Reports

Moon Illusion: An Event in Imaginary Space

Abstract. *The illusion was obtained with artificial moons viewed against a luminous ceiling, and also with an imaginary ceiling induced by first showing a luminous ceiling and then removing it before the moons were introduced.*

This study of the way in which past experience influences perception is concerned with an experimental analog of the moon illusion. Two principles are involved: first, the perceived character of an object is determined by the context in which it is perceived; second, this context is not necessarily present in immediate stimulation but may be supplied in memory or imagination. Thus, rather than influencing perceived object character directly through an associative process, past experience is regarded as generating a space of possibilities into which sensory inputs are mapped. The perceived character of the object is determined by the joint effect of immediately given sensory inputs and the particular psychological space into which they are mapped.

As applied to the moon illusion, the role of context was suggested long ago by Ptolemy. If the sky is perceived as a flattened dome, then a disk subtending a given visual angle and localized on the surface of the dome will appear as a large object if located near the horizon, and as a small object if located overhead. Recent experiments support this explanation of the moon illusion (*1–3*).

But how does the sky come to be perceived as a surface having a particular shape, thus dictating the perceived size of the moon? In our approach, this percept develops in the past experience of the individual. This proposal is rendered plausible by the work of Liebowitz and Hartman (*4*), who showed that the moon illusion varies with chronological age, reaching an adult level at about 10 or 11 years of age. The work of Rock and Kaufman suggests that the perception of cloud formations may play some role in this development. Our study deals with surfaces, both real and imaginary, upon which artificial moons are displayed; the surfaces in question are generated by experimentally controlled stimulation.

We did not attempt to approximate closely the conditions of the natural moon illusion, a venture which has been attempted by Holway and Boring (*5*), Kaufman and Rock (*2, 3*), and others. Instead we were concerned with providing an experimental model for the way which the perceived size of an object (such as the moon) may come to depend on its position relative to a "surface" (such as the night sky) which presents little direct information relevant to distance perception. King and Gruber (*1*) have recently shown that afterimages can be localized on the "surface" of a daylight sky and that the perceived size of such afterimages depends on their projected position in the sky, not on the angle of elevation of the eyes in the head. Kaufman and Rock (*2, 3*), employing different techniques, obtained similar results; they have discussed in detail the possible reasons for the difference between their findings and those of Holway and Boring (*5*) in which angle of elevation seemed to be an important variable. While our study does have some bearing on the role of angle of elevation, its main purpose was not to explore that variable but to explore the way in which an extent such as the sky can come to function as a surface.

In order to introduce a long, apparently horizontal ceiling into a short laboratory we worked with the projection of a flat, horizontal ceiling on a slanted plane. Thus, our stimulus ceiling was actually a slanted trapezoid composed of strings stretched on a frame. The strings were painted with fluorescent paint and were fluoresced with ultraviolet light. Viewing these arrangements monocularly with head motionless, gave all subjects the impression of a flat horizontal ceiling with a rectangular grid-like design.

Artificial moons were produced by ping pong balls illuminated from within by small incandescent lamps. Two such balls were suspended at the same distance, 185 cm, from the subject, but at different heights. The bottom of the lower ball was 2°20′ above eye level, and the bottom of the upper ball was 17° 40′ above eye level (*6*). The difference in angle of elevation was 15°20′; but since the two balls were laterally displaced as well, their total diagonal separation was 22°30′ (*7*). If localized in the perceived plane of the luminous ceiling, the lower one would appear as further away from the subject than the higher one. Thus, projecting the same image size to different positions in the space generated by the ceiling should produce differences in perceived size similar to the moon illusion.

Although the experimental room was dark and painted black, stray light from the apparatus illuminated some extraneous objects. These were screened from view by carefully placed shields. To eliminate head movements without preventing speech, a nose rest was used, allowing the subject's lower jaw to move freely.

Before being led into the experimental room, the subject was given brief instruction in making size-ratio judgments. He was shown various pairs of circles and asked to give a numerical judgment of the ratio of their diameters, an easy task for these subjects, who were college students. The instructions, which the subject read, indicated that his task in the experiment would be to compare the sizes of two spheres by making such size-ratio judgments.

All judgments were monocular, a patch being worn over the left eye throughout the experiment. The nose rest was adjusted to keep eye level the same for all subjects. Each subject wore a blindfold for 2 minutes, after which, still seated in the chair, he was rolled into the experiment room; when he was properly positioned, the room was darkened, objects appropriate for the particular experiment were illuminated, and the blindfold was removed, leaving the monocular patch in place.

In the first experiment, we measured the influence on perceived size of two factors: the perspective provided by the luminous ceiling and the difference in angle of elevation of the two moons. Of 21 subjects viewing the moons

Table 1. Frequency and magnitude of illusion under five experimental conditions.

Condition			N	Illusion		
Type	Before judgment	During judgment		Frequency* (%)	Magnitude† M	Magnitude† S.D.
B		Moons	22	4.6	‡	‡
E		Horizon, moons	18	22	1.26	0.59
C	Ceiling	Moons	18	28	1.29	0.36
D	Ceiling	Horizon, moons	18	50	1.40	0.32
A		Ceiling, moons	21	95	1.61	0.81

* Percentage of subjects reporting lower moon larger. † Mean size-ratio judgment for subjects reporting size-ratios not equal to one. Except as noted below for condition B, all such reports indicated that the lower moon looked larger. ‡ In condition B, two subjects reported the lower moon smaller and one reported the lower moon larger. It did not seem reasonable to compute the mean of these three responses.

against the luminous ceiling (condition A in Table 1), two reported that the moons looked equal and 19 saw the lower moon as larger. Of 22 subjects viewing the moons against the dark field of the laboratory room, with no visible ceiling (condition B), one reported that the lower moon looked larger, two that the higher moon looked larger, and 19 that they looked equal. These results, in accord with numerous preliminary observations, clearly indicate the effectiveness of the perspective provided by the ceiling. They also tend to substantiate the earlier findings of Kaufman and Rock and of King and Gruber (*1–3*) concerning the ineffectiveness of angle of regard in relation to the moon illusion.

In a second experiment we examined the persistence of the perspective space generated by the luminous ceiling *after* the ceiling had been removed from view. Since we were interested in the influence of a remembered or imagined space upon the perceived size of objects introduced into it, it was important to avoid introducing the objects while the ceiling itself was visible. Therefore, the moons were not visible during a 2-minute foreperiod in which the subject simply looked at and described the luminous ceiling. The subject then closed his eye for 5 seconds, during which time the ceiling was turned off and the moons were turned on, whereupon the subject was asked to open his eye and make size-ratio judgments.

The results, shown as condition C in Table 1, indicate that an illusion was obtained with five of the 18 subjects, the remaining subjects all reporting the two moons as equal. Since there were no reversals (lower moon reported smaller) in condition C, as compared with two reversals in condition B, it seems clear that with some subjects it is possible to generate a "remembered space effect" with 2 minutes of exposure to the luminous ceiling, this effect influencing subsequent size judgments. On the other hand, since only five subjects obtained the illusion, there is only a tenuous basis for generalizing to the natural moon illusion. Moreover, the conditions of this experiment are more extreme than those involved in the natural moon illusion, in that nothing was visible during the size-ratio judgments except the two spheres. A third experiment was designed with these considerations in mind.

For the third experiment the apparatus was modified so that when the luminous ceiling was turned off, a line corresponding to the horizon could be left on. Although this was actually accomplished with a separate light box, the effect given was the same as if the furthermost line of the grid composing the ceiling had been left on when the rest of the grid was turned off. Two groups of subjects were used. The subjects in condition E never saw the ceiling; they simply made their judgments with the horizon line and the two moons visible. The subjects in condition D saw the ceiling first, with no moons visible, as described above for condition C; the ceiling was then turned off and they made their judgments with only the horizon line and the two moons visible. The time for the change of scenes was again 5 seconds, during which the subject kept his eyes closed.

As shown in Table 1, a small illusion was obtained with some subjects (4 out of 18) in condition E; the illusion was larger and more frequently obtained (9 out of 18) in condition D, where judgments with a visible horizon were preceded by viewing the ceiling.

In testing the statistical significance of the results shown in Table 1, an analysis of variance was performed. Only conditions B, C, D, and E were included; condition A was omitted because it was felt that the most novel point of the study was not the striking effect of the visible ceiling but the less striking effect of the invisible ceiling; inclusion of condition A in the analysis of variance would have increased the statistical significance of the results. The effect of experimental conditions upon size-ratio judgments was found to be statistically significant ($F = 2.75$; $p < .05$). The difference between conditions B and D was statistically significant ($t = 2.40$; $p < .025$). Smaller differences were not significant.

In studies of the moon illusion and of other phenomena involving the interrelatedness of perceived size and perceived distance, certain paradoxical findings have been reported. For example, Gruber found a zero correlation between judgments of size and judgments of distance (*8*). In our study, therefore, after each subject had made his size-ratio judgment, he was asked to make a judgment of the distances of the two moons. The rank order correlation between size-ratio and distance-ratio judgments was .44 for condition A and .38 for condition D; only those subjects reporting that the moons differed in perceived size were used in calculating this result; if all subjects were used the correlations would be lower. Although these correlations are not zero, they are low enough to cast further doubt on the frequently made suggestion (*9*) that perceived size and perceived distance are closely coupled variables. As suggested previously (*2, 8*), there seems to be one relation between stimulus inputs and perceived size and another relation between stimulus inputs and perceived distance, but the two percepts are not closely linked.

In these experiments, the effect of remembered space on perceived size is sporadic and probably transient. But this is a space generated in only 2 minutes. There is reason to believe that longer exposure would produce more stable effects. We believe that the primary importance of these experiments is in demonstrating that appropriate past experience can generate a psychological space that will determine the perception of objects not previously seen in that space. It is this generalized effect of past experience, rather than knowledge of specific objects, which may account for the way in which the past history of the individual determines his present perceptions (*10*).

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References and Notes

1. W. L. King and H. E. Gruber, *Science* **135**, 1125 (1962).
2. L. Kaufman and I. Rock, *ibid.* **136**, 953 (1962).
3. I Rock and L. Kaufman, *ibid.*, p. 1023.
4. H. Liebowitz and T. Hartman, *ibid.* **130**, 569 (1959).
5. A. H. Holway and E. G. Boring, *Am. J. Psychol.* **53**, 109, 537 (1940).
6. With this difference in angle of elevation, in situations approximating the natural moon illusion, an illusion ranging from 50 to 100 percent of the maximum illusion might be expected, as can be calculated from data cited by D. W. Taylor and E. G. Boring [*Am. J. Psychol.* **60**, 189 (1942)].
7. Throughout these experiments the left hand moon was higher and fell within a grid-section of the upper, phenomenally near part of the ceiling, while the right hand moon was lower and fell within a grid-section of the lower or phenomenally far part of the ceiling. Counterbalancing for position effects was deemed irrelevant to the purpose of this study since we were primarily interested in the difference between conditions B and E (no ceiling at any time) on the one hand and conditions C and D (ceiling visible before but not during judgment) on the other.
8. H. E. Gruber, *Am. J. Psychol.* **67**, 411 (1954); W. Epstein, J. Park, A. Casey, *Psychol. Bull.* **58**, 491 (1961).
9. R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, New York, 1954).
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"Ages" of the Sikhote Alin Iron Meteorite

Abstract. *Measurements of the potassium and argon content of the Sikhote Alin iron meteorite, by activation analysis, enable a potassium-argon "age" of 1.7 × 10⁹ years to be calculated. Such an age is vastly different from all the ages previously measured for iron meteorites.*

Lead isotopic ratios showing an excess of the nuclides lead-206, lead-207, and lead-208 have been measured in several iron meteorites (*1–3*). As with such ratios reported for stone meteorites, these excesses may represent radiogenic contributions from the natural decay of uranium-235, uranium-238, and thorium-232, respectively. A lead-lead age calculated from the data, making the usual assumptions involved in the method, does indeed lead to an age of 4.6 × 10^9 years, in good agreement with ages calculated for stone meteorites by a variety of methods. However, in several of these meteorites there is a discrepancy between the measured uranium content and that expected from the lead content. In the Sikhote Alin meteorite, in particular, an upper limit was set to the abundance of uranium-235 which is two orders of magnitude too small to account for the excess lead-207 as radiogenic within the specified time interval (*4*).

It is not clear how to reconcile these data. It has been suggested that the lead is nonradiogenic (*1*), that radiogenic lead was added to the meteorites about 0.77 × 10^9 years ago (*2*), that uranium was removed from the meteorites about 0.1 × 10^9 years ago (*4*), or that the lead data are the result of terrestrial contamination. The data have now been reproduced by several independent observers, so it is not probable that contamination is the answer.

A suitable method for investigating the other suggestions is potassium-argon dating, since it is difficult to visualize any process which might remove uranium or add lead without melting the meteoritic material, thus removing argon as well. Such an experiment is reported here, and leads to a potassium-argon "age" of about 1.7 × 10^9 years. This indicates that a uranium/lead differentiation did not take place more recently than this date.

Three separate runs were made at the Brookhaven reactor, in which samples of 3 to 5 grams were irradiated for 3 hours at a flux of 5 × 10^{12} neutrons per square centimeter per second, together with about 200 mg of potassium chloride as a flux monitor. The samples were prepared for the irradiation by an acid bath in which approximately 20 percent of the mass was etched away. After irradiation this etching was repeated just as severely, to remove all possibility of surface contamination. The sample was placed in an alumina crucible in a vacuum line, then boiled by induction heating for 20 minutes in the presence of argon carrier. The evolved gases were passed over hot titanium, which was then cooled to remove hydrogen. The gases were then pumped into a proportional counter with a background of about 10 counts per minute (count/min). The chemical yield was 100 percent in all cases. Initial counting rates in the three samples varied from 4000 to 300 count/min. The activity followed the argon-41 half-life down to about 15 count/min, then decayed with the argon-37 half-life of 35 days for over a month. The potassium was separated from the melted mass and from the material vaporized onto the walls of the furnace by repeated ion exchange and cycles of precipitation with tetraphenyl boron. Counting was done on beta proportional counters with backgrounds of about 8 count/min. Initial counting rates varied from 7 × 10^5 to 2 × 10^4 count/min. The activity followed the potassium-42 half-life for many half-lives.

The argon-41 activity results from the $Ar^{40}(n,\gamma)Ar^{41}$ reaction, and gives directly the argon-40 content. A correction for cosmic-ray-produced argon-40 can be made from the argon-37 activity, which results from the $Ar^{36}(n,\gamma)Ar^{37}$ reaction. Argon-36 is produced in meteorites through direct nuclear production and through the decay of cosmic-ray-produced chlorine-36. The cross-section ratio, from iron targets, of $(Ar^{36} + Cl^{36})/Ar^{40}$ is about five (*5*). The correction for cosmogenic argon-40 in this meteorite is shown in Table 1. The observed variation of argon-41 activity with the potassium activity (see Table 1) indicates the close association of argon with potassium in the meteorite: The three samples show a total variation of a factor of 15 in potassium content, yet the potassium/argon ratio stays constant to within ±20 percent. This potassium-argon togetherness renders unlikely the possibilities of either contamination by primordial argon or loss of radiogenic argon by diffusion. Diffusion loss is improbable also because (i) there seems to have been no such loss of cosmogenic helium, neon, or argon during Sikhote Alin's cosmic ray age of about 150 million years (*6*), (ii) no such loss of cosmogenic rare gases is observed in other iron meteorites over periods of perhaps up to 1.5 × 10^9 years, and (iii) several other iron meteorites selected at random show no evidence of diffusion loss of radiogenic argon during their (potassium-argon) age of up to 13 × 10^9 years.

Table 1. "Ages" of iron meteorite samples. Ar_t, total argon; Ar_r, radiogenic argon.

Argon (10^{12} atom/g)			Ar^{40}_r/K^{40}	"Age" (10^9 yr)
Ar^{36}	Ar^{40}_t	Ar^{40}_r		
	Sample 1, weight 2.74 g			
3.8	14.4	13.7	0.19	1.7
	Sample 2, weight 3.0 g			
0.73	1.12	0.98	0.21	1.9
	Sample 3, weight 4.25 g			
1.0	5.3	5.1	0.15	1.5

The potassium-42 activity results from the $K^{41}(n,\gamma)K^{42}$ reaction. Terrestrial isotopic abundance of potassium is assumed in order to calculate the potassium-40 content. This abundance ratio can be modified probably only by cosmic-ray-produced potassium, and this can be estimated from the work of Stauffer and Honda (*7*). The correction for this meteorite is negligible.

The results are shown in Table 1. Stoenner and Zahringer have previously dated several iron meteorites by this method and obtained ages ranging from