## The peripheral drift illusion: A motion illusion in the visual periphery

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**Abstract.** Circularly repeating patches containing sawtooth luminance gradients produce a sensation of motion when viewed in the periphery. Illusory motion is perceived in a dark-to-light direction, but only when one's gaze is directed to different locations around the stimulus, a point outside the display is fixated and the observer blinks, or when the stimulus is sequentially displayed at different locations whilst the observer fixates one point. We propose that the illusion is produced by the interaction of three factors: (i) introducing transients as a result of eye movements or blinks; (ii) differing latencies in the processing of luminance; and (iii) spatiotemporal integration of the differing luminance signals in the periphery.

About five years ago, one of us, Jocelyn Faubert, observed motion in images such as that presented in figure la when they were presented in the periphery. When the luminance profile was reversed, as shown in figure lb, the direction of the illusory motion was also reversed. This motion illusion was not obtained for similar figures having square-wave or sine-wave luminance profiles. The images were originally presented on a high-resolution CRT, and the illusion appeared most powerful when the gaze was directed at an adjacent screen where text was presented. The illusion appeared to be linked to eye movements.

To investigate the illusion, displays 16 deg in diameter were presented on a CRT and observers were instructed to gaze at one of four points 23 deg from the centre of the image, and move their eyes smoothly to the next point clockwise from that point, continuing to move their eyes around the display for several seconds. The observers were asked to report what they saw in the figures (similar to those in figures la and lb). All five observers (including the authors) reported motion in a dark-to-light direction following a circular path within the display. Counterclockwise eye movements did not change the direction of perceived illusory motion; rather, the direction of motion was defined by the direction of the luminance gradient. Observers were also asked to gaze at one of the fixation points and blink as rapidly as possible. All observers reported illusory motion in the displays similar to that perceived when moving their gaze from one fixation point to another. No observer reported the illusion when looking directly at the display. Although most of the observers (three of five) did not report motion when first looking at the eccentric fixation points whether moving their eyes or blinking, all subjects saw the illusion after some time. When the rotation was perceived, the observers reported a robust sensation of motion.

We recently presented these displays at a conference (Faubert and Herbert 1998) and only two of over two-hundred observers did not perceive motion in the dark-tolight direction. One observer did not perceive any motion, but felt ill while viewing the images (a common report after extended viewing of large versions of the stimuli), and one observer saw motion in the direction opposite to that reported by all other observers. The remaining observers reported illusory motion in a dark-to-light direction in displays analogous to figures 1a and 1b. Approximately half of the observers initially reported no motion in the figures, although many of them were not examining



Figure 1. Sample stimuli. (a) Radial grating with a sawtooth luminance profile. To perceive the illusion the reader should look away from the image and make eye movements. The illusion may be visible while reading text adjacent to the figure. The illusion will not occur when looking directly at the image. If the illusion is not apparent when making eye movements, the reader could blink rapidly a few times while looking at a point outside of the image. The ideal fixation point depends on viewing distance, so it may be necessary to try looking at a few different points if the illusion is not observed on a first try. Counterclockwise illusory motion is perceived for this figure. (b) The triangular luminance profile is reversed from (a). Clockwise illusory motion is perceived for this figure. (c) Control display for testing the peripheral-spatiotemporal-integration hypothesis. Observers see no motion in this display. (d) Control image demonstrating that the absence of motion in (c) is not a product of segmenting the luminance profile.

the displays in the visual periphery when first examining the poster presentation. The relatively informal examination of over two-hundred observers and systematic testing with five observers revealed a very consistent motion illusion in the visual periphery that was in a dark-to-light direction regardless of whether a single point was fixated eccentrically and the observer blinked (about half of all observers preferred this method of generating the illusion), or whether eye movements were made while keeping the displays in the visual periphery (usually made while reading the text of the poster). Our observations suggested a strong role of eye movements in the illusion, whether from shifts in the direction of gaze or from blinking. In another condition, observers maintained fixation of a point outside the display, and the stimulus was presented for a second, removed, then presented at another position for a second, removed and returned to the first position, and the sequence was repeated. This manipulation generated a motion sensation similar to the one experienced when the eyes were moved. This condition demonstrates that the illusion is not produced by efferent eye-movement signals as is the case for certain motion illusions (Gregory 1966).

It is clear that at least three conditions are necessary for perceiving the illusion. (1) There has to be some 'resetting' process whereby transients are generated in the visual system as a result of eye movements, blinks, or abrupt displacements of the stimulus. (2) The luminance gradient determines the direction of perceived motion. It is well known (eg von Grünau et al 1995; Parker and Salzen 1977; Roufs 1963; Wilson and Anstis 1969) that luminance information travels through the visual system at different latencies, with lighter information passing through the system faster than darker information. (3) We propose that the illusion is only perceived with eccentric viewing because information is integrated over relatively large regions in the periphery. Our hypothesis is that the combination of these three processes generates the illusory motion (peripheral-spatiotemporal-integration hypothesis).

The first point is clearly illustrated by viewing figures 1a and 1b, and from the results of the observers we have tested. The second and third points require further elaboration, and the reader is referred to figure 2 for a schematic of the proposed spatiotemporal-integration hypothesis. There are three layers of units in figure 2, and the response of each layer to a sawtooth luminance gradient is depicted. The first layer of units responds to luminance information, and differences in transmission time result



**Figure 2.** Schematic illustration of the spatiotemporal-integration hypothesis to account for the peripheral-drift illusion. A full explanation of the figure is provided in the text. Note that this is a snapshot of the spatiotemporal-integration hypothesis. The operations illustrated in the figure would occur every time the direction of gaze is changed or the observer blinks.

from luminance changes in the image. As a consequence there is a difference in the timing of the arrival of information in units integrating the output of the first layer. We propose that the second layer is composed of units normally responding to image motion, such as Reichardt detectors (Nakayama 1985) or similar units (Adelson and Bergen 1985). These differences in the arrival time of information transmitted by the first-layer units result in small or large motion signals according to the location of the receptive field of second-layer units relative to the image (small versus large arrows in figure 2). Thus, we propose that a series of motion signals is produced by the luminance changes in the image when it is *first* processed by the visual system. The third layer consists of units with even larger receptive fields that sum the motion signals generated by the second layer, which results in a net motion percept in a dark-to-light direction. The required integration over space demands cells with larger receptive fields in both the second and third layers, such as those found at higher levels in the visual system and in the visual periphery. Figure 2 represents a snapshot of the response of the visual system to the sawtooth luminance gradients. In effect, the illusion results from luminance processing feeding into the motion system. Repeated eye movements or blinks are required to maintain the illusory motion generated by each successive 'refresh' of the image. The reason the peripheral-drift illusion is not readily seen with square-wave or sine-wave luminance patterns is that the temporal differences produced by light-to-dark edges are symmetrical in such patterns, thereby cancelling each other out.

There are two control displays presented in figure 1 to illustrate the importance of these different factors. In figure 1c the same numbers of segments are presented as for figures 1a and 1b, but the luminance gradient is reversed in equal steps from the centre of the pattern to its border. In this case our hypothesis suggests that the conflicting spatiotemporal luminance signals cancel each other out in the larger receptive fields in the periphery, and therefore no motion should be perceived. No observer reported movement in this type of display for any viewing distance or eccentricity. Figure 1d demonstrates that segmenting the luminance gradients does not impede the perception of motion, because the illusion is obtained readily with this display (some observers reported the strongest motion in this figure).

We have made a number of other observations consistent with the peripheralspatiotemporal-integration hypothesis. First, the shape of the region is not critical. Illusory motion is perceived in a series of sawtooth-waveform strips, but the motion is more easily perceived in the circular displays. The illusion may appear stronger with the circular patterns because the circular path has no termination. The perceived illusory motion is like that of a slowly turning fan, whereas sawtooth luminance gratings produce the impression of a pattern sliding down (or up) the display. The illusion is observed over a large range of stimulus sizes. With smaller shaded regions the observer merely has to fixate closer to the border of the pattern than for larger regions. The reader can perform this manipulation by varying the viewing distance from figure 1 and observing the change in eccentricity of gaze necessary to obtain the illusion. The illusion obtains over a range of viewing distances for each fixation point. Within certain limits the illusion does not appear to depend on the number of dark-to-light luminance cycles in the circular patches. It appears that at least four or five cycles are required, and the upper limit is imposed by the resolution of the visual system for a given eccentricity. The contrast between the background and the stimulus does not appear to influence the illusion.

Fraser and Wilcox (1979) presented a motion illusion they called an 'escalatorillusion'. They used different displays, but reported a similar motion illusion in the periphery. The figures they used contained many segments offset from one another throughout the pattern (their stimuli give the impression one is looking down a spiral staircase). Fraser and Wilcox reported that the perceived direction of motion was inconsistent across

different observers (n = 678). They discussed possible genetic bases for the differences between observers, but the nature of the illusory motion itself remains unexplained (Anstis 1986). We propose that our illusion is related to this 'escalator illusion'. In their stimuli the luminance gradient reverses within a small region in many places, and we propose that the inconsistency in responses was related to these steps in the displays rather than genotype. The reversals in the luminance gradient result in changes in the direction of illusory motion, such that both clockwise and counterclockwise rotation can be observed in the same figure.

In conclusion, the peripheral-drift illusion is generated by the interaction of three processes: resetting produced by eye movements, blinks, or other transients; temporal-order effects generated from the luminance inhomogeneities; and spatiotemporal integration in the visual periphery.

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