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The Moon Hits Your Eye Like a Big Pizza Pie: The Big Moon Illusion

On a warm spring evening when my daughter was still an infant, my wife and I put her in a stroller and set off for a walk through our neighborhood. Heading south, we turned onto a street that put us facing almost due west. The Sun was setting directly in front of us and looked swollen and flaming red as it sank to the horizon. It was spellbinding.

Remembering that the Moon was full that night, I turned around and faced east. There on the opposite horizon the Moon was rising, looking just as fat—though not as red—as the Sun, still setting 180 degrees behind us.

I gawked at the Moon. It looked positively *huge,* looming over the houses and trees, the parked cars and telephone poles. I could almost imagine falling into it, or reaching out and touching it.

I knew better, of course. I also knew something more. Later that evening, around 11:00 or so, I went outside. It was still clear, and I quickly found the Moon in the sky. After so many hours, the rotation of the Earth had carried it far from the horizon, and now the full Moon was bright and white, shining on me from high in the sky. Smiling wryly, I noted that the Moon appeared to have shrunk. From the vast disk glowering at me on the horizon earlier that evening, the Moon had visibly deflated to the almost tiny circle I saw hanging well over my head.

I was yet another victim of what's called the Moon Illusion.

There is no doubt that the vast majority of people who see the Moon rising (or setting) near the horizon think it looks far larger than it does when overhead. Tests indicate that the Moon appears about two to three times larger when on the horizon versus overhead.

This effect has been known for thousands of years. Aristotle wrote of it in about 350 B.C., and a description was found on a clay tablet from the royal library of Nineveh that was written more than 300 years earlier than that date.

In modern popular culture there are many explanations offered for this effect. Here are three very common ones: The Moon is physically nearer to the viewer on the horizon, making it look bigger; the Earth's atmosphere acts like a lens, magnifying the disk of the Moon, making it appear larger; and when we view the horizon Moon we mentally compare it to objects like trees and houses on the horizon, making it look bigger.

Need I say it? These explanations are wrong.

The first one—the Moon is nearer when on the horizon—is spectacularly wrong. For the Moon to look twice as big, its distance would have to be half as far. However, we know that the Moon's orbit isn't nearly this elliptical. In fact, the difference between the perigee (closest approach to the Earth) and apogee (farthest point from the Earth) of the Moon's orbit is about 40,000 kilometers. The Moon is an average of 400,000 kilometers away, so this is only a 10 percent effect, nowhere near the factor of two needed for the illusion. Also, the Moon takes two weeks to go from perigee to apogee, so you wouldn't see this effect over the course of a single evening.

Ironically, the Moon is actually a bit *closer* to you when it's overhead than when it is on the horizon, so it really appears bigger. The distance from the Moon to the center of the Earth stays pretty much constant over a single night. When you look at the Moon when it's on the horizon, you are roughly parallel to the line between the Moon and the center of the Earth and roughly the same distance away. But when you look at the Moon when it's overhead, you are *between* the center of the Earth and the Moon. You're actually more than 6,000 kilometers closer to the Moon. This difference would make the Moon appear to be about 1.5 percent bigger when it's overhead than when it's on the horizon, not smaller. Clearly, the Moon's physical distance is not the issue here.

The second incorrect explanation—Earth's air distorts the Moon's image, making it look bigger—is also wrong. A ray of light will bend when it enters a new medium, say, as it travels from air to water. This effect is what makes a spoon look bent when it sticks out of a glass of water.

Light will also bend when it goes from the vacuum of space to the relatively dense medium of our atmosphere. As you look to the sky, atmospheric thickness changes very rapidly with height near the horizon. This is because the atmosphere curves along with the Earth (see chapter 4, "Blue Skies Smiling at Me," for an explanation). This change causes light to bend by different amounts depending on the angle of the light source off the horizon. When the Moon sits on the horizon, the top part is about a half a degree higher than the lower part, which means that light from the bottom half gets bent more. The air bends the light up, making it look as if the bottom part of the Moon is being squashed up into the top half. That's why the Moon (and the Sun too, of course) looks flattened when it sits directly on the horizon.

The vertical dimension is squashed but not the horizontal one. That's because as you go around the horizon, side to side, the thickness of the air is constant. It's only when the light comes from different heights that you see this effect.

Like the distance explanation, we see that near the horizon the Moon's disk is actually physically a little smaller than when it is high in the sky, so again this explanation must be wrong. Even so, this belief is commonly held by a diverse and widespread group of people. It's taught in high school and even in college, and I have heard that it is even used in textbooks, although I have never seen it in print.

Despite what your eyes and brain are telling you, if you go out and measure the size of the Moon when it is near the horizon and again when it is near the zenith, you will see that it is almost exactly the same size. You need not measure it accurately; you can simply hold a pencil eraser at arm's length to give yourself a comparison. If you do this, you'll see that even though the Moon *looks* huge near the horizon, you won't *measure* any difference.

The big Moon on the horizon effect is amazingly powerful. But the change in size is an illusion. So if this isn't a physical effect, it must be psychological.

The third explanation relies on psychology and doesn't need the Moon to be physically bigger; the Moon just has to be near other objects on the horizon. Mentally, we compare the Moon to these objects and it looks bigger. When it's near the zenith, we cannot make the same comparison, so it looks farther away.

But this can't be right. The illusion persists even when the horizon is clear, as when the Moon is viewed from ships at sea or out airplane windows. Also, you can position yourself so that you can see the zenith Moon between tall buildings, and it still doesn't look any bigger.

For further proof, try this: The next time you see the huge, full Moon on the horizon, bend over and look at the Moon upside-down from between your legs (you may want to wait until no one else is around). Most people claim that when they do this the effect vanishes. If the illusion were due to comparison with foreground objects, it would still persist while you were contorted like this, because even upside-down you could still see the foreground objects. But the illusion vanishes, so this cannot be the correct explanation either. Note, too, that this is further proof that the effect is not due to a measurable size change in the Moon's diameter.

So what *does* causes the Moon Illusion? I'll cut to the chase: no one knows, exactly. Although it's known positively to be an illusion, and it occurs because of the way our brains interpret images, psychologists don't know *exactly* why it occurs. There have been very firm claims made in the professional literature, but in my opinion the cause of the Moon Illusion is still not completely understood.

This doesn't mean we don't understand it at least partially. There are several factors involved. Probably the two most important are how we judge the size of distant objects and how we perceive the shape of the sky itself.

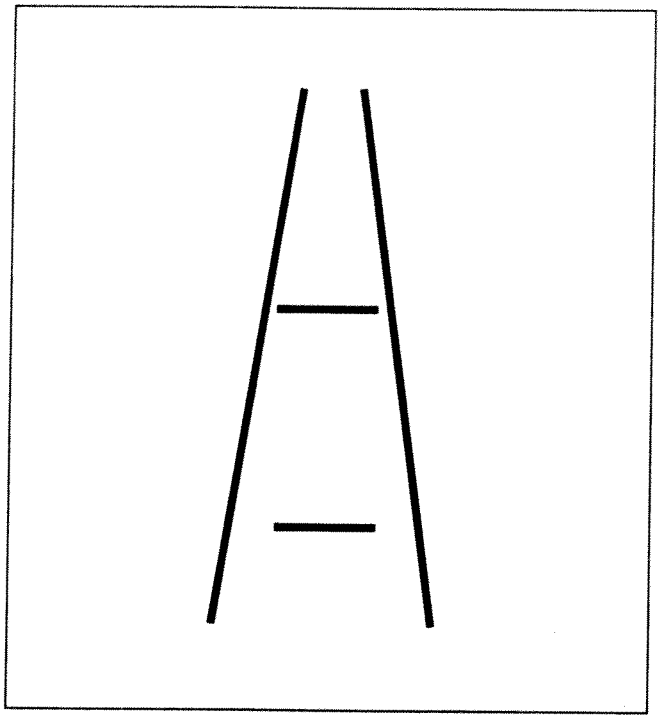
When you look at a crowded street scene, the people standing near you appear to be larger than the ones farther away. If you measured how big they looked by holding a ruler up near your eye and gauging the apparent size of the people around you, someone standing 5 meters (16 feet) away might look to be 30 centimeters (12 inches) tall, but someone twice as far away would look only 15 centimeters (6 inches) tall. The physical sizes of the images of these people on your retina are different, but you *perceive* them to be the same size. You certainly don't actually think the farther person is half the height of the nearer person, so somewhere in your brain you are interpreting those images, and you then think of the people as being roughly the same physical size.

This effect is called **size constancy.** It has clear advantages; if you actually perceived the more-distant people as being smaller, you would have a messed-up sense of depth perception. A species like that wouldn't survive long against a predator that knows very well just how far away (and how big) you are. In that sense, size constancy is a survival factor, and it's not surprising that it's a very strong effect.

However, we can be fooled. In the diagram on page 82 you see two lines converging to a point at the top. There are two horizontal lines drawn across them—one near the top where the lines converge, and the other near the bottom where they are farther apart. Which horizontal line is longer? Most people report the top one to be longer. However, if you measure them (and feel free to do so) you will see they are the same length.

This is called the Ponzo Illusion, after the researcher who characterized it. What's happening is that your brain is interpreting the converging lines to be parallel, like railroad tracks. Where they converge is actually perceived as being in the distance, just like railroad tracks appear to converge near the horizon. So your brain perceives the top of the diagram to be farther away than the bottom.

Now remember size constancy. Your brain wants to think that the top line is farther away. But since the length of the line is the same, your brain interprets this as meaning the top line is longer than the bottom line. Size constancy works in coordination with the perspective effect to trick your brain into thinking the upper line is longer when in fact it isn't.

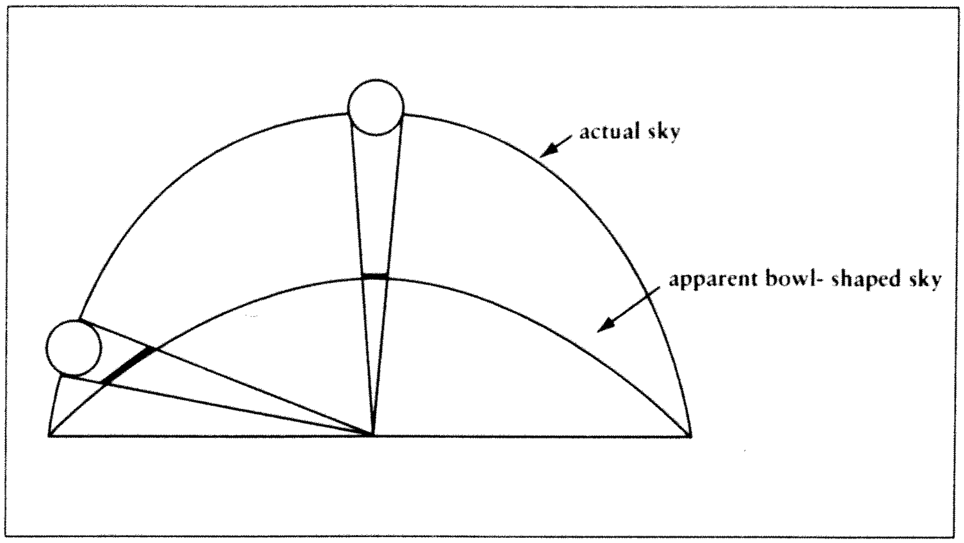


The Ponzo illusion is one of the most famous of all optical illusions. The horizontal lines are actually the same length, but the upper one appears longer because of the converging vertical lines.

What does this have to do with the Moon Illusion? For that we have to turn to the shape of the sky.

The sky is usually depicted in diagrams as a hemisphere, which is literally half a sphere. Of course, it isn't really; there is no surface above the Earth. The sky goes on forever. However, we do perceive the sky as a surface over us, and so it does appear to have a shape. In a sphere all points are equally distant from the center. The point on the sky directly overhead is called the zenith, and if the sky were indeed a sphere it would be just as far away as a point on the horizon.

But that's not really the case. Most people, myself included, actually see the sky as flattened near the top, more like a soup bowl than half a ball. Don't believe me? Try this: Go outside to level ground where you have a clear view of the sky from horizon to zenith. Imagine there is a line drawn from the zenith straight down across the sky to the horizon. Extend your arm, and point



We don't see the sky as a hemisphere, but actually as a bowl inverted over our heads. When the Moon is on the horizon, it appears farther away than when it is overhead. Our brains are tricked into thinking the Moon is bigger than it really is when it's on the horizon.

your finger to where you think the halfway point is between the ground and the zenith, 45 degrees up from the horizon.

Now have a friend measure the angle of your arm relative to the ground. I will almost guarantee that your arm is at an angle of roughly 30 degrees and not 45 degrees, which is truly halfway up to the zenith. I have tried this myself with many friends (some of whom were astronomers), and no one has *ever* been higher than about 40 degrees. This happens because we see the sky as flattened; for a flat sky the midpoint between zenith and horizon is lower than for a hemispherical sky.

The reason for our perceiving the sky this way isn't well-known. An Arab researcher named Al-Hazan proposed in the eleventh century that this is due to our experience with flat terrain. When we look straight down, the ground is nearest to us, and as we raise our view the ground gets farther away. We interpret the sky the same way. This time as we look straight up, the sky appears closest to us, and as we then lower our gaze the sky appears farther away. Although this explanation is nearly 1,000 years old, it may indeed be the correct one.

But no matter what the cause, the perception persists. The sky looks flat. As Al-Hazan pointed out, this means that the sky looks farther away at the horizon than it does overhead.

Now we can put the pieces together. The Moon, of course, is physically the same size on the horizon as it is overhead. The shape of the sky makes the brain perceive the Moon as being farther away on the horizon than when it's overhead. Finally, the Ponzo Illusion shows us that when you have two objects that are the same physical size but at different distances, the brain interprets the more distant object as being bigger. Therefore, when the Moon is on the horizon, the brain interprets it as being bigger. The effect is very strong and has the same magnitude as the Ponzo illusion, so it seems safe to conclude that this is indeed the cause of the Moon Illusion.

This explanation was recently bolstered by a clever experiment performed by Long Island University psychologist Lloyd Kaufman and his physicist son, James, of IBM's Almaden Research Center. They used a device that allowed subjects to judge their perceived distance from the Moon. The apparatus projected two images of the Moon onto the sky. One image was fixed like the real Moon, and the other was adjustable in size. The subjects were asked to change the apparent size of the adjustable image until it looked like it was halfway between them and the fixed image of the Moon. Without exception, every person placed the halfway point of the horizon Moon much farther away than the halfway point of the elevated Moon, an average of four times farther away. This means they perceived the horizon as four times farther away than the zenith, supporting the modified Ponzo Illusion as the source of the Moon Illusion.

However, some people argue with this conclusion. For example, when you ask someone, "Which do you think is closer, the big horizon Moon or the smaller zenith Moon?" they will say the horizon Moon looks closer. That appears to directly contradict the Ponzo Illusion explanation, which says that the brain interprets the bigger object as *farther* away.

However, this isn't quite right. The Ponzo Illusion is that the farther-away object is bigger, not that the bigger object is farther away. See the difference? In the Ponzo Illusion the brain first unconsciously establishes distance and *then* interprets size. When you ask people which Moon looks bigger, they are first looking at size, and *then* consciously interpreting distance. These are two different processes, and may very well not be undertaken by the same part of the brain. This objection really has no merit.

In my opinion, the Ponzo Illusion coupled with size constancy and the shape of the sky is an adequate solution to the millennia-old Moon Illusion mystery. The real question may be why we perceive all these different steps the way we do. However, I am not a psychologist, just a curious astronomer. I'll note that as an astronomer, I am not fully qualified to judge competing psychological theories except on their predictions. It's quite possible that eventually a better theory may turn up, or that a fatal flaw in the Ponzo Illusion theory may arise. Hopefully, if that happens, the psychologists can explain it to astronomers so we can get our stories straight.

As an aside, I have often wondered if astronauts see this effect in space. One way or another, it might provide interesting clues about the root of the illusion. I asked astronaut Ron Parise if he has ever noticed it. Unfortunately, he told me, the Space Shuttle's windows are far too small to get an overview of the sky. Perhaps one day I'll see if NASA is willing to try this as an experiment when an astronaut undergoes a spacewalk. He or she could compare the size of the Moon when it's near the Earth's limb, its apparent outer edge, to how it appears when it is far from the Earth and see if the size appears to change. Interestingly, the experiment could happen much faster up there than here on Earth: the Shuttle's 90-minute orbit means they only have to wait 22 minutes or so between moonrise and when it's highest off the limb!

Having said all this, I'll ask you a final question: if you were to look at the full Moon and hold up a dime next to it, how far away would you have to hold the dime to get it equal in size to the full Moon?

The answer may surprise you: over 2 meters (7 feet) away! Unless you are extremely long-limbed, chances are you can't hold a dime this far away with your hand. Most people think the image of the Moon on the sky is big, but in reality it's pretty small. The Moon is about half a degree across, meaning that 180 of them would fit side by side from the horizon to the zenith (a distance of 90 degrees).

My point here is that often our perceptions conflict with reality. Usually reality knows what it is doing and it's we, ourselves, who are wrong. In a sense, that's not just the point of this chapter but indeed this whole book. Maybe we should always keep that thought in mind.