POINTS OF VIEW

Color blindness

Since my first column on color coding[1] appeared, we have received a number of e-mails asking us to highlight the issue of color blindness. One of those correspondences was published in the October 2010 issue[2]. Here I offer guidelines to make graphics accessible to those with color vision deficiencies.
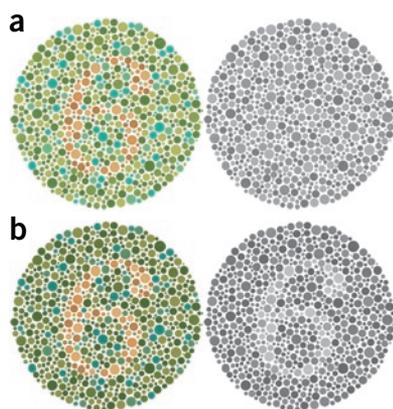
Color blindness affects a substantial portion of the human population. Protanopia and deuteranopia, the two most common forms of inherited color blindness, are red-green color vision defects caused by the absence of red or green retinal photoreceptors, respectively. In individuals of Northern European ancestry, as many as 8 percent of men and 0.5 percent of women experience the common form of red-green color blindness[3]. If a submitted manuscript happens to go to three male reviewers of Northern European descent, the chance that at least one will be color blind is 22 percent.

Picking colors suitable for color-blind readers not only enhances accessibility but also is good graphic design practice. For example, the Ishihara color vision test intentionally relies only on color hue to create contrast, as evident when the image is converted to grayscale (**Fig. 1a**). In general, colors will be easier to distinguish when they vary in lightness and saturation as well as hue (**Fig. 1b**). The palette of eight colors shown in **Figure 2** has good overall variability and can be differentiated by individuals with red-green color blindness.
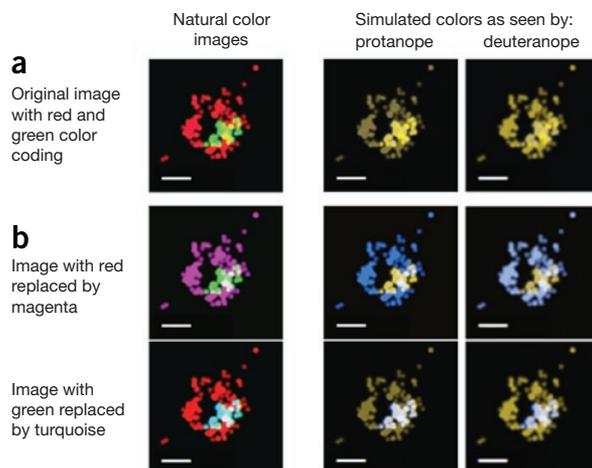
It is useful to remember that pure red and pure green are not the only culprits in color confusion—rather, any color with components of red and green can cause trouble. Authors can rely on software to simulate how images might appear to individuals with red-green color blindness. In Adobe Illustrator and Photoshop, first convert the document to RGB color space for accurate simulation and create a

Figure 1 | Ishihara color-vision test plate. (**a**) Viewers with normal color vision should see the numeral '6'. (**b**) Changing lightness of background improves contrast.

Figure 2 | Colors optimized for color-blind individuals. P and D indicate simulated colors as seen by individuals with protanopia and deuteranopia, respectively.

Color	Color name	RGB (1–255)	CMYK (%)	P	D
	Black	0, 0, 0	0, 0, 0, 100		
	Orange	230, 159, 0	0, 50, 100, 0		
	Sky blue	86, 180, 233	80, 0, 0, 0		
	Bluish green	0, 158, 115	97, 0, 75, 0		
	Yellow	240, 228, 66	10, 5, 90, 0		
	Blue	0, 114, 178	100, 50, 0, 0		
	Vermillion	213, 94, 0	0, 80, 100, 0		
	Reddish purple	204, 121, 167	10, 70, 0, 0		

Figure 3 | Red-green color coding in an immunofluorescent image. (**a**) Conventional color coding is difficult for individuals with red-green color blindness (protanopia or deuteranopia) to discriminate. (**b**) Replacing red with magenta (top) or green with turquoise (bottom) improves visibility for such individuals. Source image from reference 4.

soft proof (View > Proof Setup > Color Blindness). Simultaneously viewing the original and the soft proof (Window > Arrange > New Window in Photoshop) makes it convenient to adjust colors in order to make them universally accessible. Web-based tools such as Vischeck (www.vischeck.com) can also produce simulated images.

Perhaps the most widespread use of red-green color coding in the life sciences is in immunofluorescent images (**Fig. 3a**). To make this and other artificial color schemes accessible to readers with red-green color blindness, replace red with magenta (**Fig. 3b**, top). This can be easily accomplished using Photoshop. Because red mixes with blue to produce magenta, copy the contents from the red channel (Window > Channels) and paste them into the blue channel. This unconventional magenta-green color coding may require a key indicating that the overlap of these colors produces white. Alternatively, some individuals with red-green color blindness find that replacing green with turquoise provides the most visible difference (**Fig. 3b**, bottom).

For color-blind individuals viewing existing images with colors that are difficult to discriminate, there are several tools for computers and mobile devices that may be helpful. The DanKam app for iPhone and Android takes information coming into the phone's camera and shifts the color spectrum so that colors fall within the range that people who are color blind can see. eyePilot (www.colorhelper.com) and Visolve Deflector (www.ryobi-sol.co.jp/visolve/en/deflector.html) each use a 'lens' to enable users to manipulate colors of any content on the screen. People with typical color vision may also find these computer tools useful. For example, eyePilot permits one to isolate specific colors against a gray background, facilitating in-depth analysis of presentations with complex color-coding schemes.

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1. Wong, B. *Nat. Methods* **7**, 573 (2010).
2. Albrecht, M. *Nat. Methods* **7**, 775 (2010).
3. Deeb, S.S. *Clin. Genet.* **67**, 369–377 (2005).
4. Jones, S.A *et al. Nat. Methods* **8**, 499–505 (2011).

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