# Designing Maps for the Colour-Vision Impaired

Bernhard Jenny and Nathaniel Vaughn Kelso

## Abstract

*To design maps that are readable by the colour-vision impaired but are also appealing to those with normal colour vision successfully, cartographers need to know how the colour-vision impaired person perceives colour and which colour combinations become confused. In this article, we concentrate on red-green colour confusion, which is by far the most common form of colour-impaired vision, and suggest how maps can be designed to consider this user group. We also introduce* Color Oracle *(see* http://colororacle.cartography.ch*), a free application that allows the designer to see colours on the monitor as people with colour-impaired vision see them.*

## Introduction

Colour-impaired vision, where certain colours cannot be accurately distinguished, is typically inherited through a sex-linked gene and predominantly affects about 8% of the male population. Although this may seem a small proportion, when publishing in a mass market (e.g. for a major newspaper), the number of affected readers may reach tens of thousands. Naturally, maps with a smaller circulation will affect fewer readers, but these may be critical members of the audience. Designers of maps and information graphics therefore cannot disregard the needs of this relatively large group of media consumers. Furthermore, barrier-free, 'universal' design becomes especially important when readers have very limited time to read maps and information graphics, as, for example, when reading evacuation plans in emergency situations. Not only can universal design be required by law, but cartographers may also consider barrier-free design as part of their professional ethics, since colour-impaired vision is one of the most widespread physiological conditions to hamper map reading.

## Red-Green Vision Impairment

A wide range of colour-vision anomalies exist. Some of these are genetic and some are caused by degenerative diseases, by poisoning, or by physical injury. The commonly called 'red-green blindness' is by far the most frequent form and affects about 8% of all males, mainly causing difficulty when distinguishing colours within the red-green portion of the visible spectrum. Figure 1 shows the spectrum as perceived by people with normal vision and by people who have problems distinguishing between red and green. The degree of impairment varies from one person to another from almost full colour vision to 'pure' red-green blindness. Indeed, the measurable variation among individuals with 'normal' vision is so large that the boundary between normal and colour-impaired vision is arbitrary. Women are much less likely to be affected by red-green confusion than men, with only 0.4% women impaired (Birch, 1993). Other rare forms of colour-impaired vision exist, which affect less than approximately 0.3% of all men and women.

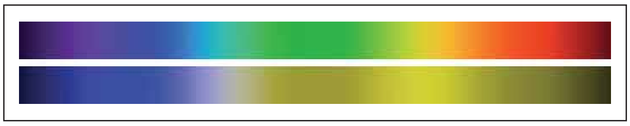

**Figure 1 The visible spectrum as perceived by the normal viewer (top) and by those with red-green vision impairment (bottom)**

The number of colours that readers with red-green vision impairment can distinguish without ambiguity is rather small. Besides confusion over the well-known red-green combination, other colour pairs may be confused, as illustrated by Figure 2. Swatches grouped at the left show those colours which readers with normal colour vision can easily distinguish, while those swatches on the right illustrate how readers with red-green vision impairment perceive these colours. Dark green, brown, orange, and dark red in the first row appear as almost indistinguishable olive-green tones to the red-green vision impaired. The second row contains less saturated blue, turquoise, and

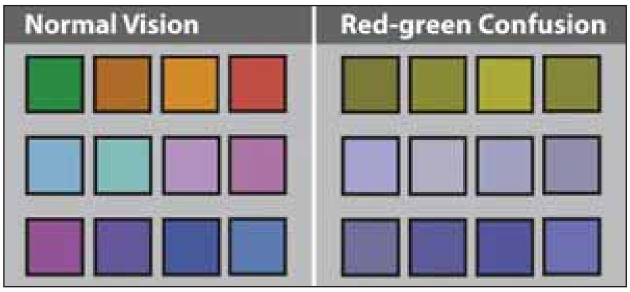


**Figure 2 Colours as they appear to readers with normal vision and to those with red-green vision impairment**

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purple, which are all seen as indistinguishable pale violet-blue. The saturated purple and various blue tones of the third row manifest as almost identical bluish tones. Cartographers should be wary of pairing these colours, especially when colour is used as the sole means for quantitatively or qualitatively distinguishing items.

## Software for the Map Designer

Specialized software, such as ColorBrewer – a popular online tool that suggests colour schemes (Harrower and Brewer, 2003; **http://www.colorbrewer.org**) – can help the designer to choose between universally-legible colour combinations. Complementary tools help to verify the legibility of a design by simulating colour-impaired vision. One example is *Color Oracle*, an application developed by the authors of this article.[1]

*Color Oracle* allows the designer to see colours on the screen as people with colour-impaired vision see them. It is accessible via the Mac OS X menu bar or the Windows system tray. The *Color Oracle* user selects the type of impairment in a drop down menu (Figure 3). The program then filters whatever is displayed on the computer monitor to simulate colour-impaired vision. The filtered image disappears when the user presses a key or clicks a mouse button and it is possible to toggle between normal colour vision and three types of simulated colour-impaired vision to identify problematic colour combinations. This approach does not interfere with the user's usual workflow and works with any graphics or mapping software.

*Color Oracle* simulates 'pure' forms of colour-impaired vision, which are not as common as the milder forms with partial or shifted sensitivity. It can, however, be assumed that if a colour scheme is legible for someone with extreme colour-impaired vision, it will also be legible for those with a minor impairment.

*Color Oracle* uses a well-established algorithm based on confusion lines (Brettel et al., 1997 and Viénot et al., 1999). Feedback from users with colour-impaired vision confirms that the simulations generated by *Color Oracle* are accurate except for very saturated colours, which might slightly deviate from the values seen by persons with 'pure' forms of colour-impaired vision.

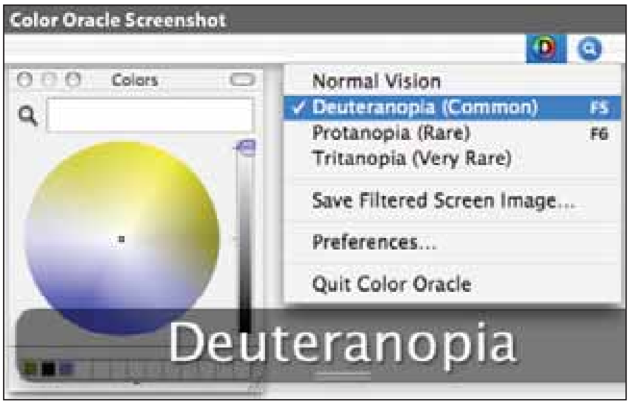


**Figure 3 Screenshot of *Color Oracle* on Mac OS X simulating red-green vision impairment on a colour picker wheel**

## Designing Maps to Accommodate the Colour-Vision Impaired

The consequence of colour-impaired vision is that afflicted people are slower and considerably less successful in search tasks where colour is the primary attribute of the target object or if colour is used to organize visual displays (Cole, 2004). A low level of illumination impedes media consumers' successful reading of colour-coded information further. Investigations have shown that under reduced illumination, subjects with impaired colour vision make considerably more errors when identifying colour[2]. Colour coding should therefore not be used as the sole means of conveying information.

Greater clarity can be brought to maps by: (1) choosing unambiguous colour combinations; (2) using supplemental visual variables; and (3) annotating features directly. These techniques will not only improve maps for those with full colour vision, but will establish a good level of distinction for those afflicted with colour-impaired vision.

## Distinguishing Point Classes

Dot maps often use hue as the only differentiating variable between classes of points. This hue coding can be difficult to interpret for readers with colour-impaired vision. Figure 4 illustrates how point symbols can be redesigned to increase legibility. Varying the saturation increases contrast and differentiates the dots only slightly for red-green impaired readers ('poor' column); shifting hue from green to blue improves legibility ('better' column); while the best solution is achieved by combining the use of different geometric shapes with varying hue and saturation. The last column shows that colour could even be discarded and the map would still be legible using the different geometric shapes. Well-designed symbols are easy for the reader to decode without consulting a legend.

## Distinguishing Line Classes

To minimize confusion, colour-coded lines on maps can be redesigned in a manner similar to colour-coded dots (Figure 5). Changes to line width must be applied with care, however, since different stroke widths can imply varying quantities ('poor' column). Directly annotating the lines with labels is a better solution that clarifies ambiguous colours and reduces the need to refer to a legend. Altering colour hue is another way to improve legibility ('better' column). A combination of modified hue and saturation with varying line patterns and annotations is our preferred solution, because it is legible to everyone ('best' column). While line patterns (e.g. dash, dot) can imply unwanted qualitative or quantitative meaning or create undesirable visual noise, for complex maps that utilize several line classes the distinction in texture can become essential.

## Distinguishing Area Classes

It is possible to devise schemes for qualitative maps using

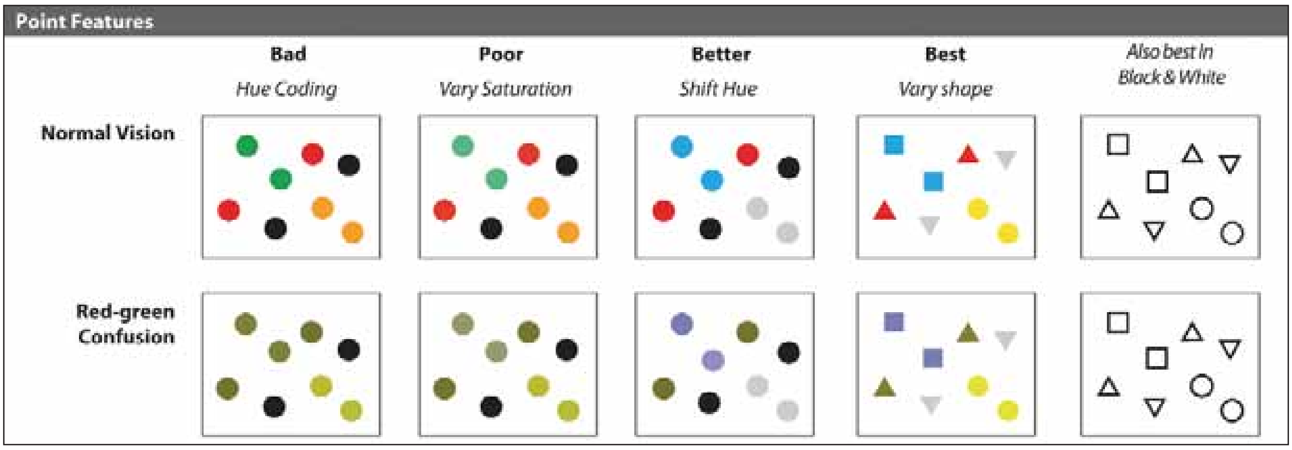


**Figure 4 Point classes typical of a dot map distinguished by saturation, hue, and shape**

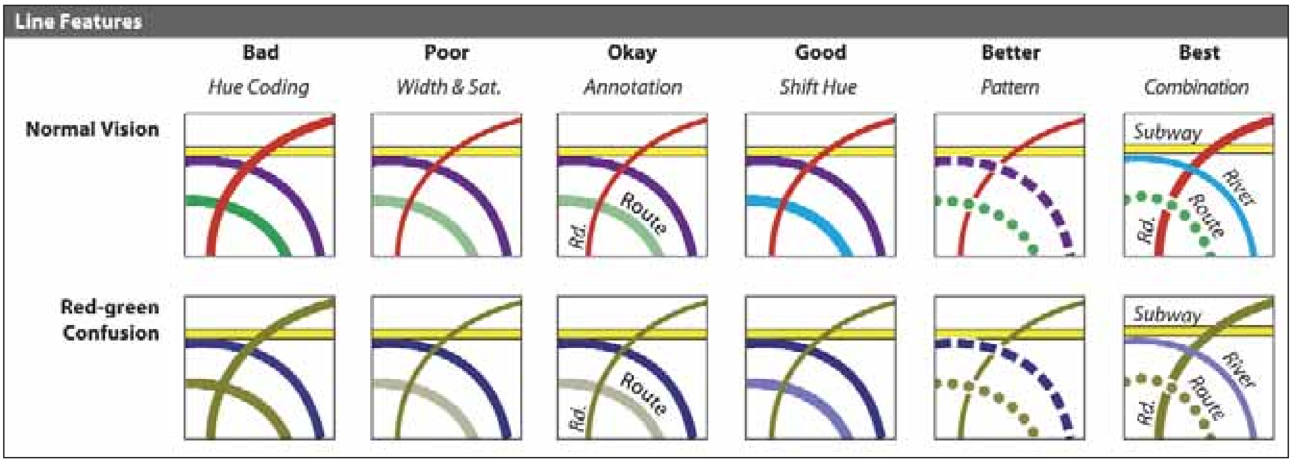


**Figure 5 Line classes distinguished by width and saturation, annotation, hue, and line pattern**

hues that are potentially problematic, provided that these are differentiated by both saturation and value (e.g. dark red, bright green), while the use of overlay hatching can sometimes present a viable alternative for choropleth maps.

For continuous-tone raster data (where colours merge into one another), scientists often apply spectral rainbow colour ramps, which typically include red, orange, yellow, green, blue and purple. Brewer (1997) found that many readers prefer such spectral colour schemes, and that they are also easy to read and interpret. This challenges the opinion of many cartographers, who advise against the use of spectral schemes for ordered data. To accommodate readers with red-green vision impairment, Brewer makes the following suggestions: (1) vary the lightness on the red-orange-yellow end of the rainbow; (2) omit yellow-green to avoid confusion with orange; and (3) for bipolar data, omit green and use a scheme with red, orange, yellow, light blue, and dark blue, and align the yellow-blue transition with the pivot point of the diverging data range.

The precipitation map in the first row of Figure 6, for example, shows low quantities of rainfall in red and intermediate values in green. Hence low and intermediate values would appear identical for readers with red-green vision impairment. The map in the second row uses an alternative spectral ramp that omits yellow-green, uses a darker red, and places the transition between yellow and blue at the mean of all values. To bring further clarity to the map, selected high and low values could be labelled when the map is printed or for a digital map, the user could query values by moving the mouse over map locations.

## Conclusion

Colour-impaired vision affects a significant portion of the population and therefore must be taken into account by the cartographer. When adjusting a colour scheme, the cartographer has to find a balance: on one side, the 8% of men who are colour-vision impaired have the right of equal access to information; while on the other side, the 96% of the population with normal colour vision would welcome pleasing maps that are easy to read. It is the cartographer's responsibility to decide when colours should be adjusted.

To avoid problematic colour combinations, the cartographer should use colours with strong contrast and supplemental visual variables, such as shape, size, and pattern variations to allow all readers to discern and directly interpret a symbol without consulting a legend. Additional techniques include simplifying the map's

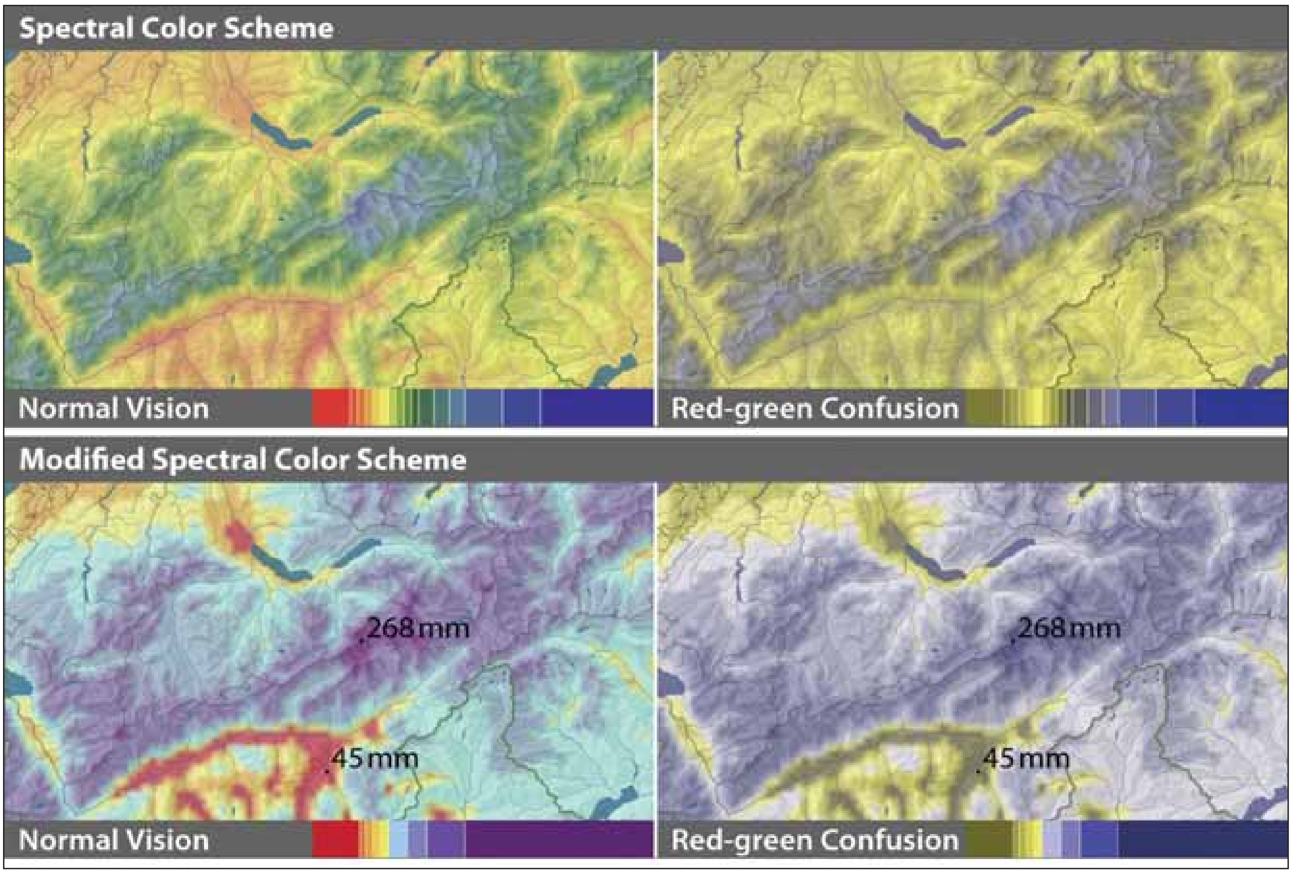


**Figure 6 Spectral colour schemes for precipitation maps, with rainbow colours (top row) and with an improved spectral scheme (bottom row). Colour ramps are depicted below the maps ('Mean monthly precipitation in January', ©Atlas of Switzerland 2, 2004)**

design and annotating the map directly wherever the reader might become confused.

Interactive digital maps can further support readers with colour-impaired vision by providing tooltips or labels that are displayed on-demand. Digital environments can allow the user to customize colour schemes to suit their needs and provide methods to query individual values.

*Color Oracle* provides a convenient method to verify that colours on a map are legible to everyone. Indeed, we have discovered many problematic colour combinations in our daily mapmaking work in using this software. Adjusting colour schemes is not always simple and forces the cartographer to reassess well-established conventions – for example, rainbow colour ramps for precipitation maps or red-green colour schemes for voting maps (Jenny and Kelso, 2007). *Color Oracle* provides a convenient tool for seeing maps in the same way as readers with colour-impaired vision. It is now an integral part of our workflow and it is hoped that others may find it a valuable tool for designing universally accessible maps.

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## Notes

1 Freely available at *http://colororacle.cartography.ch* for Macintosh, Linux and Windows.
2 For more details, refer to Cole, 2004.