The Moon illusion

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PART TWO

In this second part we take a look at the two most accredited theories among those that attempt to explain the Moon illusion. But to give a final answer is by no means simple...

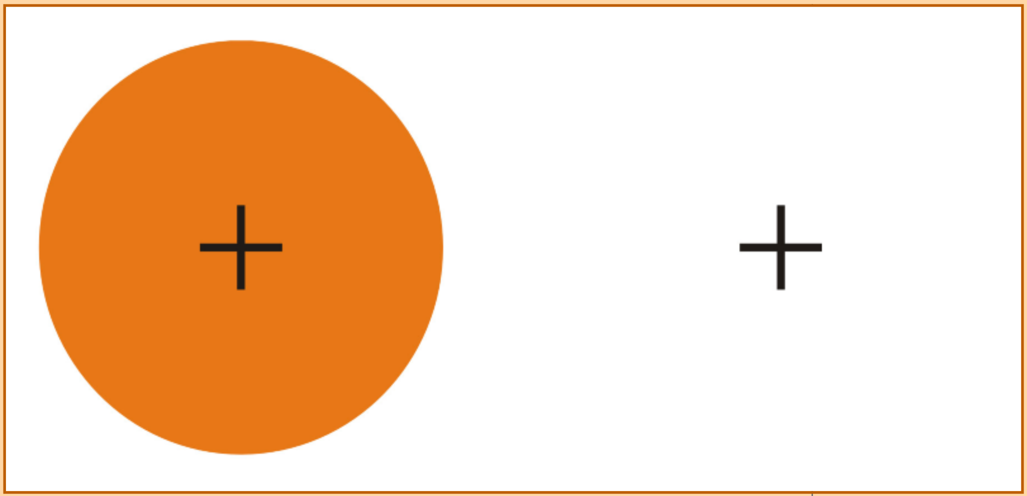
The Moon illusion refers to the fact that the Moon appears much larger when close to the horizon than when high in the sky.
In the article published in the last issue we discussed factors that contribute to the illusion but not of the theories that attempt to explain it. We do that here.
At the moment there are two competing theories, of which the first has ancient origins, while the second is relatively recent.

Theory 1: *"the illusion is due to the inappropriate application of size constancy".*
According to this theory the apparent size of the Moon is a function of its apparent distance from us: the more it seems distant the larger it appears to be. The Moon appears to be further from us when it is at low elevation than when it is high in the sky, and this is why we see it as larger in the first case.

The space between the two green bars is equal to that occupied by the red bars, but it appears less. This is the Oppel-Kundt illusion.

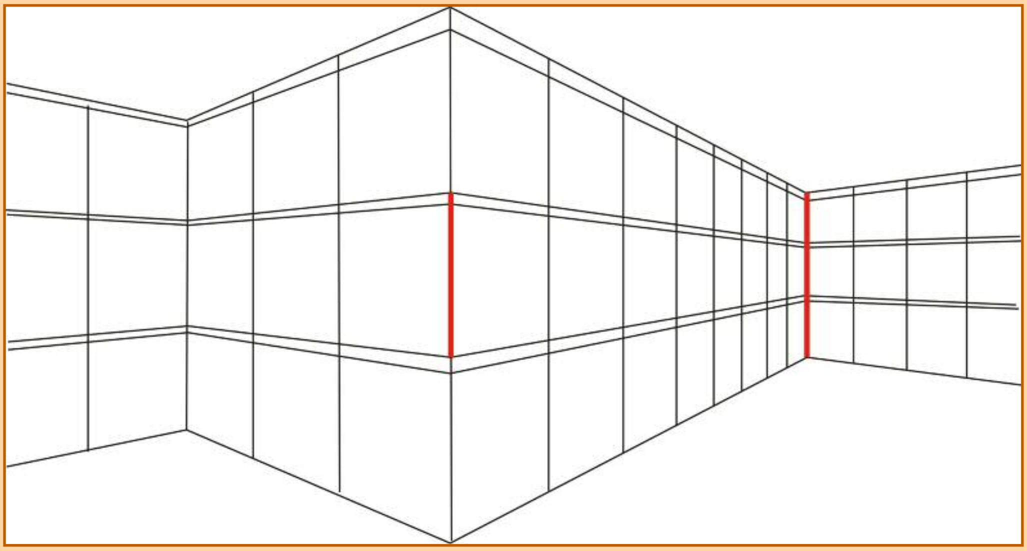
As the figure below shows, non-uniform spaces seem larger than uniform ones, and it is principally for this reason that the Moon appears further away when near the horizon; in fact, the space between us and the horizon, filled with objects of all kinds of shapes and textures, is generally much more heterogeneous that when the Moon is near the zenith.
This theory explains why the illusion is all the more pronounced if the horizon appears distant and the terrain clearly visible. As we saw in the last issue, this is the most important factor and, according to the supporters of this theory, this is because the apparent distance of the Moon increases with the apparent distance of the horizon when they are seen close together. In this case one perceives the Moon and horizon to be at similar distances, with perhaps the Moon slightly more distant.
Asserting that the Moon appears larger because it appears more distant, at first

To better illustrate the theory based on size constancy, we propose again this figure, the use of which is explained in the text.



glace seems to contradict common experience, in that an object seems smaller, not bigger, the further it is from us. But an object seems to get smaller as it gets further away from us because its angular size decreases; but this does not happen in the case of the Moon because it always has the same angular size no matter what its apparent distance from us. We therefore apply a different case to the Moon, that in which two objects at different distances have the same angular size, that is, projecting identical images on the retina. In this case the object that seems more distant also seems larger, as indeed it is, if we have correctly perceived its distance.

It is here that what psychologists call "size constancy" comes into play. This is the tendency for objects to maintain more or less the same apparent dimensions with variations (within certain limits) of their distance from us. For example, a person only seems slightly smaller when they are 10 metres from us compared to when they are 5 metres from us; where, if the perceived size was purely a function of angular size the person should appear exactly half as big. This is not so, because, in some still unknown way, our brain "calcula-



A version of the famous Muller-Lyer illusion: however incredible it may seem, the two red lines are identical and their ends are perfectly aligned.

tes" the perceived size of an object by taking into account the distance at which the object appears to lie. The relation between angular size, perceived size and perceived distance is more or less as follows:

perceived size =
angular size × perceived distance.

When the person is twice as far from us their angular size halves, but the perceived distance doubles, so that the product of these two factors, the perceived size, remains constant. When, instead, like in the case of the Moon, the angular size is constant, it is clear that increasing the perceived distance increases the perceived size. Therefore the Moon appears larger when it seems more distant and given that it seems more distant when close to the horizon it must also seem larger in this position. That's just happens, so the Moon illusion should be explained.

It is simple to experiment with size constancy. Stare for 30 seconds at the cross on the left of the figure on page 31, then shift your gaze to the cross on the right: you will notice an illusory blue disk (this is a negative consecutive image, a phenomenon discussed in the last issue). Now move away from the page, while continuing to stare at the cross on the right: you will notice that the blue disk expands drastically, and all the more the more distant you are from the page. If you then shift your gaze to a wall a couple of metres away, the disk will grow even more.

Here is how this phenomenon is explained. When you move away from the page, the consecutive image also seems to get more distant because it continues to be seen on the page; since it is correctly seen more distant, and since the angular size remains constant, its perceived size must necessarily increase, if the above equation is correct.

The Moon behaves exactly like the consecutive image according to those that support this theory. After all, the reader might remember from the previous issue that one of the methods used to study the Moon illusion involves the formation of just such a consecutive image and "projecting" it in various positions in the sky.

It is not a bad idea to illustrate further the power of size constancy because it's a phenomenon that few people notice. Take a look at the figure at the bottom of page 31: the two red lines are iden-

The four people are identical, but those that seem to be further away appear to be larger.

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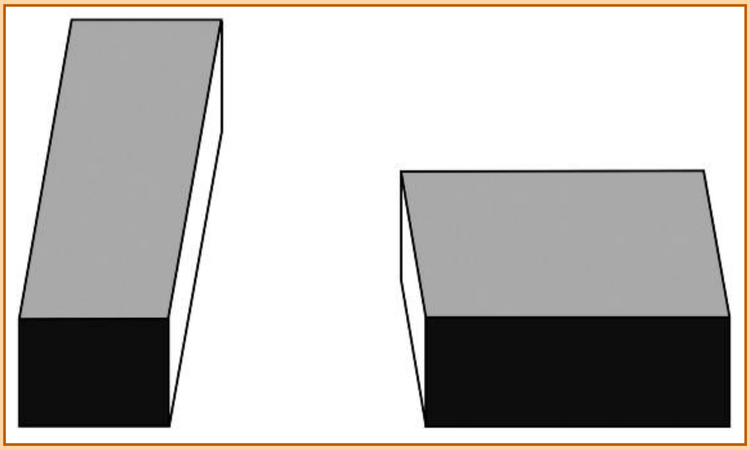
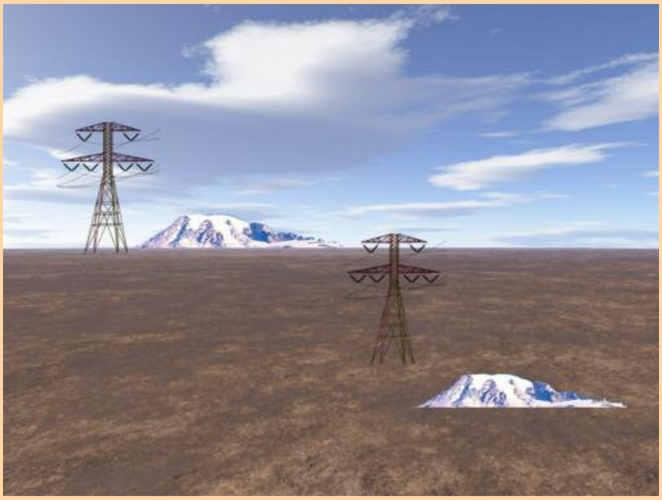
tical and their ends are aligned, but one struggles to believe it, the line on the right seems much longer. This one also seems more distant however, and it is probably for this reason that it looks longer (size constancy).
The "corridor illusion", a version of which we show on page 32, can be explained in the same way: the four people are all the same size, even though one would disagree. In fact, the more distant the person, the larger they seem to be. An "interactive" version of the corridor illusion can be found at this site:www.cut-the-knot.org/Curriculum/Geometry/Perspective2.shtml.
Another dramatic illusion probably caused by size constancy (or rather, in this case, shape constancy) is Shepards' illusion (above). Explanations based on size constancy, however, have a serious problem, the size/distance paradox: is it really true that the Moon seems more distant when at the horizon? The answer, unfortunately, seems to be "no"; most people when asked actually say the opposite, that is, that it appears closer.
This fact has been, and is, considered by many a refutation of explanations based on size constancy. Things aren't quite so simple though, and this is because of the size/distance paradox.
Let's suppose that a person finds themselves infront of two objects, placed at different distances, with identical angular sizes but different linear sizes, and that they have to say which appears largest and which appears farthest. If the distance cues are very limited, that is if one uses objects with few features on a perfectly uniform background, one finds experimentally that the smaller, closer object is judged to be smaller (correctly) but also more distant (incorrectly).



The two grey areas are identical, that is they can be superposed. To be sure of this it's necessary to print the figure, cut out the areas, and place them one on top of the other.

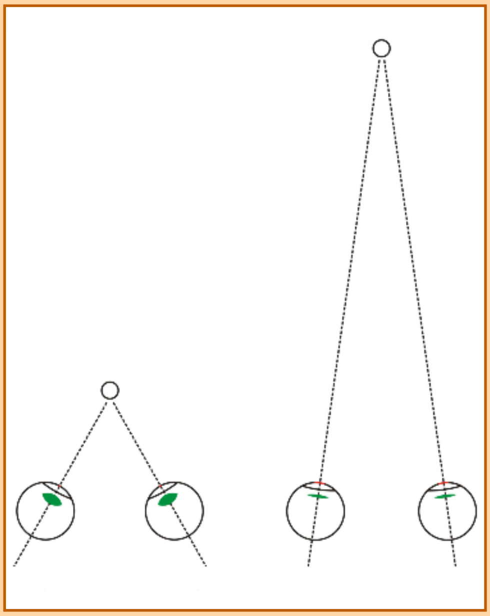
This is a paradox: given that the two objects have the same angular size, one would say that if the closer object is seen correctly as the smaller this must necessary be the case because it is also seen as the closer; the opposite however is the case.
If the smaller object is judged to be more distant it is exactly because it is smaller: all else being equal, in fact, the rule is that of two objects the smaller is seen as more distant. Therefore, one of the objects is judged to be smaller because it is closer, and then judged to be more distant because it is smaller! This is the size/distance paradox.
In the case of the Moon illusion the same paradox seems to occur: the Moon appears larger at the horizon because it seems more distant, but then it is seen as closer because it looks bigger! How can we explain all this?
The various attempts to save the theory in question share this fundamental idea: the Moon on the horizon (a) is perceived to be further away, therefore (b) is perceived to be larger, therefore (c) it is judged to be closer. So, subjects would perceive it to be more distant,



The two objects at the bottom are identical to those at the top, even if they seem much smaller. Once again, that which appears more distant appears larger.

but judge it to be closer after more or less conscious reasoning. As a result, their reply to the question, *"Does the Moon seem further away or closer when near the horizon?"* doesn't disprove the theory based on size constancy because it is the result of reasoning, not what they really see.
Nevertheless, many academics are sceptical about such arguments, and argue that the Moon at the horizon is not only judged but also perceived to be closer. The size/distance paradox is the main reason why alternative explanations to size constancy have been sought. Let's now consider the main contender among these alternatives.

Theory 2: *"the illusion is due to convergence accommodation/convergence micropsia".*



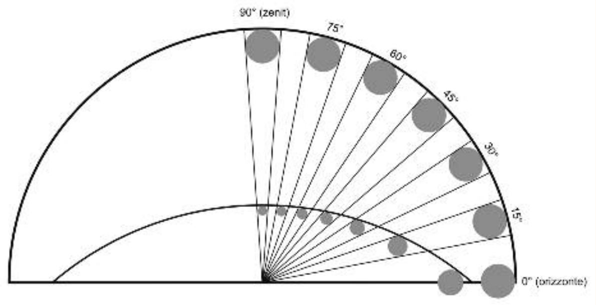
When we look at a nearby object the eyes converge, the lens (in green) thickens and the pupil (in red) contracts. When we look at a distant object the opposite happens.

The second theory attributes the illusion to so called convergence micropsia and accommodation, caused by the fact that when one looks at the Moon at the zenith, the accommodation, convergence and pupil diameter take on values appropriate for the observation of nearby objects. This theory is preferred by some to the previous one because it has the big advantage of, rather than resolving, dissolving the size/distance paradox.
We briefly illustrate here just the most simple of the various versions of this theory; those who would like to learn more can visit the web site http://facstaff.uww.edu/mccreadd/intro9.htm.
Accommodation is the focusing mechanism of the eye. This is achieved via the converging lens in the eye that changes thickness according to the distance of the object we observe: it thickens for nearby objects and thins for distant objects.
Convergence describes the fact that when we look at an object our eyes rotate in their sockets so as to converge on the object. The closer the object the more at least one of the eyes has to rotate (see figure to the side). The diameter of the pupil depends, amongst other things, on the distance of the object that is observed; the closer the object the more the diameter is reduced.

Accommodation, convergence and pupil diameter have a strong tendency to vary together, and so one sometimes talks of the "near-vision triad". The figure to the side illustrates how the three factors vary as distance to the object varies. The pupil is indicated in red, the lens in green. Further, and this is much more important, in the presence of a uniform field of view, complete darkness for example, both accommodation and convergence are those appropriate for viewing distances of 1-2 metres, with large subject to subject variation. In other words, the resting state for accommodation and convergence is for this distance.
But what is accommodation/convergence micropsia? This refers to the fact that objects seem smaller to us, even much smaller, when we accommodate and converge our eyes for nearby vision; this goes for all the objects in the field of view, not only for those at which we are looking.
You can experiment yourself with micropsia with the so-called Hering Maneuver. Close your eyes and extend your arm with your thumb raised, keeping a window or door in the background about three metres away. Stare at the tip of your thumb, but concentrate of the apparent dimension of the door or window. Slowly move your thumb towards your eye, continuing to stare at it. The window seems to shrink. Take

Alhazen's Theory

The first scientist to propose the the Moon looks larger when at the horizon because it seems further away was the Arab Ibn Al-Haytham (Alhazen), who lived between the tenth and eleventh century.
According to Alhazen, the Moon seems "glued" to the celestial sphere, and we perceive it to be closer when it is high in the sky because the celestial sphere seems lowered at the centre. In 1738 Robert Smith illustrated this theory with the figure shown here. The larger arc represents the lunar orbit, and the internal one the celestial sphere. The projection of the Moon on this sphere shows that, if this is what we perceive, the Moon must appear smaller when close to the zenith.
Robert Smith also thought to demonstrate this theory by asking people to extend their arm and indicate the half way point between the horizon and the zenith. You try, and then measure the true angle of your arm. You will certainly find that you pointed to a position much closer to the horizon than the zenith; an error of over 10 degrees in normal! This phenomenon, for geometrical reasons, corroborates the theory of Alhazen and Smith.
Another version of Smith's experiment involves estimating the elevation of the Sun or the Moon and then comparing with measured values. Also in this case the error is rarely less than 10%. Note that this phenomenon isn't apparent in photographs, and, given that the Moon illusion also disappears in photographs, this is another reason to suspect that there exists a link between the two.

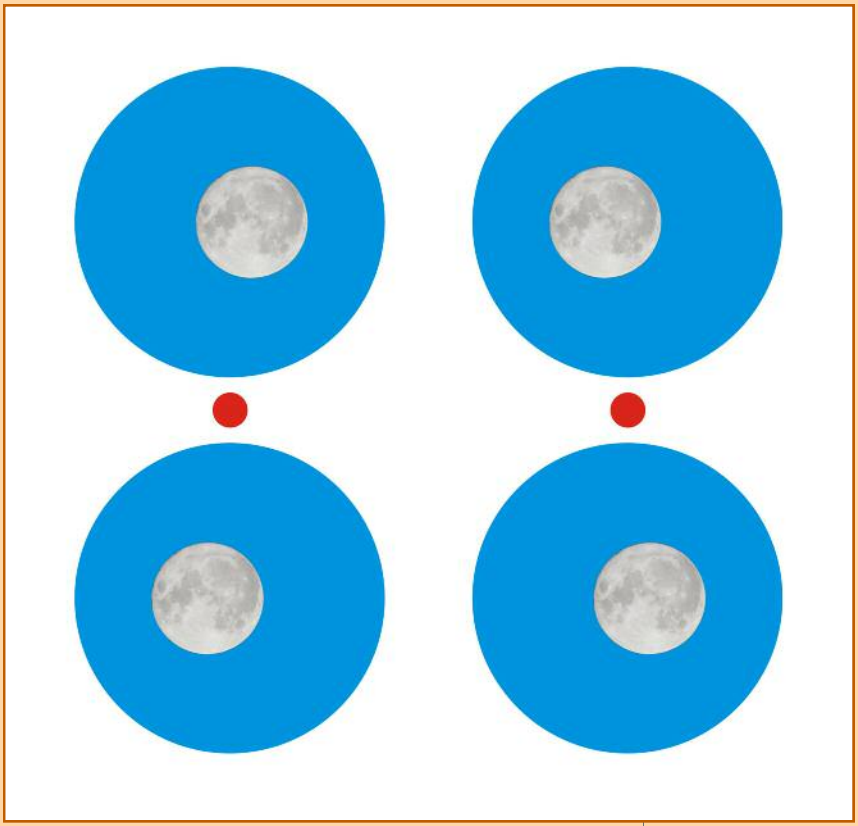


This figure (Smith, 1738) illustrates Alhazen's theory, that explains the Moon Illusion by the fact that the celestial sphere appears to us lowered in the centre.

In natural observing conditions the Sun would appear much higher above the horizon than in this image.

care however: to notice the effect you need to force yourself to think of the window and the things around it as an image, a painting.
The Hering Maneuver can be caused also by the Moon or the Sun at sunset: you just need to place your thumb next to the celestial object and carry out the maneuver.
The pupil diameter also causes micropsia, probably via its effects on accommodation and convergence. Try making an artificial pupil with a pin and a sheet of paper and look at the Moon through it. You will notice a dramatic illusion: the Moon looks much smaller, by about 50%, both when near the horizon and when high in the sky. The effect was noted already by Leonardo. But how can all this explain the Moon illusion? In the following way, for example.
The sky that surrounds the Moon when it is high in the sky is, generally, much more uniform than the environment in which it finds itself when near the horizon, and this is particularly the case on clear nights. As a consequence, when the Moon is high in the sky, accommodation and convergence will tend towards their resting state, that is for near by observations. But we have said that accommodation and convergence per nearby objects cause micropsia, and it is just this that makes the Moon seem smaller when high in the sky.
This theory is supported by various facts. Roscoe found, that in fact, his subjects accommodated for a much closer distance when they looked at the Moon high in the sky than when they observed it near the horizon (Roscoe S.N., 1989, "The zoom-lens hypothesis". In Hershenson M., "The Moon Illusion", pp. 31-57, Hillsdale, NJ: Earlbaum L. The validity of Roscoe's result is however cast into doubt by Kaufman & Rock, cited as note 21 in the article).
Another fact that casts doubt on the idea that the optical motor system plays an important role is that the illusion is much weaker if the Moon is observed with just one eye (provided that it hasn't first been observed with two eyes).

If you manage to merge these two stereograms by converging your eyes, the Moon at the top will seem closer than that at the bottom. Appearing closer, this will also seem a little smaller.



As mentioned before, this second theory dissolves the size/distance paradox. This is because it deals with only one distance, that perceived, rather than two. The confusion of the near-vision triad would have a direct effect on the apparent dimensions of the Moon, without the involvement of a distance estimate, and would make the Moon appear closer when on the horizon. There is then no space, in this theory, for a distance judgement, which avoids the paradox.

The main supporters of the first theory, Kaufman & Rock, don't deny that accommodation and convergence have a role to play, but they maintain that its role is as a distance cue. It is, in fact, well established that the brain estimates the distance to objects by making use, amongst other things, of accommodation and convergence. For Kaufman & Rock, accommodation and convergence signal that the Moon on the horizon is more distant, and this contributes to the perception that it is bigger.

Naturally, if one accepts this interpretation the size/distance paradox remains, because two distances are once again involved, that perceived and that which is first judged and then reported by the subjects.

To conclude, agreement has still not been reached on how to explain the Moon illusion, despite it being a phenomenon that has been noted and studied for millennia. This contrasts with the conclusions reached in most public-oriented works on the subject, that an agreed explanation has been found, that being the first of the two theories discussed here. The author maintains that this conclusion is not justified based on the data, but only by a long tradition that lies behind the theory of size constancy, and to the prestige, however justified, that the modern exponents of this theory enjoy.

Stefano Vezzani has been a psychology researcher at the University of Milan (Bicocca) where he lectured in cognitive psychology. He has published articles on the psychology of visual perception in international scientific journals, and currently works in the field of scientific communication.