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Choosing Color Contrasts in Low Vision: Practical Recommendations

Kenneth KNOBLAUCH and Aries ARDITI
Vision Research Laboratory, The Lighthouse Research Institute
800 Second Avenue, New York, NY 10017 USA *

Abstract. How should colors be chosen to code information in order to optimize performance for individuals with low vision? Optimal choice is complicated by the heterogeneity of color vision losses occurring among individuals with acquired and congenital color vision defects. Two guidelines often suggested are to choose contrasting colors and to maximize luminance contrast, but each of these recommendations neglects that specifications of contrast and luminance often vary from the norms in a visually impaired eye. The approach taken here begins with general properties of color vision loss in low vision and from these derives principles to guide choices to colors that would optimize contrast in spite of such visual losses.

Most color vision losses that occur with visual impairment can be described in terms of a combination of the following general types of loss: 1) contrast sensitivity loss, 2) saturation discrimination loss, 3) wavelength discrimination loss and 4) luminosity loss at one or both extremes of the spectrum. Given these types of loss, a set of six 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.

It is hoped that these recommendations will be of value to designers and architects who wish their products and environments to be accessible to individuals with low vision.

1. Need for guidelines

The optimal design of products and environments for partially-sighted consumers requires careful consideration of color for function as well as beauty. The use of color as a cue to enhance visibility of critical environmental features is sometimes mentioned in design recommendations for individuals with impaired vision, but these recommendations are usually extremely brief, often limited to emphasizing only the need for strong color contrasts [1, 2, 3]. Because of the wide range of color vision defects found in low vision, however, color appearances within this population vary widely, and colors that contrast optimally for one individual may actually be indiscriminable to another. In other cases, a few guidelines have been suggested [4], but these are neither comprehensive nor placed within a context that motivates their usage.

*After July 1, 1994 The Lighthouse Research Institute will be located at 111 East 59th St., New York NY 10022 USA

One rule for maximizing discriminability that works nearly universally is to maximize *luminance contrast* [1]. In the extreme, this simplistic rule would lead to the choice of only black and white, thus producing objects of limited æsthetic appeal and more importantly failing, in some instances, to exploit information that individuals with visual impairments could process. This brief report expands on the simple rule by taking into account certain general characteristics of visual impairment. Hopefully, these recommendations will improve the designer's ability to create objects of higher apparent contrast to most partially-sighted people, without significantly reducing salience for others, and without sacrificing too many of the designer's options.

2. Qualitative vs Quantitative guidelines

While it is possible to specify with quantitative precision differences in color perceived by a particular individual, doing so in practice is extremely complex, especially without extensive training in color and visual science, some mathematical expertise, and some fairly expensive equipment.

We take a different approach here. Instead, we make do with qualitative, categorical properties of color and visual science, and derive principles that can be used with common sense and a minimum of equipment. In brief, we present a descriptive characterization for organizing normal color percepts and assume a correspondence between this systematization and the physical stimulus.

3. Perceptual aspects of normal color vision

To accurately specify a perceived color completely requires consideration of at least three perceptual attributes. Although there are a number of different and equally valid sets of such attributes that could be used, it will be convenient to think of three dimensions within the bounds of which all colors can be categorized. These are *hue, lightness* (or brightness) and *chroma.*

Hue denotes the attribute that we name the basic colors by, such as blue, green, yellow, red, purple, orange *etc.* Hues can be ordered, and it is convenient to do so as they would be ordered from short to long wavelengths in the visible spectrum: violet–blue–turquoise–green–yellow–orange–red. Missing from this sequence are purples, which are hues that lie outside the spectrum. Purple is produced from mixtures of lights from the two ends of the spectrum (red and blue or violet), and its existence allows hues to be represented in a closed figure.

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

[1] Contrast is a measure of the difference between the intensities of light reflected or emitted from the foreground of a pattern and the background against which it is viewed relative to the average intensity. While several definitions of contrast are in common usage, one example is used by both the Americans with Disabilities Act Accessibility Guidelines [5] and the American National Standards Institute Standard A117.1–1992 [6]. Both specify contrast as $\frac{B_1 - B_2}{B_1} \times 100$ where B_1 and B_2 represent the light reflected from the brighter and darker surfaces, respectively. Increasing contrast usually results in increasing visibility of the pattern. When foreground and background share the same spectral distribution of light, the contrast is independent of the intensity measure used. When they differ, however, contrast depends on the observer's relative sensitivity to the colors. For example, luminance contrast incorporates the relative sensitivity (luminosity) to different parts of the spectrum of a standard normally-sighted observer.

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

Any color may be described by its designation with respect to these attributes. For example, brown is usually considered to be a yellow or orange hue with a low value of lightness. Its chroma can assume different values depending on the particular instance of brown.

This approach is greatly simplified but has the mitigating virtue of being of practical use to designers not expert in fields related to color science. Being a simplification, there are many exceptions to the system (*i.e.*, it is incorrect in some instances). Most of these will not invalidate its usefulness below in guiding the choice of color contrasts for partially-sighted individuals, though. For example, the association of hue with the spectrum outlined above assumes, strictly speaking, lights presented in isolation to a neutrally-adapted observer with normal color vision. (It also does not take into account hue induction effects, such as gray appearing reddish when juxtaposed with a green of high chroma.) We assume that individuals with normal color vision will be using these guidelines to make designs for individuals with impaired vision. The aim is not to describe to the designer what is seen by a visually impaired individual, but instead to outline a framework for the choice of color constrasts that will maximize visibility to visually impaired people.

4. Effects of visual impairment on color vision

Specific effects that visual impairments produce on color vision are diverse, ranging from no effect to complete loss of hue discrimination. Here are some general ways in which visual impairment tend to affect color vision:

1. **Loss of luminance contrast sensitivity.** Individuals with normal vision can often perform everyday tasks under conditions in which luminance contrast is substantially reduced. Individuals with low vision often suffer substantial decrements of performance with even small reductions in contrast.

2. **Loss of sensitivity to chroma.** Because of specific color deficits caused by some kinds of visual impairment, contrast sensitivity losses are often accompanied by even more pervasive losses in sensitivity to chroma, especially for specific pairs of hues.

3. **Greater difficulty in distinguishing nearby hues.** In addition to losses in chroma sensitivity, visual impairment also affects ability to distinguish hues from adjacent regions in the color spectrum.

4. **Loss of sensitivity to lightness for spectrally extreme colors.** Normal aging generally causes the lens inside the eye gradually to increase in yellowness concomitantly filtering out certain (short) wavelengths of light and preventing them from reaching the retina. As a result, violet, blue and blue-green surfaces (which reflect light mostly from the short wavelength region) often appear darker to older individuals. Similarly, certain other eye disorders (cone-rod dystrophies and some forms of achromatopsia) result in loss of sensitivity to long wavelength light. For individuals with these types of

disorders, red and brown surfaces appear darker. This type of loss is more typically referred to as a *luminosity loss*.

Taken together, these types of loss suggest a set of qualitative principles that can be used for choosing color contrasts in low vision. These are outlined in the next section.

5. Principles

1. **Maximize luminance contrast.** We emphasize that this rule is valid almost universally. Subsequent principles basically insure that even with substantial loss of color vision, this rule will still be in force.

2. **Choose dark colors from the spectral extremes with high lightness mid-spectral colors.** For individuals who suffer luminosity loss at the ends of the spectrum, this principle will insure that they will be able to detect a luminance difference even if they have lost sensitivity to hue differences.

3. **Avoid choosing high lightness colors from the spectral extremes against dark mid-spectral colors.** This principle is simply the converse of the previous one. If an individual suffers a luminosity loss at one extreme of the spectrum and a high lightness from that extreme is paired with a low lightness from the middle of the spectrum, than there is a greater chance that the two colors will match in lightness for this individual. If the individual, in addition, has lost sensitivity to the hue and chroma difference between these colors, then no contrast cue of any sort is available to the individual.

4. **Avoid white (or gray) against any color of similar lightness.** Many forms of color defect result in some colors losing all chroma. In other words, such colors appear *achromatic* or without color to the affected individual. This principle avoids use of all such possible pairs.

5. **Avoid mixing hues from adjacent parts of the spectrum, especially if of similar lightness.** This principle tries to take into account diminished sensitivity in hue discrimination that is shown in color defects. Note that purple can be considered to be adjacent to violet and red.

6. **Avoid using pastel colors together (of low chroma or saturation).** A common feature in defects arising from visual impairment is an overall loss in the ability to distinguish hues of low chroma from white or grey.

6. Examples

Each example below illustrates one of the principles described in the previous section. The illustrated principle is shown in parentheses.

6.1. Good examples:

- Light color against black (1)
- Dark color against white (1)
- Light yellow against dark blue (1) and (2)
- Dark red against light green (1) and (2)

6.2. Bad examples:

- Dark green against bright red (3)
- Yellow against white of similar lightness (4)
- Blue against green of similar lightness (5)
- Lavender against pink (6)

References

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