Visual Space Perception

A Primer

Maurice Hershenson

8

Empiricist View: Perceived Size and Shape

The classical empiricist analysis of perceived size and perceived shape is based on two invariance hypotheses: the size-distance invariance hypothesis (SDIH) and the shape-slant invariance hypothesis (SSIH). An entirely different approach to these problems—Gibson's psychophysical view—is described in the next chapter. A review of the vast literature on the topics contained in these two chapters can be found in Sedgwick (1986).

Perceived Size of Afterimages

The proximal stimulus produced by a distal object of size S at distance D from the observer was described in chapter 6: $\tan \alpha = S/D$. Recall that, in this distal-proximal relationship, *size* is a property of the object and *distance* refers to the space between the viewer and the object. Consequently, physical size and physical distance are independent quantities. In contrast, the corresponding quantities in the perceptual world, perceived size s and perceived distance d, are not independent; they are properties of perceptual experience. The discussion of perceived size and distance begins with afterimages. It describes Emmert's law of afterimage size and its use as a model for the perceived size of objects.

Emmert's Law of Afterimages

An *afterimage* is a visual image that is seen after the physical stimulus is removed. It may be formed by looking at a light or an illuminated object and then looking away at a surface. An image of the object or the light will be seen on the surface. The image has a definite size and shape, and appears to be at the same distance from the viewer as the surface upon which it is projected.

Figure 8.1 shows the simple relationships involved in viewing an afterimage. Figure 8.1a shows the adapting stimulus, e.g., a light of size S_L at a distance D_L from the viewer, that subtends a visual angle α: $\tan \alpha = S_L/D_L$. The viewer fixates the light for a few seconds and then looks at a gray wall. An image of the light appears on the wall, the afterimage.

Figure 8.1b shows the geometrical relationships involved in the perceived size of the afterimage. The wall is at an arbitrary distance, D', from the viewer. The perceived size of the afterimage that appears to be on the surface at D' is given by:

$$s = D' \tan \alpha. \tag{8.1}$$

Equation 8.1 is one possible formulation of Emmert's law: The perceived size of the afterimage varies directly with viewing distance (Emmert, 1881). However, D' is the physical distance of the surface, and physical quantities cannot enter mental processing to determine perception. This issue can be avoided by noting that the surface appears to be at the perceived distance d'. Therefore, the perceived size of the afterimage is given by:

$$s = d' \tan \alpha. \tag{8.2}$$

This is Emmert's law (see Hochberg, 1971, for a review of Emmert's law and constancy).

Registered Distance

In Equation 8.2, d' is a perceptual outcome, the perceived distance of the wall. Therefore, it cannot enter the causal sequence as a determiner of s, a simultaneous perceptual outcome. To solve this problem, some theorists have distinguished conceptually between perceived distance and registered distance (Epstein, 1973; Kaufman & Rock, 1962, 1989; Rock, 1975; Rock & Kaufman, 1962; Wallach & Berson, 1989; Wallach & Floor, 1971; Wallach & Frey, 1972). *Registered distance* D_r describes stimulus information about distance that is encoded and, therefore, enters perceptual processing to affect perceptual outcomes. Registered distance can be distance information produced by any of the distance cues in the proximal stimulus or by oculomotor adjustments. Depending on the specific situation, registered distance information may or may not affect perceived size or perceived distance. For example, in Kaufman and Rock's (1962) explanation of the paradoxical size-distance relations in the moon illusion, registered distance determines perceived size but not perceived distance (see the section on the

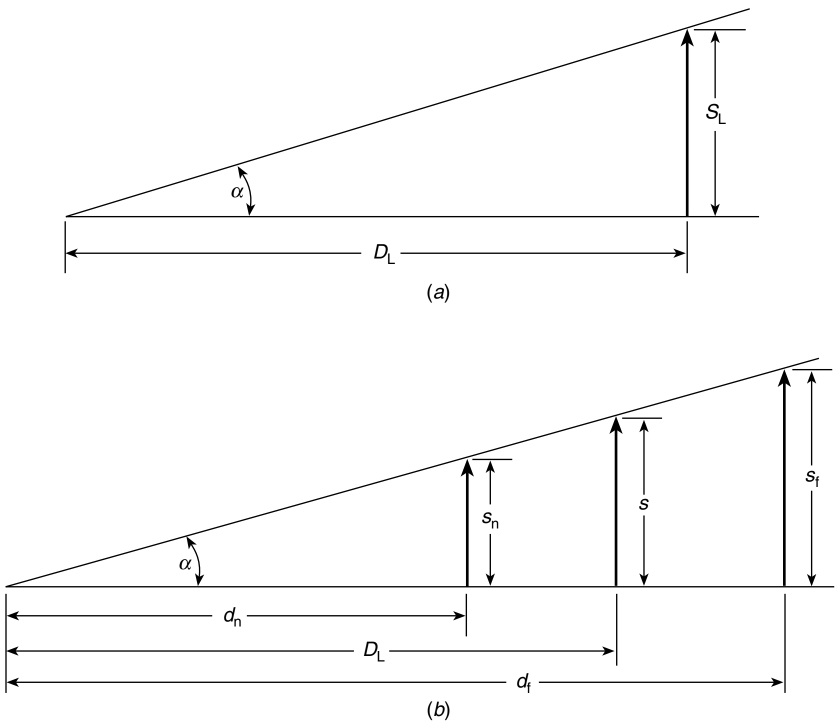


Figure 8.1
Emmert's law: the relationships involved in viewing an afterimage. (a) The adapting stimulus, a light of size S_L at distance D_L from the viewer, subtends a visual angle, α. (b) An afterimage of the light appears on a wall at distance D' from the viewer. If the wall appears to be more distant *(d_f)*, the afterimage appears larger *(s_f)*; if the wall appears closer *(d_n)*, the afterimage appears smaller *(s_n)*.

moon illusion, below). Obviously, registered distance is an inferred concept that remains controversial even among empiricists.

In the afterimage case, one could argue that information about the distance of the wall enters the processing sequence prior to the determination of the perceived size and distance of the afterimage. In this interpretation, registered distance determines perceived distance: $d = D_r$ and, in another formulation of Emmert's law, the perceived size of the afterimage is given by the algorithm:

$$s = D_r \tan \alpha. \quad (8.3)$$

Figure 8.1b illustrates the fact that an afterimage changes in perceived size as the information about the distance of the wall and, in this case, the perceived distance of the wall, changes. This relationship was demonstrated by Ames (Ittelson, 1968). An afterimage of size *s* was projected onto a card at a fixed distance *D* from the viewer. The card was made to appear closer to (d_n) or farther away from (d_f) the viewer by means of occlusion (see chapter 7). When the card appeared nearer $(d_n < D)$, the afterimage was smaller $(s_n < s)$ and, when the card appeared to be farther away $(d_f > D)$, the afterimage was larger $(s_f > s)$. Thus, the perceived size was not determined by the actual distance of the card. In this case, the relative distance information (registered distance) determined both the perceived size and the perceived distance of the afterimage. A similar change in the apparent size (Dwyer, Ashton, & Broerse, 1990) and shape (Broerse, Ashton, & Shaw, 1992) of an afterimage has been demonstrated using the distorted room (see below) to alter the apparent distance of the surface on which the afterimage was projected.

Thus, Emmert's law predicts that the size of an afterimage varies directly with the distance information about the surface on which it is projected. Consequently, afterimages have been used as a tool to investigate the perceived distance of surfaces. For example, King and Gruber (1962) had subjects form afterimages and project them onto the sky. They compared the relative size of the afterimages at different elevations to determine the relative perceived distance of the sky at each elevation. King and Gruber found that the size of the afterimage was largest at the horizon and smallest at zenith: $s_h > s_{(45\text{ deg})} > s_z$. They inferred, therefore, that the perceived distance of the sky varies directly as the perceived size of the afterimage: $d_h > d_{(45\text{ deg})} > d_z$. That is, they demonstrated experimentally that the sky is perceived as a flattened dome.

Hypotheses of Invariance

An *invariance hypothesis* defines the relationship between the proximal stimulus and perception. It is a refined notion of stimulus determinism. In general, invariance hypotheses state that, for a given proximal stimulus, the perception will be one of the distal configurations that could have produced that proximal pattern. Note that the definition does not state which of the possible distal configurations will be seen. Thus, an invariance hypothesis can be considered a rule or algorithm that relates aspects of perception to aspects of stimulation.

Size-Distance Invariance Hypothesis

Starting from an analysis of stationary objects, the traditional form of the *size-distance invariance hypothesis* describes the perceptions that are possible for a given constant visual angle (Epstein, 1977b; Epstein, Park, & Casey, 1961; Gilinsky, 1951; Ittelson, 1951a, 1951b, 1960; Kilpatrick & Ittelson, 1953; Oyama, 1977; Weintraub & Gardner, 1970). One formulation asserts that the ratio of perceived size to perceived distance is constant, i.e., perception is constrained by the proximal stimulus, in this case the the visual angle. Thus, a given visual angle α determines a ratio of perceived object size s to perceived object distance d:

$$s/d = \tan \alpha. \qquad (8.4)$$

Note the difference between equations 8.3 and 8.4—this form of the SDIH is not Emmert's law.

Figure 8.2 illustrates three possible perceptions that satisfy equation 8.4: $s_1/d_1 = s_2/d_2 = s_3/d_3 = \tan \alpha$. Clearly, the SDIH does not constrain the absolute values of perceived size or perceived distance. It only constrains their ratio (s/d). Assuming the SDIH, s and d vary directly for a given visual angle: As perceived size s increases, perceived distance d increases, and vice versa. Obviously, in this formulation, additional information is required to combine with a given visual angle input in determining a unique perceptual outcome. With respect to size, additional information can come from the familiar or known size of a given stimulus, or from relative size when two

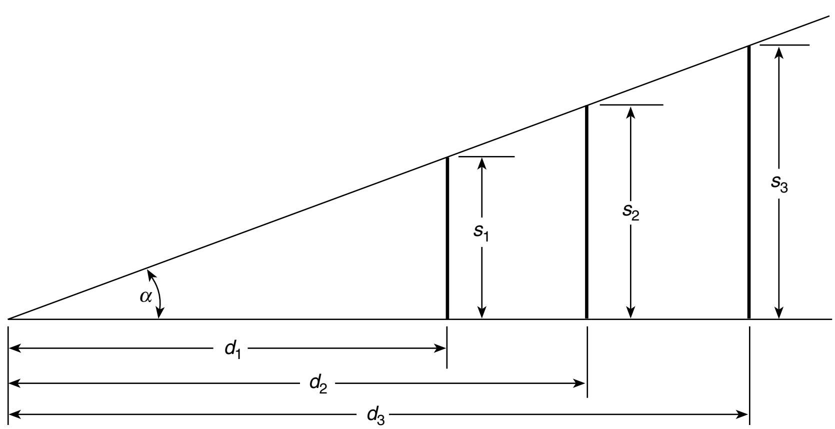


Figure 8.2
Three possible perceptions that satisfy equation 8.4: $s_1/d_1 = s_2/d_2 = s_3/d_3 = \tan \alpha$.

or more stimuli are present. With respect to distance, additional information can come from many different input sources, e.g., pictorial and oculomotor cues.

An alternative formulation of the SDIH (Kaufman & Rock, 1962, 1989; Rock, 1975; Rock & Kaufman, 1962; Wallach & Berson, 1989; Wallach & Floor, 1971; Wallach & Frey, 1972) holds that accurate size perceptions are determined by the Emmert's law algorithm, in which the perceived size of an object is determined by visual angle and registered distance. In this formulation, the invariance hypothesis relates perceived size to registered distance rather than to perceived distance. In a particular instance, perceived distance may or may not be affected by the same registered distance information that determines perceived size. When registered distance determines perceived distance, the perception is veridical and the SDIH holds as stated in Equation 8.3. However, when perceived distance is determined by factors other than the specific registered distance information that is producing the perceived size, the perceived-size–perceived-distance relations do not satisfy equation 8.3. Indeed, in some cases (e.g., the moon illusion), perceived size and perceived distance vary inversely.

Shape-Slant Invariance Hypothesis

Although the distal world contains solid objects, a viewer can see only the outer surfaces. These surfaces are extended in two dimensions and, therefore, subtend solid visual angles in the optic array. That is, the light reflected from a surface stimulates a retinal area. These spatial characteristics define the *shape* of a rigid object or surface. They do not change with translation, rotation, or change of scale.

The *shape-slant invariance hypothesis* asserts that a given proximal shape determines the possible perceived shapes at perceived slants (Beck & Gibson, 1955; Epstein, 1973; Koffka, 1935; Massaro, 1973). It is similar in form to the SDIH. A similar analysis can be applied to the SSIH, suggesting that additional information is required to specify a unique perceptual outcome. Thus, the perception of slant depends on information about shape, and the perception of shape depends on information about slant, or on psychological factors such as past experience, and Gestalt organizing mechanisms (Beck & Gibson, 1955; Epstein, 1977b; Epstein & Park, 1963; Flock, 1964a, 1964b; Koffka, 1935; Oyama, 1977). For example, Epstein (1973) proposed a "taking-into-account" hypothesis similar to that for the SDIH: Perceived shape is determined by a rule that takes slant into account in the processing of proximal projective shape. This formulation requires a registered slant concept similar to that of registered distance.

Perceived Size of Objects

The physical size of an object is described by the extent of its surfaces in 3D space. *Perceived size* is the quality of a perceived object that corresponds to its physical size.

Measuring Perceived Size: Brunswick and Thouless Ratios

The perceived size of a stationary object is frequently measured in experiments using a matching procedure. The *standard stimulus* is the object whose perceived size is being measured. The viewer adjusts the size of a similar object, the *variable* or *comparison stimulus,* until it appears to match the size of the standard. Typically, perceived size of an object is measured at different distances. Therefore, in experiments, the distance of the standard changes from measurement to measurement while the distance of the comparison does not.

The accuracy of the match can be assessed in different ways based on the assumption that the physical size of the comparison is an index of the perceived size of the standard. Under this assumption, the perceived and physical sizes of the standard can be compared directly. Because direct comparison has many shortcomings, Brunswick (1929) proposed an alternative formulation relating the matches to visual angle size. The *Brunswick ratio* (BR) relates the difference between the comparison and visual angle size to the difference between the standard and the visual angle size:

$$\mathrm{BR} = (S_c - s_c)/(S - s_c), \tag{8.5}$$

where S_c is the size of the comparison, s_c is the visual angle or projected size of the standard at the distance of the comparison, and S is the physical size of the standard. Thouless (1931) proposed an alternative formulation that does not depend on which object is the standard and which is the comparison. This measure is called the *Thouless ratio* (TR):

$$\mathrm{TR} = (\log S_c - \log s_c)/(\log S - \log s_c). \tag{8.6}$$

Both ratios vary between 0.0 and 1.0, where zero indicates a match to the visual angle subtended by the standard and 1.0 indicates a perfect match to its real size, or size constancy (see Myers, 1980, and Sedgwick, 1986, for detailed discussions).

Size Constancy

Despite the fact that a rigid object subtends different visual angles when it is viewed at different distances, its perceived size does not change. This aspect of stability in the perception of objects in space is described as *size constancy* (Epstein, 1977b; Epstein, Park, & Casey, 1961).

Holway and Boring (1941) demonstrated this basic fact of perception in an experiment that measured the effect of distance information on matched size. Subjects viewed stimulus discs of different sizes that were at different distances down a long corridor (10 to 120 feet), but always subtended the same visual angle (1 deg). They matched the perceived size of the discs using an adjustable disc of light in an intersecting corridor 10 feet away. When the stimuli were viewed either binocularly or monocularly with full distance information, the matches approximated size constancy values. When the depth information was decreased by viewing through an aperture that reduced the distance cues (a *reduction screen*), the size matches were greatly reduced. When the depth information was further reduced, the matches approached visual angle size.

One explanation for size constancy describes the perceptual processing as "taking distance into account" (Epstein, 1973, 1977b; Rock, 1975, 1977; Wallach & Floor, 1971; Wallach & Frey, 1972). In this view, registered distance information, the distance information available in everyday stimulation, is used in the processing to determine perceived size. With distance information given, the SDIH takes the form of equation 8.3 and perceived size is determined. The thereness-thatness table described in figure 7.4 illustrates how distance information can determine perceived size. In the righthand field, the occlusion pattern produces reversal of the perceived distances for the near and far cards: The near card appears to be far away and, therefore, looks unusually large, whereas the far card appears to be near and, therefore, looks very small.

Leibowitz (1974) proposed that a number of different mechanisms (e.g., oculomotor adjustments, perceptual learning, and cognitive or conceptual processes) can contribute to determining size perception and size constancy. Leibowitz noted, for example, that size constancy matches for stimuli up to 1 meter away were predicted by values of accommodation and convergence (Leibowitz & Moore, 1966; Leibowitz, Shiina, & Hennessy, 1972). Beyond that distance, constancy was underestimated. Furthermore, Harvey and Leibowitz (1967) found that eliminating visual distance cues by a reduction screen did not affect size judgments at distances less than 1 meter.

Leibowitz also noted that size matches are affected by instructions (Carlson, 1960, 1977; Gilinsky, 1955, 1989; Leibowitz & Harvey, 1967, 1969). For example, Gilinsky (1955) presented triangles of different sizes (42 to 78 inches) outdoors at different distances between 100 and 4,000 feet. A matching stimulus was placed at 100 feet, 36 deg to the right. *Objective* instructions asked subjects to match the size of the test stimulus as if it were placed beside the matching stimulus. That is, they were to match how big the triangle "really is." *Picture image* instructions asked subjects to imagine looking at a picture and to match the size of the portion of the picture that would be cut off by the stimulus. The objective or "true size" instructions yielded a slight overestimation *(overconstancy)* over the entire range (see Teghtsoonian, 1974, for a discussion of this issue). The picture image instruction yielded matches that approached visual angle. In a subsequent study, more specific visual angle instructions produced a closer match to visual angle for targets places at 10 to 100 feet (Gilinsky, 1989).

Familiar Size

In addition to visual angle, size information is frequently available as *familiar* or *known size* (Ames, 1955; Ittelson, 1960). If the object is familiar and has a known size (s_f), the SDIH becomes:

$$d = s_f/\tan \alpha, \tag{8.7}$$

and perceived distance is determined. Figure 8.3 illustrates the operation of familiar size. A normal sized playing card, S_N, is photographed and enlarged to size S_L. The enlarged card is placed at distance D and subtends the same visual angle as the normal card for a viewer at P. The card is viewed in a dark room, so there is no additional information about its size or distance. The viewer reports seeing a normal sized playing card $(s = S_N)$ at a distance d that satisfies the SDIH. Thus, in this situation, familiar size and visual angle determine perceived distance.

Gogel questioned the role of familiar size based on studies in which two different responses were used to index perceived distance (Gogel, 1977, 1981). One measure was simple verbal report. The other was a procedure in which the head was moved laterally so that motion parallax (see

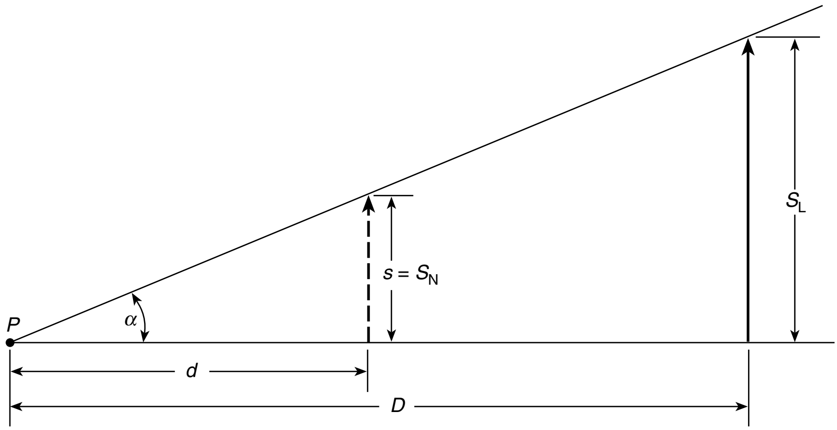


Figure 8.3
Familiar size. A normal sized playing card, S_N, is photographed and enlarged to size S_L. The enlarged card is placed at a distance, *D*. The viewer reports seeing a normal sized playing card ($s = S_N$) at a distance, *d*.

chapter 10) provided information about relative depth. Gogel found that the verbal reports of perceived distance increased as a function of familiar size whereas head-motion measurements were unchanged. Gogel suggested that perceived distance did not change in the experiment. He concluded, therefore, that the verbal reports represented the influence of cognitive factors (Gogel & Da Silva, 1987a). The role of familiarity is further complicated by Predebon's (1991) finding that, although familiar size influenced the relative egocentric distance of objects, it did not affect judgments of exocentric extents at distances from 5 to 80 meters. Predebon agreed with Gogel's assessment that nonperceptual (cognitive) factors influenced the distance reports.

Perceived Visual Angle

When distance information is not available, as, for example, when a luminous object is viewed in the dark, viewers can match the visual angle fairly accurately (Epstein & Landauer, 1969; Hastorf & Way, 1952; Lichten & Lurie, 1950; Rock & McDermott, 1964). This ability suggests that there are two types of size perceptions: object or linear size and extensivity or visual angle size (Rock, 1975, 1977; Rock & McDermott, 1964). *Visual angle size,* or the proportion of the visual field that the object subtends, is not normally in our awareness and is seldom brought into awareness without effort.

McCready (1965, 1985, 1986) noted that perceived visual angle α' is usually assumed to be equal to the actual visual angle: $\alpha' = \alpha$. In this view, linear and angular size responses are treated as two ways of measuring the same perceptual experience. Furthermore, perceived size and perceived distance are affected by visual cues, while perceived visual angle is treated as a direct response to retinal size.

McCready proposed a different conception of visual angle size. He defined *visual angle* as the optical direction difference between the edges of an object and *perceived visual angle size,* α', as the difference between the corresponding perceived directions. Furthermore, he assumed that the experiences associated with linear size and angular size are qualitatively different but simultaneously existing perceptual experiences. Thus, in his conception, when stimulated by an object of size S at distance D subtending a visual angle α, the object has a perceived linear size s at perceived distance d, and simultaneously, the object subtends a perceived visual angle α'.

In McCready's formulation of the SDIH, the two types of perceived size are not interchangeable. They are related according to a new SDIH:

$$s/d = \alpha'. \tag{8.8}$$

Thus, for McCready, the perceived-size–perceived-distance ratio is an invariant function of the perceived visual angle, not of the visual angle normally used to describe the proximal stimulus. Consequently, perceived visual angle has a unique status in the processing sequence and the two visual angles are related:

$$\alpha' = m(R/n) = m\alpha, \tag{8.9}$$

where R is the retinal extent of stimulation, n is the distance from the retina to the nodal point of the eye, and m is the phenomenal magnification, the ratio of perceived to actual visual angle.

Perceived Distance in a Scene

The perceived distance from the viewer to an object is called *egocentric distance* and the perceived distance between objects in the field is called *exocentric distance.* The perceived distances in a scene have been measured in many ways, including absolute estimates, map drawings, and comparisons among triad distances. Generally, these measurements produce a linear relationship between physical distance and judged distance up to 30 meters or so, a relationship that holds for both egocentric and exocentric distances

(Gilinsky, 1951; Levin & Haber, 1993; Toye, 1986; Wagner, 1985; Wiest & Bell, 1985).

Accurate judgments of distance have also been reported for distances between 30 and 100 meters (Gilinsky, 1989; Haber, 1983). Thus, perceived distance corresponds fairly well to real distance up to about 100 meters. Levin and Haber (1993) found a slight difference between estimates of distances oriented closer to the line of sight and those oriented closer to the frontal plane. The perceived distance between objects was slightly distorted as a function of the angular separation between objects. This resulted in an overestimation of distance in the frontal plane, which made the scene appear slightly elliptical along the horizontal axis. Consequently, perceived distances in the scene changed when the viewer changed position.

Perceived Shape of Objects

Perceived shape is the quality of a perceived object that corresponds to its physical shape.

Shape Constancy

Despite the fact that the proximal projection of a rigid object has different shapes when it is at different slants with respect to the viewer, the object appears to retain its shape. This phenomenon is described as *shape constancy.* In empiricist theory, shape constancy is a special case of the *shape-slant invariance hypothesis* (Beck & Gibson, 1955; Epstein, 1973; Epstein & Park, 1963; Koffka, 1935; Massaro, 1973; Pizlo, 1994; Sedgwick, 1986). Because the SSIH only determines a family of equivalent shapes at different slants, additional information is necessary for shape constancy to occur. This can be visual information about the shape of the object or the slant (orientation) of the surface, or cognitive information about the object's shape.

Familiar Shape

One source is familiarity with the shape of an object. The operation of this kind of information is illustrated in figure 8.4 for a trapezoidal window (Ittelson, 1968). The window is constructed as illustrated in figure 8.4a, which shows a perspective view of a real rectangular window *(C, D, E, F)* in the frontal plane of a viewer at point *P.* The window is projected onto an imaginary plane rotated about the axis *AB* so that it is slanted with respect to the viewer. In the slanted plane, the window will be trapezoidal in shape.

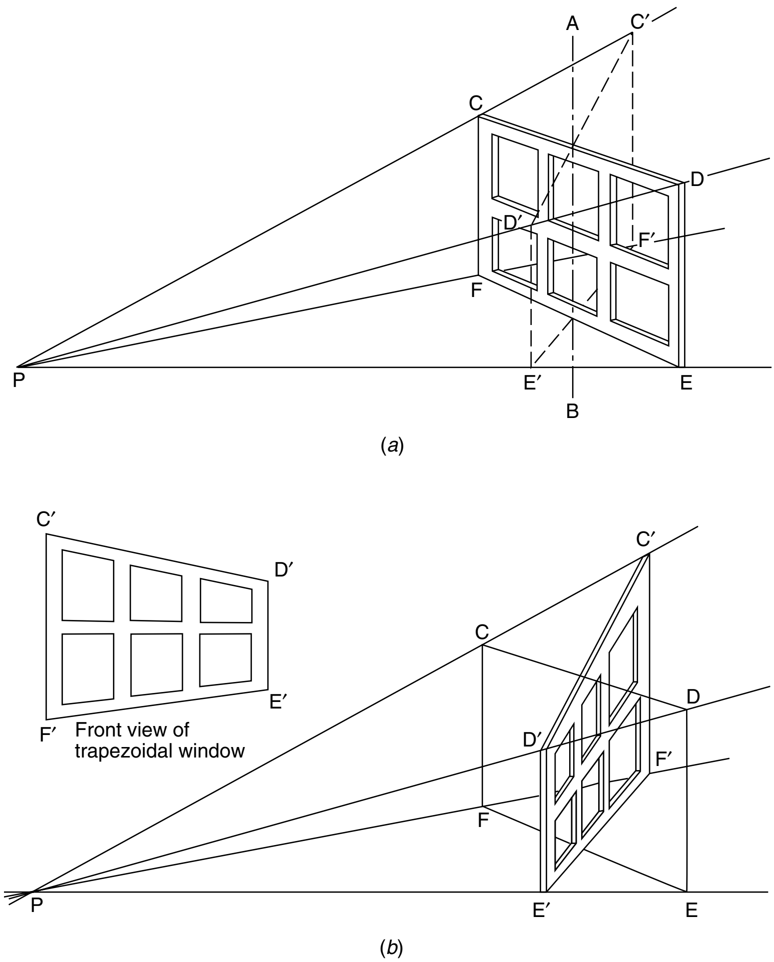


Figure 8.4
Construction of a trapezoidal window. (a) Real rectangular window *CDEF* is projected onto a plane at a slant producing trapezoidal window *C′D′E′F′*. The trapezoidal window is then constructed from a rigid material. (b) The trapezoidal window appears to be a rectangular window at a different slant.

Figure 8.4b shows the trapezoidal window C', D', E', F'. If this window is made into a real cardboard, wood, or metal window placed Cn appropriate slant to a viewer at point *P,* it appears to be a rectangular window in the frontal plane. If the trapezoidal window were placed C different slant, the rectangular window would appear to be C slant. According to Ames (Ittelson, 1968), the window appears rectangular because our past experience with windows has been predominantly with rectangular windows. That is, our familiarity with the shape of the object determines its perceived shape, and the SSIH determines its perceived slant.

Distorted Room

Both SDIH and SSIH relationships are involved in the *distorted room,* another of the Ames demonstrations (Ames, 1955; Ittelson, 1968). Figure 8.5 shows how the rear wall of a distorted room is constructed. A front view of a real rectangular room with two rectangular windows in the rear wall *(ABCD)* is shown on the right side of the figure. The left side of the figure shows a top view of the rear wall viewed from point *P.* This wall is projected onto an imaginary plane at a slant to the wall. Side *AD* projects to $A'D'$ and side *BC* projects to $B'C'$. Because the imaginary plane is at a slant to the real wall, the rectangular shapes project in perspective as trapezoids. Trapezoidal projections of the side walls, floor, and ceiling are obtained in the same way.

The projections are made into real objects from material such as plywood and painted to look like the original room. Figure 8.6 illustrates the situation when a viewer places an eye at *P* and looks into the trapezoidal room (solid lines in the figure). The room appears to be rectangular (dashed lines in the figure). The other parts of the trapezoidal room (windows, floor and ceiling patterns) also appear to be rectangular and to fit appropriately into the perceived room. In the transactionalist view, the unique perception is determined by our past experience with rectangular environments and the SSIH (Ames, 1955; Ittelson, 1968). The walls appear rectangular and, combined with the SSIH, the slant of the rear wall is determined (in this case a frontal plane).

Figure 8.7 shows two women of approximately the same size in opposite corners of the room. One woman looks very large and the other looks very small. A number of factors enter into this perceptual outcome. In reality, the woman on the right is nearer to the viewer and the woman on the left is farther away from the viewer. Therefore, the woman on the left subtends a smaller visual angle than the woman on the right. The

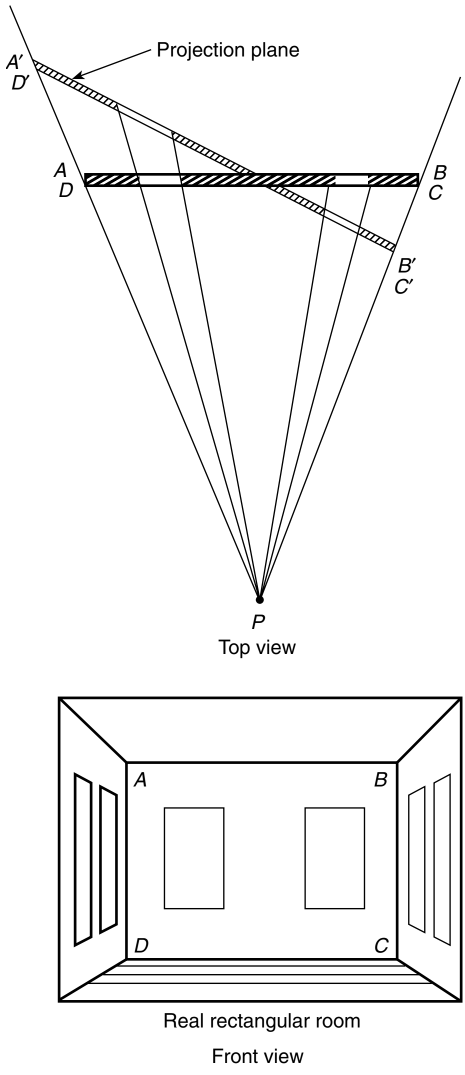


Figure 8.5
Construction of the rear wall of a distorted room (Ames, 1955; Ittelson, 1968). The bottom of the figure shows a front view of a real rectangular room with two rectangular windows in the rear wall, *(ABCD)*. The top shows a top view of this wall and its projection onto an imaginary plane at a slant to the wall. Side *AD* projects to *A′D′* and side *BC* projects to *B′C′*. Because the imaginary plane is at a slant to the real wall, the rectangular shapes project in perspective as trapezoids.

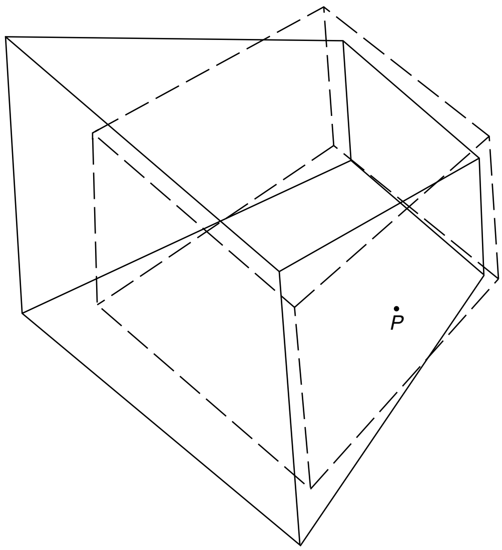


Figure 8.6
A distorted room (solid lines) viewed from point P appears to be a rectangular room (dashed lines).

women occlude a portion of the rear wall and, therefore, appear to be in front of it (i.e., closer to the viewer than the wall). Furthermore, the women's feet are approximately the same height in the picture plane, i.e., they intercept the floor at approximately the same vertical position (see chapter 9 for a discussion of this information). Therefore, they appear to be in front of the rear wall but close to it. The wall, however, appears to be in a frontal plane. Therefore, the women appear to be at approximately the same distance from the viewer.

This situation is illustrated in figure 8.8 with (a) a top view, (b) a side view of the woman on the left, and (c) a side view of the woman on the right. There is relative size information about the woman at the far end *(A′D′)* because she is physically smaller than the surrounding corner. Because the wall appears closer than it is, she appears closer and, consequently (following the the SDIH), appears even smaller. Similarly, there is relative size information about the woman at the near end *(B′C′)*. She is almost as large as the surrounding area of the walls and even may touch the ceiling. Because this portion of the wall appears to be farther away than it really is, this woman also appears to be farther away. Consequently (following the SDIH) she appears to be even larger, i.e., she looks like a giant.

Figure 8.7
Perceptual outcome when two women of similar size stand in the corners of the distorted room. One woman looks very large and the other looks very small (Ittelson, 1968).

Noninvariance Perceptions

Despite many demonstrations where invariance formulations hold, the transactionalists (e.g., Ames, 1955; Ittelson, 1960) argued that perception is not limited to invariance outcomes. They suggested that perceptions can occur which do not satisfy invariance algorithms. The S-motion demonstration illustrates perceptions of size and distance that do not satisfy the SDIH.

S-Motion Demonstration

In the S-motion demonstration, perceived space was distorted using a trapezoidal window as illustrated in figure 8.4. Figure 8.9(a) shows a perspective view of the S-motion demonstration and figure 8.9(b) shows the arrangement from the top. Figure 8.10 shows a perspective view of the illusory motion. A trapezoidal window *(A′B′)* was placed at a slant to the viewer and appeared to be a rectangular window *(AB)* at a different slant

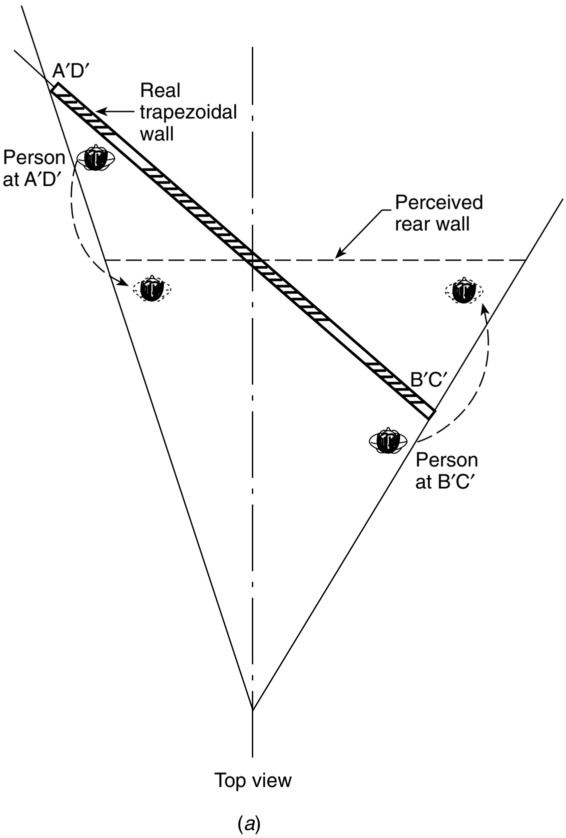
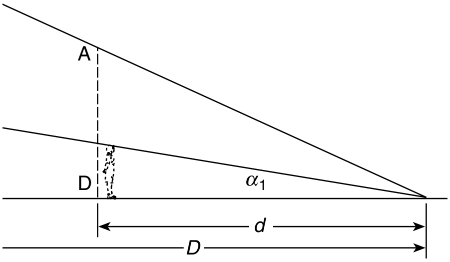


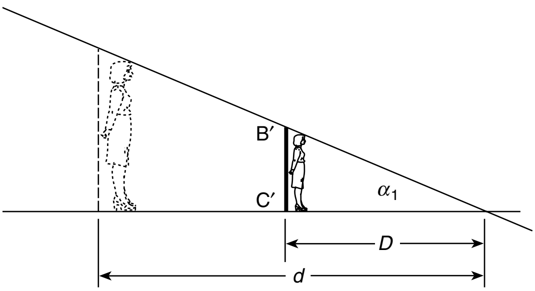
Figure 8.8
In the distorted room, one woman is nearer to the viewer at one end and the other is farther away from the viewer at the other end. However, they appear to be at approximately the same distance from the viewer. The top view of this situation is illustrated in (a). Side views are illustrated in (b) and (c).

to the viewer. The far end of the real trapezoidal window appeared to be the near end of the rectangular window and vice versa. A string passed though the righthand opening in the window and crossed the field in a frontal plane. A playing card mounted on the string moved through the window in the frontal plane. Therefore, the visual angle subtended by the playing card did not change as it moved because it was always in the frontal plane.

As the card moved across the visual field, it passed behind one side of the trapezoidal window and in front of the rest of the window. When it



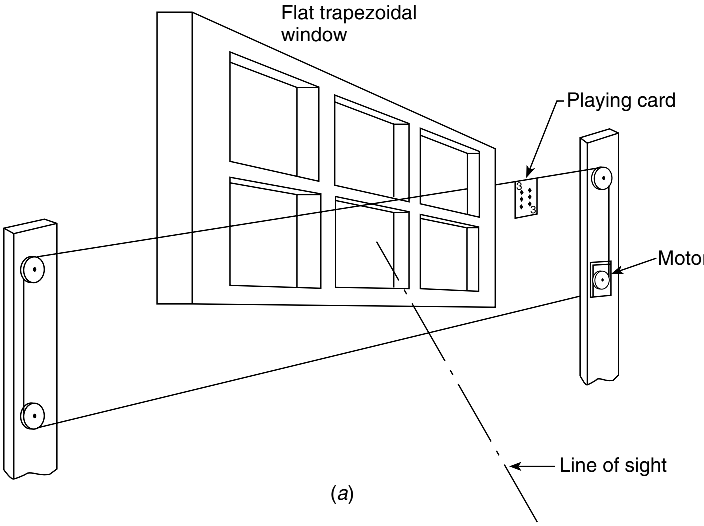
(*b*)



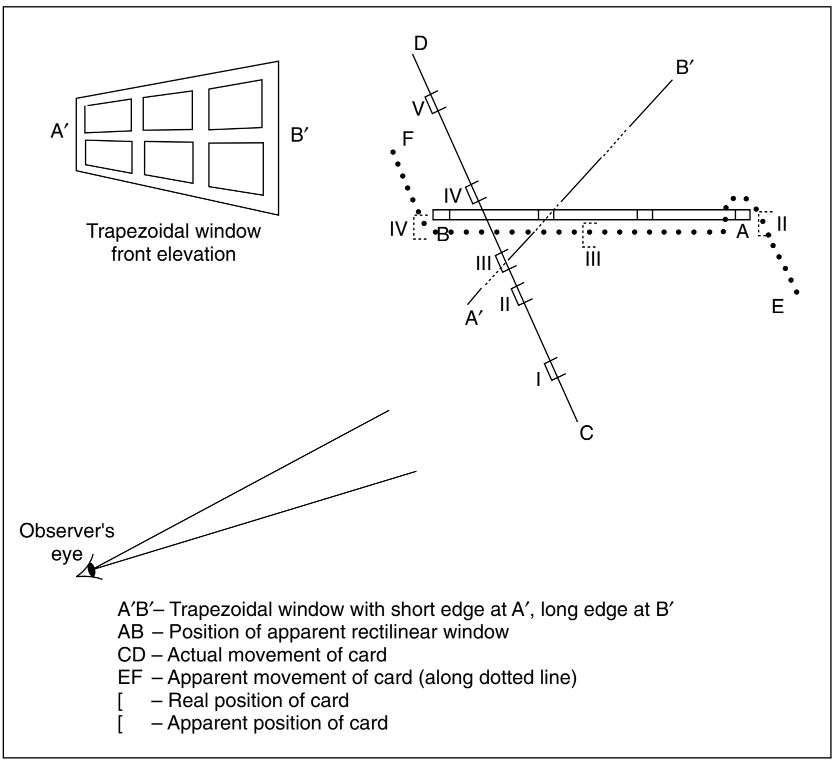
(*c*)

passed behind the window, the card was occluded, and, when it passed in front of the window, the card occluded portions of the window. This occlusion information determined the relative perceived depth of the card and window. But the trapezoidal window appeared to be in a plane whose slant was opposite that of the perceived rectangular window. Therefore, the card appeared to move in depth in an apparent "S" motion as it traversed the field (dotted line in the figure).

Viewers described the perceived size of this card as it moved in depth. The SDIH predicts that the card should appear smaller as it appears to move closer and larger as it appears to move away. However, viewers of the demonstration did not produce consistent reports (Ames, 1955; Ittelson, 1968). All possible combinations of perceived size and perceived distance changes were reported; there were also reports of no change in size. Ames concluded that size-distance perceptions are not limited by the SDIH, i.e., noninvariance perceptions are possible.


Flat trapezoidal window
Playing card
Motor
Line of sight

(*a*)


Trapezoidal window front elevation
A′
B′
D
C
E
F
A
B
I
II
III
IV
V
Observer's eye
A′B′– Trapezoidal window with short edge at A′, long edge at B′
AB – Position of apparent rectilinear window
CD – Actual movement of card
EF – Apparent movement of card (along dotted line)
[– Real position of card
[– Apparent position of card

(*b*)

Moon Illusion

The moon illusion may be a natural example of a common perceptual experience that does not follow the SDIH (Hershenson, 1982, 1989b). However, there is little agreement about the nature of the illusion despite the fact that it is one of the earliest known illusions. A reference to the illusion is clearly identifiable on clay tablets written as early as the seventh century B.C., and it was discussed by Aristotle, Ptolemy, and Ibn al-Haytham (Alhazan) among other early scientists (Plug & Ross, 1989). Thus, the illusion has been studied for over two millennia, yet it remains the subject of heated controversy (Hershenson, 1989a).

The visual angle stimulus produced by the moon does not change with elevation, i.e., there is no difference in the size of its image in a photograph of the moon at different elevations (see Solhkhah & Orbach, 1969, for a time-lapse photograph of the moon at different elevations). Nevertheless, the moon looks larger when it is near the horizon than when it is high in the sky (at zenith). There is no disagreement about this aspect of the illusion. The change in the perceived size of the moon as a function of elevation is the traditional description of the *moon illusion* and has been well documented (Plug & Ross, 1989). Similar illusions are produced by other objects in the sky. A sun illusion is easily observable at sunset and a celestial illusion that relates to other objects (e.g., stars, planets) and spaces (e.g., between stars) can be observed in the night sky (Hershenson, 1989a; Plug & Ross, 1989).

Indeed, the difficulty in finding an adequate explanation may be a consequence of another aspect of the illusion. Most observers report that the moon appears closer when it is near the horizon, and more distant when it is at zenith. This perceived-size–perceived-distance relationship contradicts the SDIH, revealing a *size-distance paradox* (Gruber, 1954; Hershenson, 1982, 1989a).

Many explanations have been offered for the moon illusion over the course of its long history (Plug & Ross, 1989). The most popular explanation in the first half of the twentieth century was based on eye elevation (Schur, 1925). She demonstrated that viewing an object in a dark room with eyes elevated made it appear smaller than when the eyes were horizon-

Figure 8.9
S-motion demonstration (a) in perspective and (b) from the top. A playing card moves across the field in a frontal plane. As it passes behind one part of the window and in front of the other part, the card appears to follow an S-shaped path (Ames, 1955; Ittelson, 1968).

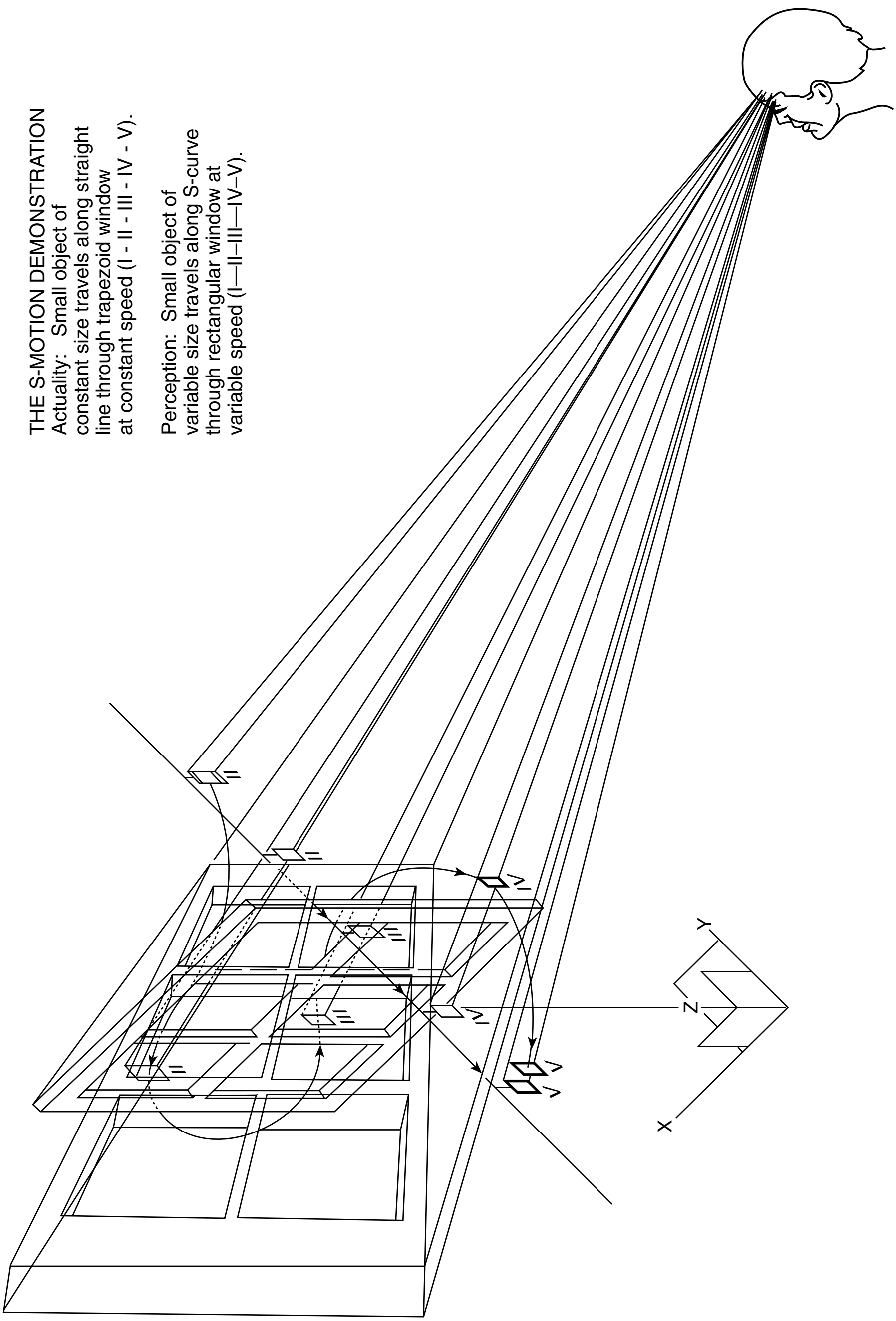


Figure 8.10
The S-motion demonstration in perspective (Ittelson, 1968). The playing card appears to travel around the window altering its distance from the viewer (see text for details).

tal. Taylor and Boring (1942) demonstrated a similar effect for direct observations of the moon. However, Kaufman and Rock (1962; Rock & Kaufman, 1962) tested the eye elevation hypothesis directly using a device that permitted viewing a moonlike object over a large expanse of ground or water with the eyes in various positions. They found no effect of eye elevation. Instead, they found that the horizon and surface terrain were the most important factors in the moon illusion.

Rock and Kaufman (1962) proposed a three-step explanation to incorporate their new finding: The terrain and horizon provide distance information that makes the area enclosed by the dome of the sky appear to be more distant at the horizon. This registered distance information enters the processing sequence in conjunction with the equidistance tendency to affect the perceived size of the moon. As the moon rises in the sky, the angular separation between the moon and the horizon becomes larger and larger. This change progressively weakens the effect of the equidistance tendency and provides information that the moon is getting closer and closer to the viewer.

In conjunction with the SDIH, this information results in a large perceived size for the moon at the horizon because of the great registered distance of the horizon. With increasing elevation, the decreasing registered distance produces a smaller perceived size of the moon. Rock and Kaufman (1962) suggested further that the reported distance of the moon is a consequence of cognitive analysis: The viewer reasons that the horizon moon looks large, large things are closer, therefore, the horizon moon must be closer. Notice that, in this explanation, registered distance determines perceived size but not perceived (reported) distance.

Gogel and Mertz (1989) proposed one of the few explanations of the paradox that retains the traditional formulation of the SDIH as a ratio of perceived size to perceived distance. They added a cognitive processing step between perception and the verbal response. In their view, relative perceived distance is determined by egocentric reference distance as a consequence of the specific distance tendency, the equidistance tendency, and oculomotor resting states. The equidistance tendency and the SDIH produce the greater perceived size and distance of the moon at the horizon. However, verbal descriptions of the moon's distance are determined by cognitive processes that produce a verbal report that the moon is close.

An entirely different explanation has been proposed by Hershenson (1982, 1989b). He agreed that the equidistance tendency interacts with the input distance information from the ground and horizon. However, instead of the SDIH (a static algorithm), Hershenson (1982) suggested that the mechanism operating in the moon illusion is a kinetic version of the invariance hypothesis (see chapter 11). This algorithm relates a changing visual angle to a constant perceived size for an object moving in depth. When presented with an object subtending the same visual angle at different perceived distances, this mechanism produces the moon illusion directly: a large perceived size for near objects and a small perceived size for far objects.

Summary

This chapter analyzed perceived size and shape from an empiricist point of view. The stimulus was described as a retinal extent (visual angle) or an outline shape, respectively. In this view, the stimulus is inadequate and cannot determine a unique percept. It must be supplemented by additional information from the stimulus or by cognitive (intelligent) processes such as inference, assumptions, or problem solving.

The possible perceptual outcomes may be constrained by various hypotheses of invariance. The SDIH constrains the ratio of perceived size and perceived distance to proximal stimulus size (visual angle). The SSIH constrains the perceived shape and perceived slant to the solid visual angle subtense. The demonstration of noninvariance perceptions, as in the S-motion demonstration and moon illusion, suggests that the invariance relationships may not be laws of perception but algorithms that work in most situations.