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CARTOGRAPHIC DESIGN OF IN-CAR ROUTE GUIDANCE FOR COLOR-BLIND USERS

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ABSTRACT

This work aims to present a preliminary cartographic design of In-Car Route Guidance and Navigation System (RGNS) for red-blind and green-blind users. According to some studies, about eight percent of the Caucasian men are color-blinds. Dichromatic vision is held by people who one of the pigments is missing. Protanopes and deuteranopes categories are more common than tritanopes. Problems with detection and discrimination of symbols can put risk to drivers' safety, particularly for dynamic-map in a moving car. However, it seems that the industry has not been worried about this issue as should do. In addition, it was found just a few indications to design visual interfaces of RGNS for color-blind vision. Thus, if the cartographer wish to add color to the design it is important to take into account some visual techniques to enhance the representations, such as color, lightness, shape and scale contrast, as well color transformation process to color-blindness. A preliminary evaluation of the visual interface of a commercial system and an in-house prototype developed for normal color-vision was carried out for protanopes and deuteranopes. The results indicate some points that should be improved. The hue and lightness properties for route, vehicle and direction arrow symbols are not always considered for people who have color-vision deficiencies. These symbols may appear less important than the base map. Since it is possible to accommodate these kinds of disabled, it was created cartographic representations for protanopes and deuteranopes. These results are being implemented in a local prototype, in which the importance of creating figure-ground segregation, by increasing the contrast between the elements, is being taken into account. Further, it is suggested to add and evaluate other 'formats of information' and 'types of modality' to verify which of them are more required and effective by color-blind drivers.

1. INTRODUCTION

Color allows clear difference of many categories of map features and facilitates visual grouping (Olson and Brewer 1997). Color can be considered as the most dominant element for visual search of static objects in a map, according to tests accomplished by Forrest and Castner (1985). On the other hand, color-blind people had longer reaction times and made more mistakes than those ones with normal color-vision when responding to color signals (Atchison and Pedersen 2003). However, for Olson and Brewer (1997), the process of adjusting colors on maps to accommodate red-blinds and green-blinds can help people in these groups to use maps effectively. Since detection and discrimination of information can be a problem for color-blind people, this is a factor to be considered in cartographic designs that work with colors (MacEachren 1995).

Unfortunately, most colorful maps are produced without any kind of consideration about color-vision impairments on the part of map users. Maps ought to be made to aid those with color impairments as often as possible (Olson and Brewer 1997). However, just a few recommendations have been found in the literature to design Atlas (Olson and Brewer 1997; Brewer 2011) and Route Guidance and Navigation Systems (RGNS) (Dingus and Hulse 1993; Carney et al. 1998). For Dingus and Hulse (1993) in commercial applications (including navigation systems) it is important to avoid relying on color coding of critical information. Carney et al. (1998) point out that redundant coding can enhance meaningfulness. For those authors, in a system without these redundant clues, a person might have strong difficult time to determine any kind of meaning.

Nowadays, drivers may use navigation systems with basically two modalities, visual and aural. Commonly, route guidance interfaces are generally classified according to the 'type of modality' (such as visual and auditory) and 'format of information' (map, turn-by-turn, countdown bar, etc) (Burnett 1998). Several formats of presentation are available in the commercial RGNS. Generally, the visual map display is considered the main part of the system. But, other formats of information can also be added as text (toponimyc and non-toponymic) on the map face or in the marginal information surrounding the map, as well turn-by-turn arrows inset, etc. Texts generally represent distance to turn and street names. The turn-by-turn inset-arrows help drivers with a depiction of the intersections ahead.

The questions addressed in this study are "how do protanopes and deuteranopes see a map display of in-car route guidance and navigation system which was designed to normal color-vision?" and "how should visual cartographic representations be for red-blinds and green-blinds?". Thus, the aim of this work is to understand basically how color-blind people perceive colorful cartographic representations of RGNS, and propose a set of maps for protans and deutans.

2. COLOR-VISION

2.1 Color-blind vision

Rods cells, numbering about 120 million, are responsible for only achromatic sensations, having no color discrimination. Cone cells, numbering about 6 million, are compound of three types with different wavelength sensitivities, being responsible for discriminating colors. For virtually colorful map, cones are most important than rods for cartographers (MacEachren 1995). Color perception is a function of the relative stimulation of the three types of cones, according to the trichromatic theory (Slocum 2009). If only one type is stimulated, so that color is perceived.

Normal trichromatic vision and impaired vision are the most general classifications that can be given to color-vision (Olson and Brewer. 1997). For those people with normal color-vision the three cones work regularly. Anomalous trichromats, dichromats and monochromats or achromats are classes of deficient color-vision. A person who has problems in seeing colors holds color-vision deficiency. If the three types of cones continue working with a shift in the sensitivity, people are anomalous trichromats (Figure 1). If one of the pigments is missing, the person is dichromat. When people have just one type of cone working, they are called monochromats. In the last case, achromats do not see any kind of color. Between dichromats, the most common problem happens with red and green pigments (Figure 1). However, sometimes also occurs with blue. About 25% of the people with red-green color-vision defects are dichromats. In the other 75%, either the red-sensitive cones present their peaks shifted towards the green part of the spectrum, or the green peak is shifted towards the red part.

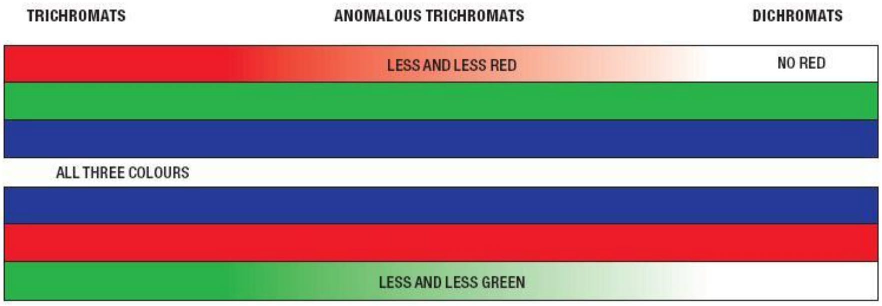

Figure 1. Relation between trichromats and dichromats. Source: Rigden (1999).

Because genes that affect color-vision are part of the X-chromosome, deficiency of color affects much more men than women. Congenital red-green color-vision defects are extremely common, affecting approximately 8% of the Caucasian males and 0.4% of the Caucasian females, having some degree of color deficiency (Pokorny et al. 1979). From the dichromats population, 1% is made up of red-blind (protanopes) and 1.1% of green-blind (deuteranopes). By considering anomalous trichromats, 1% is made up of red-insensitive (protanomolous) and 4.9% green-insensitive (deuteranomolous). Blue-blind men are represented by only 0.002% (tritanopes). Furthermore, 0.003% of men are totally color-blind (achromatic vision). In the color palettes showed in Figure 2 is presented how those color-blind people perceive the equivalent colors that are seen by normal trichromats.

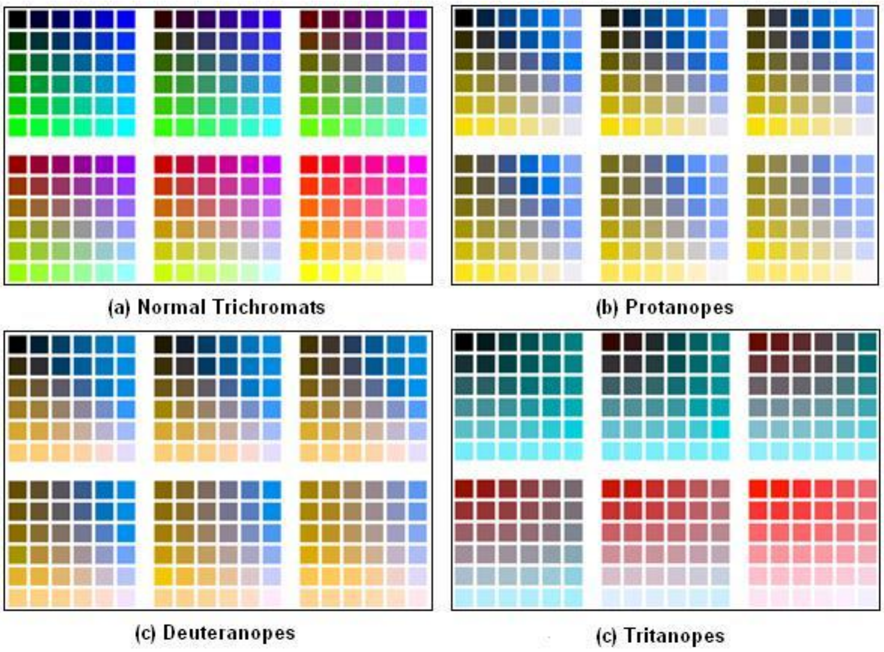

Figure 2. Color palettes as seen by (a) normal trichromats, (b) protanopes, (c) deuteranopes and (c) tritanopes. Source: Iamcal.com (2010)

In this study it was adopted the term color-blind vision instead of color-vision impairment because the cartographic design is focused on people with blindness in red or green color. Nevertheless, a number of variations is also used here, such as color-vision deficiency, color deficiency, color deficient-vision, color-blind vision, impaired color-vision and color-impairment.

2.2 The Importance of Contrast

The contrast is a concept used to make a distinction between visual elements by differentiating them in terms of, for instance, color, lightness, shape and scale (Dondis 2003). The visual organization must be related to the aim of the design (Dondis 2003). This author emphasizes contrast as a effective element of visual communication, which can be used to intensify the result and, consequently, simplify the communication. Acording to Dent (1993) it is the most important design element in the thematic mapping and in visual communication (Dondis 2003; Dent et al. 2009). For Arditi (2002) it is important to remember that people with impaired color-vision may see less contrast than the normal color-vision. Thus, one important aspect of color choice is augmenting the contrast between figure and ground (MacEachren 1995; Hess 2000; Dent et al. 2009).

Color dimension is based on three perceptual attributes, as lightness (value), saturation (chroma) and hue, like described in the Munsell's cylindrical arrangement of colors (Slocum 2009). From the three perceptual attributes of colors, value is the most important attribute in making contrast more effective. The contrast of colors can make colors more discernible rather than individual ones themselves (Arditi 2002). However, for reaching that point contrast of lightness is required to work with colors. To choose effective colors when creating figure-ground segregation, Arditi (2002) suggests increasing lightness difference between figure and ground colors, as well to avoid contrasting hues from adjacent parts of the colors in the visible spectrum.

2.3 Color Transformation

To understand how dichromats see the visual designs, color transformation needs to be applied on them (Rigden 1999). A Windows 16 color palette gives an idea of which colors are likely to cause confusion (BTexact Tecnologies 2002). In the Figure 3, the upper horizontal row is the palette simulating the colors as seen by normal color-vision. The second row simulates the appearance to protanopes and the third row to deuteranopes. The top half of the horizontal figure is compound by the three palettes seen in a black background. The lower half contains the same colors as seen against a gray background. The results of transformations for protanopes and deuteranopes can be seen basically as a set of yellows, ochre and blues.

Also, it is presented a palette of 216 colors as seen by a person with normal color-vision, as well by protanopes and deuteranopes (Figure 4). This is based in a standard 216-colors web safe palette (Siegel 19998). In a general overview, it is possible to see that protanopes see colors a little greenish and deuteranopes see them slightly orangey. In these cases, red and green disappear from the palettes, as well purples and oranges. According to Rigden (1999), the values were calculated following established algorithms from HCI Resources Network, and these palette files were created from the results in the *.pal format to be used in the Paint Shop Pro software.

Figure 3. Windows 16 color palette. Source: BTexact Technologies (2002).

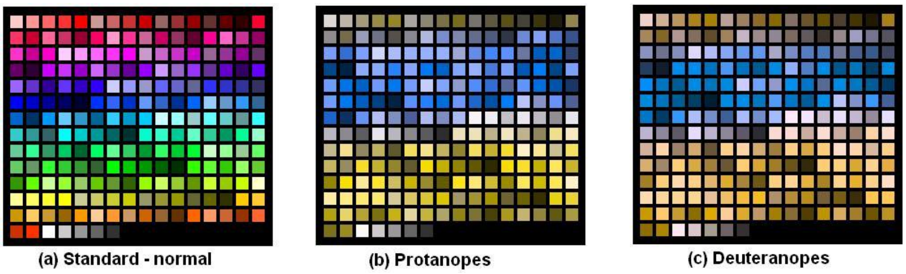

Figure 4. Palettes of 256 colors as seen by normal trichromats (a), protanopes (b) and deuteranopes. Source: BTexact Tecnologies (2002).

3. CARTOGRAPHIC DESIGN FOR PROTAN AND DEUTAN USERS

An attempt was made to answer the question "how do protanopes and deuteranopes see a map display of an In-Car Route Guidance and Navigation System which was designed to normal color-vision?". It is supposed that acknowledging such difference involving dichromats and normal trichromats can help the designer to improve the figure-ground segregation. The method was based on color transformation by using the software Paint Shop Pro with specific palettes for those kinds of impairments. The pictures were opened in the software and the palettes were loaded separately. Since color palette for tritanopes is not available, this study focuses only on protan and deutan vision. The comparisons pin down on the most important elements for in-car route following, based on Streeter et al. (1985), Burnett (1998), Labiale (2001), Pugliesi and Decanini (2009). This kind of spatial information is discussed in terms of color, lightness, scale and shape contrast.

3.1 Basic Analysis of a Commercial System

A basic map display of a commercial route guidance system was investigated. The choice was based on the following criteria: someone of the research group should possess an equivalent model of the system; a map display of the model should be available in the internet without restrictions of use; the map display should present a strategic situation of the route following with a maneuver ahead. It was taken into account if the systems allow their users to change color of the symbols. Although it is possible to do that in some route guidance, it is assumed that the systems also should have appropriate map designs, so users could easily choose.

By considering protanopes, the colors that seem to be the most appropriate to create figure-ground are, generally, white, black, dark greenish-yellow, yellow, gray and blue (Figure 3 and Figure 4). When thinking about deuteranopes, the other colors that appear to be the most acceptable to make figure and ground are, in general, pastel, black, gray, 'orange', ochre and blue (Figure 3 and Figure 4). For deutans, white color is not perceived because it is shifted to 'light salmon', which must be worked carefully. Additionally, the following color combinations as seen by normal color-vision should be avoided for those individuals: cyan and gray, yellow and light green, green and brown, red and black (Travis 1990; Thorell and Smith 1990).

The Slimway Apontador TV10 (Mercado Livre, 2010) was the system to be considered (Figure 5). The map is displayed in a perspective view. Inside a car, in a light day, the colors applied for car and route do not presented the best contrast, when considering both color-blind and normal color vision. For red-blind and green-blind, the arrow on the junction indicating the next maneuver is presented in a color almost similar to the main avenues. In this particular case, the arrow contour could be understood as an important attempting to segregate the elements. Also, the shape of the car symbol could be presented more pictorially, so it could help drivers to differentiate easier the elements, as outlined by Pugliesi (2007).

Further, according to Atchison and Pedersen (2003), deutans perform worse than protans in terms of reaction time end error rates when recognizing traffic signal color. As can be seen in the results of color transformation, the map as seen by deutans (Figure 5-c) presents lower contrast than that one as seen by protans (Figure 5-b).

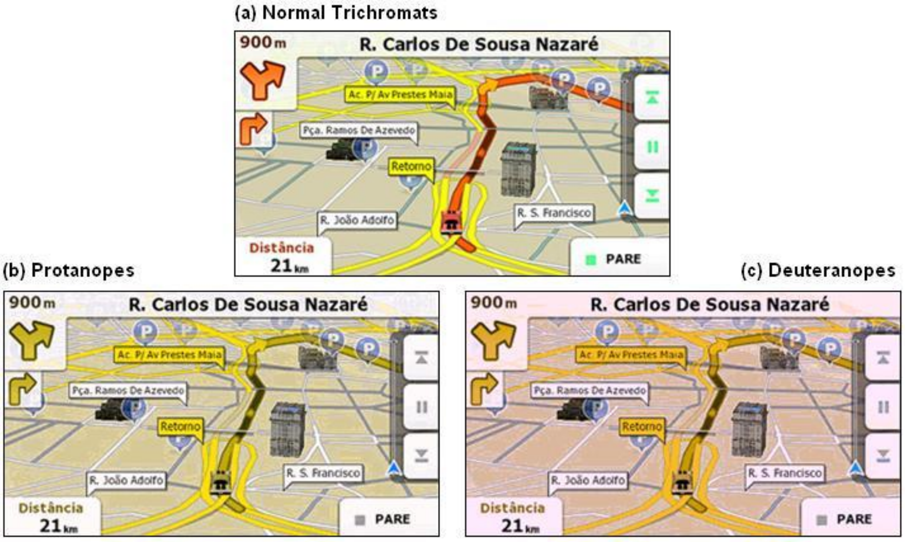

Figure 5. Display of a commercial map display as seen by (a) normal trichromats and results of color transformation as seen by (a) protanopes and (b) deuteranopes.

3.2 Basic Analysis of an In-house Prototype

An in-house system was designed and developed for research proposals (Pugliesi 2007; Pugliesi et al. 2009). The system was developed by using ESRI MapObjects library and Microsoft Visual Basic. The RGNS is an audio-visual-dynamic ego-centered map, which does not displays texts for distances and neither turn-by-turn inset- arrows, in the same display. The map design of the representations for the prototype was based on the approaches of Keates (1989), Decanini and Imai (2000), Pugliesi (2007) and Pugliesi et al. (2009). The system has also been improved by Marques (2011) (Figure 6-a).

To develop a module for red-blinds and green-blinds it was necessary to understand how color-blind users see the map created for normal trichromats. The Paint Shop Pro was also used with those specific color palettes (Figure 4-b and Figure 4-c) and the results are showed in the Figure 6-b and Figure 6-c. When these interfaces are presented inside a car, in a light day, the direction arrow, car and route symbols do not present acceptable contrast for protanopes and deuteranopes. In addition, the map for deuteranopes was the worst case in terms of figure-ground segregation. So it was necessary to adjust the colors by using a reduced number of available options in each palette.

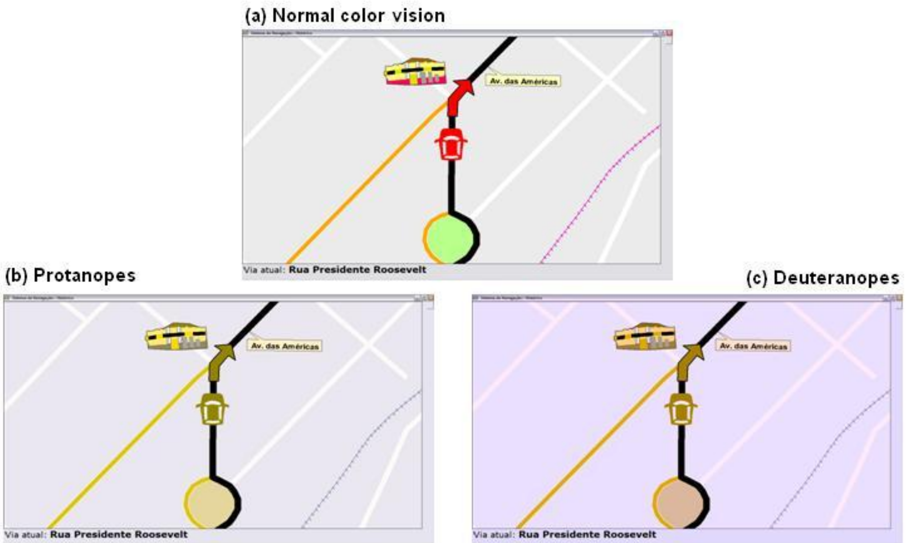

Figure 6. Display of the in-house RGNS as seen by (a) normal trichromats and results of color transformation as seen by (a) protanopes and (b) deuteranopes.

3.3 Cartographic Representations for Color-Blind

To answer the question "how should visual cartographic representations be for red-blinds and green-blinds?" it was used those maps as seen by protans and deutans which are presented in the Figure 6. The main strategy was to augment the contrast between figure and ground. In order to do so the Paint Shop Pro palettes were employed to the maps showed in Figure 6-b and Figure 6-c, for protans and deutans.

A XENARC small-screen LCD display, seven-inch monitor, was used to present the maps inside a car, in a light day. The maps were analyzed visually and it was noticed that some symbols did not present appropriate contrast for representing the spatial elements for route following tasks. For protanopes and deuteranopes a total of five symbols had their color changed: roundabout, car, route, direction arrow and main roads (Table 1 and Figure 7). For Deuteranopes, the options were harder to create segregation between figure and ground. That is because the streets in white and the blocks in light gray had their colors shifted to something similar to 'light salmon'.

Symbols	Colors	
	Protanopes	Deuteranopes
Roundabout	RGB(238,226,189)	RGB(225,216,253)
Car	RGB(0,101,202)	RGB(0,115,194)
Route	RGB(94,93,97)	RGB(103,79,0)
Direction arrow	RGB(0,121,242)	RGB(0,140,236)
Main roads	RGB(236,211,15)	RGB(246,188,35)

Table 1. Colors proposed for protans and deutans.

For both maps, it was applied differences in lightness for car and direction arrow symbols. The reason is to show a visual hierarchy between the elements, by contrasting car with the blocks in 'gray' colors, as well the arrow with route. The same blue color also purposes to create a visual grouping by proximity.

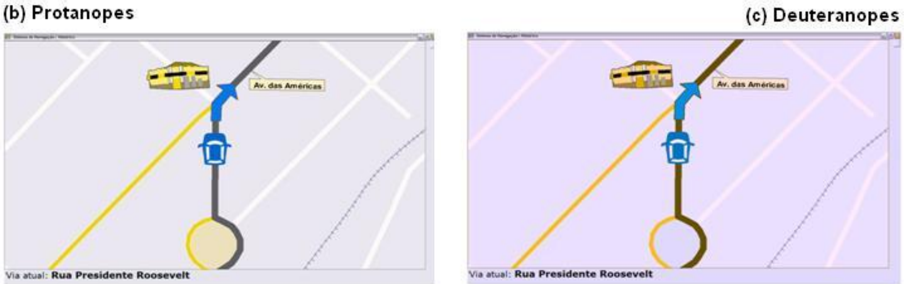

Figure 7. Final cartographic representations for (a) protans and (b) deutans.

4. DISCUSSION AND RECOMMENDATION

This work intended to explore two basic questions related to the design of cartographic representations for protanopes and deuteranopes. It was showed that RGNS are being developed without reasonable considerations about figure-ground segregation for visual impairment. It was discussed that a visual map interface designed for trichromats may not be understood by dichromats. Thus, the systems should have options for color-blind people.

The second part of this work aimed to create some cartographic representations for protanopes and deuteranopes, based on increasing the contrast between figure and ground, as well by grouping car and direction arrow symbols. Although blue is a color commonly used to represent water, the color blind palettes just present a few options (Figure 4). The blue was the best option remained to be applied in order to create segregation. Due to limitations of MapObjects, which does not have tools for perspective view, the map was designed only in orthogonal view. Probably other technology will replace this one.

Visual audio-dynamic maps have presented advantages for drivers with normal color- vision. Spatial information, depicted visually, like the actual position of the car, route segments, roads, junctions, distance to turn and so far, have been required by the drivers (Streeter et al. 1985; Burnett 1998; Labiale 2001; Pugliesi and Decanini 2009). Furthermore, new systems with tactile information will be introduced in the market to indicate maneuver direction, for instance. Visual, tactile and sound variables can be used to present spatial information to the users (Alm 1993; Slocum 2009).

The results reached in this work are being implemented in the prototype. Necessary it to evaluate the cartographic representations in terms of subjective preference for color-blind users without using voice messages and turn-by-turn arrows. Further, it is suggested to add and evaluate other 'formats of information' and 'types of modality' to verify which of them are more required and effective for color-blind users.

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