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Color Vision: Glasses Half Full

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A new study finds that individuals with color deficiencies report long-term changes in their color vision after only a few days of wearing glasses that boost color contrasts, potentially because they learn to see or interpret color in new ways.

How do colors look to someone with a color deficiency? This question has exercised scientists and philosophers at least since the chemist John Dalton first described his own color blindness [1]. However, we remain far from an answer. We can now precisely account for the wavelength sensitivity of the eye's light receptors, and for the nature of the photopigment molecules on which this depends [2,3]. Yet how the brain interprets the receptor signals to create our conscious impressions of color is still deeply mysterious. Moreover, the processes involved are shaped by each individual's unique experience — adapted both to their environment and their visual system [4]. A new study reported in a recent issue of *Current Biology* from Werner *et al.* shows that despite a lifetime of color deficiency, changes with experience can happen on a surprisingly short timescale [5].

Normal human color vision (trichromacy) depends on comparing responses in three classes of receptors that absorb light using photopigments sensitive to different but overlapping wavelength ranges. Common color deficiencies result from errors in the genes coding the pigments, causing a loss of one receptor type (dichromacy) or a shift in the spectral peak of the receptor (anomalous trichromacy) [3]. The latter results in smaller sensitivity differences in the medium (M) and long (L) wavelength receptors, weakening the 'reddish' versus 'greenish' colors coded by their difference.

Simulations of color blindness typically take an image and render the colors for the altered cone sensitivities (Figure 1). This can illustrate the information lost, and with some assumptions may predict how colors actually appear [6]. However, these simulations typically ignore the fact that vision is a highly plastic process, and one purpose of this plasticity is to discount the observer from the percept. A striking example is that we do not experience the receptor-free blind spot of our eyes, because it is more important to 'see' the world than ourselves. The variety of these calibrations is only beginning to be appreciated, and range from camera-like exposure adjustments in receptors and later neurons to high-level cognitive strategies.

Though it has a long history, recent studies have revived interest in whether color-deficient observers might compensate for their sensitivity losses. For example, dichromats can become trichromatic with large stimuli, by taking advantage of sensitivity variations across

Figure 1. Anomalous trichromacy.
An image filtered for the receptor sensitivities of an anomalous trichromat (middle). Weakened color differences could be enhanced by physically filtering the light spectrum or increasing neural gain (right). Images are for illustration only and not intended to simulate actual percepts or filters.

the eye [7]. Several studies have focused on anomalous trichromats. Even if the L versus M comparison is weaker, neurons signaling this difference could amplify their gain to restore strong responses [8,9]. There is evidence that this happens, because anomalous observers give more weight to reddish–greenish colors than their cone sensitivities predict [10,11]. Moreover, it would be surprising if this did not occur, because all sensory systems must adapt their outputs to match the range of inputs. For example, even in normal trichromats the receptor differences conveying color are much weaker than the sums signaling brightness, yet colors in the world do not appear washed out [12].

There is also intense interest in ameliorating color deficiencies, including the prospects of gene therapy for introducing the missing cone [13]. In the new study from Werner *et al.* [5], the authors used commercial filters (EnChroma®) designed to boost color differences compromised by the anomalous receptors. The filters block wavelengths where the longer-wave receptors overlap, effectively increasing their separation. This cannot undo the color deficit, and wearing the glasses does not lead to improvements in diagnostic color tests [14]. However, the filters do enhance the saturation of reddish and greenish hues, and this is readily visible when the glasses are worn. Notably, wide-color-gamut displays and lighting based on narrowband LEDs [15] produce similar spectral filtering and could produce similar enhancements.

Remarkably, after only a few days of wear, colors continued to appear enhanced even with the glasses off [5]. This was assessed by an ingeniously simple scaling procedure where participants judged similarities across contrast levels [16]. As someone who has spent hours using traditional techniques to measure the color contrast response, it is striking (and disheartening) to discover that the entire function can be mapped within a few minutes. Responses in anomalous observers — but not controls — increased as they wore the glasses over several days, suggesting a rapid recalibration of their color vision.

These intriguing findings pose a number of puzzles. The first is why — after a lifetime to adjust to their color deficits — would a brief intervention change their perception. While surprising, this parallels visual rehabilitation studies that treat deficits by encouraging reliance on the compromised signals [17]. These weak signals may tend to be ignored, and focusing attention on them allows individuals to recognize and utilize them. Thus the normal controls may not have changed because the colors were already strong.

A second question is what was changing. As the study notes, an increase in salience is at odds with conventional adaptation, because stronger contrasts with the glasses should have been compensated by reducing sensitivity [4]. The alternative of perceptual learning has been associated with how signals are decoded rather than encoded [18]. Thus it may not be that neural gain was amplified, but that the experience changed how attuned they were to the signals. This is a general uncertainty when interpreting participants' self-reports, and it would be valuable to also explore objective probes of the adjustments.

What experiences might trigger learning? The changes happened with only passive viewing. However, participants presumably knew they were color deficient and that the glasses were designed to help, and from their comments they were aware and interested in monitoring changes. It would be interesting to see what might happen if they were given more directed training, or told only that they were trying a new pair of sunglasses. The salience of color also depends on what we are trying to see. Glasses (Variantor®) have also been designed that block red–green contrasts to simulate dichromacy. I first tried these at a market, and despite a career in color was shocked by my incapacity to judge the strawberries and tomatoes. Yet the next time I wore them for a walk in the woods, and while colors were distorted, there seemed to be surprisingly little missing. Similarly, many individuals are not even aware they have a color deficiency until they take a screening test, and almost all of us go through life blissfully unaware of the infinite spectral variations we are blind to.

To understand a boy it helps to ask his mom. Most color deficiencies are X-linked recessive traits [3]. Except for rare cases where they are themselves color deficient, mothers of anomalous trichromats are carriers, with the normal gene for the L or M opsin on one X chromosome and the altered version on the other. This not only protects them from color losses, but potentially confers an extra dimension of color vision — if both variants are expressed and can be distinguished. This advantage is well documented in new world monkeys, where in many species there is only a single pigment coded on the X chromosome but common polymorphisms [19]. Males are all dichromats of different flavors, but a proportion of females inherit different alleles on the two chromosomes and become trichromats. Whether human female carriers similarly become tetrachromats remains difficult to demonstrate [20]. If the weaker color signals carried by their fourth receptor are present but hidden in the shadows of trichromacy, perhaps similar principles of selectively boosting these signals could help coax them better into awareness.

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Behavior: Local Lateral Habenula Interneurons Mediate Aggression

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A recent study has shown that local inhibitory GAD2-positive neurons regulate the activity of lateral habenula neurons, thereby governing aggressive behavior in male mice.

Aggressive behavior is observed throughout the animal kingdom, and has likely evolved to serve an important purpose [1]; aggressive displays are a mechanism by which animals can attract mates and establish territorial dominance and social hierarchies. With huge rewards at stake, perhaps then it is logical that a positive motivational valence should be attached to aggressive behavior, making this rewarding to the aggressor and driving animals to seek out aggressive encounters. Thus, it would also seem logical that this behavior is at least in some way governed by the brain's reward system, and indeed there is growing

