Chapter 79. Objectless Motion: The Pedestalled Motion Paradigm

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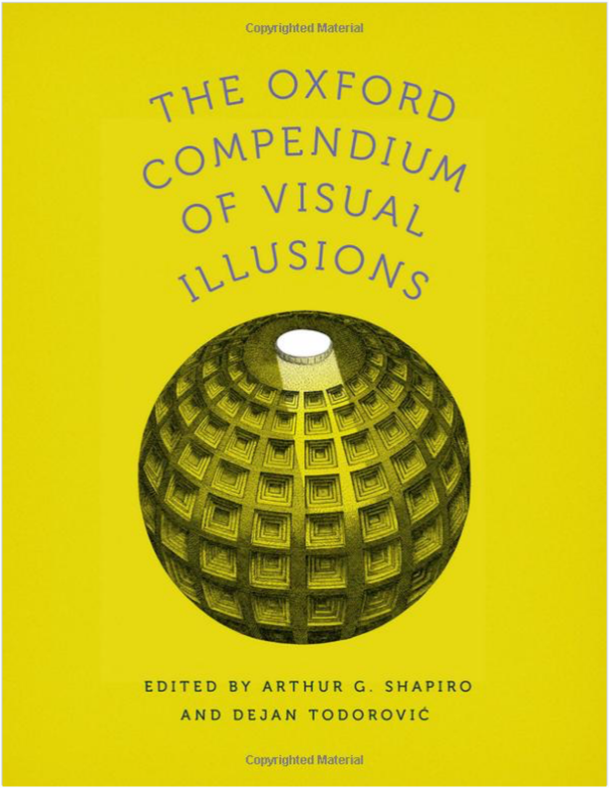

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Chapter 79
Objectless Motion
The Pedestalled Motion Paradigm

George Sperling and Zhong-Lin Lu

The clearest case of objectless motion occurs in patients who have suffered brain injuries in which cortical area V1 (visual striate cortex) is so severely damaged that they are blind and have zero pattern or object perception. When presented with motion stimuli, they say they can see nothing, and indeed they cannot report anything greater than chance about stimulus shape or color. Nevertheless, they can report the direction of stimulus motion with accuracies that are significantly greater than chance (e.g., Azzopardi & Hock, 2011). This is possible because there is a neural pathway from the retina to cortical motion area MT that bypasses V1. That is not the case for any other visual modality. In sighted observers, the concept of objectless motion seems to have originated with Wertheimer (1912) in his description of a display that produced what he called phi motion. His phi motion consisted of two adjacent separated objects, flashed alternately with about 30 msec between successive flashes.

Wertheimer's observations were repeated and elaborated recently by Steinman, Pizlo, and Pizlo (2000). In very quick alternations, two adjacent white disks on a dark background appeared stationary and flickering, and pure (objectless) motion occurs between them. That is, there was apparent back-and-forth motion but, at high alternation rates, the only objects (the two disks) were perceived as stationary, merely flickering. Since Wertheimer (1912), there have been several reports of displays to which terms such as "objectless motion" have been applied (Allport, 1968; Ekroll, Faul, & Golz, 2008; Hock & Nichols, 2013; Petersik & McDill, 1981; Saucer, 1953, 1954; Tyler, 1973; Zeeman & Roelofs, 1953). We present here what we consider to be an even more compelling objectless-motion display, the pedestalled motion paradigm. A computational theory exists for this display that both predicts (prior to the demonstration) the magnitude of the motion that is perceived and why it appears to be objectless.

First, we wish to remove from consideration a degenerate case of objectless motion that can be perceived in extremely low-contrast stimuli. In a normally sighted person, it is usually possible to find grating stimuli of extremely low contrast for which motion sensitivity is greater than contrast sensitivity so that motion is perceived when contrast is not. These extremely faint presentations represent objectless motion, but they are hardly impressive illusions.

On the other hand, as in phi motion, in the pedestalled motion paradigm the perception of motion is strong and perfectly reliable, yet every visible object appears to be absolutely stable and motionless, or simply wobbling back and forth, while there is a powerful sensation of linear motion in a consistent direction.

The pedestalled motion paradigm (Lu & Sperling, 1995, 2001) emerged as a prediction (van Santen & Sperling, 1984) from Reichardt's (1961) theory of first-order motion. Figure IV.79-1 illustrates the stimuli. We first consider only the "luminance" stimuli (Figs. IV.79-1d through IV.79-1f) that stimulate primarily the first-order motion system. Figure IV.79-1a schematically illustrates five consecutive frames of a stationary sine wave. Figure IV.79-1d illustrates these same five frames, each of which consists of a cutout midsection of a much larger vertically extended sine-wave grating (Fig. IV.79-2) with the modulation shown in Figure IV.79-1a. When displayed dynamically, the stimulus depicted in Figure IV.79-1d appears as a steady, stationary sine-wave grating called "the pedestal" because of its function in the pedestalled motion paradigm.

Figures IV.79-1b and IV.79-1e illustrate five consecutive frames of a sine-wave grating that moves 90° to the right in consecutive frames, the "moving sine wave." The slanting line indicates the rightward movement of the peak. When the frames of Figure IV.79-1e are shown consecutively at any speed up to about 120 frames/s (30 Hz), they produce a vivid sensation of motion to the right. Critically, the modulation amplitude of the frames in Figures IV.79-1b and IV.79-1e is only half the amplitude of the modulation in Figures IV.79-1a and IV.79-1d. Figures IV.79-1c and IV.79-1f show the algebraic sum of the pedestal and the moving sine wave. In fact, the sum of two sine waves of the same frequency is yet another sine wave of that frequency, although it may differ in phase and amplitude. Because of the greater amplitude of the pedestal, in the summed stimulus, the motion is concealed. There is only a wobble (indicated by the dashed line in Fig. IV.79-1c) in the location of the peaks of the pedestal plus moving sine wave.

When the stimulus in Figure IV.79-1f is shown slowly, for example, at 4 frames/s (one full cycle per second, 1 Hz), the stimulus is perceived as wobbling back and forth, as indicated by the dashed line in Figure IV.79-1c. We know

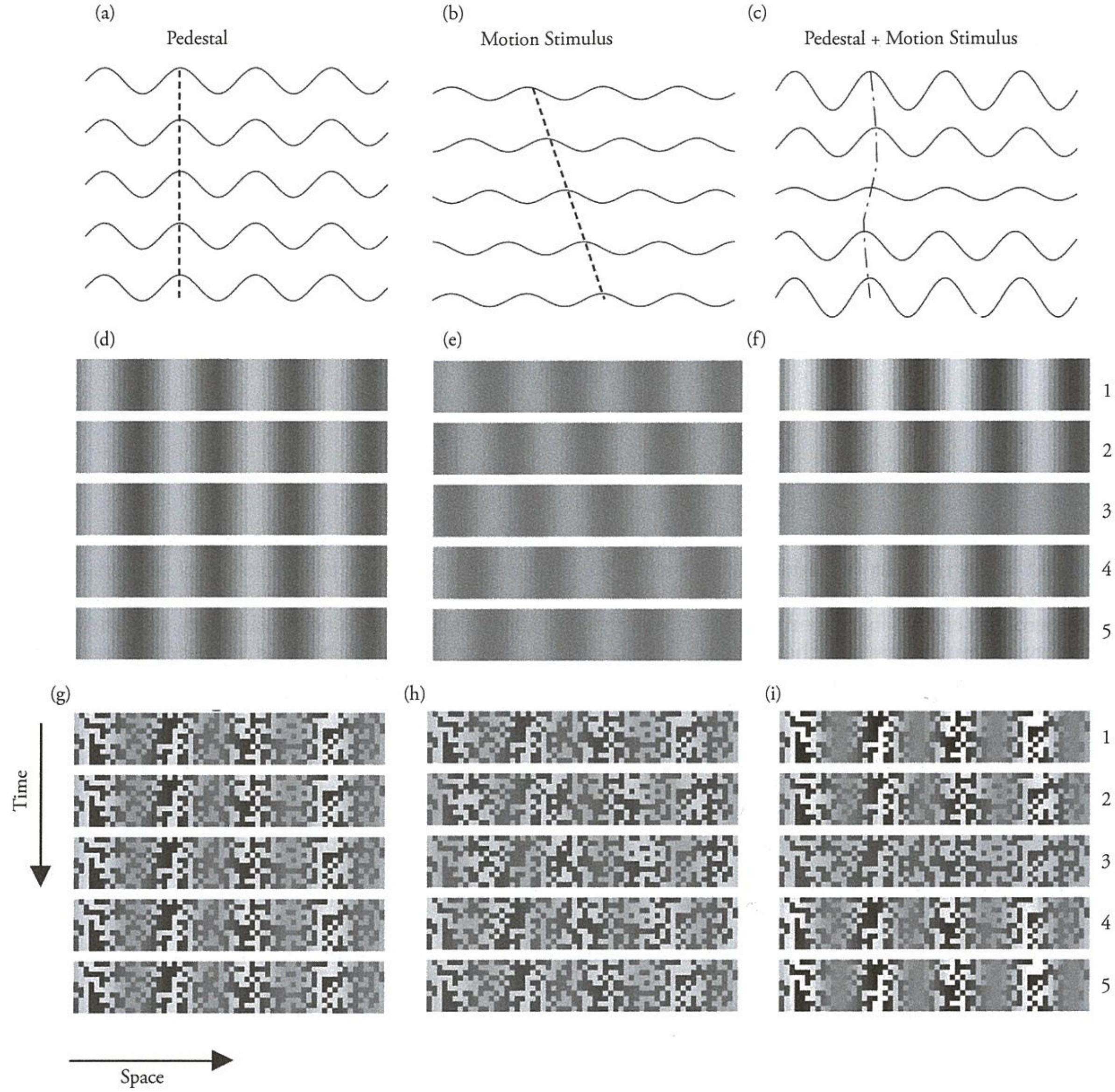

Figure IV.79-1. Five consecutive frames of (a) a stationary sine wave, (b) a moving sine wave, and (c) the sum (a + b). These sine waves are instantiated as luminance-modulated (first-order) gratings in d, e, and f and as texture contrast modulated (second-order) gratings in g, h, and i. Left-to-right motion-direction perception is as good in f, i as in e, h. The pedestalled motion in f, i is perceived as an invisible "wind" above a back-and-forth wobbling grating at low temporal frequencies and above a stationary grating for temporal frequencies greater than about 10 Hz. (After Lu and Sperling, 1995, with permission.)

that at such slow speeds, the perception of motion in such a stimulus is produced primarily by the third-order motion system that tracks the peaks and valleys of the stimulus (Lu & Sperling, 1995). At about 3 Hz, the contribution of the first-order system becomes significant, and the contribution of the third-order motion system begins to diminish. At this point, the real (and perceived) rate of wobble has greatly increased, but there is also a perceived "wind" that seems to flow from left to right above and independently of the wobble. At a temporal frequency of 10 Hz (40 frames/s), for most observers, the wobble is no longer perceived, the grating looks perfectly stationary as in Figure IV.79-2, and only a left-to-right wind seems to pass over the stationary sine-wave grating. For some subjects, the temporal frequency must increase to 12 or 15 Hz before the wobble ceases. Note: We use *temporal frequency* rather than *speed* to describe the movement of a grating because temporal frequency is the critical variable for the motion system.

A remarkable theorem derived from Reichardt's theory (Lu & Sperling 1995; van Santen & Sperling, 1984) is that the strength of a Reichardt model's motion output is just as high in the pedestalled motion display of Figure IV.79-1f as in the ordinary motion of Figure IV.79-1e.[1] Insofar as first-order motion is well described by the Reichardt model (which it is; cf. van Santen & Sperling, 1984), an observer should be just as accurate in judging motion direction in pedestalled motion stimuli as in ordinary motion stimuli. This surprising prediction has been verified numerous times. However, there is a caveat: light adaptation, contrast gain control, and other early visual processes distort

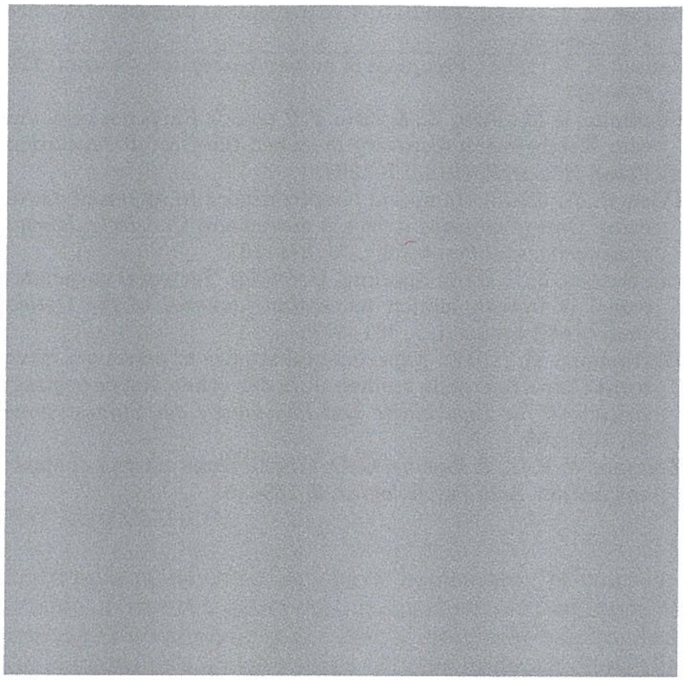

Figure IV.79-2. A low-contrast, stationary sine-wave grating. This is how the pedestalled motion display looks at high temporal frequencies. The perception of left-to-right linear motion (illustrated in Fig. IV.79-1) is not representable pictorially; observers describe it as an invisible "wind" that passes from left to right over the grating. (Figure by George Sperling and Zhong-Lin Lu.)

visual inputs before they reach the stage of motion perception (Lu & Sperling, 1996). Conveniently, low modulation amplitude inputs are distorted less. Therefore, tests of the Reichardt model are performed with stimuli that have modulation amplitudes of less than about 5% (which is still more than 20 times threshold amplitude for most observers). For these stimuli, predictions of the Reichardt model are verified experimentally with mathematical precision (Lu & Sperling, 1995; van Santen & Sperling, 1984).

Pedestalled motion produces as strong a motion perception as ordinary motion. Because the sine-wave pedestal is the only visible object, and because it either merely wobbles or at high temporal frequencies remains motionless, the perceived motion of the moving sine-wave grating does not relate to any visible object and is perceived simply as the direction of an invisible wind—pure, objectless motion. Remarkably, it has been demonstrated repeatedly that observers can report the direction of the wind as accurately in the pedestalled objectless motion display as when the pedestal is absent and they report the direction of motion of a clearly visible moving grating. That observers can clearly see a grating is the result of a shape/object computation; this computation neither helps nor hinders the first-order motion computation, which is independent of the static shape.

Figures IV.79-1g, IV.79-1h, and IV.79-1i show texture contrast modulated (second-order) stimuli analogous to the luminance modulated (first-order) stimuli of Figures IV.79-1d, IV.79-1e, and IV.79-1f. In the second-order stimuli, texture contrast is modulated between high contrast and low contrast analogous to luminance modulation between light and dark. Properly constructed, there is no luminance modulation in the second-order stimuli—their motion is invisible to the first-order system. Nevertheless, these second-order stimuli exhibit the same pedestal immunity as first-order stimuli, and observers now perceive a directional motion "wind" passing over a wobbling or stationary contrast-modulated texture. The wind is second-order objectless motion.

Note that at temporal frequencies of about 3 Hz, the pedestalled second-order stimulus is perceived both to wobble and to have a left-to-right wind. As the first-order motion system has been cancelled, and the wind is second-order motion, the wobble is the result of yet another computation—third-order motion. An interesting property of these multisystem illusions is that, in peripheral viewing, the higher-order system is relatively disadvantaged (Lu & Sperling, 1999). Looking to the side when viewing either first-order or second-order pedestalled motion disadvantages the third-order motion system and thereby diminishes or eliminates the perceived wobble.

In addition to being fascinating illusions, the objectless motion stimuli have two important properties. They demonstrate vividly that the first- and second-order motion computations are separate from and independent of shape and object computations. Also, whereas natural stimuli invariably activate more than one motion system, the pedestalled motions are pure first-order and pure second-order motions; that is, they stimulate only the motion system to which they are directed. This makes pedestal stimuli ideal stimuli for psychophysical and physiological investigations of visual motion systems.

ACKNOWLEDGMENTS

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NOTE

1. This follows because when two sinusoidal inputs to a Reichardt model have different temporal frequencies (and meet certain other technical conditions ; Lu & Sperling, 2001), the output to the sum of the inputs is equal to the sum of outputs that each would have produced individually. The pedestal is not changing, and therefore it has a temporal frequency of zero. The motion stimulus, by definition, has a nonzero temporal frequency. As the output of a Reichardt model is zero for any stimulus with zero temporal frequency, the motion response is just as strong for a pedestalled as for an ordinary motion stimulus.

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