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Dynamic neon colors: Perceptual evidence for parallel visual pathways

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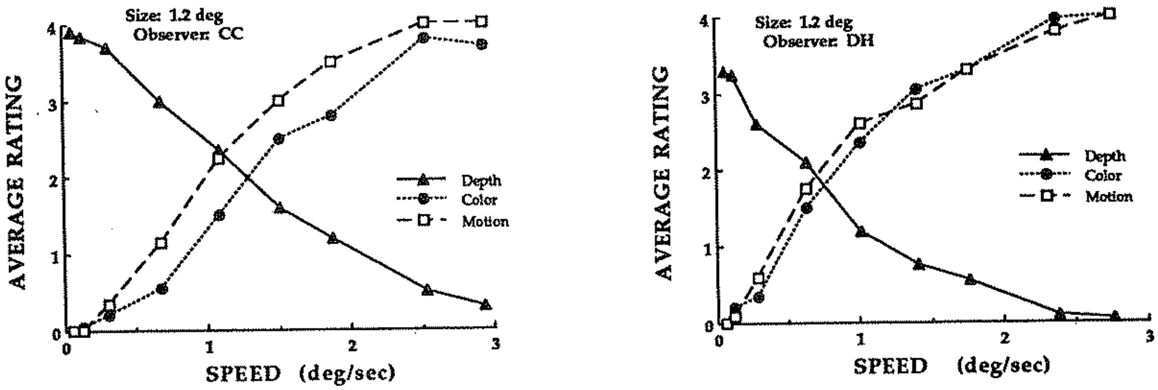
There is accumulating neurophysiological evidence that the primate visual system constructs multiple representations of the visual world (1-5). Each of these representations, based on classes of neurons with distinctive properties and roles, provides an analysis of some aspect, for example motion, of the visual world. In everyday life, a smooth interleaving of the information provided by these parallel pathways leaves us unaware of this segregation of function: Effortlessly, we use a complex tapestry of form, color, depth, and motion to make sense of the patterns of light and dark falling upon our retinae.

We report here a novel stimulus configuration which illustrates the working of these parallel neural pathways. The stimulus consists of a circular patch of randomly scattered green dots in a surrounding field of randomly scattered, less luminous red dots. In still views on a computer-driven crt, the region occupied by the green dots appears to be closer in depth and the white areas within this region appear slightly red due to color contrast. Now, with the location of all dots held constant, the assignment of color to dots is progressively changed from frame to frame according to an algorithm that paints all dots green within a shifting circular area and all other dots red. Not unexpectedly, apparent motion and a clear, circular subjective contour are perceived. Unexpectedly, a diffuse green color spreads throughout the area defined by the circular subjective contour (6). This green disk appears as a spotlight moving over the dots (11). Furthermore, one perceives a change in the depth of the green-colored dots as compared to the static view. One now perceives a static field of dots all located at the same depth, with only the green spotlight moving. Our explanation is as follows: In the static display the elevated depth and green color are linked by the visual system to the individual dots in the circular region; however, when motion is perceived, the green color and the motion are linked with the circular region bounded by the subjective contour, and all dots are perceived to be in the same plane (12).

Two color normal, emmetropic observers were instructed to maintain fixation at the center of the display and to rate, on a scale from 0 to 4, the perceived depth, motion, and spreading of color for each stimulus presentation. Zero was to be used if the observer was absolutely certain of the absence of the attribute, one if moderately certain of its absence, two if uncertain, three if moderately certain of its presence, and four if absolutely certain of its presence. Both observers in fact used the full range of ratings for each attribute (color, motion, depth). In each of four experimental sessions an observer viewed four sets of stimuli, one for each diameter (0.30, 0.60. 1.2, and 2.4 degrees of visual angle). Within a set, each of the nine update rates (equivalent to speeds of 0.063, 0.125, 0.300, 0.675, 1.08, 1.50, 1.88, 2.53, and 2.93 degrees per second) were presented five times in pseudo-random order.

Shown in the figure is a composite of the results measured with the 1.2 degree circular region for the two observers (CC and DH). Each graph shows the average ratings for perceived depth, color, and motion as a function of speed. There is good agreement between the two observers. As the ratings of perceived motion increase, the ratings of neon color spreading increase and the ratings of perceived depth differences between the green and the red dots decrease. For observer CC, the rate of increase of neon color spreading is slower than that for the perception of apparent motion with stimulus sizes 1.2 and 2.4. As well, the asymptotic value for neon color spreading is less for these sizes. For observer DH the rate of increase of neon color spreading matches that for the perception of apparent motion for all sizes except 0.6, for which color spreading increases more slowly than the perception of apparent motion. Within our range of stimulus sizes, the 1.2 degree stimulus was optimal in that this size stimulus produced the most compelling perception of apparent motion, subjective contour, and neon color spreading. This size also produced the greatest reduction in perceived depth at the fastest speed as compared to the static view.



Luminance is critical in these displays as the following observations show (13). At isoluminance, the perception of motion and of a subjective contour is decreased and may be eliminated altogether for some observers. Concommitantly, color spreading ceases. A display using gray and black dots, instead of colored dots, shows that luminosity by itself yields a clear subjective contour and spreading of luminance within the subjective contour.

Perception of apparent motion is required for the novel perceptual effect reported here. This effect, which we call *dynamic neon colors,* refers to the spread of a uniform color in the area bounded by the subjective contour defined by motion. The appearance of a subjective contour defined by motion is not new (17,18), nor is neon color spreading in static displays (7-10). What is novel is the spread of neon color within a subjective contour *defined by motion.* This reassignment of color, induced by motion, is accompanied by a change in the depth relationships among the dots: a depth difference perceived in the static view is abolished when motion and dynamic neon colors are perceived. Our finding that the perceptual attributes of motion, color, form, and depth can be grouped and regrouped by our visual systems into different combinations provides perceptual evidence for selective activation of multiple visual pathways. We propose a relationship of these effects to recent physiological results on the middle temporal visual area known as MT (19-24).

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6. This is similar to "neon colors" previously observed only in static displays [W. Ehrenstein (7); H. van Tuijl (8); C. Redies and L. Spillman (9); K. Nakayama, S. Shimojo, and V. S. Ramachandran (10)].
7. W. Ehrenstein, *Zeitschrift Fur Psychologie*, **150**, 83 (1941).
8. H. van Tuijl, *Acta Psychologica*, **39**, 441 (1975).
9. C. Redies and L. Spillman, *Perception*, **10**, 667 (1981).
10. K. Nakayama, S. Shimojo, and V. S. Ramachandran, *Perception*, **19**, 497 (1990).
11. All previously reported displays in which an illusory contour moves against a background of static texture have produced an effect known as "motion capture" [V. S. Ramachandran, *Percept. Psychophys*, 39, 361 (1986)]: the static texture appears to move with the encompassing subjective contour. In our case, the dots encompassed by the subjective contour do not move with the contour, instead they are perceived as stationary, an effect that we call *motion escape*.
12. Treisman explains the *illusory conjunctions* observed in her experiments according to a model of representation which conjoins, sometimes incorrectly, the information from multiple maps for different features of a visual stimulus [A. Treisman, *J. Exp. Psychol.: Human Percept. Perf. 8*, 194 (1982); A. Treisman, *Sci. Am. 255* (5), 114 (1986)]. Although Treisman's observations and theoretical framework are consistent with our own ideas, the stimuli we describe here are novel in that activation of the motion pathway produces new features, e.g., the neon color and new depth relationships.
13. Others have noted that luminance is critical to the formation of static subjective contours [R. L. Gregory (14)] and the perception of apparent motion [V. S. Ramachandran and R. L. Gregory (15); P. Cavanagh, J. Boeglin, and O. Favreau (16)].
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