Short and Sweet

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Orbiting Black/White Rays Produce an "Illusory" Gray Disk

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Abstract
An orbiting ray pattern produces an unexpected gray disk. Here we demonstrate this visual effect and its possible insights into visual temporal integration.

Keywords
Illusion, motion perception, temporal integration

Figure 1 shows a set of black and white ray patterns, which when moved in a circular orbit generate the percept of a smaller uniform gray disk within the ray pattern. This phenomenon was shown to us by professional magician Mark Mitton from New York City, who has been presenting this optical illusion for 25 years (www.markmitton.com; https://youtu.be/PWGeUztTkRA). To explore this in a controlled fashion, we placed the patterns (each 40 mm in diameter) on the moving bed of an orbital shaker that orbited the patterns around a 20-mm circle, without rotating them, at a speed of 3.7 rps. If you do not have an orbital shaker, then lay this page of the journal, face up on a smooth surface (or print out Figure 1) and use your hands to slide it around in a circular orbit as fast as you can (about 3 rps is good). Within the ray pattern, you will see a spatially uniform gray disk with a disk diameter approximately equal to the size of the circular orbit. Random dot patterns, whether coarse or fine, produced no illusory gray disks, but filled the whole area with a fine random

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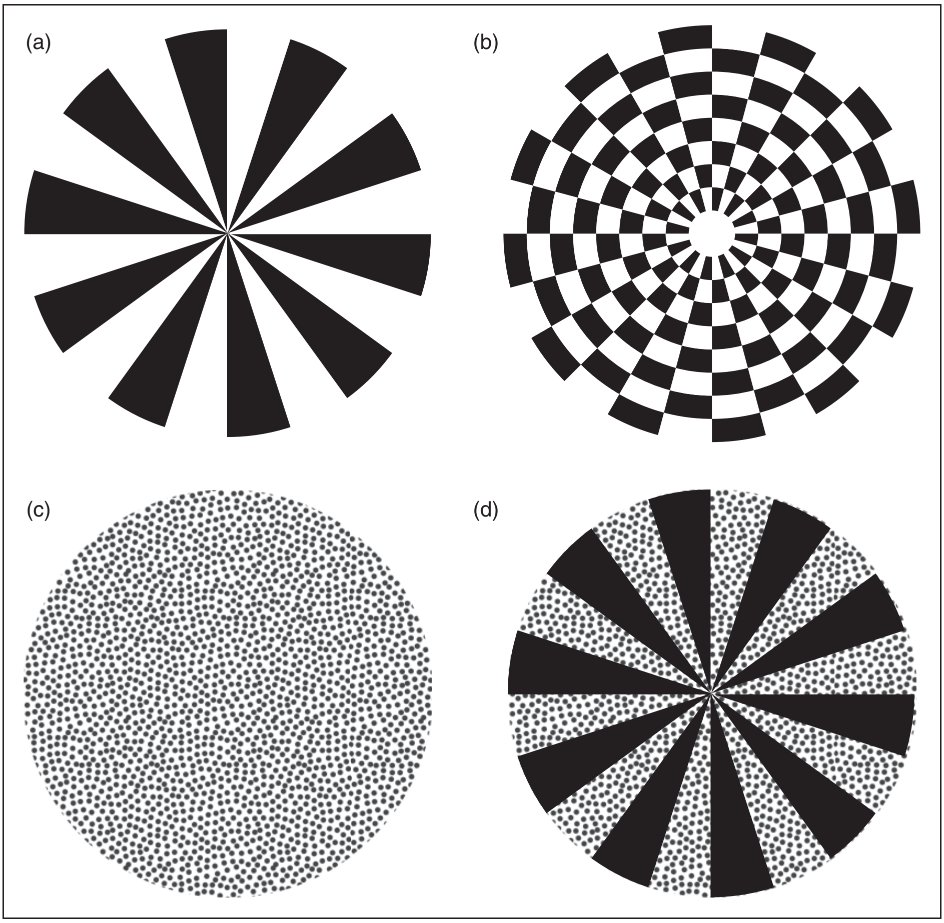

Figure 1. When orbited at ~3rps, the 10-sectored disk (a) creates a smaller gray disk within it, whose diameter is about the same as the orbit. The radial checkerboard (b) gives a complex pattern. Random-dot noise (c) gives no disk. A disk with black sectors alternating with random dots (d) gives a gray disk with a fine texture superimposed. (Some people report apparent jittery rotations even in the stationary patterns).

texture that was denser in the middle. The gray disk is only clearly seen with continuous motion of a printed image. A monitor that refreshes even at a rate as high as 120 Hz gives strobed motion of the disks that are filled due to aliasing with complex rotating textures.

Figure 2 shows that the central gray disk is a real property of a time average of the orbiting ray pattern that would be visible to any time-averaging visual system, whether a camera or a human. The image of a 10-sectored disk was moved over an orbit half the pattern diameter and the traces accumulated over a single orbit. The gray disk fills the region inside the path taken by the center of the ray pattern as it orbits. At all points inside the central gray disk, all the rays sweep through in succession, leading to an overall gray if averaged, whereas outside this central area, fewer of the rays sweep through each point on each orbit.

We attribute the fusion of the rays into a perceptual gray disk to temporal integration by the visual system. When a 10-sector disk is orbiting at 3.7 rps, the black and white rays pass through each point in the central region at approximately 37 Hz, which is close to the critical

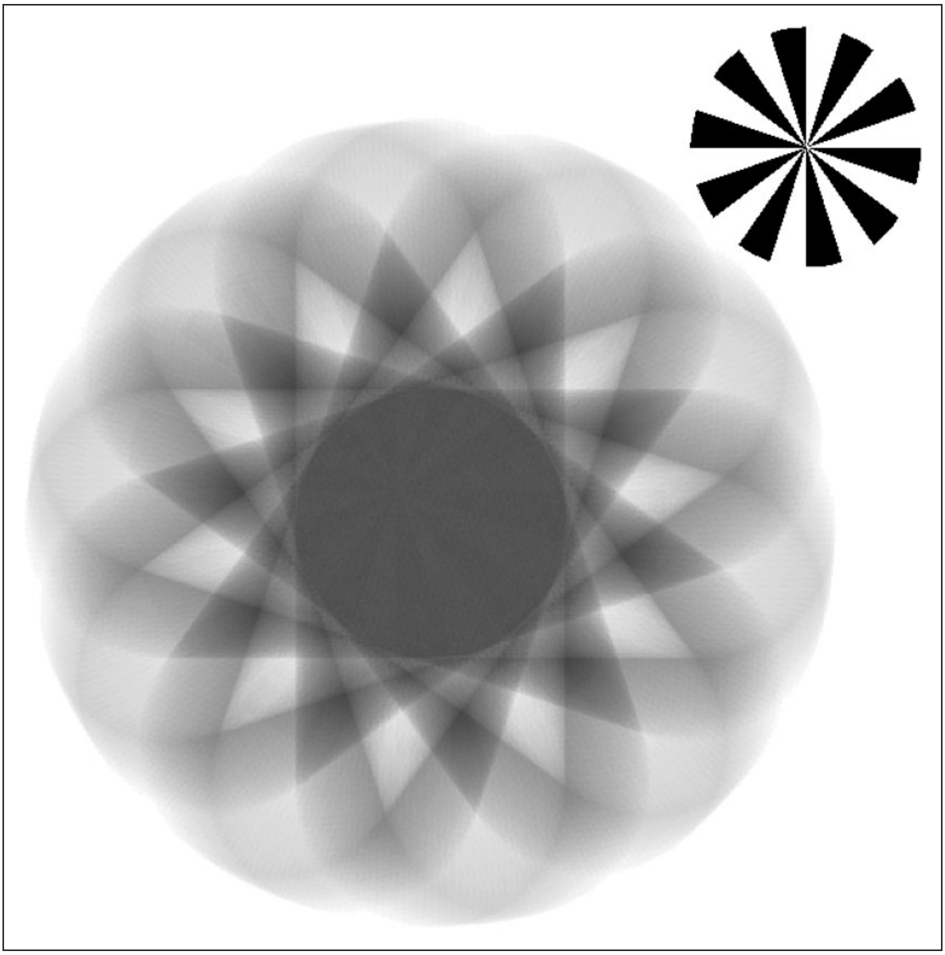

Figure 2. Time exposure of an orbiting 10-sectored disk. The gray disk is bounded by the circular orbit of the center point of the ray pattern. See text.

flicker fusion frequency (CFF) at the light levels we used (Hecht & Shlaer, 1936; Kelly, 1964), and this fuses the central region into a steady gray.

Figure 3(b) shows that in the central region of the orbit (halfway between the two red lines), blacks exchange with whites at a fairly constant rate reading down the page, giving a constant temporal flicker rate ($\sim$37 Hz) during an orbit. However, for points near the edges of the orbit (just inside the red lines), the flicker rate varies markedly during each orbit between fast and slow, indicating that the region above CFF is shifting around within the orbit circle.

Figure 4 shows the temporal frequency modulations (FM) inside the orbit circle. There is always a gray disk area with all portions above CFF, and it is not centered at the center of the orbit circle but precesses around it as the FM slips above and below CFF on opposite sides of the area within the orbit circle. This allows for shifts in mean luminance to change the size of the gray region. Dimming the lighting lengthens the visual integrating time and lowers the CFF, and so incorporates larger portions of the orbit into the perceptual gray disk, but never larger than the orbit size.

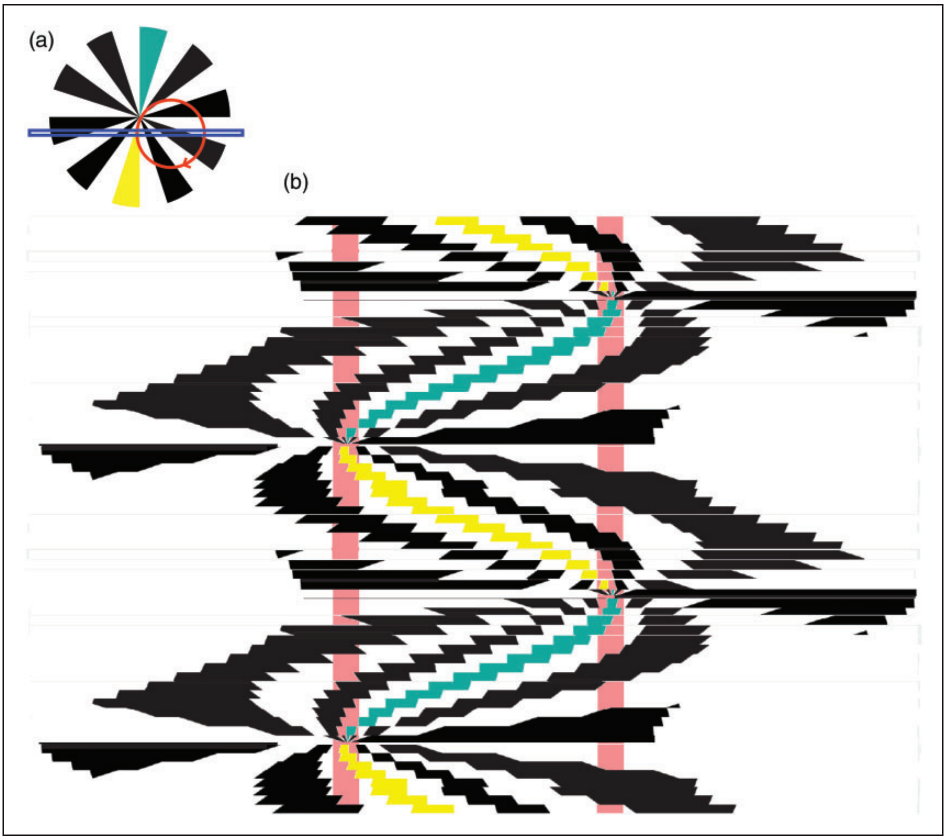

Figure 3. a) The center of the rays pattern orbited around the path of the red circle. The thin equatorial strip is the window we monitored for each of the 32 frames per orbit. (b) These 32 screenshots are stacked with time running down the page. The mean temporal frequency is highest within the orbiting region that gives a gray disk, with a sharp falloff outside this zone.

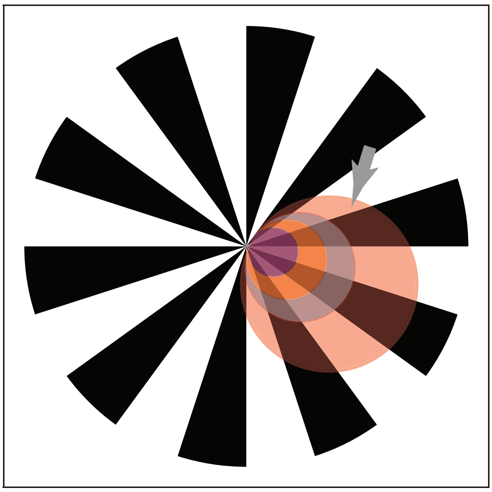

Figure 4. As the center of the ray pattern sweeps around the orbit (arrowed circle), it generates isofrequency contours that define disk-shaped areas. These flicker at different rates and most rapidly near the rays' center. These areas precess around inside the orbit area, always radiating out from the rays' center.

We have identified averaging, mimicked by the time exposure images (Figure 2), as the process producing the uniform gray disk. However, the random dot pattern in Figure 1d remains visible as a fine texture within the whole area over which the pattern orbits, rather than overlapping circular traces as might be expected from time averaging. Indeed, we find that a time average of random dots does produce a mottled texture, but we cannot rule out the possibility that perceptual motion deblurring (Burr & Morgan, 1997; Morgan & Benton, 1989) might increase the subjective sharpness of the dot texture within the gray disk. As evidence of independent effects of motion on the rays and the random dots, try orbiting the pattern with both rays and random dots (Figure 1(d)). The rays again produce a gray disk but the random-dot texture continues to be visible and dot-like throughout, even on top of the uniform gray disk.

This "illusion" is a fascinating, easy-to-demonstrate visual phenomenon that shows that some effects that we think of as illusions may have a largely physical explanation.

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Declaration of Conflicting Interests

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