that perceived distance as measured by judgments of distance does not correspond to the variations in "distance" demanded by changes in perceived size. We believe this challenge stems from a misunderstanding of the meaning of "distance" in this context. What is taken into account is the distance as *registered* by certain stimulus correlates, regardless of whether or not the observer is always consciously aware of such correlates. Stimulus correlates that normally accompany changes in distance may be registered by the brain and automatically affect size perception without conscious recognition of this effect on the part of the observer. For a recent illustration of this fact, see E. G. Heinemann, E. Tulving, J. Nachmias, *Am. J. Psychol.* **72**, 32 (1959). Hence, distance correlates which affect judgments of size may not be accurately reported in judgments of distance.
2. E. G. Boring, *Am. J. Phys.* **11**, No. 2 (1943).
3. A. H. Holway and E. G. Boring, *Am. J. Psychol.* **53**, 109 (1940).
4. ———, *ibid.* **53**, 537 (1940).
5. D. E. Taylor and E. G. Boring, *ibid.* **55**, 189 (1942).
6. R. Smith, *A compleat system of opticks* (Cambridge, England, 1738), vol. 1.
7. A. Miller, thesis, Pennsylvania State College (1943).
8. H. Neuberger, in *Compendium of Meteorology* (American Meteorological Society, Boston, Mass., 1952).
9. A collimator is a positive converging lens used with a small light source placed at its focal point. The rays of light coming through the lens from any point on the source are then parallel, as if emanating from infinity.
10. The fact that this apparatus requires the observer to look through glass in viewing the sky might be considered a drawback because the moon illusion often disappears when the sky is viewed through a window. In the arrangement described, however, the observer is outdoors, and the glass, which is not framed, subtends a wide visual angle. The observer has the impression of looking directly at the sky. In other experiments, a small combining glass is used in front of one eye only, while the other eye freely surveys the entire sky. In any case, the fact is that a large illusion is obtained with this apparatus. (We have also performed a little experiment to demonstrate that varying the distance of the observer from the combining glass has no effect; such a procedure should have an effect if the glass were playing any role at all.)
11. E. Schur, *Psychol. Forsch.* **7**, 40 (1925).
12. T. G. Hermans, *J. Exptl. Psychol.* **48**, 204 (1954).
13. A. H. Holway and E. G. Boring, *Am. J. Psychol.* **53**, 587 (1940).
14. Hermans interprets his findings in terms of torsional movements associated with convergence when the eyes are raised. One piece of evidence supporting this interpretation (and contradicting our speculation concerning change in intensity) is that we obtained a nonsignificant ratio of 0.96 when we performed an experiment identical to the one reported except for the fact that a smaller collimator was used, so that the disk could be seen with only one eye. This suggests that the convergence or torsion theories discussed by Holway and Boring (see *4*) may be factors here. In view of the small size of the effect, however, it would seem wise to suspend judgment as to the cause until experiments can be undertaken with a greater number of subjects, to test these hypotheses.
15. The new units were designed to our specifications by Erwin Streisinger of Research Instrument Laboratories.
16. A. Ames, *Nature and Origin of Perceptions* (Hanover Institute, Hanover, N.H., 1949).
17. G. Berkeley, *An essay towards a new theory of vision* (Scribner's, New York, rev. ed., 1929).
18. Part 2 of this study will appear in the next issue of *Science*. A portion of the work was completed while we were both at the New School for Social Research. Some of the findings were reported at the meeting of the Eastern Psychological Association of April 1960. We wish to thank J. M. Chamberlain for making it possible for us to conduct experiments at the Hayden Planetarium and M. N. Chappell for permitting us to experiment on the Hofstra College campus. We also wish to thank David Begelman, Robyn Posin, and Stanley Riklin for their help in performing certain of the experiments.