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On Seeing Reddish Green and Yellowish Blue

Abstract. *Four color names—red, yellow, green, and blue—can be used singly or combined in pairs to describe all other colors. Orange, for example, can be described as a reddish yellow, cyan as a bluish green, and purple as a reddish blue. Some dyadic color names (such as reddish green and bluish yellow) describe colors that are not normally realizable. By stabilizing the retinal image of the boundary between a pair of red and green stripes (or a pair of yellow and blue stripes) but not their outer edges, however, the entire region can be perceived simultaneously as both red and green (or yellow and blue).*

A fundamental observation that forms the basis of the opponent-processing model of color vision is that human observers never see a color that simultaneously evokes the percepts of red and green or those of yellow and blue (*1, 2*).

Ample physiological evidence indicates that at various stages within the visual system the colors we describe as "red" and "green" are encoded by the same opponent-processing channel (*3*). The encoding process is such that if redness is signaled by an increase in the electrical activity in this channel, then greenness will be signaled by a decrease in activity (*4*). Similar antagonistic encoding of yellow and blue stimuli has also been found (*5*). According to these models, it would be impossible for an observer to perceive both red and green simultaneously, as this percept would require simultaneous transmission of positive and negative signals in the same channel. The same situation would obtain in the blue-yellow channel.

Normally, the color perceived in any region of visual space is determined by the intensity distribution of the wavelengths of light illuminating that patch of retina. There are situations, however, in which the color perceived in a given area of visual space becomes dissociated from the wavelength distribution falling on the corresponding retinal area. For example, Krauskopf (*6*) showed that by stabilizing the image of a green (529 nm) disk on a larger, circular orange (593 nm) background whose perimeter was not stabilized, the disk would disappear and the region occupied by the disk would be uniformly and completely filled with the orange color of the background. Under these (stabilized image) conditions, the green disk, illuminated by a relatively narrow band of wavelengths centered at 529 nm is indistinguishable from a relatively narrow band of wavelengths centered at 593 nm that illuminates the orange background. Krauskopf also noted the similarity between the appearance of the stabilized image and the more familiar "filling-in" phenomenon (*7*). In both cases the information at the boundary of the stabilized, or insensitive, area appears to determine the perceptual attributes of the entire bounded area.

We have conducted a number of stabilized-image experiments in which we provided conflicting information to the filling-in process at the boundaries of a stabilized area. Under these conflict conditions, the visual system cannot simply fill in a uniform color consistent with all the boundary conditions as it could with the Krauskopf experiment. Image stabilization was accomplished with an SRI dual-Purkinje-image eyetracker (*8*) and visual stimulus deflector (*9*). Horizontal and vertical eye-rotation signals from the eyetracker drove the corresponding deflection mirrors in the stimulus deflector. By adjusting the gain and polarity of the eyetracker signals, it is possible to eliminate all motion of the retinal image that would normally result from the observer's eye movements. A special feature of the stimulus deflector allows us to present normal, unstabilized features to the observer while he simultaneously views stabilized images.

Among the stimuli presented to our observers was a vertical pair of red and green stripes whose common boundary was stabilized and whose outer edges were formed by unstabilized black occluders (Fig. 1). Generally, the red and green stripes were produced by transilluminating colored gelatin filters affixed to a rear projection screen, or by transilluminating narrow-band (100 Å half-amplitude bandwidth) interference filters with peak transmissions at 640 and 540 nm, respectively. The luminance of the bipartite field was in the range 4 to 60 foot lamberts (1 foot lambert = 3.43 cd/m^2) for all observers. The dashed line along the red-green boundary of Fig. 1 is the convention we have adopted to indicate a stabilized edge.

When an observer first views this stimulus configuration, the percept is of a juxtaposed pair of red and green stripes whose outer edges are sharply defined by the unstabilized black occluders. The top and bottom of the stripes extend vertically out of the observer's field of view. After a few seconds of viewing, the stabilized boundary between the red and green stripes disappears. Under these conditions, observers report that the field may have one or more of three distinctly different appearances: (i) the entire field appears to be a single unitary color composed of both red and green; (ii) the field appears to be composed entirely of a regular array of just resolvable red and green dots; or (iii) the field may appear as a series of islands of one color on a background of the other color.

The appearance of the field can best be described by using an analogy to colors that can be perceived under normal viewing conditions. An observer viewing a field composed of an additive mixture of red light and blue light such that the proportion of red and blue light varies across the field—from strongly red on the left side of the field to strongly blue at the right side of the field—could describe the field as both red and blue. He might describe the field as lavender near the blue edge, purple in the middle, and magenta near the red edge, but all of these color names imply a mixture of both blue and red light. This analogy is a good description of the field seen by those observers who describe the stabilized field as simultaneously red and green, although greener near the unstabilized green boundary and redder near the unstabilized red boundary.

The second type of percept, that of a pattern of red and green dots, can also be described by the analogy presented above, except that instead of being produced by a mixture of lights, the field could be represented by a pattern of marbles viewed at a distance such that each marble is just resolvable. Then, instead of seeing a uniform color, which he might describe as purple, the observer would see the distinct red and blue elements. The proportion of red to blue elements would vary as it did in the first analogy, so the field could be described as both red and blue everywhere, but not as a mixture of red and blue anywhere. Some of our observers reported only this granular appearance of the stabilized field, whereas others reported that the field appeared to alternate between granular red and green elements and fusion of those elements into a single unitary color.

The third type of percept, that of seeing islands of one color on the background of another, was much less stable than either of the other two percepts. Although the percept remained more strongly red overall at the left edge of the field and more strongly green at the right edge, it was possible to see islands of the contrasting color floating anywhere in the field. The percept of islands could also alternate with either the uniform or the granular reddish green field. Finally, these strange percepts were in all cases of a significantly diminished saturation compared with that of the unstabilized stimulus pattern.

To date, more than a dozen observers of both sexes and a wide variety of ages, with normal or corrected visual acuity, have viewed this unusual stimulus. Although most reported that regardless of where they attended in the field, the color was simultaneously both red and green, some observers indicated that although they were aware that what they were viewing was a color (that is, the field was not achromatic), they were unable to name or describe the color. One of these observers was an artist with a large color vocabulary.

We also presented a few observers with the other antagonistic pair of colors in the form of a pair of juxtaposed yellow and blue stripes produced by narrowband (100 Å half-amplitude bandwidth) interference filters. The stripes were again flanked by unstabilized black occluders. Under these conditions, when the boundary between the blue and yellow stripes disappeared, observers reported seeing the field as simultaneously blue and yellow, regardless of where in the field they turned their attention, although a unitary color was reported more often than a granular mixture.

These results indicate the primacy of the filling-in phenomenon in determining the perceptual attributes of bounded areas in visual space. They also suggest that it is not the occurrence of chromatic contrast at edges in the retinal image per se, but the perceived chromatic contrast at edges that determines the color of filled-in areas. Furthermore, when the perceived chromatic contrast at one part of the boundary of an insensitive or stabilized area (for example, the unstabilized red boundary) conflicts with the perceived chromatic contrast of another part of the boundary (the unstabilized green boundary), the visual system resolves the conflict by filling in the entire bounded area consistent with the chromatic contrast information at both parts of the boundary, that is, with both red and green.

At first glance, these results seem to violate a basic premise of opponent-processing models of color vision. However, these psychophysical models do not directly apply to the filling-in phenomenon. Generally, these models are supported by electrophysiological evidence gathered from animal research and obtained under conditions in which chromatic information is presented to a patch of retina and the resulting signals traced and measured at corresponding positions along the primary visual pathway. In studies of filling-in, however, color is reported in regions in which there are no corresponding retinal signals (*10*); this is true both for cases of scotomata (*11*) and, as reported here, for partially stabilized images. Thus, filling-in seems to be more of a lateral process; one that we might think of as resulting from corticocortical rather than retinocortical connections. If so, our results suggest that the percepts of reddish green and yellowish blue, although not reported under conditions of retinocortical color perception (that is, chromatic processing in the primary visual pathway as described, for example, by opponent-processing models), apparently are possible in corticocortical color vision processes.

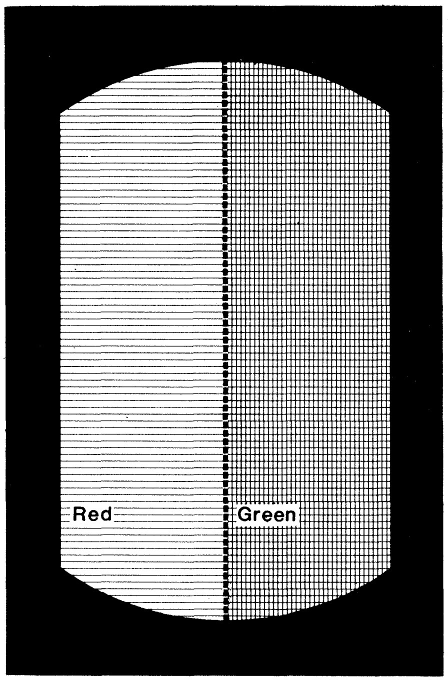

Fig. 1. A typical stimulus field. The dashed line indicates the stabilized boundary.

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Performance of Concurrent Tasks: A Psychophysiological Analysis of the Reciprocity of Information-Processing Resources

Abstract. *The resources allocated to a primary and secondary task are reciprocal. Subjects performed a tracking task in which the discrete displacements of the tracking cursor could be used to elicit event-related brain potentials. As the resource demands of the tracking task were increased, potentials elicited by the task-defined events increased in amplitude, whereas those elicited by secondary task auditory stimuli decreased.*

The limitations on the capacity of the human information-processing system have long been recognized. When the human mind is occupied with one task it often lacks the capacity to perform others. Under some circumstances, however, many tasks can be performed concurrently. Much ingenuity has been devoted to defining the limits of processing capacity and to elucidating the way capacity varies under different conditions to influence the success of dual task performance. In a conceptualization that owes much to Kahneman (*1*) and that has been developed by others (*2–4*), performance of a task is assumed to consume resources that are in limited supply. The degree to which two tasks interfere with each other depends on the extent to which they compete for the common supply of resources.

Any attempt to study the limitation on the human capacity for time-sharing must contend with the impossibility of assessing resources directly. Furthermore, resources cannot be inferred from the quality of task performance: performance can remain constant in quality despite changes in the demands on the operator. To overcome these difficulties, a frequently used technique for measuring resource allocation is to assign to the operator yet another, secondary, task that must be executed concurrently with the primary task. The operator is instructed to perform the primary task in the best possible manner and the secondary task as well as possible under the circumstances. Performance of the secondary task is used to assess the resource demands imposed by the primary task (*5*).

In a series of investigations, Donchin, Wickens, and their co-workers have established that the amplitude of the P300 component of the human event related potential (ERP) can serve as a secondary task measure of the resource demands of a primary task (*6*). To subjects who were performing a variety of complex tasks they presented a concurrent Bernoulli sequence of stimuli with unequal probabilities. If such a sequence is attended, the rare stimulus elicits a P300 whose magnitude is inversely related to the probability of the eliciting event (*7*). When this secondary task is performed concurrently with a primary task, the amplitude of the P300 elicited by the rare stimuli depends on the difficulty of the primary task, provided that difficulty is manipulated in the perceptual-cognitive domain.

These data suggested that the amplitude of the P300 can serve as an index of the resources available to the operator from a primary task. This hypothesis implies that when the primary and secondary tasks tap common resources there is a reciprocity in the availability of these common resources to the primary and the secondary task. As a consequence, there will be a reciprocity in the amplitude of the P300 associated with the two tasks as the difficulty of the primary task is varied. In other words, while P300 associated with the secondary task decreases in amplitude with increasing difficulty of the primary task, it should be possible to observe a corresponding increase in the amplitude of the P300 elicited by stimuli associated with the primary task (*8*).

Twelve right-handed students (eight males and four females), performed a pursuit step-tracking task. A target executed a series of discrete horizontal displacements, the magnitudes of which were determined by a random process. The displacements occurred at 3-second intervals. The subjects manipulated a control stick and attempted to superimpose a cursor on the target. Changes in the difficulty of the task were accomplished by manipulating two variables. (i) The directional regularity of the sequence of the step changes had two levels. Under the condition of high predictability, the step displacements alternated in a regular left-right sequence. Only the magnitude of the step change remained unpredictable. Under the condition of low predictability, both magnitude and direction were uncertain so that two successive steps in the same direction were possible. (ii) The relationship between the movement of the joy stick and the movement of the cursor was varied. When the subject had first-order control, constant displacement of the control stick caused the cursor to move at a constant velocity in the direction of the movement. Under the more difficult second-order control conditions, constant movement of the stick accelerated the cursor's movement. These two manipulations were combined to create three conditions of increasing difficulty: First-order control with predictable input (1P), first-order control with unpredictable input (1U), and second-order control with unpredictable input (2U) (*9*).

Concurrently with the tracking tasks, the subjects were assigned one of three secondary tasks designed to elicit the ERP's (*10*). Two of these were clearly secondary, whereas stimuli for the third were embedded in the primary task itself. (i) Auditory probe: subjects heard a Bernoulli series of tones of high and low pitch, occurring with equal probability. Subjects were instructed to count the number of occurrences of the low-pitched tone. (ii) Visual probe, flash: a horizontal bar was imposed along the course traversed by the target. The bar was flashed for 100 msec. On a randomly selected half of the trials the flashes were brighter than on the other trials; the subject was instructed to count the dimmer flashes. (iii) Visual probe, step: subjects counted all steps in which the target moved in a given direction; the probes eliciting the P300 were embedded in the primary task. In an additional control condition subjects tracked the step changes in the absence of a secondary task. In the control condition and in the visual probe step condition, the averaging computer was triggered by the step changes so that ERP's elicited by the change in the target's direction were recorded. Finally, three additional conditions were included in which each of the three secondary counting tasks (audi-