The Moon Illusion Explained

Finally! Why the Moon Looks Big at the Horizon and Smaller When Higher Up.

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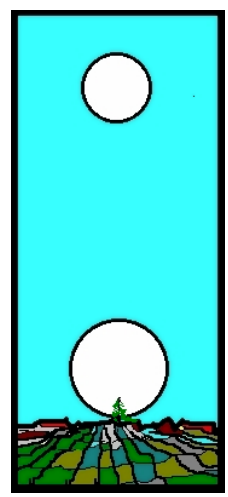
Introduction and Summary [Revised 12/07/02]

For many centuries, scientists have been puzzled by the illusion that the full moon at the horizon usually looks larger than it does later, at higher elevations toward the zenith of the sky. Many explanations (theories) have been offered. But, it is fair to say that the two dozen (or so) scientists most familiar with current research on the illusion have not yet accepted any one theory. The jury is still out.



The theory reviewed in this article is relatively quite new (McCready, 1983, 1985, 1986). It begins with the basic assumption that, when most people say "the moon looks larger," they are referring primarily to the moon's angular subtense (McCready, 1965).
That is, the horizon moon looks a larger *angular size* than the zenith moon.
That experience is imitated if you look at the circles in the figure at the right, because the lower circle subtends a larger angle at your eye than the upper circle does.

Angular Size Illusion.
For the moon, that appearance is known as the moon illusion, because the angle the moon's diameter subtends at your eye measures about 1⁄2 degree of arc no matter where the moon is in the sky. That is, there is no physical (optical) reason why the horizon moon should look larger than the zenith moon: For instance, it has been known for centuries that the horizon moon is not "magnified' by the earth's atmosphere. Indeed, the 11th century Arabian astronomer, Ibn al-Haytham, [Alhazen] is credited with being the first scientist to point out that the illusion is entirely a subjective (or "psychological") illusion (see Ross & Plug, 2002).

Also a Linear Size Illusion
Given that for most people the moon illusion begins as an angular size illusion, for many of them, the horizon moon's physical (metric) diameter, its *linear size* in meters, also looks larger than the zenith moon's linear size. That is, for most observers two quite different "size" illusions occur at the same time.

Also a Distance Illusion
There also usually is a distance illusion: Most people say the distance from them to the horizon moon usually looks less than the distance to the zenith moon. It is very

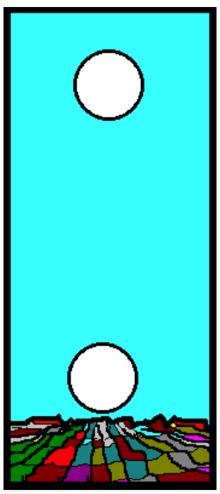
important to keep in mind that the report most often given is that the horizon moon "looks larger and closer" than the zenith moon. The reason it "looks closer" is because its angular size "looks larger." Of course, "looks larger" often refers, as well, to the linear size comparison, but an apparently larger linear size is not a perceptual cue to a shorter distance.

The same illusion also occurs for the sun and for the constellations as they appear to move between horizon and zenith positions. The term 'moon illusion' commonly is used for all such examples, however.

For more than 100 years, vision scientists (a specialty within psychology) have been conducting experiments on the moon illusion. It has been discussed in perception textbooks and even in introductory psychology textbooks for more than 60 years. Those texts typically have offered one or two explanations (theories). A few texts also have pointed out, however, that these conventional theories simply do not explain the moon illusion.
To see why that is, consider the most widely published explanation.

The Conventional Theory

Today the best-known explanations are versions of the apparent distance theory.



That theory implicitly assumes that the horizon moon and zenith moon look the same angular size (in degrees), as imitated for us by the two equal circles in the diagram at the left. So, the only "size" the theory refers to is the moon's metric size, its physical diameter in meters, here called its *linear size.* (Thus also its volume in cubic meters.)

Next the apparent distance theory proposes that, with both moons looking the same angular size, the horizon moon's linear size necessarily looks larger because, for one reason or another, it looks farther away than the zenith moon: That theory *requires* that the observer must report that the horizon moon "looks larger and farther away" than the zenith moon. Specifically, its diameter looks a larger linear size (in meters), so that moon's *volume* looks very much larger (in cubic meters) than the zenith moon's.

However, only about 5% of the population seems to experience that illusion: As already noted, about 90% say, instead, that compared with the zenith moon, the horizon moon looks either "larger and about as far away", or "it looks larger and *closer."*

That very serious contradiction between what most people see and what the conventional theory *requires* was pointed out long ago (Boring, 1962; Gregory, 1965). It is known as the "size-distance paradox." And, as some texts point out, that is why most of the illusion experts long ago rejected the apparent distance explanation.

Nevertheless, the paradox is completely ignored in virtually all popular articles on the moon illusion, especially those on the internet (see for example, the one by Wenning, 1985) even though introductory psychology textbooks have been mentioning that destructive paradox at least since 1970.

Those badly mistaken articles often use terribly misleading erroneous diagrams and examples like those discussed below: These diagrams and examples clearly do not describe an *angular size illusion* so they certainly do not even properly describe the majority moon illusions. Consequently they cannot possibly "explain" the moon illusion that most people suffer.

Misleading Illustrations.

The basic illusion is that horizon moon looks a larger angular size than the zenith moon. But the best-known published diagrams clearly illustrate an illusion in which the horizon and zenith moons look the same angular size. It thus becomes necessary to examine (later) why these erroneous diagrams continue to be used.

Consider first the Apparent Sky Dome Idea.

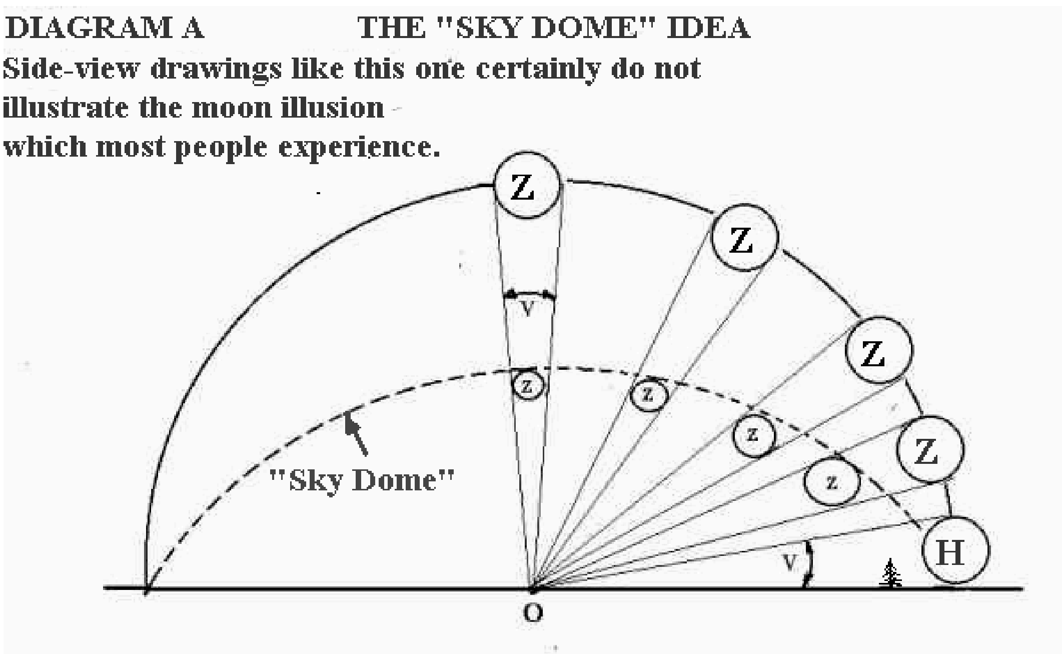


Diagram A resembles well-known "sky dome" pictures. As a side-view it illustrates that we are looking northward at a person at point O who is facing east (to the right) and looking at the rising horizon moon (H). For that person, the sky looks like a flattened dome, with the zenith sky looking closer than the horizon sky. The moon supposedly appears to sit upon that surface and to glide along it as it rises.

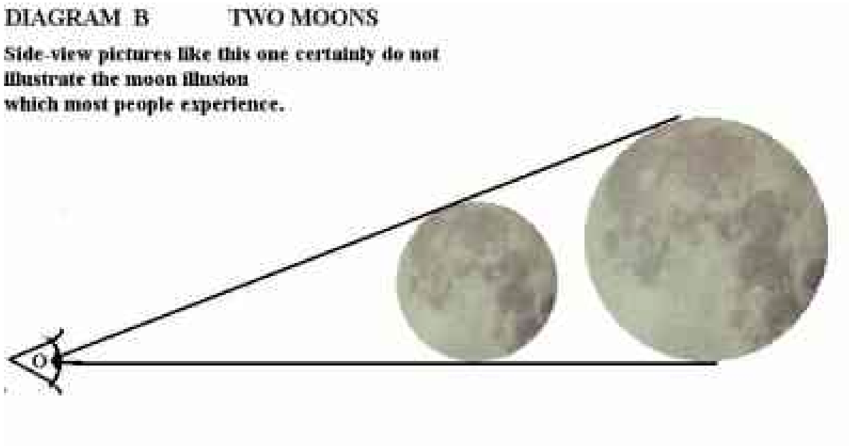
According to the theory, that sky dome illusion thus makes the horizon moon (H) look farther away than a zenith moon (z). So, the H moon must look a larger linear size than the z moon in order to keep the angular sizes looking equal.
The observer at point O is *required* to say "the horizon moon looks farther away than the zenith moon." But, again, that absolutely does not describe the majority moon illusions.

Carefully notice that the sky dome diagram specifies that, for the person at point O, all of those H and Z and z moons look the *same angular size*. That is, what the person at point O is seeing is not being shown to us readers by the different sized circles in the sky dome drawing. Instead, what that person at point O is seeing is shown to us by the front view drawing at the left: Here we (like the person at point O) are looking east to see a string of rising "moons," all of which look the same angular size.
So, don't let the sky dome illustration trick you into thinking that it describes the moon

illusion!

Consider next a diagram using two circles.

Diagram B at the right represents some other popular side-view diagrams which are used to illustrate that, if the horizon moon looks farther away than the zenith moon, it must look a larger linear size in order to have both looking the same angular size.



A front view that shows us what the person at point O is seeing would be a single circle, because the front sphere exactly occludes the rear sphere.
Such diagrams obviously do not illustrate the moon illusion that most people experience.

The Very Serious Misinterpretation Problem

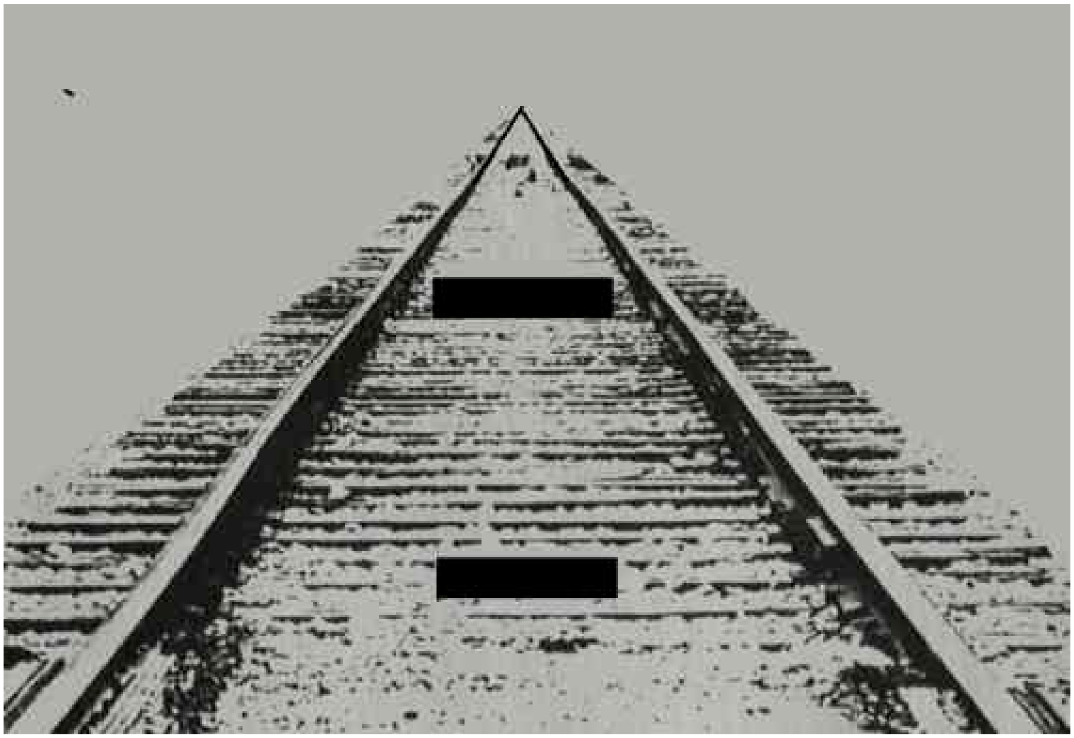
Because such diagrams fail to describe (or explain) the moon illusion which most people experience, it is fair to ask, *why* they are still being presented in moon illusion articles. One answer is that they are being misread.
For instance, notice that the unequal-looking circles in those side-view diagrams imitate the unequal-looking angular sizes which most people experience as their own moon illusion. So, because that experience "rings true," a hasty reader easily could be misled into thinking those diagrams illustrate his or her own moon illusion. But they don't. After all , those diagrams are deliberately constructed to show us that the observer at O sees the H and Z spheres as being the same angular size, as represented for us by the front view diagrams with all circles having the same size.

It is quite likely that this easy misinterpretation of side-view drawings is very common, and is responsible for much of the confusion in the moon illusion literature. Authors who publish them are either misreading them, or else their own personal moon illusion happens to be that the moon looks the same angular size at the horizon and zenith.

Either way, the use of those faulty side-view diagrams is contributing to the continuing survival of the flawed, apparent distance theory.

Front views are less likely to be misread. So, consider next a front view often used in moon illusion articles. It is a 'railroad tracks' version of the classic *Ponzo Illusion.*

The picture offers two dark rectangles on the page which subtend the same angular size at the viewer's eye. The illusion emphasized in moon illusion articles does not concern the 'apparent sizes' of the two rectangles on the page: It concerns, instead, the *pictorial illusion* of tracks going into the distance, and the 'apparent sizes' of the two *objects* those rectangles can portray in that picture.


For instance, the upper rectangle can appear to be a rectangular object lying on the roadbed at a greater distance than the object the lower rectangle appears to be, let's say twice as far away. If so, the viewer properly says, "the upper object looks about twice as far away and about twice as long (in inches) as the lower object." (Also "twice as thick", hence four times the area.) That large 'size' illusion obviously is a linear size illusion.

This "looks linearly larger and farther away" perceptual outcome correctly illustrates how the apparent distance theory applies to a pictorial illusion: Indeed, the logic behind that theory truly explains why, when we look at a flat photo or a TV screen, we see three-dimensional objects which have certain linear sizes arranged at different distances in a three-dimensional space.

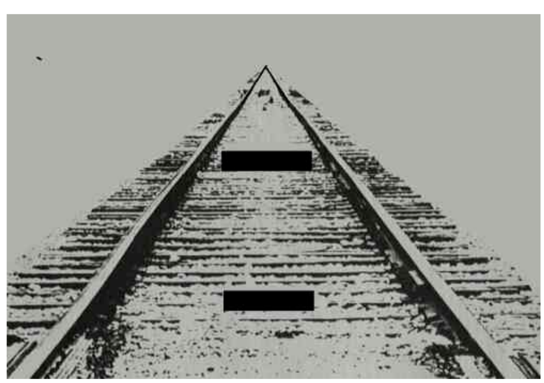
Therefore, some writers claim that the moon illusion is simply the railroad tracks illusion upside down.

But, of course, even upside down, the pictorial Ponzo illusion of one object looking farther away and a larger linear size than another object completely fails to imitate the majority moon illusions.

The 'Paradoxical' Ponzo Illusion.

A quite different additional 'size' illusion is yielded by the Ponzo diagram. It begins as an angular size illusion.

It is that the two equal rectangles can correctly look like flat bars printed on the same flat page, hence they correctly appear at the same viewing distance, but the upper bar looks slightly bigger than the lower bar. That illusion clearly illustrates an angular size illusion, with the upper bar appearing to subtend a slightly larger angular size than the lower bar. In turn, that causes the linear size of the upper bar to also look slightly larger on the page than the lower bar does.



This very small combined angular size and linear size illusion actually is much more interesting than the bigger, pictorial linear size illusion, for two reasons:
First of all, it slightly imitates the angular size illusion for the moon, but only to a small degree. (As discussed later, it also can be explained as another example of oculomotor micropsia.)
Secondly, it cannot be explained by the popular apparent distance theory, which theory requires that, if the upper bar 'looks linearly larger' it must look farther away than the lower one, and certainly not on the same page.
Attempts to resolve that paradox for flat pattern illusions (for instance see Gregory, 1963, 1970, 1998) while still holding onto the *logic* behind the apparent distance theory have failed, because they use only one 'apparent size' concept, which logically must be only the apparent linear size.

Those three diagrams, and the many similar diagrams used to present the apparent distance theory all fail to describe, or explain, the majority moon illusions.

The Flawed Afterimage Argument.

Another popular misleading example refers to the fact that an after-image of constant angular size looks a larger linear size when it is "projected" to a greater distance. This perception illustrates what psychologists call "Emmert's law."
That perception has been presented as a model of the moon illusion, as follows. First the sky dome illusion is described. Then it is pointed out that, if an afterimage of constant angular size were projected onto the horizon sky it would look farther away, and thus look a larger *linear* size than when projected onto the closer-looking zenith sky. The observer would say the 'horizon' afterimage "looks larger and farther away" than the 'zenith' afterimage, with 'looks larger' referring only to the linear size.
But, again, that does not describe the majority moon illusions and cannot explain them.

"Textbook" Articles.

Unfortunately, the misleading diagrams described above, as well as the faulty afterimage example, continue to appear in textbooks, and in hundreds of articles and class notes on the internet, especially some very popular 'astronomy' articles, (or instance, Wenning, 1985). Only one other current website (Borghuis, 199_) properly critiques standard approaches and adequately describes the angular size illusion and explanations for it. (He uses equations and sentences from my 1986 article.)

Of course, the complete story has been presented in the scientific literature of perceptual psychology. Also, the 1989 book, "The Moon Illusion," edited by Maurice Hershenson, offers 20 chapters contributed by 26 'moon illusion' researchers. Nearly all the chapters reiterate the problems with conventional theories. And, four chapters offer new theories which properly address the illusion as an angular size illusion (Enright, 1989; Hershenson, 1989; Reed, 1989; Roscoe, 1989).

The earlier 'new' theory (McCready, 1983, 1986) is discussed in several chapters in Hershenson's book, and emphasized in the chapters by Enright (1989), and by Reed (1989). [In 1987, I unfortunately had to decline Hershenson's invitation to contribute a chapter to his book. In a sense, this present article is a version of the chapter I might have written (but updated).]

Let's begin by considering some illustrations that reveal what the moon illusion really is.

Describing The Moon Illusion.

The moon's horizontal (azimuth) diameter always subtends 0.52 degrees at an earthly observation point; so photographs of the horizon moon and zenith moon taken with the same camera settings yield images which are the same size, as represented by Figure 1.

Figure 1. A sketch which represents what a double-exposure photograph of the horizon moon and zenith moon would look like. The two moon images have the same diameter on the page, so the angle the diameter subtends at the reader's eye is the same for both circles.

Many researchers have taken such photos in order to convince themselves. They all were convinced. You can try it yourself.

Most people are quite amazed when they first learn that fact: They had expected, instead, that a photograph would resemble the very different sketch in Figure 2, with the lower circle drawn larger than the upper circle.

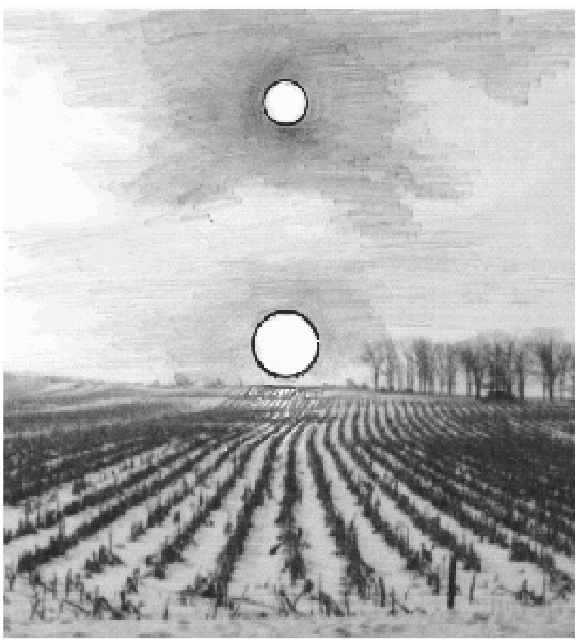
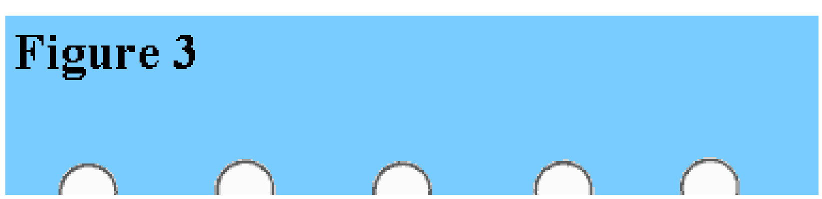


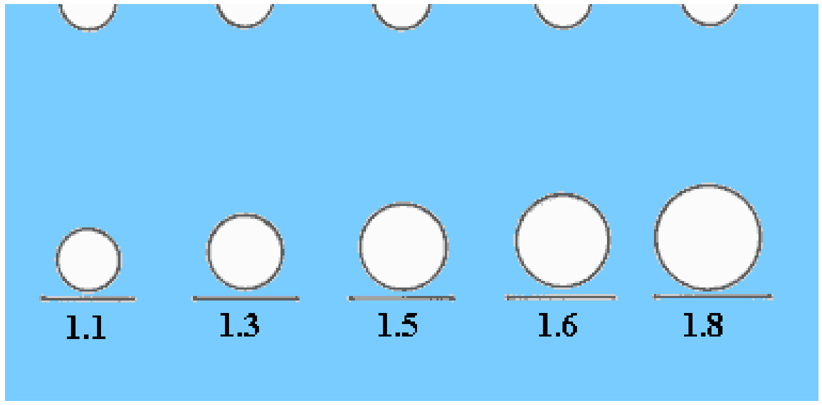
Figure 2. A sketch that portrays two moon-like spheres with the lower one's diameter subtending an angle at the reader's eye 1.5 times larger than the angle subtended by the upper one's diameter. This picture represents what most people initially think a photograph of the horizon and zenith moons would look like.

Indeed, most people will say that Figure 2 imitates their moon illusion experience. Of course, the ratio of 1.5 for the circles' diameters in Figure 2 will not exactly agree with the size ratio many readers see for the moon, so Figure 3 is included below to offer a range of choices.

In Figure 3 the number under each pair of circles is the ratio of the lower circle's diameter to the upper circle's diameter. In each pair the diameter of



the lower circle has a larger linear size, in millimeters, on the page than does the upper circle.



Consider next the important fact that the endpoints of each circle's diameter subtend an angle at the reader's eye: That is, a line from, say, the left edge of the circle to your eye forms an angle with the line from the right edge of the circle to your eye, and that angle is the circle's angular size in degrees.

Technical Note: Optics. In optical terms, the ray of light from the left edge to the center of your eye pupil is called the *chief ray* of the bundle of light rays that focus to a small point on your eye's retina to form the optical image of that edge point on your retina. Likewise for the right edge. The angle between those two chief rays is the physical angular size, also called the *visual angle, V degrees.*
The optical image of the circle formed on your eye's retina is just like the real image formed on the film in a camera. The linear diameter of this *retinal image*, R millimeters, is determined directly by the circle's angular size, V degrees, in accord with the simple rule, R = n(Tan V) with n equal to about 17 mm. (See Figure A1 in the Appendix.)

For each pair of circles in Figure 3 the angular size for the lower circle obviously is larger than that for the upper circle. Consequently the retinal image of the lower circle is larger than the retinal image of the upper circle.

The Angular Size Illusion.

Because virtually all readers will choose a picture like those in Figures 2 and 3 as a representation of their moon illusion experience, it tells us a great deal about the illusion. It means the illusion is *as if* the retinal image of the horizon moon were larger than the retinal image of the zenith moon. Researchers have shown, however, that the moon's retinal image, which is an illuminated disk about 0.15 mm in diameter, remains essentially the same size, no matter where the moon is in the sky.

We cannot escape the logic that the basic illusion for most people is *as if* the angular size of the horizon moon were larger than the angular size of the zenith moon.
For some people the horizon moon's angular size can look as much as twice as large as the zenith moon's, but a value from 1.3 to 1.5 times larger is about average. The ratio of 1.5, illustrated by Figure 2, will be used in most of the examples in this article.

For some readers it may be difficult, at first, to understand that a viewed object's width (or height or diameter) looks a particular *angular* size, in degrees. It is less difficult to understand that a viewed object's width looks a particular *linear* size, in inches or centimeters, especially for a familiar object. Evidently the most difficult concept to grasp, however, has been that we see *both* of those qualitatively different "sizes" at the same time for a given object.
Of course, the viewed object also looks a certain distance from us.

The Two Sizes.

The distinction between an angular size perception and a linear size perception, and the

fact that they are simultaneous experiences, was clearly pointed out long ago by R. B. Joynson (1949; Joynson & Kirk, 1960). Unfortunately, relatively few researchers have made use of Joynson's revelation. Recognizing that distinction is crucial to understanding the new theory (McCready, 1965, 1985, 1986).

An impediment to recognizing the distinction has been the very common usage of just *one* 'size' concept called simply 'perceived size' (or 'apparent size'). In some articles it consistently refers only to the perceived linear size. Some other articles, however, use the amazing idea that it sometimes correlates with an object's linear size in meters, and sometimes correlates with the object's angular subtense in degrees! In those confusing articles the reader often is forced to try to figure out which concept the ambiguous "size" term refers to at the moment!
Among the most confusing treatments of the moon Illusion are those that invoke the concept ambiguously called "size constancy" and "size constancy scaling" (Gregory, 1963. 1965, 1970, 1998). The concept properly refers to constancy of the perceived linear size. But in many discussions (e.g., Trehub, 1991) "size constancy" is defined as if it were not constancy of perceived linear size, but constancy of perceived angular size, which, in the present view, doesn't make sense.

Therefore, to summarize; when we look at a given object's frontal width (or height or diameter) we see that it subtends a certain angular size, in degrees, and has a certain linear size, in meters, and lies at a certain distance, in meters. Sometimes, however, we cannot *say* exactly what those three perceived values are, especially for unfamiliar objects at great distances. But we often can give rough estimates, which may improve with training. (Notice, however, that even professional golfers do not always trust their expert distance perception, so they pace the remaining distance to the green or else consult their list of prior measurements.)

How those three qualitatively different perceptions for the moon logically should relate to each other will be summarized in the following outline of this article.

Ross and Plug's New Book.

In Chapter 2 in Hershenson's 1989 book "The Moon Illusion," Cornelis Plug and Helen Ross (1989) reviewed the long history of research and speculation on the moon illusion. In their concluding paragraphs they mentioned that the distinction emphasized by McCready (1986), between the "perceived [linear] size" and the "perceived extensity" [perceived angular size], as well as the idea that the horizon moon has a larger perceived angular size than the zenith moon, ..."might turn out to be the most important conceptual and methodological development in the history of the moon illusion since Ibn al-Haytham [Alhazen] redefined the illusion as a psychological phenomenon" (page 22).

In September, 2002, Ross and Plug published their marvelous book, "The Mystery of the Moon Illusion" (Ross & Plug, 2002). It currently is the most complete source of information about the illusion. On page 195 they state: "The moon illusion is one of the few perceptual phenomena that tap a broad spectrum of sciences: astronomy, optics, physics, physiology, psychology, and philosophy. Its explanation illustrates the history of scientific explanation, and in particular the history of perceptual psychology."

Ross and Plug review all theories of the illusion, examine in detail the published experimental research data which any theory must explain, and in the process also

review the incredibly long history of speculation about the illusion.

They take an objective stance toward current theories that use accepted principles of perceptual psychology. They review in detail the present "new" theory (McCready, 1965, 1985, 1986) and cite this present web article (as it was in 2001). They also conclude, of course, that, "No single theory has emerged victorious." (p. 188).

Ross and Plug strongly support the idea that the moon illusion begins as an angular size illusion. However, they hesitate to fully accept that there are two "perceived size" magnitudes for a viewed object [the *perceived angular size* and the *perceived linear size*]. They suggest that it is difficult to understand how those two "perceived size" values differ and how they coexist for a viewed object.

They are not alone in that view. Indeed, the most influential *general* theory of human spatial perception still uses only one "perceived size" (or "apparent size") concept (see Gregory, 1963, 1965, 1966, 1968, 1970, 1998). And some moon illusion researchers reject use of the concept of a perceived angular size (Kaufman and Rock, 1989; Kaufman and Kaufman, 2000). Therefore, in December 2002, extra illustrations and comments were added to this article to help clarify the simple idea that there are two different "perceived size" experiences, and they coexist. Also, in February 2003, the Appendix was completely revised to present the 'new" theory in more detail.

Outline of the New Theory

The four main sections of this article are summarized below.

Section I Summary

Section I describes the moon illusion more completely than is customarily done.
The three most common versions of the moon illusion are summarized below. Each one is illustrated by a side-view diagram and a front view diagram.

Outside of my class notes since 1964, and lectures on the moon illusion (McCready, 1964-1982) side-view diagrams like those below have appeared in very few places (McCready, 1983, 1986). Most readers thus are probably seeing them for the first time.

Each side-view diagram (on the left) portrays that we are looking northward toward an observer at point O who is looking eastward. The circles indicate the perceived (subjective) moon the person is seeing at the horizon and then at a zenith elevation. For that person the perceived angular sizes are 1.5 angular units for the portrayed 'horizon' sphere and 1.0 angular units for the portrayed 'zenith' sphere. That person would say, "the horizon moon looks about one-and-a-half times angularly larger than the zenith moon."

Each front view (on the right) portrays for us what that person is seeing. For that picture we now are looking eastward, where we see a portrayed 'horizon' moon whose angular size looks about 1.5 times larger than the 'zenith' moon's. Our angular size experience thus imitates the same experience the side view diagram describes for the person at O. All three front views are identical, of course, because each side-view shows that the person at O sees the horizon moon as being 1.5 times angularly larger than the zenith moon.

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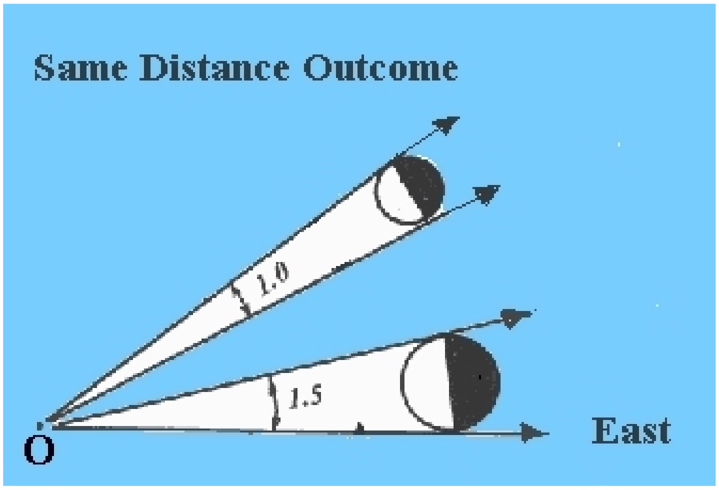
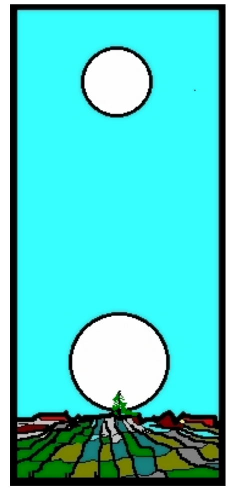
The Same Distance Outcome:

For some people, the horizon moon looks angularly larger than the zenith moon and about the same distance away, hence its linear size necessarily looks larger by the same proportion its angular size looks larger. Accordingly, the horizon moon appears to have a much larger *volume* than the zenith moon. That is, despite the person's *knowledge* that the moon cannot possibly change its physical size, the illusion here is that it appears to become deflated as it rises.



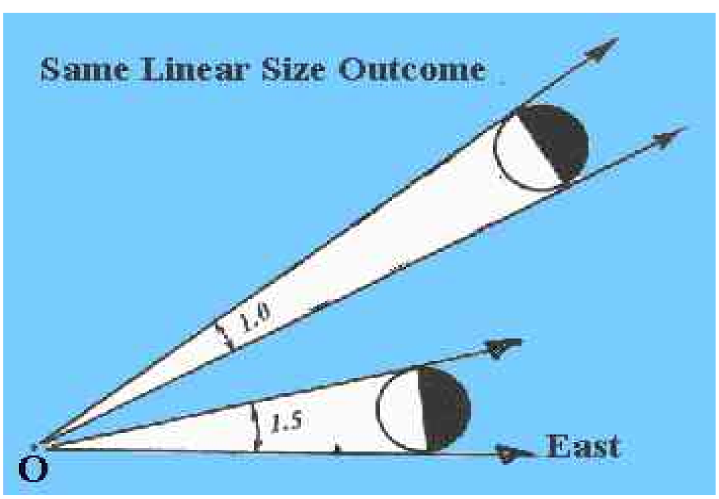


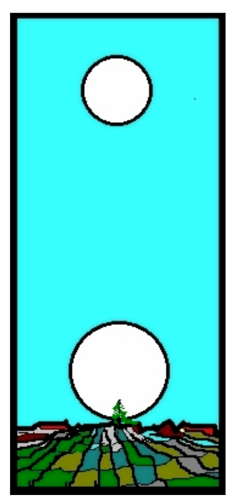
As noted earlier, a serious problem can arise if we think our angular size experiences for the *circles* in a side-view diagram also are supposed to imitate the angular size experiences being illustrated for the person at O. They just happen do so for a 'same distance' side-view, but only in a 'same distance' side-view. How the circle sizes appear in the side-view diagrams of other variations of the moon illusion fails to imitate the illusion being described. For instance, see the illustration below for the equal linear size perception.

The Same Linear Size outcome:

For some people, the horizon moon again looks angularly larger, but looks about the same linear size (and volume) as the zenith moon. That illustrates *linear size constancy.* Here, in agreement with one's *knowledge* that the moon remains the same physical size, it appears to stay the same.

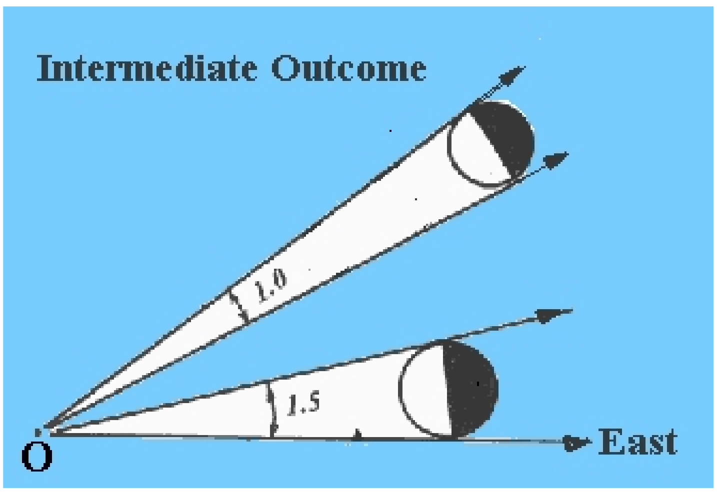
Therefore, because it looks angularly larger, the horizon moon necessarily looks closer than the zenith moon, despite one's knowledge that they are the same distance away. That distance illusion which accompanies the constancy of linear size illustrates the very powerful distance-cue properly called, the *relative angular size cue to distance.*

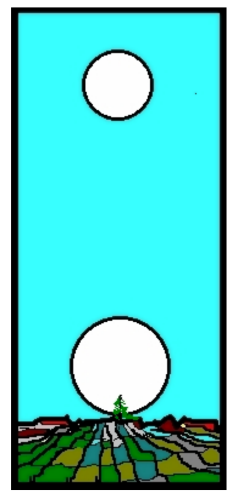




Notice that the two circles in the side-view look the same angular size. So, obviously, your equal angular size experience for them does not imitate the illusion the diagram is illustrating for the person at O. Only the front view (at the right) provides you with circles that mimic the angular size experience the side-view is describing for the person at point O.
As already noted, it is crucial that side-view diagrams of the moon illusion be correctly interpreted.

An Intermediate Outcome:
For some other people, all three of those relative illusions occur; the horizon moon looks angularly larger than the zenith moon, and larger linearly, and closer.





In many published experiments on the moon illusion the participants were asked about their combined "size" and distance experiences: Most said "larger and closer" and hardly any said "larger and farther."
Audience polls I took during my classes and invited lectures (McCready, 1964-1992), indicate that the three outcomes described above account for the moon illusions of about 90% of the population. Only about 5% said "larger and farther away. Similar data were reported by Hershenson (1989).
Moreover it seems that an intermediate outcome is the most common one.

Notice that the most popular simple report, "looks larger and closer," is incomplete. It also is ambiguous, because it can refer either to a same linear size outcome or to an intermediate outcome.

In Section I, Figure 4 shows how those illusions logically must relate to each other. Figure 6 (also in Section I) is a more complex side-view diagram which reveals some additional nuances of the moon illusion that logically would be expected for some observers, and which sometimes were mentioned as anecdotal reports.

The Main Task.

The angular size illusion is the basic "size" illusion and precisely the one that has defied

explanation for so long.
In order to move toward an explanation for it, it is crucial to keep in mind that virtually all experiments on the moon illusion have shown, convincingly, that this angular size illusion is controlled by changes in those factors known as the "cues to distance."
Therefore, the primary scientific task is to explain *why*, for an object that subtends a constant angular size, the perceived angular size for it is altered by changes in the distance-cue patterns for that object.
Once that angular size illusion is explained, it becomes relatively easy to explain the linear size illusions and distance illusions that accompany it.

That task is addressed in Section III, after Section II reviews conventional theories.

Section II Summary.

Section II reviews the two most common explanations of the moon illusion. Most theorists agree that both are unsatisfactory.
The most popular theory is the *apparent distance theory.*
The best-known replacement for it has been the *'size' contrast theory.*

The Apparent Distance Theory.

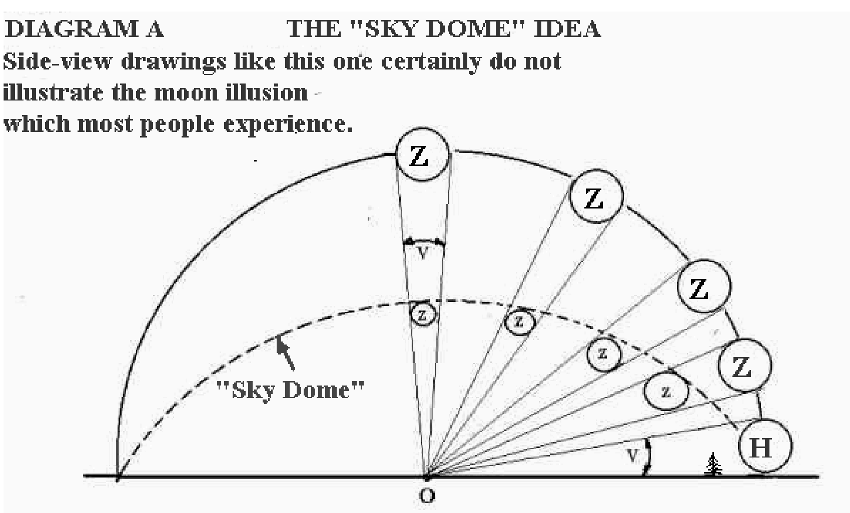
As already noted, the apparent distance theory does not use the concept of perceived angular size. Therefore, it does not (indeed cannot) describe or explain an angular size illusion for the moon.

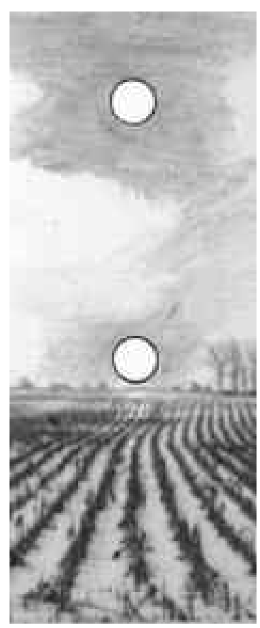
Nevertheless, the apparent distance theory is reviewed in detail in Section II, because the research and arguments offered to support it reveal the important role of distance-cues.

Articles that favor the theory typically illustrate it using diagrams like the sky-dome picture and Ponzo illusion discussed above. It is instructive to briefly reconsider the sky-dome picture.

The Obsolete "Sky Dome."

Side-views like Diagram A are frequently published. But, rarely has a front view that logically goes with it been published next to a sky-dome diagram. So, part of Figure 1 is included below.





Again, the only moon illusion the diagram is trying to explain is that the person at O would say, "the horizon moon looks the same angular size as the zenith moon, and it looks farther away, so it looks a larger linear size (and volume) than the zenith moon.

That person's "same angular size" experience is imitated for us by the two equal circles in the front view at the right. And, if we use our imagination while viewing that front view, we can see the portrayed horizon moon as being farther away and a larger linear size (and volume) than the portrayed zenith moon

If that describes your own moon illusion, then you are among the few who experience it that way, and the apparent distance theory fits you. But, again, that does not describe the moon illusion which most people experience.

At any rate, the sky dome argument has become obsolete.
Indeed, long ago Rock & Kaufman (1962a; Kaufman & Rock, 1962a) clearly showed with their famous experiments that there was no need to appeal to a supposed sky dome illusion in order to explain the moon illusion. Their experiments and many others have shown that the moon illusion correlates most strongly with changes in distance-cues.

"Size Constancy" Approaches.

Some discussions of the moon illusion appeal to "size constancy" mechanisms (Gregory, 1963-1998). These treatments are very confused, however, because they use just one ambiguous "size" term, called merely "perceived size" (or "apparent size"). The reader often cannot tell whether it refers to the perceived linear size or the perceived visual angle. Indeed, although all published descriptions of "size constancy" include a proper definition of it as *linear size* constancy, virtually all them also unwittingly define it as *angular size* constancy, which makes no sense. This logical error (the "size constancy pseudoproblem") is discussed in detail in the Appendix.

The Angular Size Contrast Theory.

To replace the failed apparent distance theory, some researchers have offered a 'size contrast" explanation for the moon illusion (Restle, 1970; Baird, Wagner, and Fuld, 1990). The word "size" is, of course, ambiguous. But, the units of measure those researchers use are degrees of arc, so they implicitly accept the perceived angular size concept. The theory thus must be called the *angular size contrast theory* (to distinguish it from a 'linear size contrast theory').

The theory suggests that the vista near the horizon moon typically is filled with many visible elements, such as very distant trees (etc.) which subtend angles smaller than the moon's 1/2 degree. And, the visible elements in the zenith moon's vista usually subtend angles larger than 1/2 degree, especially the large, relatively empty, zenith sky.
Next, it is claimed that those two different contrasts between the moon's 1/2 degree subtense and the subtenses in its surroundings somehow make the horizon moon's 1/2 degree subtense look larger than the zenith moon's 1/2 degree subtense.

However, published measures of angular size contrast effects indicate that they are too small to contribute much to the moon illusion.

Description versus Explanation.

The first task always is to describe the moon illusion properly.

The quite different second task is to explain *why* the moon illusion described in a particular way occurs.
As noted, some researchers describe the moon illusion only as a linear size and distance illusion that does not include an angular size illusion (as discussed in Section II).
Other researchers now describe the moon illusion in the relatively new way, as basically an angular size illusion necessarily accompanied by a linear size illusion or by a distance illusion or by both (as discussed in Section I).
Abundant research has shown that the 'size' illusion for the moon correlates most strongly with changes in distance-cue patterns in the vista for the moon. So, the main task is to explain that correlation.
The conventional, apparent distance theory fully explains that correlation only for a moon illusion described as just a linear size and distance illusion. The moon illusion described that way is experienced by relatively few people, however.
As noted earlier, several chapters in Hershenson's 1989 book offer 'new' explanations for the moon illusion described in the 'new' way, as basically an angular size illusion. This 'new' description fits the experiences of most people.
The main task thus has become to explain the correlation between changes in distance-cue patterns and changes in the perceived angular size for the moon.
The angular size contrast theory approaches that task by making use of the fact that the most important distance-cues for the horizon moon happen to be the very small angles subtended by the very distant terrestrial objects seen near it.
Another explanation is the oculomotor micropsia/macropsia theory reviewed in Section III.

Section III Summary.

In order to explain why changes in distance-cue patterns result in changes in the perceived angular size for the moon, the search can turn to an examination of other illusions that illustrate that same correlation. There are many.

Chief among such illusions is oculomotor micropsia (McCready, 1965, 1985, 1994a; Ono, 1970; Komoda & Ono, 1974). This remarkable illusion was first described in print by the physicist Charles Wheatstone (1852), who experienced it while experimenting with the stereoscope he had invented.
As its name indicates, oculomotor micropsia is an illusion of "looking small" caused by changes in the activity of eye muscles. (It also is known as "accommodation micropsia" and "convergence micropsia.") Specifically, for an object of fixed linear size (in inches) at a fixed distance from the eyes, its constant angular size (in degrees) will look slightly smaller when the eyes are focused and converged to a distance closer than that object. Four consequences are likely, and all have been found in research studies.

1. The object may appear to remain at about the same distance as before and become a smaller linear size (a same distance outcome).
2. It may appear to remain the same linear size and look farther away than it did (a linear size constancy outcome accompanied by the relative angular size cue to distance).
3. It may appear to become both a smaller linear size and farther away (an intermediate outcome).
4. A fourth possible outcome may be that observers say the object looks smaller and closer; but that outcome of oculomotor micropsia is rare.

The first three outcomes are the most common ones. They captured scientific attention long ago because they contradict the apparent distance theory. After all, the relevant version of that theory had proposed that the eye muscle contractions which change the focus and convergence of the eyes to a closer distance, send neural signals to the brain to

act as distance-cues that would make the object look closer, thus the object would have to look a smaller linear size in order to keep the angular size the same. The contradictory majority reports (that the object instead looks smaller and farther away) were very early examples of the size-distance paradox.
Indeed, Wheatstone (1852) remarked that he was uncertain about the distance the smaller-looking object appeared to move to, but it did not necessarily look closer, as required by the prevailing theory.

It should be pointed out that researchers know for sure that oculomotor micropsia is not due to a change in the retinal image's size (Heinemann, Tulving, & Nachmias, 1959; Smith, et al., 1992).

Cue Conflicts.
The most common perceptions during micropsia, that the object looks both smaller and either about the same distance away or farther away than it did, obviously disagree with the perceived distance relationships being 'signaled' by the cues that control the oculomotor events responsible for the micropsia. But this is not a serious 'paradox'. Instead, it illustrates the presence of other distance-cue factors that conflict with the initiating cue pattern and dominate the final percept. Again, the strongest cue probably is the relative perceived angular size cue: It obviously is responsible for the report, "looks smaller and farther away." The report, "looks smaller and about the same distance away," undoubtedly is the result of an intrinsic "equidistance tendency" (Gogel, 1965) or an "equal distance assumption" (McCready, 1965, 1985). The intermediate outcome illustrates a balance among the several conflicting distance-cue patterns available.

For that reason, and some others, vision researchers concluded, long ago, that, even if neural feedback from the eye muscles were a cue to distance, which most of them doubt, it certainly is not an important cue. They have concluded, instead, that what controls micropsia is either the neural activity patterns in the brain which are the efferent "commands" being sent to the eye muscles, or, most likely, the neural patterns which are *about* to be sent to the eye muscles, the brain pattern referred to as the "efference readiness."

The converse of micropsia is oculomotor macropsia ("looking large"). Here a fixed object's angular size will look slightly larger when the eyes are adjusted to a much greater distance than the object's distance. (For that macropsia example let the viewed object be, say, one meter from the face.)

Oculomotor micropsia/macropsia seems to be a truly fundamental angular size illusion. It shows up in many different kinds of visual spatial illusions (McCready, 1965, 1983, 1985, 1986, 1994a, 1994b, 1995). The present theory simply proposes that the moon illusion also is an example of the ubiquitous illusion of oculomotor micropsia/macropsia

Indeed, two independent researchers, J. T. Enright (1975, 1987b, 1989a, 1989b)) and Stanley N. Roscoe (1979 1984, 1985, 1989) have demonstrated that oculomotor micropsia occurs during viewing of the "zenith" moon, and oculomotor macropsia occurs during viewing of the "horizon" moon:

In a nutshell, that can explain why the horizon moon looks angularly larger than the zenith moon.

A demonstration of oculomotor micropsia can be conducted by most readers as follows.

A Simple Demonstration.

The next time you look at the horizon moon, deliberately create oculomotor micropsia by strongly converging ("crossing") your eyes, say by looking at the bridge of your nose, but pay attention to the moon. That over-convergence of the eyes will create double vision of the moon and some blurring, but notice that the moon's angular size momentarily looks smaller than it did. At the same time, the moon will look either farther away than it did, or its linear size will look smaller, or else both of those secondary illusions will occur. That illusion imitates what occurs during viewing of the zenith moon. However, in this demonstration the apparent decrease in angular size undoubtedly is greater than the decrease found during natural viewing of the zenith moon. [Indeed, this demonstration of micropsia even works for the zenith moon, which already looks angularly smaller than the horizon moon.]

When you then return both eyes to being aimed straight ahead (their "far," divergence position) the moon will look single again and momentarily will look angularly larger than it just did (relative macropsia). Hence it also will look either closer than it just did, or its linear size will look larger, or else both of those secondary illusions will occur.

[For readers who cannot carry out that demonstration, the oculomotor micropsia explanation for the moon illusion remains valid nevertheless (see later).]

Distance Cue Control

The new theory points out that the reason the focus and convergence of the eyes change during natural viewing of the moon as it rises is because of changes in the visible patterns in the scene near the moon, which patterns are known to psychologists and artists as the many *cues to distance*, or distance-cues.

The most likely relationship is as follows: While one is viewing the horizon moon over a typical landscape, the details one sees in the landscape form distance-cue patterns that signal "very far" for objects at the horizon. Those distance-cues for "far" make the eyes adjust for a great distance, and that induces macropsia (larger apparent angular size) for the horizon moon.

On the other hand, the vista for the zenith moon typically offers relatively few distance-cue patterns, and when distance-cues are sparse, the eyes tend to adjust to a relatively near position, known as the resting focus position, about 1 or 2 meters from the face. That oculomotor adjustment to a relatively near point induces micropsia for the zenith moon

Cue Conflicts, Again.

The most common perceptions that the horizon moon either looks about the same distance away as the zenith moon or looks closer disagree with what is being 'signaled' by the distance-cue patterns responsible for the oculomotor micropsia/macropsia. As previously noted, other distance-cue factors are dominating the final percept. The report, "looks larger and closer" undoubtedly is due to relative perceived angular size cue. The report, "looks larger and about the same distance away," undoubtedly is the result of an intrinsic "equidistance tendency" (Gogel, 1965) or an "equal distance assumption" (McCready, 1965, 1985). The intermediate outcome illustrates a balance among the several conflicting distance cue patterns available.

The discussion in Section III reiterates that those oculomotor micropsia and macropsia illusions, controlled by changes in distance-cues, occur not only for the moon, but for *all* viewed objects: That is, all objects seen near the horizon during normal viewing of an extended and detailed landscape typically look angularly larger than objects of the same angular size seen in less detailed surroundings (Higashiyama, 1992).

Flat Pictures

Oculomotor micropsia and macropsia also occur while one views a flat picture, because changes in distance-cue patterns in the flat picture typically induce slight changes in accommodation and convergence. [This phenomenon thus can explain the relatively small angular size illusions found in many of the flat patterns that are well-known "size" illusions, including the aforementioned 'paradoxical' Ponzo illusion, (McCready, 1983, 1985).]

Moreover, the evidence from published studies of those flat pattern illusions indicates that the changes in distance-cue patterns in them actually can induce the angular-size illusion more or less directly, without first having to create overt changes in oculomotor adjustments as an intermediate step. That is, a *conditioned relationship* seems to exist between changes in distance-cues and changes in angular size perceptions.
In other words, oculomotor micropsia/macropsia evidently may occur for the moon without there being an actual change in the eye's focus and convergence.

Section IV Summary.

To propose that the moon illusion is merely an example of another, more basic illusion does not yet fully explain it. It becomes necessary to also explain why oculomotor micropsia occurs. Section IV reviews an explanation which seems satisfactory (McCready,1965, 1983, 1985, 1994; Ono, 1970). Enright (1989) has offered a similar explanation. There currently seems to be no other explanation.
Briefly stated, oculomotor micropsia seems to be a normal perceptual-motor adaptation which "corrects" angular size perceptions in order to improve the accuracy with which one can rapidly turn one's head from one nearby viewed object to another nearby viewed object.

Why Is It a "New" Theory?

In the long history of speculation about the moon illusion, the explanation for the moon illusion being reviewed here is a very recent development. That happens because, first of all, it applies a relatively new general theory of the perception of "size, distance, and the visual angle" (McCready, 1965, 1985). This new general theory wholly replaces the most commonly used "textbook" theory of visual space perception, known as the "size-distance invariance hypothesis."

The present theory also is 'new' because its formulation has depended upon information about oculomotor micropsia published only since 1965: Likewise, it has depended upon having moon illusion research data published since about 1975 (Enright, 1975 to 1989; Roscoe, 1979 to 1989).

The 'new' general theory gradually is being accepted by other theorists (Baird, Wagner, & Fuld, 1990; Enright, 1989; Komodo & Ono, 1974; Gogel & Eby, 1994; Higashiyama, 1992, Higashiyama & Shimono, 1994; Ono, 1970; Reed, 1989). That is, although this present article focuses upon the moon illusion, the arguments go far beyond that illusion: They need to be taken into consideration in all discussions of the visual perception of spatial relationships.

Other "New" Explanations for the Moon Illusion.

Five other relatively new explanations also treat the moon illusion as basically an angular size illusion.
1. Hershenson (1982, 1989) offered a theory which appeals to a perceptual process he calls the "loom-zoom system."
2. Reed (1984, 1989) appealed to a perceptual experience he calls "terrestrial passage."
I won't try to review those two theories. They are reviewed in Ross & Plug (2002).

3. Baird, Wagner, & Fuld (1990) have offered a 'simple explanation' of the moon illusion. They revive the "size"-contrast explanation advocated by Restle (1970), but bring it up to date by clearly defining it as an *angular size-contrast* illusion, and also by restating it in terms of the present "new" general theory (McCready, 1986).

4. Enright (1989) has proposed that the moon illusion certainly illustrates oculomotor micropsia: His many experiments have left no doubt about that. The explanation he proposes for oculomotor micropsia (Enright, 1989) is similar to the perceptual adaptation explanation I have offered, but differs in some details (see Section IV).

5. Roscoe (1984, 1985, 1989) and his colleagues have conducted many experiments which clearly show that the moon illusion illustrates oculomotor micropsia.
He has proposed that changes in accommodation somehow change the size of the moon's "effective retinal image." But, that idea has not been accepted by experts on the eye's optics. For the most part, however, Roscoe prefers an atheoretical approach.

Roscoe's many publications have emphasized the largely overlooked role that oculomotor micropsia has played in some airplane crashes (Roscoe, 1979) and some automobile accidents (such as highway pile-ups in a fog). Briefly stated, the oculomotor changes which induce the illusion that the zenith moon looks angularly smaller and *farther away*, may arise in certain viewing conditions which cause pilots to see the airport runway as too far away, so they may land ("crash") beyond the runway (and some have).
Also, a person driving with a wet windshield, especially at night, or driving in a fog, would be expected to experience oculomotor micropsia, so objects in the road ahead will look too far away, and he or she will overestimate the safe braking distance.
In other words, the 'moon illusion' is more than just an idle curiosity!

NEXT SECTION. (Section I)