# The phantom spokes illusion


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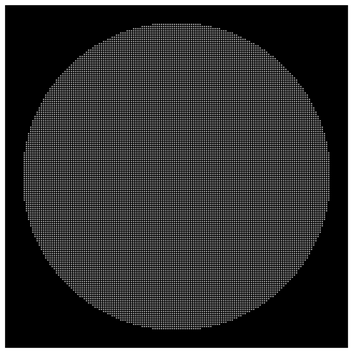
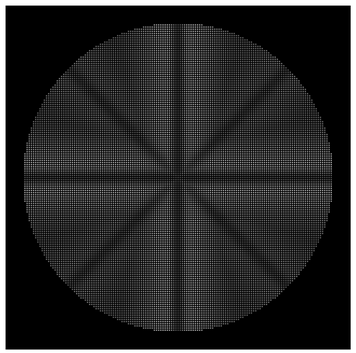


## The stimulus

Pick up one of the loose mounted version, and rotate it back and forth while fixating the center. Some observers can also see the effect in a static version like the one here by moving their head in and out in depth.



## The percept

An approximation of the author's percept when the pattern is rotated about its center.

## The puzzle

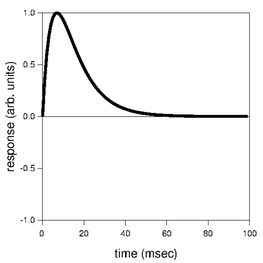
Because the dots are regularly spaced, the physical stimulus has a constant local space-average luminance, and the output of any linear mechanism integrating over a region containing many dots should be constant. What, then, is responsible for the radial bands?

## Motion blur

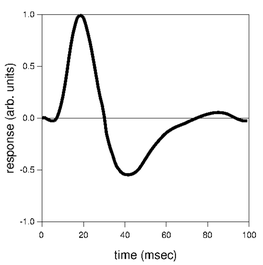
The real motion of the pattern on the retina produces smearing due to temporal integration in the visual system. This produces a grating at the grid frequency when the motion vectors are parallel to the grid. Here we simulate motion blur for a stimulus rotating at 30 RPM, using two different impulse responses: a double-exponential (the convolution of two exponentials with a time constant of 10 msec), and a multiphasic impulse response derived by Tyler (1992).

## Visual nonlinearites

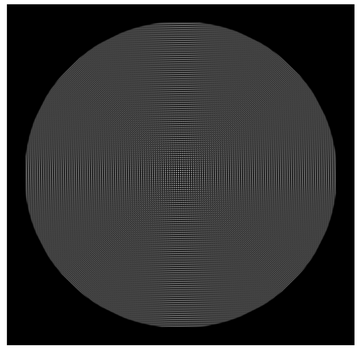
A variety of nonlinearities have been noted at various stages of visual processing. He and MacLeod (1998) described a compressive nonlinearity used to explain perceived dimming of high-frequency gratings. Conversely, physiological measurements of retinal ganglion cells (Chichilnisky, 2001) and units in the LGN (Duong & Freeman, 2008) exhibit expansive nonlinearities.

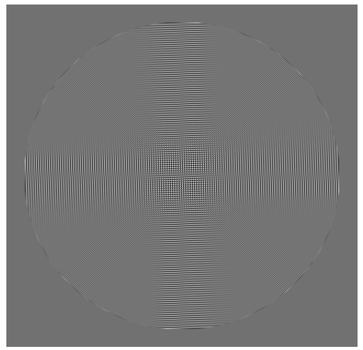


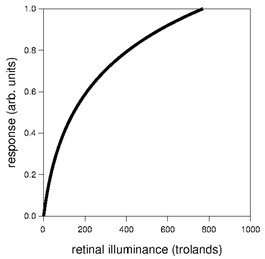

Synthetic low-pass temporal integration function



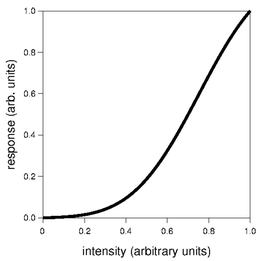

Temporal impulse response function from Tyler (1992)



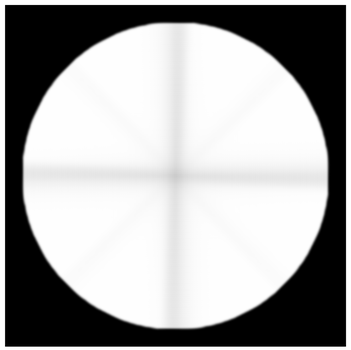


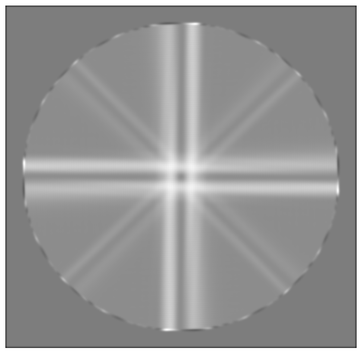



After He & MacLeod (1998). Maximum response corresponds to a luminance of 20 candelas per meter squared viewed through a 7 millimeter pupil.




After Chichilnisky (2001), who fit responses of retinal ganglion cells with a cumulative Gaussian.





## Conclusion

Combinations of temporal filtering followed by nonlinear processing are capable of explaining the observed phenomena, at least qualitatively. Because the stimulus requires real motion, it is difficult to study using a conventional computer-monitor-based setup. An optical method for rotating the image (such as a rotating dove prism) combined with a continuously illuminated display (such as an LCD monitor) would enable the effect to be measured precisely via nulling.

### References


Chichilnisky, E. J. (2001). A simple white noise analysis of neuronal light responses. *Network: Comput. Neural Syst.*, **12**, 199-213.

Duong, T. and Freeman, R. D. (2008). Contrast sensitivity is enhanced by expansive nonlinear processing in the lateral geniculate nucleus. *J. Neurophysiol.*, **99**, 367-372.

He, S. and MacLeod, D. I. A. (1998). Contrast-modulation flicker: dynamica and spatial resolution of the light adaptation process. *Vision Res.*, **38**, 985-1000.

Tyler, C. W. (1992). Psychophysical derivation of the impulse response through generation of ultrbrief responses: complex inverse estimation without minimum-phase assumptions. *J. Opt. Soc. Am. A*, **9**, 1025-1040



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