Research Article

THE MYSTERY SPOT ILLUSION AND ITS RELATION TO OTHER VISUAL ILLUSIONS

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Abstract—*Observations at The Mystery Spot, a roadside attraction near Santa Cruz, California, suggest intriguing visual illusions based on tilt-induced effects. Specifically, a tilted spatial background at The Mystery Spot induced misperceptions of the orientation of the cardinal axes (i.e., true horizontal and vertical), which then led to illusions in the perceived height of two individuals. This illusion was assessed at The Mystery Spot and replicated in the laboratory using pictorial and lined displays rotated in the picture plane. These findings are described in terms of the* orientation framing theory, *which suggests that these and other tilt-induced illusions (e.g., Ponzo illusion, Zöllner illusion) can be attributed to distorted frames of reference.*

Visual illusions offer provocative insights into the ways in which perceptual processes distort reality. In real-world scenes, perceptual illusions—such as the moon illusion (Kaufman & Rock, 1962)—distort the perceived size of common objects. In geometric illusions, such as the Ponzo or rod-frame illusions (see Gillam, 1980; Gregory, 1968; Witkin & Asch, 1948), simple line drawings distort the perceived length and orientation of line segments. For more than a hundred years, an assortment of visual illusions has been placed under scientific scrutiny, with both psychological and physiological interpretations being used to explain these phenomena (for review, see Coren & Girgus, 1978; Rock, 1975). Indeed, it has been suggested that the investigation of visual illusions will help define basic perceptual mechanisms used for the analysis of real-world scenes. Yet, even after a century of investigations, there is controversy over the underlying processes that mediate these illusions.

Our investigation was initiated by an interesting illusion that occurs in a real-world setting and distorts the apparent height of individuals. This illusion was observed at The Mystery Spot, a roadside attraction near Santa Cruz, California (for a listing of other related sites, see Banta, 1995, and the World Wide Web site at www.illusionworks.com). The main attraction is a shed that is tilted and abuts a hillside. Within the shed, and at places along the hillside, various illusions occur—such as balls appearing to roll up a plank and individuals appearing to be oriented at such angles as to defy gravity. Also, when two individuals face each other, with one looking uphill and the other downhill, they misperceive their own height relative to one another. In this illusion, one's own apparent height is distorted by changes in perceived eye level due to the pitch (i.e., downward or upward slope) of the background environment (see Matin & Li, 1992; Stoper, 1999; Stoper & Cohen, 1986).

Our interest was piqued by another illusion at The Mystery Spot in which observers are asked to compare the height of two individuals standing in front of an angled hillside or in front of a tilted shed. When viewed in this way, the background is tilted from left to right by approx-

imately 18° in the picture plane. The apparent height of the two individuals—as seen by observers—changes as the two individuals move from one position to another (see Fig. 1). We refer to this misperception of the height of two individuals as the *Mystery Spot illusion.*

In our investigation, we evaluated the Mystery Spot illusion and recreated the illusion in the laboratory. In this article, we discuss our findings and offer a theoretical interpretation. Clearly, the illusion can be attributed to interactions in the perception of objects in relation to the background. That is, a tilted background, such as the shed or an angled hillside, appears to distort the perceived orientation of the "true" horizontal axis with respect to the level ground. Thus, the Mystery Spot illusion has similarities with the rod-frame and distorted-room illusions (Asch & Witkin 1948; Witkin & Asch, 1948). In these displays, a rotated frame induces a distortion in the perception of the horizontal and vertical axes. For example, when subjects attempt to align a rod to the true horizontal, they misalign the rod toward the orientation of the tilted frame. What is interesting and different about the Mystery Spot illusion is that it is a distortion in the perceived height of two individuals rather than in perceived orientation.

To what extent are illusions in the height of two objects similar to misperceptions of frame orientation? That is, to what extent is the Mystery Spot illusion related to the rod-frame illusion and other illusions involving tilt-induced effects (see Gibson & Radner, 1937; Howard, 1982; Kramer, 1978; Tyler & Nakayama, 1984)? We suggest that these and other illusions can be interpreted in terms of a unified theory based on orientation frames of reference that are used to make a variety of perceptual judgments, including judgments of height, spatial location, line length, and line orientation.

EXPERIMENT 1

In Experiment 1, we measured the illusion of height in 2 observers at The Mystery Spot. We also assessed the ability of the observers to adjust a rod to the horizontal with respect to the ground.

Method

Data were collected from 2 observers (A.P.S. and H.S.E.) on two different occasions. Both were tested at The Mystery Spot, where the background scene consisted of a fence that was angled down a hillside from left to right by approximately 18°. In front of this scene, two poles (3 m long) were situated on level ground (1.63 m apart for A.P.S., 1.98 m apart for H.S.E.). On the left pole, a marker was placed 1.32 m from the ground. The observer adjusted a marker on the right pole to match the height of the marker on the left pole. Specifically, the experimenter moved a marker along the extent of the right pole, and the observer indicated when that marker matched the height of the marker on the left pole. The height of the adjusted marker was recorded.

We also assessed the degree to which the observers could determine the true horizontal—that is, the horizontal with respect to the

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Fig. 1. The Mystery Spot illusion. In this illusion, observers view two individuals standing in front of a tilted background. As the two individuals move from one side to the other, their heights appear to change relative to each other. In these images, the two individuals were digitally inserted into the scene to avoid distortions resulting from other perceptual anomalies, such as viewer position. For example, if the viewer (or camera) is not exactly equidistant from the two individuals (i.e., views the individuals from an oblique angle), then the individual standing closer to the viewer will have a larger retinal image compared with that same individual standing further away.

level ground. This judgment was measured by having each observer determine when a 1-m-long rod mounted on a tripod was oriented at the true horizontal. The experimenter moved the orientation of the rod until the observer indicated that the rod appeared to be oriented at the true horizontal. The angle subtended by the rod and the true horizontal was then recorded. This measurement assessed the degree to which the tilted background affected the perception of the horizontal orientation. It is tantamount to assessing a rod-frame effect using the Mystery Spot location as the frame.

Results and Discussion

A height illusion and a rod-frame illusion were apparent in both observers. That is, when the two markers were judged to be at the same height, the actual height of the left marker was greater than the height of the right marker by an average of 11 cm, which represented an 8.3% distortion in perceived height in the direction of the tilted background (see Table 1). In the adjustment of the rod to the true horizontal, the observers misjudged the perceived horizontal by an average of 3.4° in the direction of the tilted background.

We compared the height and rod-frame illusions by calculating the height illusion in terms of the angular displacement from the true horizontal. That is, we used the disparity in height between the two markers (Δh) and the distance between the two poles (d) to calculate the magnitude of the perceived tilt between the two markers with respect to the true horizontal. The following equation was used to define this *tilt-induced effect* (α):

$$\alpha = \arctan (\Delta h/d). \qquad (1)$$

The tilt-induced effect observed in the height illusion averaged 3.5°. For both observers, the magnitude of this illusion was comparable to the perceived tilt distortion as measured by the rod adjustment (see Table 1). That is, the Mystery Spot "frame" distorted both the height of the markers and the perceived orientation of the horizontal to nearly the same magnitude. Thus, we interpret the Mystery Spot illusion to be induced solely by a tilted frame, which causes misperceptions in spatial alignment. When two individuals move in front of a tilted environment, a height distortion will occur because the perceived elevation of their heads will appear to change with respect to the background. This finding suggests that tilted frames induce changes in the perceived spatial location of objects. At The Mystery Spot, this effect influences the apparent height of two individuals—as well as inducing changes in the perceived orientation of lines.

Table 1. *Observations at The Mystery Spot: Height illusion, tilt induction, and rod orientation alignment*

Observer	Distance between left and right poles (d)	Height of standard marker (H)	Judged height of standard marker (H')	Height error (Δh)	α	β
A.P.S.	1.63 m	1.32 m	1.19 m	0.13 m	4.5°	4.0°
H.S.E.	1.98 m	1.32 m	1.23 m	0.09 m	2.6°	2.8°
Mean	1.80 m	1.32 m	1.21 m	0.11 m	3.5°	3.4°

Note. Δh = difference between H and H'; α = height error expressed as tilt-induced effect (angular distortion); β = rod orientation alignment expressed as tilt-induced effect.

EXPERIMENT 2

Observations at The Mystery Spot suggest that objects can appear to be spatially misaligned as a result of a tilted background. However, it may be that in addition to the tilted background, other peculiarities—such as the position at which observers view the scene and the odd manner in which the background scene is constructed (e.g., distorted shed)—influence the illusion observed at The Mystery Spot. Experiment 2 was a laboratory study in which we controlled for these and other factors by using visual displays that consisted of real-world photographs that were simply rotated in the picture plane. While subjects viewed each tilted pictorial display, we superimposed two dots into the scene and asked subjects to place the dots at the same height with respect to the ground (see Fig. 2).

Method

Subjects

Twelve volunteers from the University of California, Berkeley, participated as subjects. The volunteers were paid for participation in this experiment.

Stimulus displays

Two real-world scenes were obtained by digitizing color images from two postcards. One image depicted the University of California, Berkeley, campus (Publisher: H & B Trading Company), and the other depicted a beach in Maui, Hawaii (Publisher: Island Heritage Publishing). For each scene, three orientations were used: 18° negative tilt (i.e., clockwise tilt), no tilt, and 18° positive tilt (i.e., counterclockwise tilt). Each tilt orientation was presented twice. Thus, participants made a total of 12 height adjustments (2 pictures × 3 orientations × 2 repetitions). The presentation order of these trials was random.

Fig. 2. A campus scene rotated +18°. The two black dots superimposed on the image are aligned horizontally, but they are misperceived as different in height. In Experiment 2, a color version of this image, with dots smaller in size, was shown to subjects.

Procedure

A Macintosh computer was used to display the stimuli and record responses. Subjects were seated in a dimly lit room and positioned with a chin rest that was placed 30 cm from the monitor. No other attempts were made to restrict viewing the monitor or the rest of the room. A black dot (approximately 1 × 1 mm) was placed on the left side of the stimulus. This "standard" dot was fixed. Subjects adjusted the vertical position of a similar (target) dot located 78 mm to the right of the standard dot. They were told to adjust the target dot so that it was at the same height as the standard dot.

For each trial, the starting position of the target dot was randomized between 15 mm above and below the height of the standard dot. Subjects used the up and down arrow keys to move the target dot higher and lower, respectively. When subjects were satisfied that the dots were aligned at the same height, they hit the "enter" key. The final position of the target dot was recorded for each trial and compared with the height of the standard dot in terms of pixel displacement. This displacement was then calculated in terms of a tilt-induced effect (see Equation 1).

Results and Discussion

Table 2 displays the tilt-induced effects we obtained using real-world pictures. We analyzed these results in a 2 × 3 analysis of variance with picture (campus vs. beach) and tilt (–18°, 0°, +18°) as factors. No significant differences were found for the main effect of picture, $F(1, 11) = 3.07$, $MSE = 1.09$, $p = .11$, or for the Picture × Tilt interaction, $F(2, 22) = 0.67$, $MSE = 0.50$, $p = .52$. There was, however, a significant effect of tilt, $F(2, 22) = 21.6$, $MSE = 5.50$, $p < .0001$. Planned comparisons indicated significant differences between the 0° tilt condition and each of the other two tilt conditions, $Fs > 10.5$, $p < .01$. There also appeared to be a general positive response bias. This effect is evident in the 0° tilt condition, in which subjects exhibited a tilt-induced bias of 0.58°.

These findings suggest that rotated pictorial displays in the laboratory distort the relative height of two objects within the display, just as the relative height of two individuals is distorted at The Mystery Spot. Specifically, in tilted frames, when two dots were perceived to be horizontally aligned, the alignment of the two dots was actually biased toward the orientation of the tilted frame.

EXPERIMENT 3

In this experiment, we used a simple geometric display in which frame orientation was altered by lines rotated away from the true horizontal or vertical (similar displays have been used in previous studies of tilt-induced illusions; see Gibson & Radner, 1937; Kramer, 1978). This display overcomes any peculiarities that may occur in pictorial

Table 2. *Horizontal dot alignment using real-world scenes*

Scene	Tilt		
	−18°	0°	+18°
Campus	−1.50° (0.36)	0.70° (0.25)	3.14° (0.75)
Beach	−1.84° (0.49)	0.45° (0.27)	2.44° (0.51)
Mean	−1.67° (0.30)	0.58° (0.18)	2.79° (0.51)

Note. Standard errors are in parentheses.

displays, such as influences that linear perspective and perceived depth may have on the perception of spatial location. We tested both horizontal and vertical alignments at various orientations (see Fig. 3). The extent to which subjects exhibited a height distortion with tilted lines would strengthen our interpretation that a distorted orientation frame of reference plays a role in the Mystery Spot illusion.

Method

Subjects

Twelve volunteers from the University of California, Berkeley, participated as subjects in this study. The volunteers were paid for participation.

Stimulus displays

A display frame consisted of 10 parallel lines separated by 16 mm (see Fig. 3). The orientation of the lines was varied away from the true horizontal or vertical axes at 5° intervals (from –45° to +45°, excluding the 0° orientation). We excluded the 0° conditions because we thought that subjects would simply rely on obviously horizontal or vertical lines to make their judgment. The orientation displays can be viewed as multiple lines rotated at the center (negative = clockwise rotations; positive = counterclockwise rotations).

Procedure

For horizontal-alignment trials, there was a total of 18 different orientations (9 positive and 9 negative orientations). The procedure for these trials was similar to that used in Experiment 2. Specifically, subjects were asked to adjust the position of the target dot to match the

standard dot in height. Each orientation was presented four times, for a total of 72 horizontal-alignment trials. For vertical-alignment trials, there was another set of 18 orientations, each presented four times. For these trials, subjects adjusted the left-right position of the target dot so that this dot was vertically aligned with the standard dot. Subjects used the left and right arrow keys to move the dot to the left and right, respectively.

The horizontal- and vertical-alignment trials were blocked. Within each block, trials with different line orientations were ordered randomly. Half the subjects adjusted the right dot for horizontal-alignment trials and the bottom dot for vertical-alignment trials. The other subjects adjusted the left dot for horizontal-alignment trials and the top dot for vertical-alignment trials.

Results and Discussion

Figure 4 displays the tilt-induced illusions for both vertical- and horizontal-alignment judgments. The data were subjected to a three-factor analysis of variance with judgment (horizontal vs. vertical), direction of orientation (positive vs. negative), and frame tilt (9 tilts between ±5° and ±45°) as factors. The analysis revealed a significant main effect of judgment, $F(1, 11) = 47.1$, $MSE = 3.4$, $p < .001$, with greater tilt-induced illusions for vertical judgments than horizontal judgments. There was also a main effect of the direction of orientation, $F(1, 11) = 5.4$, $MSE = 15.1$, $p < .05$, indicating that positive (i.e., counterclockwise) tilts—away from either the true vertical or the true horizontal orientation—elicited greater tilt-induced illusions than negative tilts.

The tilt-induced effect varied as a function of the magnitude of the frame tilt. As shown in Figure 4 and by the significant main effect of frame tilt ($F[8, 88] = 9.6$, $MSE = 1.5$, $p < .0001$), the tilt-induced effect was greatest for frame tilts of 15° to 20°, at which point the effect diminished as the frame orientation increased in tilt away from the true
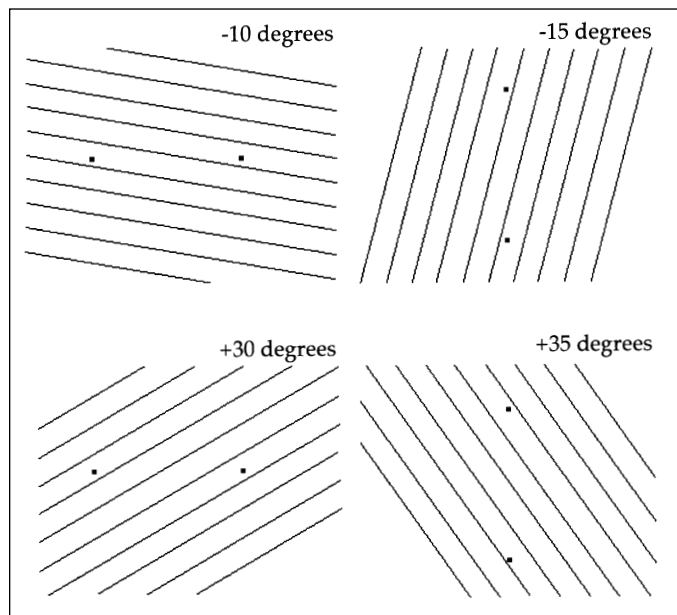

Fig. 3. Examples of multiple-line displays used in Experiment 3. Both horizontal-alignment (left displays) and vertical-alignment (right displays) judgments were obtained. The lines varied in tilt from –45° to +45° away from the judged alignment (negative tilts refer to clockwise tilts; positive tilts refer to counterclockwise tilts). In these displays, the dots are aligned at the true horizontal or vertical.
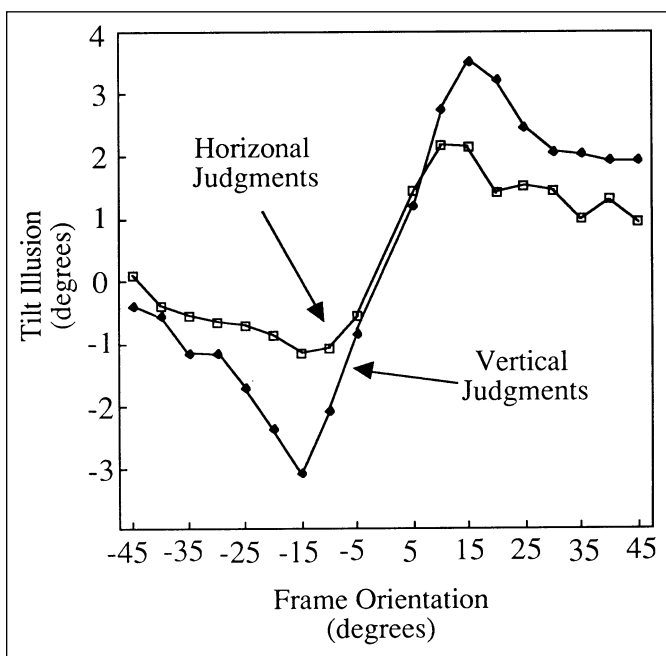

Fig. 4. Tilt-induced illusion as a function of frame orientation and alignment judgment (vertical vs. horizontal) in Experiment 3.

horizontal or vertical. The change in the magnitude of the tilt-induced effect as a function of frame tilt was greater for vertical judgments than for horizontal judgments, as indicated by the significant Judgment × Frame Tilt interaction, $F(8, 88) = 5.2$, $MSE = 0.65$, $p < .0001$. No other interactions approached statistical significance.

GENERAL DISCUSSION

This investigation analyzed a height illusion observed at tilted-room attractions, such as The Mystery Spot. In Experiment 1, we measured the height illusion at The Mystery Spot by having observers indicate when markers on two poles were aligned horizontally. Interestingly, the magnitude of this illusion (average = 3.5°) was comparable to adjustments of a rod to the perceived horizontal axis at the same location (average = 3.4°). That is, misperceptions in the relative height of two markers closely paralleled distortions in the perception of the horizontal orientation. Indeed, it is rather clear that the misperception of the horizontal axis can completely account for the Mystery Spot illusion. Thus, it is not necessary to resort to physical anomalies, such as distortions in magnetic or gravitational fields, to account for the phenomenon. In the next two experiments, we assessed a comparable height illusion in the laboratory. In these experiments, rotated pictorial scenes and rotated parallel lines induced reliable illusions in the spatial alignment (e.g., height) of two dots.

These findings suggest that the Mystery Spot illusion can be related to misperceptions of the orientation frame. Therefore, these findings are related to other tilt-induced illusions, such as the rod-frame illusion. Indeed, some illusions at The Mystery Spot, such as the appearance of balls defying gravity by rolling "up" a plank and individuals appearing to stand at unusual angles, can be explained directly by the kind of rod-frame distortions described by Asch and Witkin (1948). Yet the height illusion shown in Figure 1 and studied here extends beyond misperceptions of line orientations and angles. Our findings suggest that misperceptions of tilt can induce distortions in spatial relations, such as misperceptions in the height of two individuals or in the spatial location of two objects in a scene.[1]

Another important finding is the similarity between tilt-induced effects obtained using real-world scenes and using simple geometric displays. The findings from Experiment 3 showed that multiple parallel lines as frames produced tilt-induced illusions comparable to those that we observed at The Mystery Spot. In another study (Shimamura & Prinzmetal, 1997), we reduced the inducing "frame" to a single line tilted 18° (see Fig. 5). Such single-line displays produced small but reliable illusions (mean = 0.55°) in nearly every observer. It is clear that the greater the number of cues to an orientation frame of reference, the greater the illusion. The present findings also suggest that optimal tilt-induced illusions are obtained with frame tilts of 15° to 20° (see also Gibson, 1937; Kramer, 1978). It is interesting to note that at The Mystery Spot, height illusions are observed at locations where the background frame is tilted by about 18°.

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1. The term "height" can refer to the spatial location of a stimulus with respect to the environmental context or to the spatial extent (i.e., length) of a stimulus. Although there is ambiguity in this term, we use it to refer to the illusion because subjects were explicitly asked to assess the "height" of two dots in our experiment. Also, we believe that evaluation of the "height" of two individuals is generally made by comparing the relative spatial location of the heads of the individuals against a background rather than by estimating the overall extent or length of the individuals.
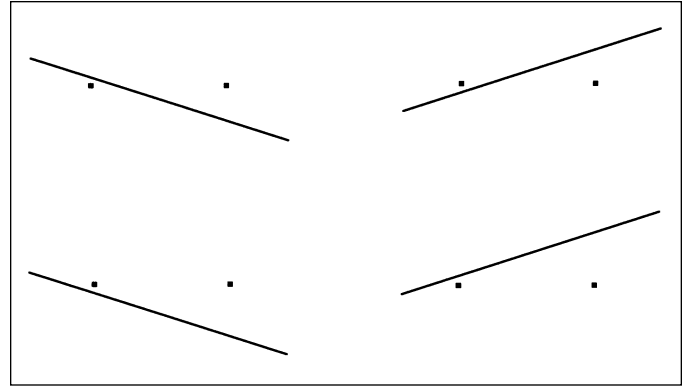

Fig. 5. Single-line displays from Shimamura and Prinzmetal (1997). In each of the two displays on the left, the line tilts −18°, and subjects perceive the right dot to be slightly higher than the left dot. In each of the two displays on the right, the lines tilt +18°, and subjects perceive the right dot to be slightly lower than the left dot. In these displays, all dot pairs are aligned at the true horizontal.

In our investigations, the height illusion appeared to be affected more by local cues than by distal cues. For example, we observed tilt-induced illusions despite the fact that subjects could view the rectangular frame of the monitor and other room cues. Although these cues could have been used to make reliable height adjustments, subjects still exhibited significant distortions. Findings at The Mystery Spot also suggest the dominance of local cues, because the illusion exists despite knowledge that the floor is level and thus oriented at the true horizontal. Consistent with the importance of local cues in tilt-induced illusions are findings by Zoccolotti, Antonucci, and Spinelli (1993), who showed that the rod-frame illusion is larger when the distance between the rod and frame is reduced.

Relation to Other Visual Illusions

Our experiments extend tilt-induced effects to include spatial-alignment judgments, such as comparing the height of two objects. These findings can be directly related to other tilt-induced effects involving judgments of line or rod orientation (Asch & Witkin, 1948; Witkin & Asch, 1948). Indeed, findings from our experiments can be used to unify a variety of other geometric illusions (for views, see Day, 1972; Gregory, 1968). For example, we suggest that tilt-induced effects can be used to explain illusions of line length (Ponzo illusion), line displacement (Poggendorf illusion), line orientation (Zöllner illusion), and line curvature (Wündt-Hering illusion). Indeed, the tilt illusion based on a single inducing line can be viewed as the basic unit to explain and unify all of these illusions (see Fig. 6). To our knowledge, misperceptions resulting from distorted orientation frames of reference have never been used to account for illusions of length or height.

In a recent study, we demonstrated that the Ponzo illusion effectively produces a height (i.e., line length) illusion that is twice the magnitude of the dot-alignment illusion observed in single-line displays such as those shown in Figure 5. This finding was predicted, because the Ponzo illusion is essentially a double version of the single-line display. More important, the orientation framing view was shown to account for the Ponzo illusion better than other extant theories, including theories invoking spatial frequency tuning or linear perspective (Prinzmetal, Shimamura, & Mikolinski, 1999).
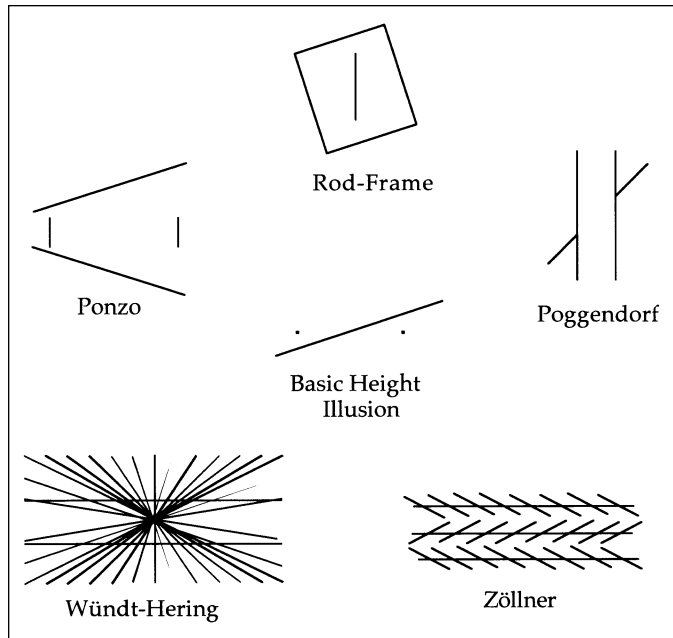
Fig. 6. Relation of the single-line height illusion to other illusions. The single-line height illusion (see center of figure) forms the basis for other geometric illusions, such as the Ponzo, rod-frame, Poggendorf, Wündt-Hering, and Zöllner illusions. All of these illusions can be attributed to tilt-induced effects and thus can be explained by the orientation framing theory (see General Discussion).

Orientation Framing Theory

To account for these illusions, we introduce a theoretical framework that we call *orientation framing theory* (OFT). This view is functional in that it suggests that tilt-induced illusions provide information about perceptual mechanisms important for the visual analysis of real-world scenes. OFT suggests that a prominent role of visual processing is the development of spatial frames of reference (see Rock, 1990). These frames are used to provide cues to the orientation of the picture plane. Considering the poor anchoring of retinal cues to orientation—because of eye movements, head tilts, and body movements—the development of stable mental representations of spatial frames is critical. These frames of reference can then be used to locate and orient objects in the spatial environment. Four basic principles of OFT are as follows:

1. For any visual scene, orientation frames are constructed and anchored in terms of perceived vertical and horizontal axes.

2. Perceived frames are largely driven by local cues to orientation. There may be multiple orientation frames and multiple levels of frames within the same visual scene.

3. Misperceptions of the true gravitational axes distort many aspects of perceptual processing, including object orientation, object location, line length, and angles.

4. Orientation frames contribute to higher-level spatial representations by marking spatial frames of reference (e.g., perceived horizontal and vertical).

OFT offers a way to link mechanisms responsible for tilt-induced effects with those involved in the development of spatial frames of reference. A finding by Gibson (1937) demonstrated that tilt-induced effects occur even when the inducing stimulus is presented in one eye and the test stimulus is presented in the other eye. This finding suggests that the locus of tilt-induced effects is at least postretinal. Recently, Sauvan and Peterhans (1995) found cortical cells whose orientation tuning is invariant with the tilt of the animal. Thus, in terms of a neural basis for these effects, a plausible role for cells tuned to orientation may be to develop local orientation frames that are then integrated for the construction of larger-scale spatial representations. We believe our findings could contribute to the integration of physiological properties of orientation-tuned receptive fields with higher-order analyses of spatial frames of reference.

In sum, we explain the properties of the height illusion at The Mystery Spot in terms of a tilt-induced effect. This illusion is thus closely related to the rod-frame and other tilt-induced illusions. These findings extend tilt-induced illusions to include distortions of height and spatial location. Moreover, we believe that a variety of illusions can be unified and accounted for by distortions in orientation frames of reference. Finally, even though we believe we have provided a simple and useful explanation of a rather convincing illusion at The Mystery Spot, it in no way detracts from the amusing and intriguing perceptual phenomena encountered at such sites.

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