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5.3: Choosing Effective Display Colors for the Partially Sighted

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ABSTRACT

We derive, from general properties of acquired color vision defects in the partially-sighted population, a set of simple principles to guide display color choices that optimize effective contrast while allowing for flexibility in the use of color.

INTRODUCTION

Partial sight (also called low vision) refers to impairment resulting from eye disease that cannot be remediated by conventional spectacle correction and which seriously disrupts performance of tasks requiring vision. The ranks of the partially-sighted are rising sharply today, both because medical science's progress in combatting eye disease has not kept pace with those advances that allow people more years of life, and because the "baby boomers" are now approaching their middle-age years, when serious eye diseases tend to begin. The partially-sighted population, many of whom are legally blind, is a large and growing force for which accessibility in public spaces and the workplace must be provided under the law. Equally important, the group's very size makes it a potent economic force, a market that designers of information displays cannot afford to ignore.

Since people can perform most critical pattern processing tasks of everyday life (such as 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 processing of visual patterns. However, defects and anomalies of color vision that are acquired with eye diseases producing partial sight 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 their ocular disease. Additionally, color, especially in graphic displays, often codes information or conveys æsthetic features that are important elements of the presentation to the user.

How can colors for information displays be chosen for maximum discriminability and legibility for individuals with partial sight, while still allowing flexibility in color choices? Guidance on this question in the literature is nonspecific, 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, 2, 3]. There has been one recent attempt to provide some color guidelines [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 partial sight: color vision deficits vary greatly across both eye disorders and individuals. This heterogeneity extends to color appearances, and more importantly, 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 attempting to specify *maximal* effectiveness, the approach we take here derives, from the most prevalent forms of color vision loss in partial sight, a set of principles to guide color choices that ought to lead to more effective color choices for the vast majority of partially-sighted people. These principles also happen to yield effective color contrasts for most people with congenital color defects as well, and do not result in less effective contrasts for people with normal color vision.

We use a conceptual framework that is only as complex and as accurate as it needs to be for conveying how to apply the principles intelligently. We assume that the guidelines will be used by designers with normal color vision for individuals with acquired color vision losses.

BASIC COLOR ATTRIBUTES

There are at least three perceptual attributes associated with any color: *hue*, *lightness* (or brightness), and *chroma*. Hue denotes the attribute by which we name the *basic* colors such as blue, green, yellow, red, and purple[1].

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[1] Many nonbasic color names also imply color attributes other than hue. For example, brown usually refers to dark yellow; pink refers to light red.

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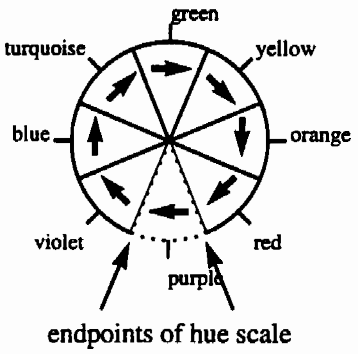

a.

PURPLE—VIOLET—BLUE—TURQUOISE—GREEN—YELLOW—ORANGE—RED—PURPLE

b.

Figure 1: The hue scale. **a.** illustrates the perceptual ordering of similarity of observers with normal color vision, arranged on a circle. This circle may be considered to be a slice of constant lightness through the solid depicted in Figure 2b. Variations in chroma would be radial, with maximum chroma at the outer edge of the circle. Purple, which appears similar to both red and violet, is shown in dashed lines, indicating that it is adjacent to, but beyond, these endpoints of the scale. **b.** depicts the hue scale linearly. This representation, excepting purple, orders the hues in the same sequence as the appearance of monochromatic lights viewed under special laboratory conditions, when ordered by wavelength.

Hues fall into a natural perceptual order, shown in Figure 1a, that, once sorted by similarity by observers with normal color vision, can be arranged on a circle. We call this ordering the *hue scale*. It has the same repetitive property as musical scales, in that hues, as notes, repeat at the end of the scale sequence. Excepting purple, the ordering coincides with the hues of monochromatic lights in order of their wavelengths, when the lights are viewed under special conditions, but it is neither necessary nor accurate to assume any fixed association between the perceptual attribute of hue and the physical wavelength of light. Although the hue scale can be considered to be a closed (e.g. circular) dimension, as depicted in Figure 1a, it is also necessary, for purposes of this analysis, to label two colors, violet and red, as *endpoints* of the scale. The hue scale, anchored by these endpoints, is depicted linearly in Figure 1b. In general, when referring to *adjacency* of hues, the circular representation is more convenient; when referring to *location* on the scale, the linear representation is more apt. Notice that purples have no location in the linear representation of Figure 1b, but they are, at the same time, adjacent to both endpoint hues. There is nothing special about the appearance of purple to correspond to its unique status, nor about red and violet hues to justify their anchoring function, but our scheme needs these features in order to incorporate certain aspects of the physiology of color perception that are beyond the scope of this paper[2].

Lightness (or brightness) refers to the degree of apparent light intensity. 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.*

Chroma refers to chromatic intensity—the degree to which a surface color differs from an achromatic surface of the same lightness. Another term used for chroma is *saturation*. A surface or illuminant of zero chroma or saturation appears achromatic (white, grey or black).

Although the color solid depicted in Figure 2 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 be-

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[2] Our reasons for designating these endpoints has to do with the tendency, in the long run, of lights (or surfaces) of a given hue to emit (or reflect) energy in the bands of wavelengths that under certain laboratory conditions have the same hue. We thus exploit a statistical association between hue and wavelength that is incorrect in most specific instances. The visible wavelength spectrum under such conditions has hues ranging from violet to red. There is no wavelength in the visible light spectrum that appears purple under such conditions, but a mixture of lights from the extremes of the spectrum does. Some chromatic aspects of vision derive from the responses of light receptor neurons, which are differentially sensitive to wavelength, whereas others derive from higher-level processing, where neurons are differentially sensitive to different mixtures of wavelengths. The hue scale described herein attempts to incorporate important properties of both levels of visual processing.

tween 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 most directly be accomplished through changes in actual intensities (luminances or reflectances). This property of the color solid is reflected in Guideline 1 below. 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.

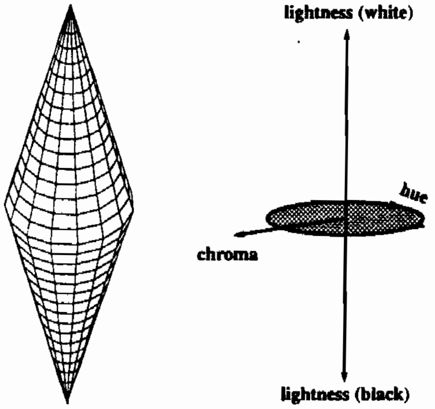

Figure 2: A solid representation of perceptual attributes of color. Hues are ordered on a closed dimension (shown here as circumferences of the solid). Shades of gray fall on the lightness axis and are called achromatic colors. Chroma is horizontal distance from the lightness axis, and represents the chromatic intensity of the color, independent of its lightness.

COLOR DEFECTS ASSOCIATED WITH PARTIAL SIGHT

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

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 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 and some forms of achromatopsia) result in loss of luminosity of long wavelength light. For individuals with these types of disorders, colors with hues near the red end of the hue scale appear darker.

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[3].

Chroma discrimination

Surfaces and lights that are matched in lightness and hue are less discriminable in many visual disorders, 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, due to ocular disease. Chroma discrimination is also reduced for particular pairs of hues in both congenital and acquired color vision deficits.

Wavelength discrimination

Color deficits associated with visual impairment also affect 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 in the hue scale.

Given these types of functional losses, a set of five 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 maximized even when an individual has lost the ability to discriminate the chromatic component in the pair.

GUIDELINES FOR EFFECTIVE COLOR CONTRAST

1. *Maximize luminance/reflectance contrast.* Despite differences in visual effect across the wavelength spectrum between partially- and normally-sighted indi-

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[3] 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, reductions in luminance contrast sensitivity in an individual with a color defect are almost always associated with effects on hue and chroma as well.

viduals, this rule will maximize effective contrast in nearly any situation. Since there is a close relationship between reflectance and (assuming a constant illuminant) lightness (or, as the case may be, luminance and brightness), it simply means that colors close to white and black will contrast effectively. This rule can be implemented with inexpensive equipment such as a photometer or photographic exposure meter. Guidelines 2–5 simply insure that when color choices other than black and white are made, there will be sufficient effective contrast.

2. *Contrast dark colors from the extremes of the hue scale with high lightness mid-scale colors, and avoid contrasting light colors from the extremes of the hue scale against dark mid-scale colors.* Most partially-sighted people suffer sensitivity losses at one or both ends of the wavelenth spectrum; this guideline helps insure that there will be an effective contrast even in the presence of concomitant reductions in sensitivity to hue and chroma differences.

3. *Avoid use of any color against an achromatic color (white, gray, black) of similar lightness.* Many color vision losses result in some colors losing saturation. (Uniform chroma loss can be visualized as a narrowing of the color solid towards the lightness axis.) The use of such colors, which may appear achromatic, against normally achromatic appearing colors, may result in poor effective contrast. A common violation of this guideline is the use of pastel colors against white.

4. *Avoid contrasting hues from adjacent parts of the hue scale.* (Recall that although purple falls outside the *wavelength* spectrum, it is adjacent to both violet and red in the hue scale.) Diminished sensitivity to differences in hue are common in virtually all losses of color perception.

5. *Avoid contrasting colors of low chroma and similar lightness.* Low chroma colors include the pastels, which are close to white, and colors close to gray or black. Using such combinations may result in especially poor effective contrast since conditions leading to partial sight often diminish ability to distinguish colors of low chroma from white or gray—thus both may be perceived as achromatic colors of the same lightness.

EXAMPLES

Colors	Guidelines
Good contrast	
any light color against black	1
any dark color against white	1
light yellow against dark blue	1,2
dark red against light green	1,2
Poor contrast	
dark green against bright red	2
yellow against white or light gray	3,5
turquoise against green	4
lavender against pink	5

CONCLUSION

It is hoped that these simple recommendations will be of value to display designers without extensive training in color science, who wish their displays to be accessible to individuals with partial sight.

REFERENCES

[1] J. Duncan, C. Gish, M. E. Mulholland and A. Townsend, Environmental modifications for the visually impaired: A handbook. *Visual Impairment & Blindness*, (1977) 442–455.

[2] C. M. Hood and E. F. Faye, Evaluating the living situation. *The Aging Eye and Low Vision.* Lighthouse National Center for Vision and Aging, The Lighthouse Inc., New York (1992) 46–54.

[3] R. Tideiksaar, Avoiding falls. *The Aging Eye and Low Vision.* Lighthouse National Center for Vision and Aging, The Lighthouse Inc., New York (1992) 55–60.

[4] M. M. Gelhaus and M. R. Olson, Using color and contrast to modify the educational environment of visually impaired students with multiple disabilities. *Journal of Visual Impairment & Blindness* (1993) 19–20.