The Moon Illusion, II

The moon's apparent size is a function of the presence or absence of terrain.

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The horizon moon appears to be larger than the zenith moon; this is called the moon illusion. In the last issue of *Science* (*1*) a new technique for studying this illusion was described. It consists of a device which permits the observer to view a disk of light or artificial moon on the sky. The size of the disk can be varied. Using two such devices the observer can compare a standard disk set in one position of the sky (for example, on the horizon) with a variable disk set in another position (for example, at the zenith) (see Figs. 1 and 2). The variable selected by the observer to match the standard in size gives a measure of the magnitude of the illusion. Experiments carried out with this technique failed to support the earlier finding that the illusion was based on the elevation of the eyes with respect to the head (*2*). It was also shown that the illusion was not based on changes in the color or brightness of the moon. Here, in part 2, we discuss work on the apparent-distance hypothesis.

The Apparent-Distance Hypothesis

We are now ready to consider the hypothesis that the illusion is based on the sense of great distance which the observer has when viewing the moon directly above the horizon. This sense of distance is created by the terrain, which, for present purposes, may be defined as a stimulus which yields the impression of a plane receding from the observer. (It should be noted here that the sense of distance or apparent distance need not necessarily correspond to the subject's report of distance. This point was discussed earlier (*1*, ref. 1) and is covered in more detail later.) We have already shown that the moon illusion cannot be explained by factors operating in complete darkness, even when the moons compared are at optical infinity. This finding can be taken as supporting the apparent-distance hypothesis, because, in the case of the ordinary illusion, the zenith moon is essentially a disk at optical infinity surrounded by a homogeneous field. Therefore, in effect, the dark-field experiments may be said to eliminate the visible terrain in viewing the horizon moon, and in so doing, to abolish the illusion.

The effect of obscuring the terrain from view. We also tested this deduction somewhat more directly by obscuring the terrain under outdoor conditions. The observer compared an artificial moon set near the horizon with another artificial moon seen through a ⅛-inch aperture in a large cardboard mounted in front of the second instrument. The latter "reduction moon" was located approximately 10° above the horizon to make sure that no part of the terrain would be seen through the opening. The observer was required to place his head against the cardboard and look through the aperture at the moon reflected by the combining glass. Because the reduction moon could be viewed with only one eye, the observer was required to view the unobstructed horizon moon with one eye. The observer also compared the reduction moon with the (monocularly viewed) zenith moon. For this purpose the assembly for viewing the unobstructed moon was tilted back on the tripod so as to locate the disk in the zenith. With these exceptions the procedure for each of these comparisons was identical to procedures followed previously. Ten male students from Hofstra College were used as observers. They viewed the scene across Mitchel Air Field; the sky in that direction was clear throughout the afternoon of the experiment.

The mean ratio obtained in a comparison of the normal moon with the reduction moon was 1.34 (standard deviation, 0.08), where the reduction moon was considered to be the zenith moon of the previous experiments. In other words, we obtained an illusion with both moons in a horizontal direction merely by eliminating the visible terrain in viewing one of them. Moreover, the magnitude of the effect was about the same as that obtained, with other subjects, for the ordinary moon illusion for this same scene (1.38), under similar sky conditions. [It is worth noting in passing that this result, obtained with monocular viewing, fails to support the conclusion of Taylor and Boring (*3*) that binocular vision is essential for a moon illusion. We know of two monocular individuals who report experiencing a moon illusion. Binocular viewing should not be crucial, according to the apparent-distance hypothesis, because the important stimulus to distance, the terrain, is received monocularly.] The mean ratio obtained in a comparison of the reduction moon with the zenith moon was 0.99 (standard deviation, 0.04). There is thus no illusion when the terrain is blocked from view.

Reversal of the illusion by means of mirrors. If the presence of the visible terrain is indeed crucial, as the foregoing evidence suggests, it should be possible to reverse the illusion by giving the zenith moon a terrain, so to speak, and at the same time depriving the horizon moon of its terrain. In other words, if one were to see the zenith moon over a horizon at the end of an apparent terrain, it should appear larger than a moon viewed horizontally but not in connection with a terrain—a moon surrounded on all sides by sky.

We achieved this condition by requiring the subject to view each artificial moon through a right-angle prism, which is essentially a mirror at a 45° angle to the line of sight. The observer is seated with his back to the terrain scene he is to view. To see one moon he tilts his head and eyes upward to 90° so as to view the scene through the prism. The prism opening is 5¼ inches long and 1⅛ inches high. The observer places his eye as close as possible to the prism. Directly behind the prism and

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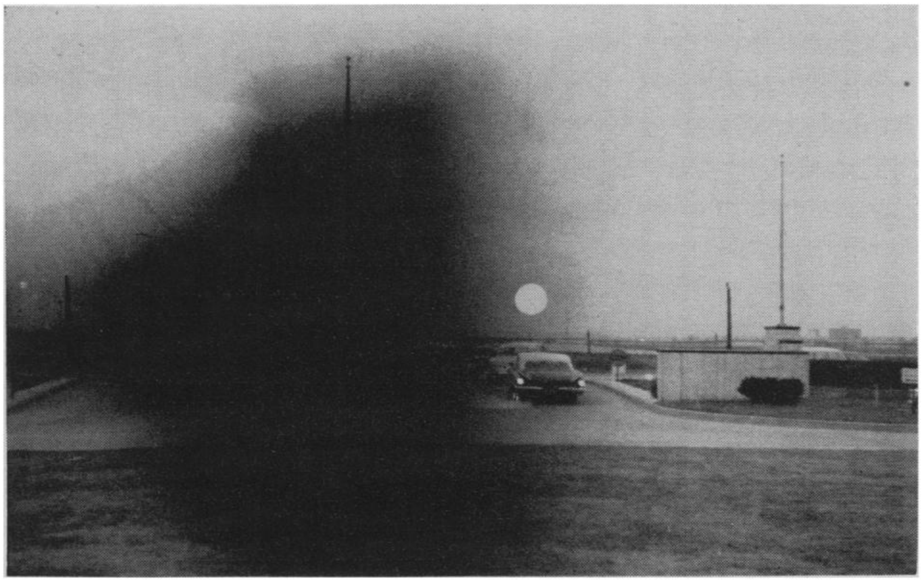

Fig. 1. The artifical moon as it would be seen by an observer looking at the horizon through the combining glass, with one eye. The observer would view the scene directly with his other eye; thus any disturbing images of the edges of the combining glass, or of the clamp, would tend to be washed out.

off to one side is the small combining glass which reflects an artificial moon so as to make it appear within the mirrored scene. The observer then sees the terrain stretching vertically upward. The artificial moon is made to appear on top of the perceived horizon. To see the other moon, the observer looks through a second prism (below a combining glass), which reflects the zenith sky in a horizontal direction. Hence he sees the artificial moon straight ahead, in a horizontal direction, but instead of seeing terrain below it he sees sky surrounding it.

This particular experiment was performed on the roof of the Graduate School of Education Building of Yeshiva University, on 57th Street in Manhattan. Because it was not necessary to remove the apparatus daily, as was the case on the Hofstra campus, the instruments were attached to a wooden framework. The zenith unit was clamped to a horizontal board, which the observer could view from a sitting position. The horizontal unit was attached to a vertical board, which the observer could view from the same sitting position. The framework provided a firm anchorage for the right-angle prisms used in this experiment. The view facing east from the roof included the street, lined with buildings, and the horizon at the end of 57th Street, which was at a distance of well over a mile (Fig. 3).

Ten students of Yeshiva University were used as subjects. To compare the illusion obtained with the mirrors with that obtained under normal conditions, we had the subjects of the mirror experiments view the same scene without the mirrors. This control condition indicated the magnitude of the illusion to be expected under conditions that were comparable except for the use of mirrors. Half of the subjects viewed the mirror scene one day and the regular scene the following day. For the other half the order was reversed. The procedure of measurement was otherwise identical to that employed in the previous experiments.

The mean ratio for the mirror experiment was 1.37 (standard deviation, 0.28) and for the control variation, 1.56 (standard deviation, 0.25). The difference is statistically significant. Because the scene of a city street with buildings surrounding the horizon sky might be considered a special case (and certain facts support this view), the experiment was also performed at the Hofstra College site, with minor variations in the physical arrangement of the apparatus. For nine subjects the mean ratio was 1.34 (standard deviation, 0.25). This value is significantly lower than the ratio obtained without mirrors at the same location and under similar cloud conditions—namely, 1.54 (standard deviation, 0.19). The ratios obtained with and without reversal are strikingly similar in the two experiments.

The results thus show that we were successful in reversing the illusion, although the magnitude of the effect obtained is not as great as that of the ordinary illusion. Does this mean that the visible terrain is not the whole story —that some other factor, such as angle of regard, also plays a role? It must be borne in mind that, from the standpoint of an angle-of-regard theory, not only should the illusion not have been reversed but the true horizon moon should have continued to appear larger. Hence, if both factors were operating and were of equal strength, we should

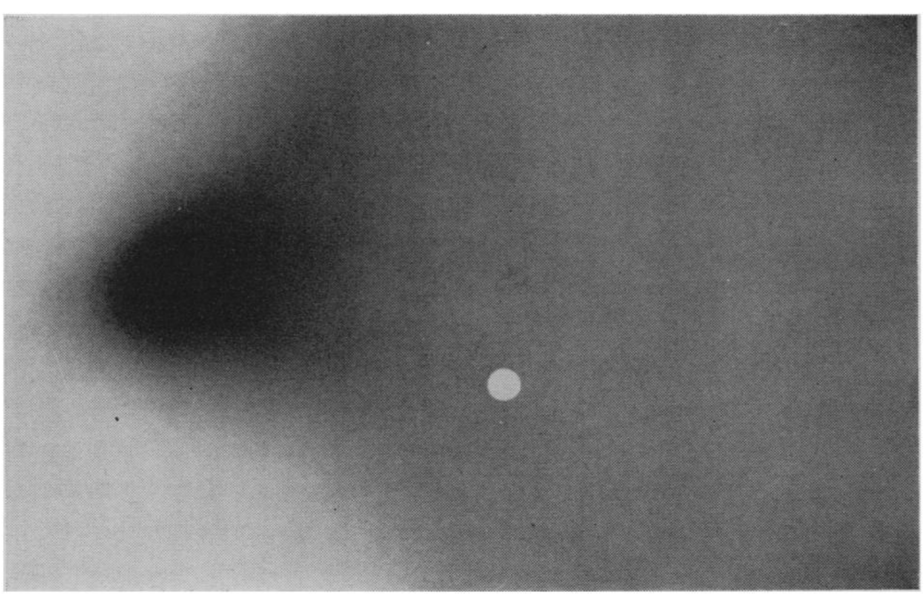

Fig. 2. The artificial moon as it would be seen by an observer looking at the zenith through the combining glass. The dark regions in the two pictures are an out-of-focus image of the clamp that holds the combining glass.

expect them to cancel each other out, because they are in opposition. The obtained reversed ratios of 1.37 and 1.34 in the two experiments can then only mean that if an angle-of-regard factor were involved, it must have exerted only a very weak influence. More plausible, therefore, in the light of this reasoning and all the evidence cited earlier against an angle-of-regard theory is the conclusion that the reduction in the size of the visible field, as the observer looked through the tank prism, reduced the impression of depth yielded by the scene. (Also, the frame of the prism may have provided a constant reference system for judging visual angle.) Moreover, looking up at a landscape aligned perpendicular to gravity is unnatural, and this may have been a factor. If these conjectures are correct, one may say that the effect nevertheless obtained is very impressive indeed.

It seems clear, then, that it is the presence of terrain in one case and the absence of terrain in the other that is the major factor in the moon illusion. But the objection can justifiably be made that this in itself is not sufficiently analytical proof of the apparent-distance hypothesis. Perhaps the presence of the terrain stimulus pattern adjacent to a moon creates the effect for reasons other than that the pattern yields a sense of great distance. Although there may be no obvious rationale for such an effect, it still must be established that it is the distance aspect of the terrain stimulus which is crucial.

An inverted terrain. It is a fact known to psychologists in the field of perception that an inverted photograph of a landscape often loses much of its effect of depth (Fig. 4). Although this is as yet unexplained, there is no question about the fact, and we decided to make use of it to test the apparent-distance hypothesis. If an observer were to view an inverted scene he would have a sense of less distance to the horizon moon than he has in viewing the scene without inversion. Hence, according to the apparent-distance hypothesis, the illusion should be diminished. Yet the terrain stimulus pattern would remain adjacent to the horizon moon, and thus, if the crucial factor is some aspect of the terrain pattern other than distance, the illusion created should be undiminished.

The observer viewed the 57th Street scene through two large Dove prisms, each 1 9/16 by 1 1/16 inches in cross section, mounted side by side directly in front of the combining glass. The subject sat with his eyes close up against the prisms. The prisms were mounted in a thick cardboard in which a hole had been cut equal in size to the cross-sectional area of the two prisms combined. The cardboard thus surrounded the prisms on all sides, serving as a shield which prevented the observer from seeing the scene in any way except through the prisms. He viewed the zenith moon normally, without prisms. To compare results of observations with and without inversion of the scene, a control condition was included in which the observer viewed the scene through an aperture equal in size to the two prisms combined—that is, an aperture 3 1/8 by 1 1/16 inches. Four subjects were tested first under the experimental condition and six subjects first under the control condition. Otherwise the procedure was identical to the measurement procedures described previously.

The mean ratio for ten naive subjects was 1.66 (standard deviation, 0.32) without the prisms (*4*) and 1.28 (standard deviation, 0.17) with the prisms. (Three of the control subjects selected apertures at the upper end of the series, so the mean ratio of 1.66 is somewhat conservative.) These two values differ significantly from one another, and the second differs significantly from unity. Thus there are two conclusions to be drawn: (i) the inversion of the scene does very appreciably reduce the moon illusion, and (ii) there is still an illusion even with inversion.

The first conclusion provides important support for the apparent-distance hypothesis. The second leaves us with an unsolved problem. It is probable that the inverted scene does not completely eliminate a sense of depth. This conclusion is especially plausible in the case of this particular scene, which contains a perspective pattern derived from the vertical lines of buildings as well as one derived from the horizontal elements along the ground plane. The perspective based on the vertical elements is not changed with inversion. Furthermore, there are other possible cues to the scene's true depth, such as monocular parallax. We retained some sense of depth in viewing the inverted scene. But there is another factor to be considered in the case of this particular scene. The moon is seen between tall buildings. Thus, it is framed on three sides, and this frame of reference might very well affect the moon's apparent size (*5*). Some additional evidence on this point was obtained in experiments conducted in the laboratory with slides of outdoor scenes. In one such experiment a slide of the 57th Street scene was shown, and, as a control, a slide of a pattern virtually identical to that scene with respect to line elements but

Fig. 3. One of the scenes used to study the moon illusion. One moon was located between the buildings directly over the horizon. The other was placed in the zenith sky. When this scene was inverted by means of prisms the illusion was considerably reduced. Note the reduction in the impression of depth when the scene is viewed upside down.

drawn so as not to convey a sense of three-dimensionality. The moon seen in the control slide was, therefore, also framed on three sides. This slide yielded an illusion ratio close to 1.2, quite similar to the ratio obtained with the inverted scene. Such a relational effect would be in no way changed by inversion of the scene. Thus, it is possible that the slight illusion obtained with the inverted scene is due to a residual depth impression or a relational effect of the surrounding buildings, or both. It would be instructive to repeat this experiment with slides of a more typical landscape, such as the scene at Hofstra College, which does not produce a framing effect.

Various authors have commented on the apparent destruction of the moon illusion that occurs when an observer views the horizon moon between his legs. Boring interpreted this as evidence supporting the angle-of-regard hypothesis. Our finding of a diminution of the illusion with an inverted scene (which does not involve any change in angle of regard) suggests an alternative explanation: inverting the head brings about an inversion of the retinal image, and the latter inversion, for whatever reason, diminishes the impression of depth yielded by the landscape. (It might also be pointed out that looking between one's legs inevitably lowers the observer's vantage point. Looking at the terrain from a point nearer the ground would also decrease the apparent distance to the horizon.)

Variation of distances and cloud conditions. It should follow from the hypothesis under investigation that the moon illusion would increase with apparent distance to the horizon. We therefore performed an experiment in which the illusion was compared for two scenes which differed substantially in the impression of distance to the horizon. One scene extended north from the Hofstra College campus and encompassed Mitchel Air Force Base; for this scene the apparent distance from the viewing point to the horizon was roughly 2 miles. The other scene was 30° west of the first. In this direction trees and shrubbery obscure the horizon at a distance of about 2000 feet. Thus, the apparent distance ($D1$) for the first scene was much greater than that for the second ($D2$).

Another factor which might conceivably contribute to the differential impression of distance to horizon and zenith is the presence of clouds, as Helmholtz (*6*) and others have speculated. In fact, Miller (*7*) found the half-arc angle to vary inversely with the degree of cloudiness. We therefore decided to include a test of the effect of cloudiness on the illusion. This was done by testing different subjects on totally clear days, on totally overcast days (with structured stratocumulus cloud coverage), and on days with broken coverage (that is, with clouds predominantly cumulus, and with coverage judged to be between 0.3 and 0.7). It was expected that the illusion would be maximal on totally overcast days, minimal on totally clear days.

The design of this experiment involved testing subjects under six sets of conditions—combinations of the two apparent distances and the three types of cloudiness. It was not feasible to use subjects as their own controls by testing them under all conditions of cloudiness, because we obviously could not manipulate the cloud conditions at will (although we were able to test some subjects for both distances). Altogether, 55 Hofstra College students, male and female, served as subjects, 20 on overcast days, 20 on days with broken cloud coverage, and 15 on clear days. Half the subjects tested under overcast and broken-cloud conditions viewed the horizon moon over scene $D1$ and half over scene $D2$. Five of the subjects tested under the clear-sky condition viewed the moon over both scenes, and the remaining ten viewed it over one or the other. In this experiment each subject made two ascending and two descending series of matches for each moon that served as the standard. The procedure followed was otherwise the same as in the other experiments. The zenith moon was set at an elevation of 80°.

The results are given in Table 1 in terms of the average ratios for each of the six subgroups and for overall distance and overall cloud conditions. The data of Table 1 reveal an increase in the illusion with increasing cloudiness and a greater illusion with greater apparent distance to the horizon ($D1$). An analysis of variance shows that the cloud-condition ratios differ significantly, as do the distance-condition ratios. (As noted above, five of the subjects were tested for $D1$ as well as for $D2$. An additional four subjects were also tested for both $D1$ and $D2$. In all these tests the sky was clear. For eight of the nine subjects the illusion was larger for $D1$. For the ninth subject the illusion was the same for $D1$ and $D2$. The average for these nine subjects was 1.25 for $D1$ and 1.14 for $D2$.) These results support the apparent-distance hypothesis and confirm Helmholtz's speculations on the role of cloudiness, as well as the findings of Miller, Neuberger (*8*), and others.

Error of the Standard

In most of the experiments reported in this article the illusion obtained was greater when the horizon moon was the standard than when the zenith moon was the standard. This is apparent in Table 2, where the results are given separately for the two cases for all experiments. Only in the eye-elevation experiment in which the "binocular" collimator was used, and in the experiments in which no illusion was obtained, does this difference fail to appear. We would be inclined to believe that the exceptional result in the former case is a function of the slight differences in the apparatus were it not for the fact that in other experiments, not reported in this article, in which the binocular collimator was employed a similar effect was obtained. The absolute magnitude of the effect is considerably smaller than that of the moon illusion itself. A rough approximation is yielded by dividing by 2 the average difference between

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

and

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

for those experiments where such an effect occurred. This yields a value of approximately 15 percent; that is, a comparison object would have to be made 15 percent greater in size than a standard object if only such an error were operating.

One way of viewing this finding is in terms of a tendency to overestimate the standard; this tendency has in recent years been discovered by others working on size judgments and called "the error of the standard" (*9*). In our experiments this tendency would increase the magnitude of the illusion when the horizon moon is the standard because it makes the already phenomenally large moon seem even larger. It would decrease the magnitude of the illusion when the zenith moon is the standard because it makes the smaller-appearing zenith moon seem larger, thus offsetting the illusion to some extent. This constant error might be considered to be a positive time error for size except for two considerations. (i) It has not been experimentally demonstrated that the error is a function of the order of presentation, only that it is associated with the stimulus made to serve as the standard. In fact, in many of our experiments the subject was allowed to check the standard after setting his variable. (ii) The effect does not seem to appear in our experiments when the moon illusion itself does not appear, although this should provide an ideal opportunity for observing the operation of a time error if one exists.

The fact that, in our experiments, the effect does not seem to be present unless the moon illusion itself is present suggests another interpretation relating to certain phenomenal differences between the horizon and the zenith moons. We will therefore return to this problem.

Table 1. Average illusion ratios for various distances and cloud conditions (ten observers for each cloud-and-distance condition).

Distance	Cloud condition						Overall (mean)
	Clear		Broken		Overcast		
	Mean	SD	Mean	SD	Mean	SD	
Near (*D*2)	1.28	0.17	1.35	0.27	1.45	0.21	1.36
Far (*D*1)	1.40	.22	1.54	.19	1.58	.28	1.51
Overall	1.34		1.45		1.52		

Discussion

Methodology. Since our results on the matter of eye elevation fail to substantiate previous findings, the difference in method employed becomes crucial. In addition to the points made earlier concerning our reasons for dissatisfaction with the method used by Boring and his associates, we would like to make a comment concerning our method. Assuming that viewing the sky through glass does not affect the results—an assumption that we think justified (see *1*, note 10, to which we may now add the observation that in our dark-field experiment the observer does not see the apparatus and is looking directly at the artificial moon—we believe we have duplicated the conditions of the moon illusion in nature)—comparison of a moon in one region of the sky with a moon in another region. Our observers merely have to compare one moon with the other, they do not have to compare either moon with anything else. The one remaining difference between our experimental conditions and the conditions in daily life is that of immediate versus delayed comparison. But this is a difference which we deliberately introduced in order to eliminate any dependence on memory; impressions of the moon illusion in daily life may be somewhat spurious because of the unknown role of memory.

In support of our contention that we have duplicated the conditions found in nature, we performed an experiment in which three observers were asked to compare the *real* horizon moon (viewed over the ocean) with our artificial moon pointed at the zenith. The average illusion ratio obtained was 1.83, a value slightly inflated by the lack of a control for an error of the standard. Observations by these same subjects yielded no illusion ratio whatever when the artificial moon was pointed at the horizon but 40° to one side of the real moon. In the latter comparison the subjects selected an aperture identical to the one they had selected when the artificial moon was directly superimposed on the real moon. In other words, the aperture of our apparatus, known to subtend approximately the same visual angle as the real moon, yielded a phenomenal disk equal in size to the phenomenal moon when the two were seen at the same elevation. But when that aperture was viewed at the zenith it appeared much too small. These checks demonstrate the phenomenal equivalence of our artificial moon and the real moon.

If our reasons for questioning the method used by Boring and his associates are valid, and if our method is indeed a duplication of the illusion as it exists in nature, two problems remain unsolved: how their observers were able to arrive at a satisfactory match, and why these matches revealed a moon illusion dependent on eye elevation. It is a fact worth noting that, for the most part, either Boring, his colleagues, or other persons familiar with the problem under investigation served as subjects. A more serious contradiction exists, however—one between our findings and those of Holway and Boring in experiments carried out with their direct-comparison (reflected mirror-image) method. The contradiction is serious because, as we have noted, the essential conditions of the moon illusion are successfully duplicated in this method. Boring and his colleagues obtained only a verbal estimate of the difference in size, and again it should be noted that the observers were familiar with the problem under investigation. The same is true for the findings of Holway and Boring concerning an illusion of the sun seen through dense filters. Nor can we shed any light at this time on Schur's findings of an illusion based on differ-

Table 2. Average ratios given separately for the horizon standard and the zenith standard.

Condition	Horizon standard	Zenith standard	Average
Eyes raised versus eyes level			
Eyes raised	1.46	1.51	1.48
Eyes level	1.47	1.46	1.46
Both moons in same region of sky			
	1.07*	1.01†	1.04
Dark field			
	1.03	1.03	1.03
Color (red and white horizon moons combined)			
	1.49	1.23	1.36
Brightness			
	1.53	1.28	1.40
Obstructed versus unobstructed terrain			
	1.41	1.27	1.34
Obstructed terrain versus zenith			
	1.02	0.97	0.99
Mirror reversal			
57th Street	1.54	1.20	1.37
Control	1.79	1.33	1.56
Hofstra	1.49	1.20	1.34
Inverted terrain			
Prisms	1.37	1.19	1.28
Control	1.95	1.38	1.66
Various distances and cloud conditions			
Long distance (*D*1):			
Clear	1.56	1.23	1.39
Broken	1.75	1.33	1.54
Overcast	1.73	1.43	1.58
Short distance (*D*2):			
Clear	1.40	1.15	1.27
Broken	1.44	1.25	1.34
Overcast	1.61	1.28	1.44

* Moon viewed with eyes level taken as the standard. † Moon viewed with eyes raised taken as the standard.

ences in perceived direction inside darkened buildings (*10*). As already noted, it would seem that our dark-field experiment is the ideal test for such an effect, yet the result we obtained was only negligible.

Very recently Leibowitz and Hartman reported an experiment (*11*) in which subjects in a darkened theater made size comparisons of disks seen overhead with disks seen straight ahead. The disks were 35 feet away. The overhead disk was underestimated by 19.1 percent by adults and by 32 percent by children of 5 to 8 years of age. We are at a loss to explain this finding, in the light of our planetarium and dark-field experiment, except to note that some stray light from the projector enabled the observers to detect the outlines of chairs on the ground (*12*), and that the cues for distance in the horizontal direction were thus probably better than those in the vertical direction. There is nothing but empty space between observer and overhead disk. (The same point is relevant to Schur's experiment.) Leibowitz and Hartman obtained similar results outdoors with a disk suspended outward from the roof of an 85-foot building. The latter finding could also be a function of the superior cues for distance along the ground or a function of the "framing" of the horizontal disk by the wood backing and by objects behind it.

The context effect. It seems quite clear from the various experiments reported here that a visible terrain is essential for the appearance of the illusion. Have we demonstrated that the terrain produces the illusion because it increases the perceived or registered distance of the horizon moon? There were two findings in support of this conclusion: (i) when the horizon appeared farther away the illusion increased; and (ii) the illusion decreased when the terrain pattern was inverted, presumably because the impression of depth decreased. Logically the only alternative to the distance hypothesis is the theory that the terrain pattern, as a two-dimensional structure or context, increases the apparent size of a disk seen adjacent to it as compared to the apparent size of a disk seen within a homogeneous surround. On the face of it this alternative is not a particularly plausible one, since the typical terrain lies entirely to one side of the moon—that is, it does not frame the moon except in the case of scenes containing tall buildings or the like. It is unlikely that, under these circumstances, such a context effect, even if it existed, could approach in magnitude the moon illusion obtained. In any event, we ruled out this possibility in experiments in which we sought to achieve an illusion indoors by means of slides of terrain patterns. On the whole, only a negligible illusion was obtained when a disk seen above the terrain on the screen was compared with a disk seen within a homogeneous surround. No illusion at all was obtained when a control slide was substituted which duplicated the terrain pattern in all structural essentials but which was deliberately drawn so as not to yield an impression of depth. If the moon illusion is a function of such a context effect, we can see no reason why it should not be easily created in the laboratory. On the other hand, if it is a function of apparent depth, one can readily see why it is difficult to create it in the laboratory. Hence, we may consider these negative results still a third piece of evidence in support of the distance interpretation of the role of the terrain.

The size-distance invariance hypothesis. We turn now to certain theoretical questions bearing on the apparent-distance hypothesis. As noted earlier (*1*, ref. 1), there has been considerable dissatisfaction in the last few years with explanations of size perception based on the taking into account of distance—or with what is being called the size-distance invariance hypothesis. We need not repeat our reasons for questioning the basis for this dissatisfaction. In any case, it is not clear whether those who question the invariance hypothesis wish to argue that phenomenal size is not at all a function of distance or merely that the precise nature of the function is not known. As far as the moon illusion is concerned, our claim is not that every increment in perceived or registered distance will necessarily yield some proportional increment in the phenomenal size of the moon but merely that, in a gross way, the horizon moon appears larger because it appears much farther away, or that a very-distant-appearing horizon moon looks larger than a not-so-distant-appearing horizon moon.

Recently the so-called paradox concerning the relative apparent distances of the two moons first pointed out by Boring has been cited as further evidence against the invariance hypothesis (*13*). The horizon moon allegedly appears nearer, not farther away. We dealt with this problem earlier in terms of certain logical considerations and cited experimental evidence in support of our position (*1*), but it might be well to reiterate our belief that what is crucial is not distance as judged but distance as registered by the nervous system on the basis of certain stimuli. Woodworth and Schlosberg have made this very point in discussing the seemingly paradoxical results of stereoscopic studies of changes in convergence. They proposed a solution "in terms of a multilevel view of perception" (*14*). "We may assume" they state, "that convergence and the resulting appropriate distance are registered at a low level of the perceptual sequence and serve as cues for judgments of size, although the cues themselves are not directly available through introspection. The size judgments then serve as cues for another judgment of distance, which may conflict with the lower-level cue." This is precisely the way in which we have tried to deal with the paradox reported by Boring. We propose that changes in phenomenal size may be a better index of changes in registered distance than of reportable changes in perceived distance. To support the invariance hypothesis one need only show that specifiable changes in registered distance (as indicated by convergence, accommodation, and so on) yield predictable changes in phenomenal size; not that changes in phenomenal or judged distance yield predictable changes in phenomenal size (*15*). Nevertheless, in the case of the moon illusion, when judgment can be eliminated as a factor by removing the moon from view, observers then do report the horizon *sky* to be farther away.

Stimulus correlates of distance. We have not tried to tackle the question of what the important stimulus correlates of distance are in the case of the moon illusion, except indirectly. The importance of clouds, and of scenes which allow one to view the horizon at a very great distance, suggest that configurational properties of the stimulus are crucial, because physiological correlates cease to be important at great distances. By *configurational* we mean relationships within the stimulus pattern, such as perspective, interposition, and the like (*16*). The effect of inverting the scene supports this line of reasoning. In any case, we can rule out convergence and accommodation, because these adjustments are the same for horizon and zenith moons in daily life as well as in our experiments. One can easily eliminate other nonconfigurational correlates of distance perception, such as retinal disparity and movement parallax, by viewing the real moon with one eye and with the head stationary; an observer viewing it in this way still seems to obtain a substantial illusion—at least we do. If this reasoning is correct, and if, as is plausible, the configurational correlates are a product of experience, then the illusion itself would be indirectly dependent on experience.

The constancy function. In one respect the apparent-distance hypothesis oversimplifies the problem of the moon illusion. On the one hand the horizon moon can be said to take on the size of a region of the terrain of equivalent visual angle at the horizon. That region, in turn, has a large phenomenal size because of the constancy function—the observer's tendency to take distance into account. (This way of stating the matter is similar but not identical to the popular explanation that the horizon moon looks large because we compare it with familiar objects seen adjacent to it on the horizon. For example, the image of the moon is larger than that of a house on the horizon. Ergo, the moon is at least larger than a house. The fact is, however, that familiar objects need not be present, as in the case of the moon seen over the ocean. But one *can* say that the

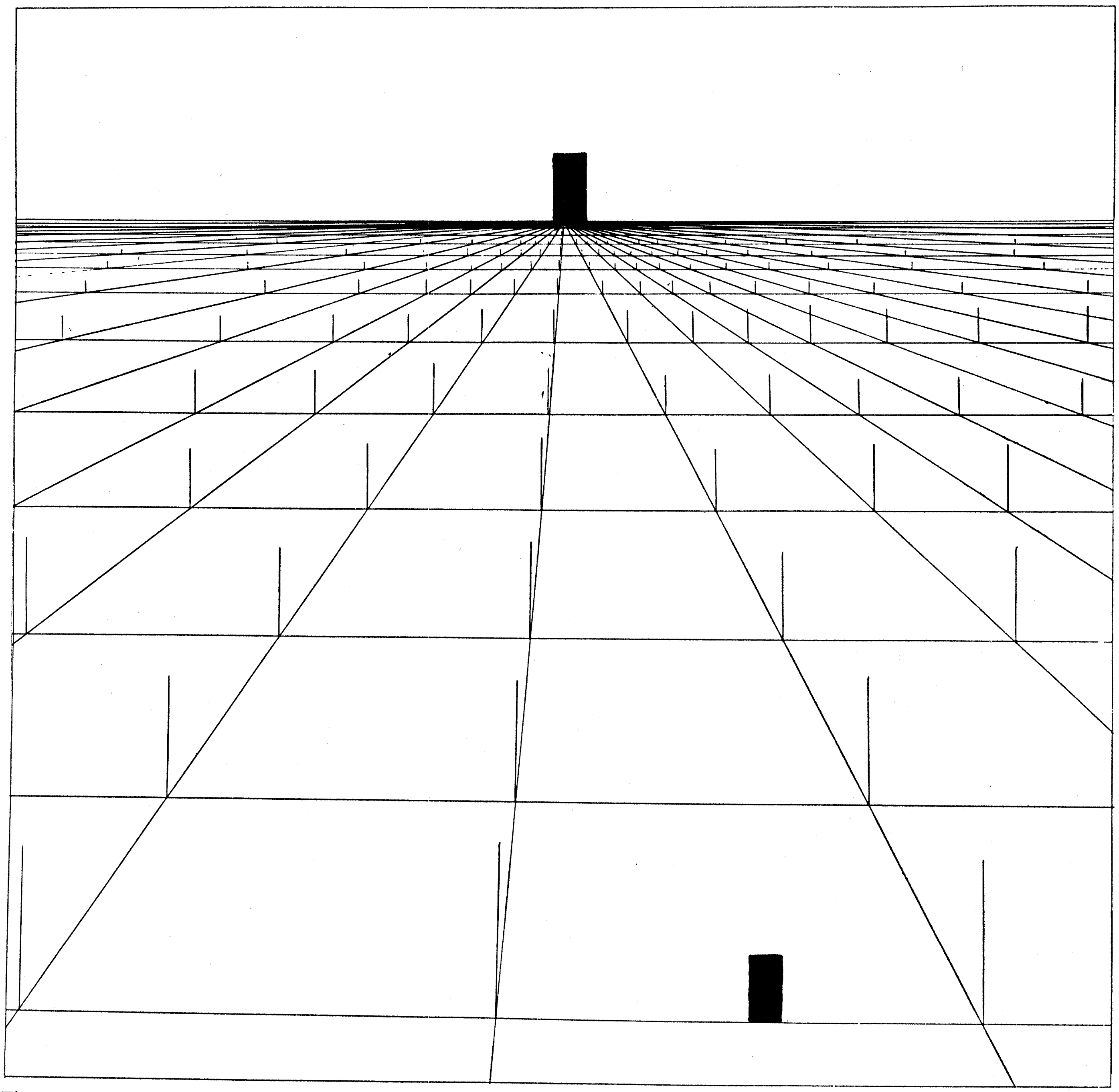

Fig. 4. The effect of distance on size. The black rectangle on the horizon appears larger than the one in the foreground, although they are identical in size. The effect would be much greater in viewing a truly three-dimensional scene, where binocular and other cues would enhance the impression of depth. Conversely, the effect can be increased by viewing the picture with only one eye, because the impression of the two-dimensional surface of the page can be somewhat reduced.

moon must be at least as large as an extent of water of equivalent visual angle at the horizon, and that that extent is seen to be quite large because of the constancy function. See Fig. 4.)

By contrast, the zenith moon cannot be related to any other regions of the field, and in that sense its distance is essentially indeterminate. In fact, it is more or less a reduction object. We have shown that the horizon moon viewed through an aperture appears to be the same size as the zenith moon. Although the distance of the zenith moon is indeterminate, relative to the horizon moon the zenith moon nevertheless seems to register as "nearer."

If this way of putting the matter is correct, it suggests an interesting explanation of the error of the standard, discussed earlier. When the observer views the horizon moon as the standard he approaches the zenith variable with the immediate memory of a disk which, at least to some extent, is seen as a thing with an objective size (if not a thing of any *particular* linear size). When, however, the zenith moon is the standard, because his viewing of it is more of a "pure visual angle" or "pure extensity" experience, he approaches the horizon variable with a visual-angle set. It is known that such a set can reduce the tendency toward constancy (*17*). In the instance under discussion, it would reduce the illusion when the zenith moon is the standard. According to this interpretation, the error we obtained may be viewed as a special case and not as an instance of a more general error of the standard, as was implied earlier.

This leads to a second reason for stating that the apparent-distance hypothesis is oversimplified. As noted earlier the zenith moon is at an indeterminate distance and is therefore of indeterminate size. The horizon moon appears very far away, and objects at very great distances also are of somewhat indeterminate size (*18*). Ordinarily we say that distance is taken into account in a particular impression of linear size; thus, as stated in Emmert's law, a greater distance yields an impression of a particular larger size. In the case of the moon illusion we have to extend this reasoning to say that distance influences size perception (in the sense that one moon looks larger than the other) despite the fact that neither moon appears to be of any specifiable size. That is, in the case of the moon illusion it would seem that distance affects the relative-extensity experience, not a relative-linear-size experience.

Miscellaneous considerations. The moon illusion has often been cited as an example of the anisotropy of visual space, in that there is a nonequivalence of phenomenal space in different directions. In our opinion, not only is this term not clear but it presupposes something which may not be true. *Anisotropy* could refer to direction within two-dimensional space—could pertain to facts such as the phenomenal changes and recognition changes brought about by disorientation of shapes (for example, a square becomes a diamond when tilted 45°, or text is difficult to read upside down). Or it could refer to three-dimensional space. In either case it remains to be proved that phenomenal changes such as those just mentioned, or the moon illusion (or the presumably related fact that size constancy is more marked in the horizontal than in the vertical direction), require an explanation in which visual space is, per se, anisotropic. The two-dimensional effects can perhaps be explained in a different fashion (*19*), and the apparent-distance explanation of the moon illusion is based on the different *content* of the visual scene in the different directions. Our failure to achieve anything more than a minute effect in the dark-field experiments argues against any inherent anisotropy of three-dimensional space.

The question of whether the moon illusion is based on an experiential enlargement of the horizon moon or a shrinkage of the zenith moon has often been raised. Such a question pressupposes a normative base line against which the effect can be measured. In the Müller-Lyer illusion one might compare either line seen within the arrowheads with one seen in isolation and ask, Is the illusion due to the apparent enlargement of the line seen within the outward-pointing arrowheads, to the apparent diminution of the line seen within the inward-pointing arrowheads, or possibly to both? Here the isolated line is the base line, and the question can be investigated. In the case of the moon illusion, however, there is no "normal"-size moon, and the visual angle remains constant. From the standpoint of the tendency toward size constancy, however, one might say that the horizon moon approaches the veridical size of the moon more closely than the zenith moon does. Of course, the departure from constancy is extremely large in either case, but it is somewhat less for the horizon moon. Therefore, if the illusion is defined in terms of size constancy (or the objectively true size of the moon), one must conclude that it is based on the smaller appearance of the zenith moon resulting from the inadequate registration of distance, which was discussed earlier.

As is evident from Table 1 of part 1 (*1*) and from the variability reported for many of the experiments, there are great differences in the illusion for different individuals; this was true in all experiments where an average illusion of any magnitude was found. Findings for individual observers were consistent in repetitions of the experiment ($r = .82$ for the experiment on the effect of distance and cloud condition) and even from condition to condition ($r = .83$ for the experiment on the effect of eye elevation). How should we interpret such consistent individual differences? It is possible to argue that some observers respond more readily than others on the basis of visual angle uninfluenced, so to speak, by distance. Thus, in the literature on size constancy it has often been argued that there are "analytical" perceivers who show less than average tendency toward constancy (*20*). Such persons presumably would not experience much of a moon illusion. Although this may indeed be the case, we are somewhat reluctant to accept the notion that the actual sensory experience of the moon's size differs for different individuals viewing the moon at the same time and in the same place. The alternative is the somewhat radical proposition that, while perceived size does not vary, the judgments nevertheless do vary because the comparison is a more difficult one to make than would be the case if two disks were simultaneously perceived on the same background at the same distance. Faced with the difficulty of making a precise match—where it is necessary for the observer to remember the size of the standard while he inspects the variable series—each observer settles on a particular value and then, in order to be consistent, continues to select a value close to his original choice. Of course, such variability centers around a value which reflects the illusion per se. It is possible that a nonperceptual process of this kind accounts for individual differences in various perceptual tasks reported in the psychological literature.

Summary and Conclusions

We have examined the two types of explanations of the moon illusion—the egocentric, in which the differences in direction of the horizon and the zenith moons are thought of in relation to different angles of regard of the observer, and the objective, in which the presence or absence of the terrain is considered crucial. The former type is exemplified chiefly by the eye-elevation hypothesis in the work of Boring and his colleagues; the latter, by the apparent-distance hypothesis based on the superior cues to distance provided by the terrain. Boring had rejected the apparent-distance hypothesis on the grounds that the horizon moon is reported as nearer, not farther away, by most observers. He then performed experiments which supported the eye-elevation hypothesis.

Our own work started with our reservations about Boring's conclusions because of (i) logical considerations and contradictory data of our own concerning the question of which moon appears to be farther away; (ii) the observation that in daily life eye-elevation does not seem to account for the moon illusion; and (iii) logical difficulties connected with Boring's method of studying the phenomenal size of the moon. We developed an apparatus which made it possible for an observer to view an artificial moon in the sky at optical infinity. The size of this moon could then be varied. Using two such units, one pointed at the horizon and one at the zenith, the observer could compare the moons directly with one another and match the variable with the standard. A series of experiments were performed with this apparatus. The major conclusions from these experiments are as follows.

1) An appreciable illusion is obtained, varying in average magnitude from a diameter ratio of 1.2 to a ratio of 1.6, depending on terrain and sky conditions.

2) Eye-elevation does not account for the moon illusion (nor, for that matter, does head elevation).

3) A minute illusion (ratio 1.03) is obtained in a completely dark field for binocularly viewed moons at optical infinity. The reliability and possible significance of this slight effect warrant further study, but it is clear that whatever produces the effect cannot be considered a factor of any importance in the ordinary moon illusion.

4) Neither apparent color nor brightness can even partially account for the moon illusion. The frequently noted reddish color of the horizon moon, or its lower brightness as compared with the brightness of the zenith moon, or both, are apparently coincidental concomitants of the phenomenal size.

5) The presence of the terrain is crucial for the existence of the illusion. The evidence is as follows: (i) The illusion disappears when the observer's view of the terrain is obstructed; (ii) the illusion can be obtained when a reduction horizon moon (here analogous to a zenith moon) is compared with a normally viewed horizon moon; and (iii) the illusion can be reversed with respect to the direction of regard by means of mirrors, so that the elevated moon seen directly above the terrain's "horizon" looks larger.

6) The apparent (or better, the registered) distance along the terrain plays a causal role. The evidence is as follows: (i) The illusion is considerably reduced when the terrain is optically inverted; (ii) the illusion can be shown to be a function of the apparent distance to the horizon and of the degree of cloudiness; and (iii) only a minute illusion can be produced indoors by means of slides that yield an impression of a terrain, although the patterns of the slides are structurally similar to outdoor patterns which do yield an illusion. The only difference would seem to be that the slides do not convey a sufficient impression of depth. No illusion at all is produced by control slides which duplicate the structural features of terrain but which do not yield an impression of depth.

7) There is some evidence that a secondary factor contributes to the moon illusion under certain special conditions—namely, a framing or relational effect when the horizon moon is seen between buildings or other large terrestrial objects.

8) The illusion is greater when the horizon moon is the standard than when the zenith moon is the standard, a fact which may be an instance of what has recently come to be known as the error of the standard.

9) The apparent-distance hypothesis as an explanation of the moon illusion requires some elaboration. (i) Distance influences the apparent size of the moon despite the fact that the moon does not appear to be of any specifiable linear size (distance here affects the relative-extensity experience, not the linear-size experience). (ii) The zenith moon, while appearing less far away than the horizon moon, is to some extent a reduction object—its distance is essentially indeterminate. (iii) The observer may not be consciously aware that he is responding to a greater subjectively registered distance in viewing the horizon moon. In fact, when asked to compare the distances of the two moons, he may even judge the horizon moon to be the nearer. The latter judgment, however, depends strictly upon the relative sizes of the two moons.

References and Notes

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