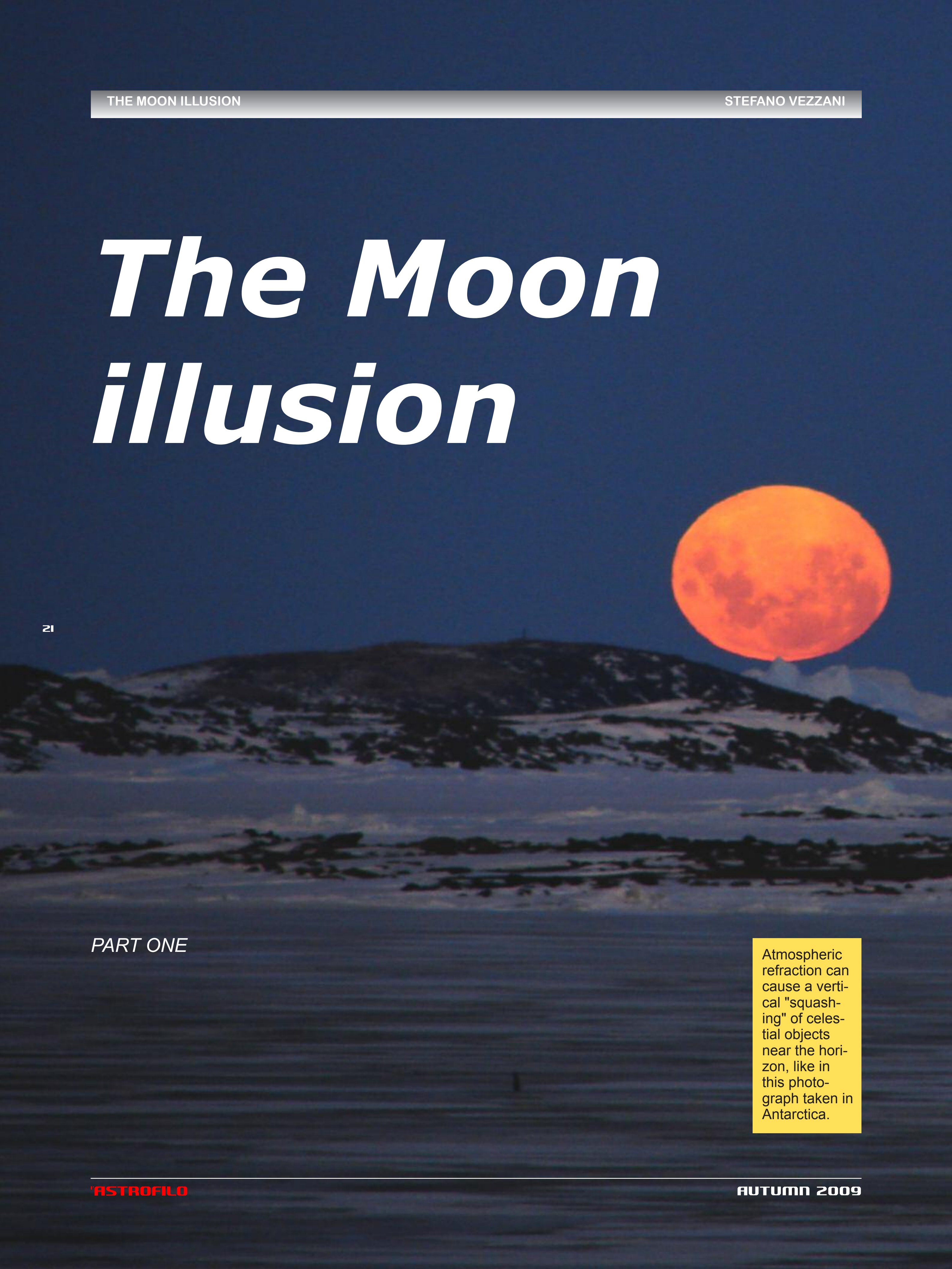
The Moon illusion



21

PART ONE

Atmospheric refraction can cause a vertical "squashing" of celestial objects near the horizon, like in this photograph taken in Antarctica.

Everyone will have paused to note how much larger than usual the Moon, Sun, or constellations look when close to the horizon. What causes this optical illusion?

Many phenomena observable in the sky with the naked eye are due to the characteristics of the observer, and are thus studied with psychology. The most famous among these is the "celestial illusion": the Moon, Sun and constellations seem much larger when they are close to the horizon than when they are close to the zenith. We are all familiar with how much larger the Sun looks at sunset, and how small the Moon appears by comparison high in the sky: even though their angular diameters are virtually identical.

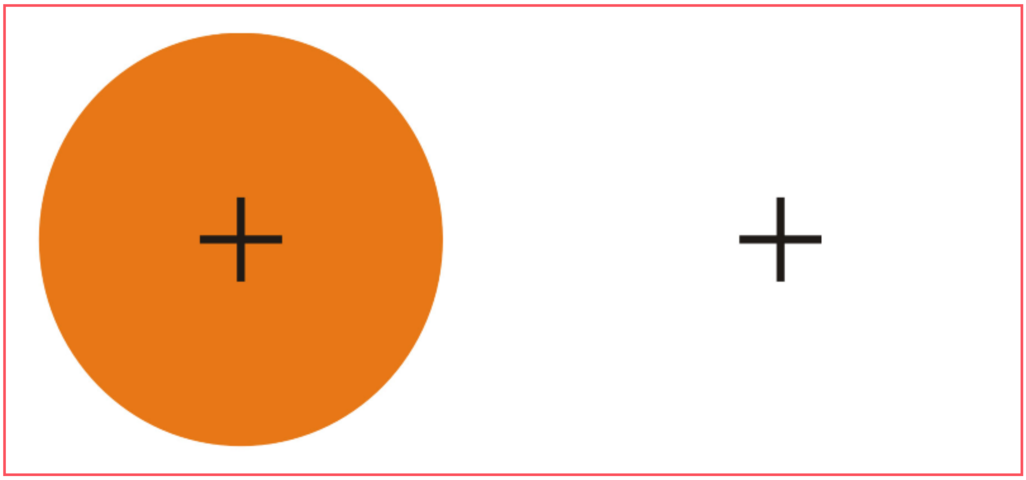
That aspect of the celestial illusion that regards the Moon, or the "Moon illusion", has particularly well studied and discussed by every kind of scientist and philosopher, probably because of the ease with which it can be observed.

The first certain reference to the illusion was by Aristotle, who, like the later Ptolemy in his Almagest, attributed the effect to atmospheric refraction. However, today we are certain that the illusion has neither this nor other physical causes: in fact the Moon is slightly smaller when near the horizon because it is slightly further from the observer. In addition refraction also compresses vertically the image of the Moon, therefore making it smaller, as illustrated in the background photograph on page 21. Even though radically wrong, this explanation has been re-proposed many times through the centuries, and even today one can come across it in some less prudent texts.

If the causes of the illusion are not physical the explanation must lie with the observer, and must therefore be psychological or physiological. The Arab, Ibn al-Haytham, already realized this in the tenth century, suggesting that the Moon seemed larger at the horizon because it seemed more distant. As we will see, this is still today one of the most credible explanations.

In the course of time the illusion has been studied using ever more sophisticated techniques. In an early phase studies were carried out using anecdotal observations and estimates based on memory: subjects were asked if and since when they could remember the Moon being larger at the horizon. In this way, however, a comparison was made between two memories, or rather a perception (that is from direct observation) with a memory and not two perceptions, so that there was no guarantee that the illusion was to do with perception rather than memory.

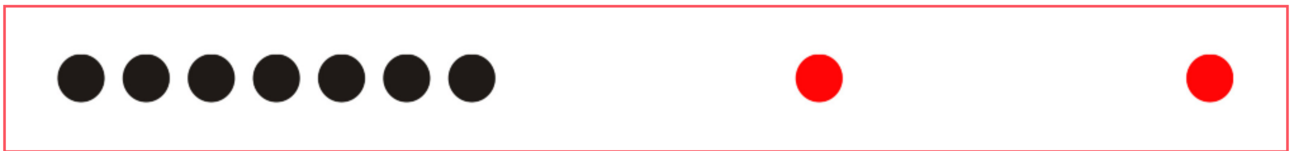
Another method used in some scientific studies, starting with Zeno in 1862 ("On the changes in the appar-



If one stares at the cross on the left for about 30 seconds and then shifts the gaze to the cross on the right, an illusory blue disk can be seen. This is a negative consecutive image.

ent size of the Moon", *Philosophical Magazine*, 24, pp. 390-2), though not very precise is still useful today for those who want to experiment themselves, consists of the use of a "consecutive image" (a curious example can be seen at www.michaelbach.de/ot/cog_Darwin/index.html.
Now stare at the cross on the left of the above figure for about 30 seconds without moving your gaze. Then move your gaze to the cross on the right: you will notice an illusory blue disk, as large as the orange one to the left. This is a negative consecutive image, due to retinal fatigue, and can be "projected" onto any surface one likes, because it moves with the eye. The image is called "consecutive" because it follows the prolonged observation of a real image, and "negative" because its colour is different to (complementary to) the object that generated it. The method in question involves producing a consecutive image by observing (carefully) the Sun at sunrise and sunset for about 30 seconds, and then "projecting" it first at the zenith and then at the horizon: the illusory celestial body looks larger in the second case. The consecutive image, however, is unstable and doesn't last long; also, it is not possible to measure precisely how its appar-

The magnitude of the Moon illusion measured by Kaufman & Rock (1962) in one of their experiments. The Moon near the horizon (right) seemed to have a diameter 1.5 times that of the Moon at an elevation of 70 degrees (left). Note that the figure can be misleading, due to a further illusion: the Moon on the right, in fact, seems erroneously to have a diameter well above 1.5 times and an area well over 2.25 times that of the Moon on the left.

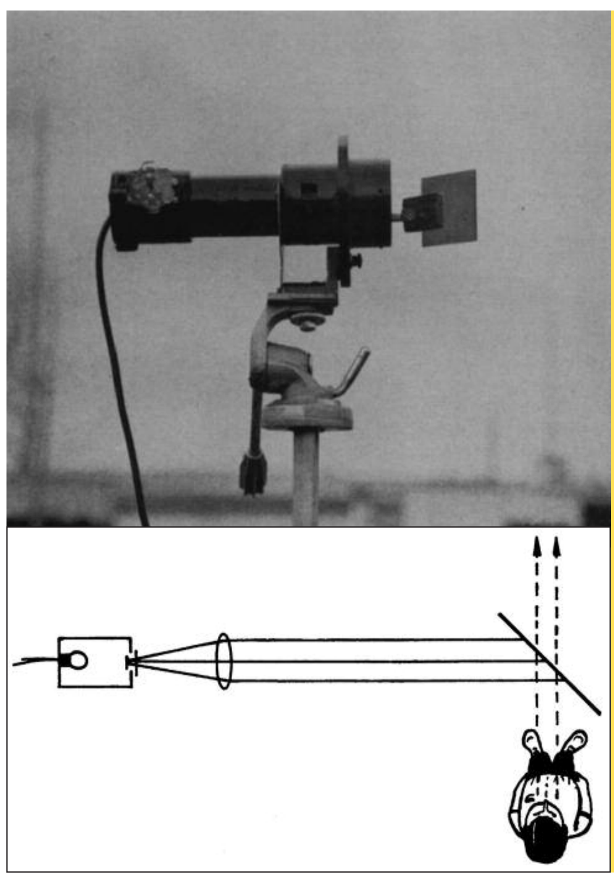


The space on the left, delimited by black circles, seems larger than that on the right, delimited by red circles (the Oppel-Kundt illusion). In general, non-uniform spaces expand relative to uniform spaces.

ent dimensions change as a function of sky position. For this reason the method is rarely used in present day scientific works. The best method is undoubtedly that developed by Lloyd Kaufman and Nyla Irvin Rock in 1962 ("The Moon Illusion" I and II, Science, 136, pp. 953-961 & 1023-1031) and adopted in almost all relevant experiments since. With an optical system called a "Moon machine" two artificial full Moons are presented, one at the horizon and one high in the sky, and the subjects are asked to compare the apparent dimensions: this guarantees that we are dealing with an authentic perceptual illusion because two perceptions are compared. In addition, the observer can also change the size of one of the Moons so as to make it subjectively similar to the other, and this allows a precise quantification of the illusion.
If, for example, the Moon on the horizon looks as large as the other when it is really only 50% the size, the illusion has a magnitude of 50%. In most cases studied by Rock and Kaufman, the Moon on the horizon had an apparent diameter 1.5 times that of the Moon at an elevation of 70 degrees, as shown on the preceding page, but ratios of 2/1 were reached with a very distant, smooth horizon, such as that of the sea.
This leads us the conditions that give rise to the illusion. It seems that the phenomenon is caused by several factors that add up, of which one is particularly important. Let's look at them.

The terrain and the apparent distance of the horizon

The most important factor seems to be the apparent distance of the horizon:



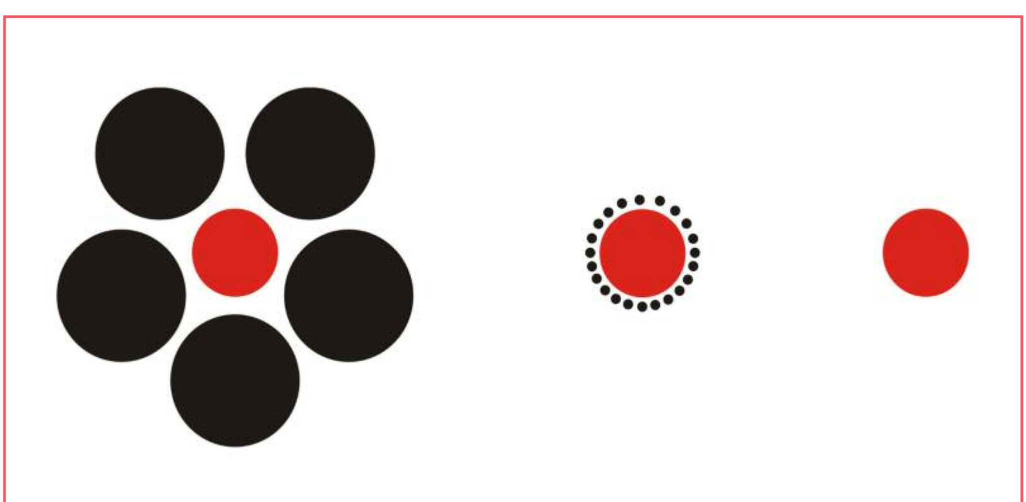
To the left we see the so-called "Moon machine" used by Kaufman & Rock in their experiments. The diagram at the bottom shows how it was used: the machine projects a luminous disk (the fake Moon) onto a glass plate angled at 45 degrees; the subject looks towards the plate and sees the luminous disk as an object placed among the many others visible through the glass.

the more the division between the sky and the ground (or sea) seems distant and well visible, the more the Moon seems larger when close to it. If instead one blocks the horizon with a screen the illusion weakens, and weakens more when the screen is closer to the observer, as observed for the first time by a student of Galileo Galilei, Benedetto Castelli (Ariotti P. 1973, "Benedetto Castelli and Berkeley as Anticipators of Recent Findings on the Moon Illusion", Journal of the History of Behavioral Sciences, 9, pp. 328-332).
The illusion can be inverted by swapping the positions of the Moon at the horizon and at the zenith: the Moon that is now presented at the zenith, together with the land and therefore the horizon, is now perceived to be larger.
The apparent distance of the horizon is determined by the makeup of the terrain and the presence of objects. If the terrain or sea were perfectly uniform, the horizon would appear closer.
The well known illusion of Oppel-Kundt, illustrated in the figure at the top of page 24, is a demonstration of how non-uniform spaces seem to expand relative to uniform ones: the space to the right seems narrower than that to the left, although they are actually the same.

The part of the Moon in shadow is often weakly visible, and the disk to which it seems to belong has a diameter smaller than that to which the bright side appears to belong.

The viewing angle

In general, if the Moon is at the horizon we look at it with our eyes and head straight, while if it is high in the sky we look at it by raising our head and/or rolling our eyes high in their orbits. It has been proposed in the past that this effect, that is the viewing angle, can explain the illusion.
This factor does have a real effect, but it seems to be of relatively little importance. Although the values reported in the literature show a large variation it seems that looking up causes a reduction in the perceived size no larger than 10%, too little to entirely explain the Moon illusion.



Titchener's illusion: the red disk surrounded by large disks seems smaller than that surrounded by much smaller disks.

Nonetheless, the reader can check for themselves if the effect is really so small: try to observe the Moon at the horizon by pointing your head towards the ground and raising your eyes in

The constellations also appear larger when close to the horizon. Orion, for example, when it rises seems far more extended than when near the zenith.

their sockets; or try to observe it when it is close to the zenith lying on your back. By how much does the apparent size change?

Cloud cover

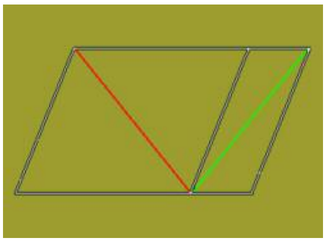
As demonstrated by Rock and Kaufman, the illusion is stronger when the sky is cloudy then when it is clear (52% vs 34%).
It is likely, however, that this is due to the fact that the horizon appears more distant in cloudy conditions. We have said that greater texture of the terrain has the effect of distancing the horizon from us; that of the sky, visible only when the sky is at least slightly cloudy, has the same effect.
If this is so this third factor is actually the same as the first.

The relative size

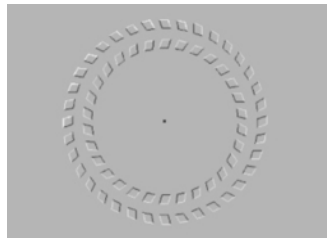
The Moon on the horizon is often seen close to relatively small objects, simply because they are distant. It has been proposed that the Moon appears large because it is relatively larger than these objects; the Moon when high in the sky is isolated and its size cannot be visibly compared with any other object of familiar size.
The effect of relative size is demonstrated, for example, by Titchener's illusion, illustrated on page 25 (for a collection of illusions of this type see www.illuweb.it/prosp/prosbina.htm and

Optical illusions from www.ophtasurf.com

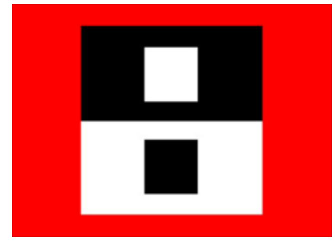
(for the answers and other exemples visit the site)



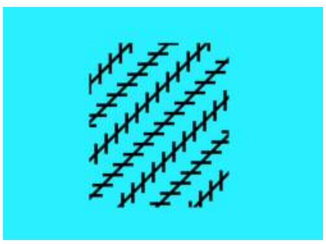
Which line is longer?
Red or green?



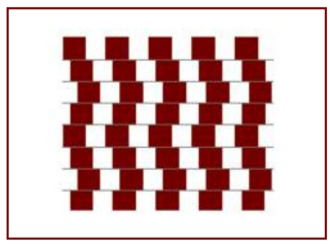
Staring at the point in the centre, move towards and away from the page...



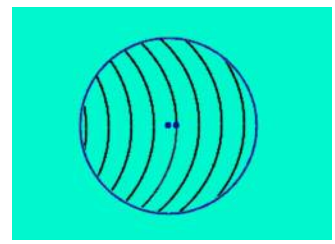
Is the white or the black square larger?



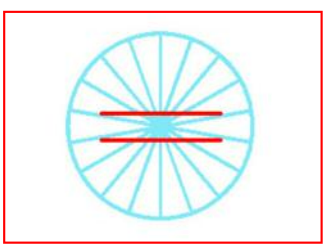
Are the diagonal lines parallel?



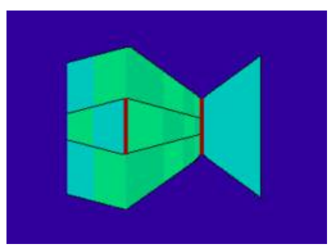
Are the checkered lines parallel or not?



Which of the blue points is at the centre of the circle?

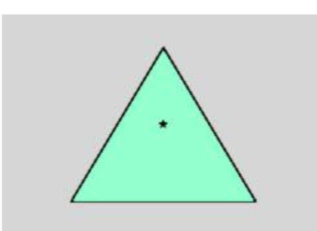


Are the red lines parallel or not?

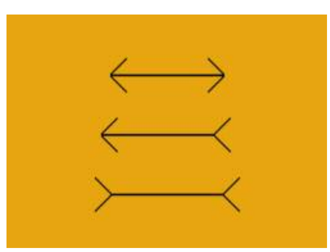


Which of the red lines is longer?

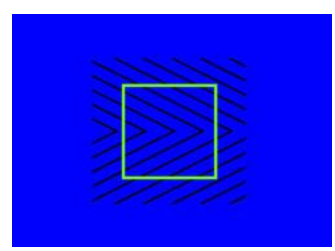
Vibration of a flat static figure....



Is the point closer to the apex or the base?

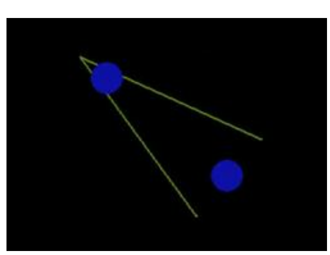


Which of the lines is longer?

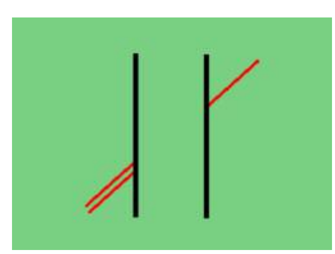


Is the polygon a trapezium or a square?

Is the red or the green shape smaller?



Is one of the circles larger than the other?



Which line is the continuation of that on the right?

www.ophtasurf.com/en/illusionpage2.htm.) The three red disks are identical, but that in the centre appears larger than the others (especially than that on the left). Despite this we have said that the optimal conditions for the Moon illusion is a smooth marine horizon. This seems to exclude the idea that relative size is an important factor because in these conditions there are not generally any objects close to the Moon. In addition, it has been well-known since the 18 hundreds that the illusion is greatly reduced if the scene is inverted (for example if the observer bends over to observe the scene backwards from between their legs); even though the relative sizes obviously remain identical.
In summary, it is thought that the relative size effect can contribute to the illusion but only in certain conditions.

Luminance, contrast and colour

When it is near the horizon, the Moon is generally less luminous and has a lower contrast with the background than when near the zenith. This is due to the fact that the light from the Moon has to pass through a thicker layer of atmosphere, and the atmosphere has the effect of increasing the brightness of dark objects and decreasing that of bright objects, thus reducing both the brightness of the Moon as well as its contrast with the sky. Could reduced brightness and contrast contribute to the illusion? Bishop Berkeley, in the 17th century, thought that this was even the main explanation (section 69-71 of: Berkeley G. - 1709, “An essay towards a new theory of vision”, Dublin: Rhames and Papyat).
What little experimental evidence that exists however, is negative. Kaufman and Rock, for example, found that contrast with the background did not contribute to the illusion. In fact, at least as far as images on paper or screens is concerned, the rule is that objects appear smaller, not larger, when contrast with the background is low. Further, at fixed contrast it is the brighter object that appears larger.
Even some celestial phenomena falsify the idea of the importance of luminosity and contrast. For example, Tycho Brahe, in the 15 hundreds pointed out that the Moon appears larger when it is brighter and more contrasted with the sky. Further, when the Moon is not full its unilluminated part is often weakly visible, the disk to which this seems to belong has a smaller diameter then that to which the illuminated part seems to belong (the photo on page 25 illustrates the idea).
Neither contrast nor brightness seem to contribute then to the illusion, but what can we say about colour? The Moon is often reddish when near the horizon. Do red objects seem larger? In the laboratory, in fact, the colour red can cause a perceived increase of 3-6% in size; on the other hand, an experiment carried out by Kaufman & Rock with their Moon machine seems to exclude any influence of colour. This factor then also seems either to have no influence or only a small influence on the illusion.
In conclusion, the principal factor in the Moon illusion seems to be the presence of a visible and distant horizon: the more distant the horizon appears the more the Moon seems larger. Other contributory factors are the angle of observation, and, in certain circumstances, the relative size.
How do we explain the importance of these factors, especially the first? We will discuss this in the next issue.

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.