Arditi, Aries and Knoblauch, Kenneth (1996)
Effective Color Contrast and Low Vision
In B. Rosenthal and R. Cole (Eds.):
Functional Assessment of Low Vision, Mosby:
St. Louis, MO, 129-135

C H A P T E R

8

Effective Color Contrast and Low Vision

Aries Arditi
Kenneth Knoblauch

Key Terms

Contrast	Saturation	Color deficit
Chroma	Brightness	Reflectance
Hue	Luminance	Wavelength
Lightness		

Since people can perform most critical pattern processing tasks of everyday life (e.g., reading or driving) even in the absence of hue discrimination capability, chromatic attributes of visual stimuli are generally thought to be of secondary importance in form vision. However, defects and anomalies of color vision that are acquired with eye diseases and produce low vision can affect luminosity and hence effective contrast of most colored visual stimuli. The partially sighted individual whose pattern processing capabilities are already challenged by a high degree of optical and/or neural image degradation often cannot afford additional losses in effective contrast arising from color deficits acquired with ocular disease. In addition, color, especially in graphic displays, often codes information or conveys esthetic features that are important elements of the presentation to the user.

How can colors for information displays be chosen for high discriminability and legibility for individuals with low vision, while still allowing flexibility in color choices? Guidance on this question in the literature is vague, being confined to the mention of color as a cue to enhance visibility of critical environmental features, or to the plea for use of strong color contrasts in designing for partial-sight.[1-3] There has been one recent attempt to provide some guidance in the use of color,[4] but it is neither comprehensive nor easy to generalize.

There are valid reasons for the paucity of specific information guiding the use of color in low vision: color vision deficits vary greatly among eye disorders and individuals. This heterogeneity extends to color appearances, and more important, to discriminability; that is, colors that contrast optimally for one individual may actually be indiscriminable to another. Thus it is not possible to derive a single set of guidelines that are maximally effective for the entire partially sighted population.

Rather than attempt to specify *maximal* effectiveness for each individual, the approach we take here derives, from the most prevalent functional characteristics of color vision loss in low vision, a set of three rules to guide color choices that ought to lead to more effective color choices for the vast majority of partially sighted people. These rules also yield effective contrasts for people with congenital color defects as well, and do not result in less effective contrasts for people with normal color vision.

Hue, Lightness, and Chroma (Saturation)

To understand how to make color contrasts that are effective for everyone, a few basic definitions will be useful. In particular, we need to characterize colors by their three most important perceptual attributes: *hue*, *lightness*, and *saturation* (see color plate 20).

Hue is the attribute by which colors are categorized with terms like blue, green, yellow, red, and purple. Newton first noted that people with normal color vision report that, when ordered in terms of similarity to one another, hues fall naturally into a closed figure like a circle (see color plate 22).

Lightness (or brightness) is the attribute that corresponds to how much light *appears* to be reflected (or emitted) from a surface relative to that from nearby surfaces. It is the most important attribute in effective contrast between two colors. Notice that different terminology is conventional depending on whether we are referring to the color of surfaces such as walls, whose perceived intensity depends more on the *proportion* of light reflected (or reflectance) rather than on the absolute amount of light coming from the surface, or the color of illuminants such as lamps or the moon, which are seen as sources of light. With the former, we refer to *lightness;* with the latter, *brightness.* Throughout this chapter we refer mostly to lightness, but our rules apply to brightness as well. Another way to think about lightness is as the gray value that appears most similar to the color. Thus pastel colors, which appear to be close to light gray or white, generally have high lightness.

Although it is commonly believed that optical devices such as photographic exposure meters can be used to compute the lightness (or brightness) of a color, they in fact give results that agree only with those of an average observer. The values they register often do not match the observations of many people, especially partially sighted people with acquired deficits and some people with congenital color deficits. Thus one cannot simply measure lightness or brightness (or any other perceptual attribute, for that matter), with an optical device.

Chroma (also called *saturation*) refers to chromatic intensity—the degree to which a surface color differs from an achromatic surface of the same lightness. It is the attribute of color intensity in the sense of its perceptual difference from a white, black, or gray, of equal lightness. Slate blue is an example of a desaturated color, because it is similar to gray. A deep blue of equal lightness to the slate blue would be more saturated.

Because hue, lightness, and saturation can all be abstracted from a stimulus by an observer independently of one another, it is possible to represent perceived color as a solid in three-dimensional space. Illustrated in color plate 20, a **color solid** helps to visualize the three perceptual attributes of color enumerated above. Although the color solid depicted in the figure is highly schematized and is not intended to represent the perceptual color space of any real observer, it has three features worth noting. First, the greatest perceptual distances between colors can be realized by separation on the lightness axis; that is, highest effective contrasts can be achieved by manipulating apparent light intensities. This can be accomplished most directly through changes in actual intensities (luminances or reflectances). Second, the solid is widest in the middle range of lightnesses, reflecting the fact that colors at the lightness extremes have restricted ranges of chroma, and that colors with the highest chroma are found only in the midrange of lightnesses. Thus one can generally increase the apparent intensity of a highly saturated surface or light source only at the expense of its chroma. Finally, hues also tend to be more similar to one another at the lightness extremes.

Color Defects Associated with Low Vision

Most color vision deficits that occur with serious ocular disease are usefully described in terms of the following functional losses.

Luminosity losses. Ocular disorders (and typical aging) often result in a loss of transparency of the ocular media, reducing the amount of light reaching the retina. Such losses are generally greater for short rather than long wavelengths of light. Violet, blue, and blue-green surfaces, which tend to reflect shorter wavelengths, often appear darker to individuals with losses in ocular transparency. Such losses in lightness are often termed luminosity losses. Similarly, certain other eye disorders (cone-rod dystrophies, protan defects, and some forms of achromatopsia) result in loss of luminosity of long wavelength light. For individuals with these types of disorders, surfaces and lights with hues near the red end of the hue scale appear darker.

CLINICAL PEARL

Violet, blue, and blue-green surfaces, which tend to reflect shorter wavelengths, often appear darker to individuals with losses in ocular transparency.

Luminance contrast sensitivity. Many optical and neural factors in eye diseases may contribute to a loss of sensitivity to differences in light intensity. Since apparent light intensity (lightness/brightness) is strongly affected by actual light intensity (luminance), reductions in sensitivity to luminance contrast are also associated with reductions in lightness and brightness contrast.*

CLINICAL PEARL

Because apparent light intensity (lightness/brightness) is strongly affected by actual light intensity (luminance), reductions in the sensitivity to luminance contrast are associated with reductions in the sensitivity to contrast between lightness and brightness.

Chroma discrimination. In many visual disorders, surfaces and lights that are matched in lightness and hue become less discriminable, particularly those that lie close to the achromatic (lightness) axis of the color solid, such as the pastel colors. This is often due to a reduction in the amount of light that reaches the retina

*However, since luminance is itself defined in terms of the efficiency of each wavelength to evoke a visual response in a standard normally sighted observer, wavelength-dependent reductions in luminance contrast sensitivity in an individual with a color defect are almost always associated with effects on hue and chroma contrast as well.

because of ocular disease. Chroma discrimination can also be reduced for particular pairs of hues in both congenital and acquired color vision deficits.

CLINICAL PEARL

In many visual disorders, surfaces and lights that are matched in lightness and hue become less discriminable, particularly when they lie close to the achromatic (lightness) axis of the color solid (e.g., pastel-colored objects).

Wavelength discrimination. Color deficits associated with visual impairment also affect the ability to distinguish nearby wavelengths of monochromatic light. Because wavelength is such an important factor in hue, such losses also produce deficits in discriminating adjacent regions of the hue scale.

CLINICAL PEARL

Color deficits associated with visual impairment also affect the ability to distinguish nearby wavelengths of monochromatic light. Because wavelength is such an important factor in hue, such losses produce deficits in discriminating adjacent regions of the hue scale as well.

Three Rules for Obtaining Effective Color Contrast

Given these types of functional losses, a set of three qualitative recommendations is derived for choosing pairs of colors that, if followed, would minimize the likelihood of using color contrasts that are indiscriminable for individuals with low vision. The guidelines are designed to result in choices of color contrasts for which the residual luminance contrast will be good even when an individual has lost the ability to discriminate the chromatic component in the pair. These recommendations are addressed to anyone who wishes to increase the visual accessibility, discriminability, and/or legibility of environments, displays, or colored print materials to patients with low vision. Because of the diversity of color deficits associated with low vision and the fact that we have exploited a statistical association between hue and wavelength composition of lights and ignored adaptation and induction effects, these rules can be incorrect in some instances. However, the rules will be valid for most low vision patients, viewing most colored stimuli under neutral adaptation and illuminating conditions.

1. **Increase lightness differences between foreground and background colors, and avoid using colors of similar lightness against one another, even if they differ in chroma or hue (see color plate 21).** Although the designer cannot be confident that the lightnesses and lightness differences he or she perceives will correspond to the lightnesses and differences perceived by people with color deficits, he or she can generally assume that additional contrast between colors of different lightness will be required for the individual with color deficits. Thus use of lighter light colors and darker dark colors than typically used will increase visual accessibility to all.

CLINICAL PEARL

Increase the lightness differences between foreground and background colors. Also avoid using colors of similar lightness against one another, even if they differ in chroma or hue.

2. **Choose dark colors with hues chosen from the bottom half of the hue circle shown in color plate 22 against light colors from the top half of the circle, and avoid contrasting light colors from colors on the bottom half against light colors on the top half.** Most people with partial sight and/or congenital color deficiency tend to suffer losses in visual efficiency for colors shown in the bottom of this circle; this guideline helps to minimize the deleterious effects of such losses on effective contrast.

CLINICAL PEARL

Choose dark colors, with hues from the bottom half of the hue circle, to accompany light colors, with hues from the top half. Also avoid contrasting light colors from the bottom half against light ones from the top half.

3. **Avoid contrasting hues from adjacent parts of the hue circle (see color plate 23), especially if the colors do not contrast sharply in lightness.** Color deficiencies associated with partial sight (as well as congenital) make colors of similar hue more difficult to discriminate than they are in normal vision.

CLINICAL PEARL

Avoid contrasting hues from adjacent part of the hue circle, especially if they do not differ significantly in lightness.

TABLE 8-1
Color Contrast

Colors	Rule(s)
Good	
Any light color against black	1
Any dark color against white	1
Light yellow against dark blue	2
Dark red against light green	2
Poor	
Dark green against light red	2
Yellow against white or light gray	1
Turquoise against green	3
Lavender against pink	1, 3

Examples

In Table 8-1 above, a few examples are given of good and poor color contrast, as well as the rule(s) applied to classify them as good or poor.

Conclusion

Although the diversity of color deficits in low vision and congenital color deficiency, as well as the diversity of illuminating and adaptation conditions, makes identification of highly specific recommendations very difficult, there are three simple rules that can be applied that are likely to increase effective color contrast in low vision and congenital color deficiency, without decreasing effective contrasts in normal vision. It is hoped that these simple rules will be of value to all who wish their displays to be accessible to individuals with acquired and congenital color deficits.

References

1. Duncan J, Gish C, Mulholland ME, and Townsend A: Environmental modifications for the visually impaired: A handbook. *J Vis Impair Blindness*, 442-455, 1977.
2. Hood CM and Faye EF: Evaluating the living situation. *The Aging Eye and Low Vision.* Lighthouse National Center for Vision and Aging, The Lighthouse Inc., New York, 1992, pp. 46-54.
3. Tideiksaar R: Avoiding falls. *The Aging Eye and Low Vision.* Lighthouse National Center for Vision and Aging, The Lighthouse Inc., New York, 1992, pp. 55-60.
4. Gelhaus MM and Olson MR: Using color and contrast to modify the educational environment of visually impaired students with multiple disabilities. *J Vis Impair Blindness* 19-20, 1993.

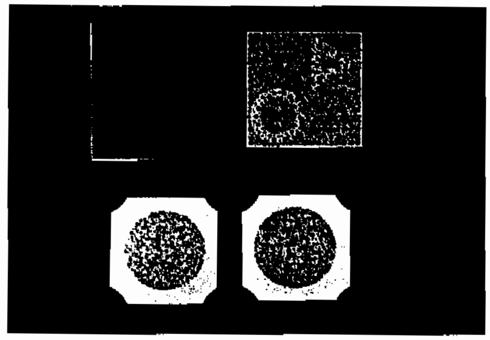

PLATE 19 Two examples of pseudoisochromatic plate (PIP) tests. **Top**: The AO-HRR plates; **bottom**: Ishihara's Tests for Colour Blindness.

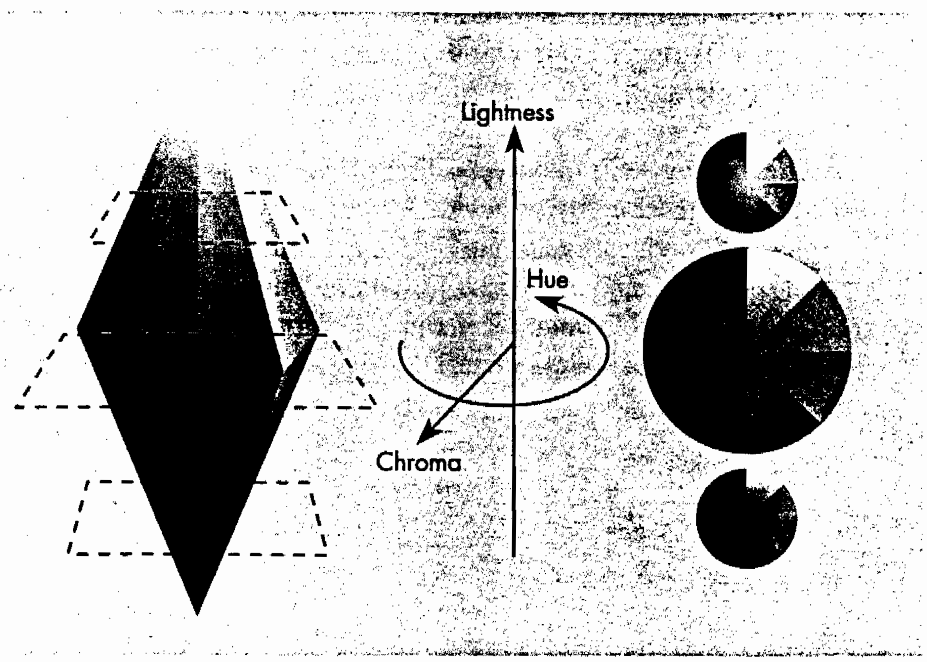

PLATE 20 Solid representation of the perceptual attributes of color. Hues are ordered on a closed dimension (shown here as circumferences of the solid). Shades of gray fall on the lightness axis and are called achromatic colors. Chroma is the horizontal distance from the lightness axis and represents the chromatic intensity of the color, independent of its lightness. The three color circles on the right represent slices through a colored solid taken at planes indicated by the dashed lines on the solid.

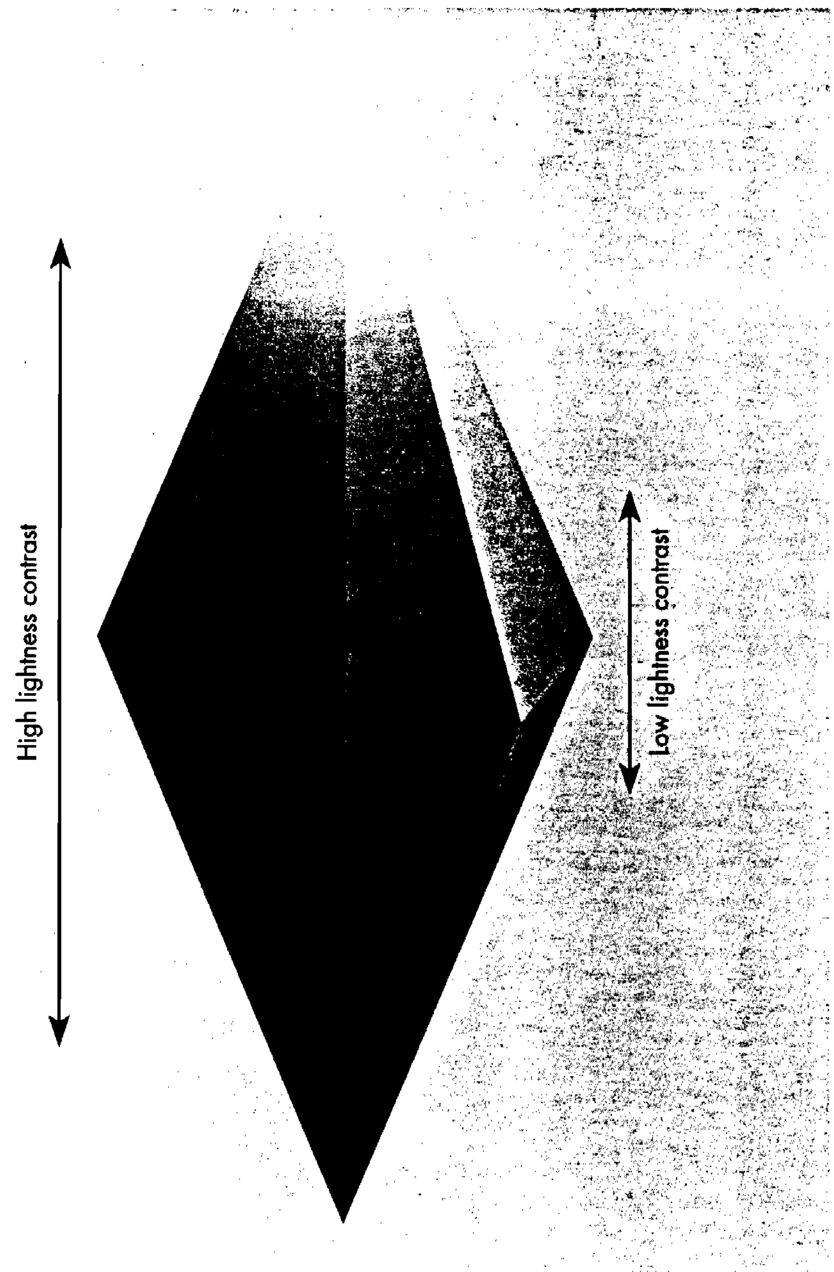

PLATE 21 Effective contrasts for patients with color deficits generally require using colors with very different lightnesses.