Analysis and Improvement of the OpenStreetMap Street Color Scheme for Users with Color Vision Deficiencies

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Abstract. In this paper we analyze the street class color scheme of the "Standard" openstreetmap.org map style in regards to users with color vision deficiencies. We describe the process of adjusting the existing color scheme to accommodate these users whilst trying to preserve the overall appearance. The results of an online user study to test both the original and the adjusted color scheme are presented.

Keywords: color vision impairment, color vision deficiency, color blind users, color design, color scheme, OpenStreetMap

1. Introduction

In a field like cartography, where color is used as a graphical variable, color vision deficiencies can turn interpreting a map into a hard, frustrating or even impossible task. Affected users tend to confuse certain colors and have problems to comprehend the presented content. If a map style is designed without accessibility in mind, problems are very likely. This is especially true for organically grown map styles like that of the crowdsourced open map data project OpenStreetMap[1]. Objective of our research is to evaluate the color vision deficiency issues of the street class color scheme of the default map on openstreetmap.org, improve and test it in an online survey.

2. Background and Related Work

About 8 % of males are affected by red-green color vision deficiencies (CVD). For genetic reasons women are much less likely to be affected

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[1] http://www.openstreetmap.org

(~0.4 %). About 4.6 % of men are affected by deficient green color vision (deuteranomaly), about 1.3 % by green blindness (deuteranopia). Deficient red color vision (protanomaly) affects about 1.1 % of men, another 1 % are red blind (protanopic). (Sharpe et al. 1999)

These deficiencies lead to an altered perception of color. Both deutan and protan deficiencies lead to confusion of red and green color shades. Sharpe et al. (1999) could not reference any well researched estimates for the very rare tritan deficiencies (deficiency or lack of blue color vision), however they mention numbers from 1:1,000 to 1:65,000 people being affected. *Figure 1* shows the estimated perceived color spectrum of affected observers that was calculated with the software tool Color Oracle[2] presented by Jenny and Kelso (2007). Color Oracle allows the user to filter the computer display's colors as if seen by a color vision deficient user. All simulations in this paper were done using this software.

Figure 1. Estimated perceived color spectrum of deuteranopic (top), protanopic (middle) and normal sighted (bottom) observers (Jenny and Kelso 2007).

Color vision deficient users take longer to find information in primarily color coded graphics, if they can recognize it at all (Cole 2004). To counter this in cartographic applications Jenny and Kelso (2007) advise to use safe color combinations with annotations and additional non-color codings. For the classification of line classes Jenny and Kelso (2007) suggest using different colors, labels and patterns. In a quantitative scheme a change of stroke width might be appropriate, in a qualitative scheme this would suggest a hierarchical order of likely non-hierarchical classes. Labeling lines would help tremendously. For complex maps Jenny and Kelso (2007) also suggest the use of different line patterns. A combination of multiple coding

[2] http://colororacle.org/

styles with annotations would be advisable. Brewer (2005) notes that especially differences in lightness can help CVD affected users to differentiate between colors. Zhang and Montag (2006), Wijffelaars et al. (2008), and Ramathan and Dykes (2011) described studies that also evaluated and compared color schemes. However they test colors used in choropleth maps, images with 256 classes or just evaluated them from an aesthetic perspective and did not consider CVD. In contrast Brewer and Olson (1997) describe a study about color selection for users with CVD. Results show that participants with CVD were as accurate as those with normal vision if adjusted colors were used. Olson & Brewer (1997) noted that previous research on the topic of color confusion was based on „averages and on stimuli that are far different from maps". Culp (2012) developed an algorithm that facilitates a re-coloring of maps after publication for scenarios where accessibility was not considered in the initial map design.

3. The openstreetmap.org Street Style

The openstreetmap.org (OSM) map uses a dynamic interface that allows the user to change the map scale on 18 pre-defined zoom levels. Incrementing the zoom level by one halves the map scale. openstreetmap.org allows the user to choose different map styles. This paper deals with the "Standard" style[3] which is the default general-use style (previously also known as "Mapnik" style).

The map style uses five distinctly colored street classes. These are, in descending hierarchical order: "motorway" in blue, "trunk" in green, "primary" in red, "secondary" in orange and "tertiary" in light yellow (see *Table 1*). This qualitative color scheme corresponds with street class colors traditionally used in the United Kingdom. All these street classes are displayed as continuous lines, on higher zoom levels with casings. Other street classes such as "residential", "living_street" or "road" are displayed in gray, white with a gray border, or with different stroke styles. In the following the street classes are named by their main color hue, as to ease understanding for the reader: motorway is *Blue*, trunk is *Green*, primary is *Red*, secondary is *Orange* and tertiary is *Yellow*.

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[3] Displayed by default on http://www.openstreetmap.org, selectable by using the layer menu in the upper right and choosing "Standard"

Original color scheme		Class	Adjusted color scheme	
HSL value	**Color**		**Color**	**HSL value**
152,86,160		**Motorway** (*Blue*)		168,86,144
85,103,181		**Trunk** (*Green*)		85,95,132
254,176,194		**Primary** (*Red*)		240,255,194
24,249,210		**Secondary** (*Orange*)		31,190,192
42,255,217		**Tertiary** (*Yellow*)		42,255,217

Table 1. HSL values and colors of the original and the adjusted color schemes.

The presentation of the street classes changes with the zoom level: *Blue* and *Green* are displayed at zoom level 5 and above, *Red* at zoom level 7 and above, *Orange* at zoom level 9 and above, *Yellow* at zoom level 10 and above. The streets are also displayed with different stroke widths, generally getting wider with an increasing zoom level. Additionally a casing in a darker shade of the main color of the class is added at zoom level 12 and above. The *Orange* class' color is changed to a slightly lighter shade at zoom level 12 when the casing is added. The color of the *Yellow* class is changed from a gray to a light yellow with gray casing at zoom levels 13 and above.

Regarding problems for CVD affected users the following hypotheses were formed based on analyzing an intersecting grid of colored shapes (*Figure 2*) as well as map images (*Figure 3*) with Color Oracle:

The main problems are confusions and indistinguishability between the classes. When displayed with a considerable stroke width and directly adjacent, *Green* and *Red* can be differentiated by both deutan and protan deficient users, however the identification is problematic. If displayed with a thin stroke width as on low zoom levels, these classes are indistinguishable for deuteranopic users. *Green* and *Orange* are problematic for users with protan deficiencies, regardless of zoom level or combination. Another problem for them is the *Blue* class in combination with *Red* on lower zoom levels. The *Yellow* class can be distinguished by all users in all cases. Users affected by tritan deficiencies should have no particular problems with the existing street class color scheme.

For a normal sighted users the street class color scheme has no intuitive hierarchical order. For deuteranopic or protanopic users however all street colors apart from the *Blue* class have a seemingly similar green-yellow-gray-brown-ish hue. The *Red* class then appears darker than *Green*, so if the similar hue induces the color vision deficient user to interpret the colors in a hierarchical order, then the user might falsely interpret the hierarchy as *Blue*, *Red*, *Green* etc., with *Red* and *Green* interchanged.

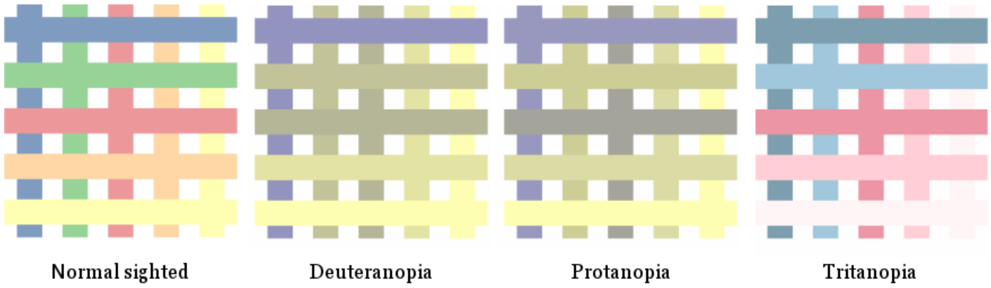

Figure 2. The original street class colors arranged in a grid displayed in simulated color blindnesses.

Figure 3. Example map data rendering using the original colors on zoom level 13 in simulated color deficient vision (Map data: © OpenStreetMap contributors, CC-BY-SA 2.0).

4. Adjusting the Color Scheme

To solve these problems we attempted to find colors which

- are distinguishable,
- allow the unambiguous identification of street classes,
- do not suggest a wrong hierarchy,
- closely resemble the original color scheme.

The HSL color space was used as its parameters hue, saturation and lightness resemble human color perception (Brewer 2005) and thus simplify the application of appropriate color changes.

To account for the uncontrolled user environment the research was conducted on a standard, uncalibrated TFT monitor. Findings were evaluated on several other uncalibrated end-user displays, such as a netbook, a smartphone and a tablet before the user study.

Colors were mixed in an iterative process, one HSL parameter was changed at a time. Changes were focused on hue and lightness. For evaluation the colors were visualized both in an intersecting grid (*Figure 4*) as well as rendered with actual OSM data (*Figure 5*). The darker casings were created using the adjusted color scheme's hue with a lightness difference equal to that in the original scheme. Color Oracle was used to simulate CVD. The color scheme's appeal to a normal sighted observer was taken into account. *Table 1* shows the final color scheme.

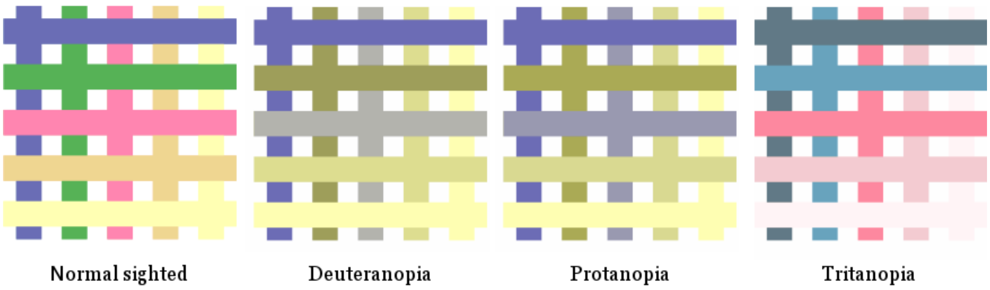

Figure 4. The adjusted street class colors arranged in a grid displayed in simulated color blindnesses.

Figure 5. Example map data rendering using the adjusted colors on zoom level 13 in simulated color deficient vision (Map data: © OpenStreetMap contributors, CC-BY-SA 2.0).

5. Test Stimuli and Experimental Design

To test both the original and the adjusted color scheme a comprehensive experiment was designed and conducted as online survey.

5.1. Street Combinations

Three relevant street class combinations were identified and tested, see *Figure 6* for an example of each:

A **single street segment** gives the user no opportunity to compare its color to an adjacent or nearby segment of another, differently colored street.

To test a **combination of street classes**, allowing the user to compare colors of nearby streets, a combination of multiple unconnected streets was displayed. They were connected by a white street in a circular crossing.

A **network of highly connected streets** allows the user to consider directly adjacent street colors for comparison purposes. Here at least one instance of every street class was displayed and each class was connected at least once with every other class. The style's rules as to which class was displayed "on top" another at crossings were not changed.

5.2. Zoom Levels

Four zoom levels were identified as being representative because of their significant changes in contrast to the other tested zoom levels. The images in *Figure 6* show an example at each zoom level.

Starting at **zoom level 7**, the classes *Blue*, *Green* and *Red* are being displayed. The streets are displayed at a sub-pixel size with graphical filtering leading to a slight alteration of color.

From **zoom level 10** onwards, all five discussed street classes are being displayed.

Starting with **zoom level 13**, the stroke widths of the lines are significantly increased. There are no color changes past this zoom level in the original color scheme. Casings were added at zoom level 12.

The styles of street classes are not altered past **zoom level 17**. The stroke widths are at their maximum.

5.3. Tasks and Procedure

Suitable simple street courses were created and rendered in both the original and adjusted color scheme using the same setup as openstreetmap.org. The street courses were scaled to look the same at each tested zoom level.

The test images display street courses on the map style's neutral background color, a very light gray. Testing the colors on various backgrounds such as green or brown would have required considerably more tests and was not conducted. For the same reason no other map features were displayed in the images. *Figure 6* shows examples.

To counter learning effects the test questions were displayed in randomized order within the survey. The images were randomly rotated to prevent recognition.

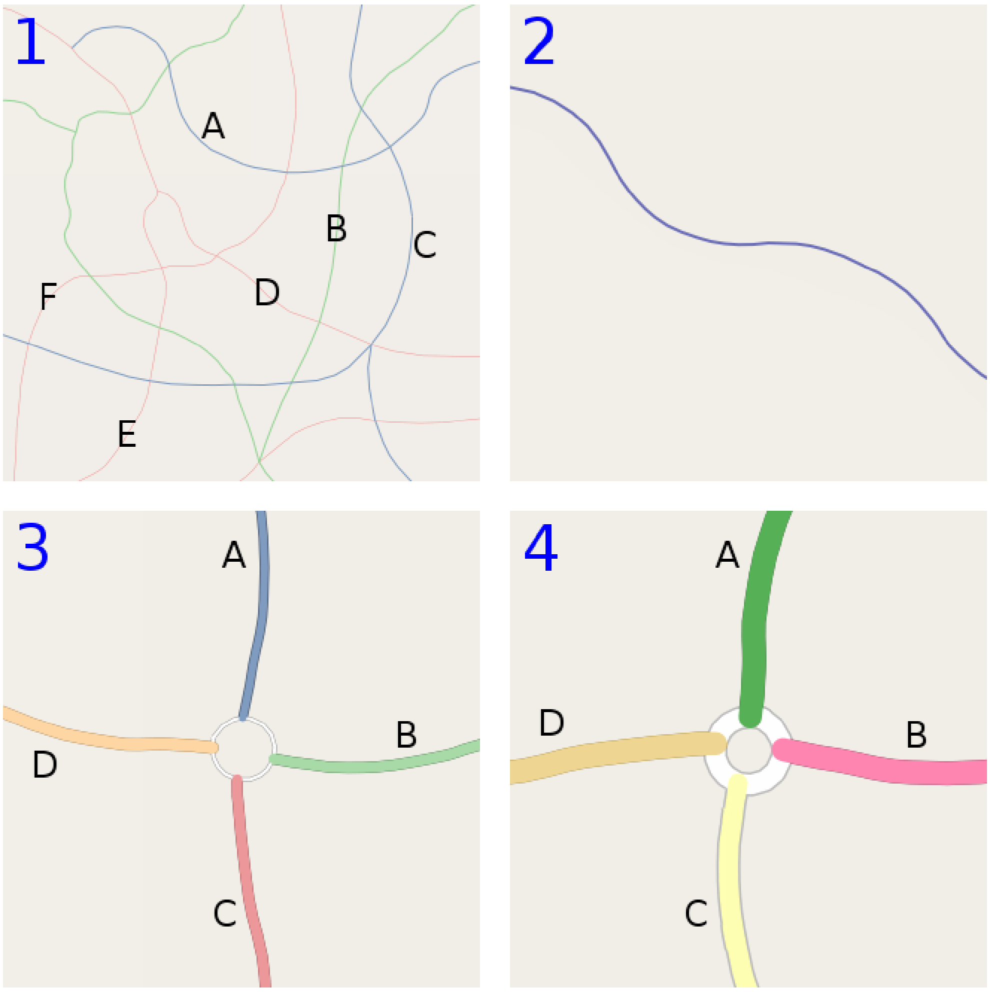

Figure 6. Examples of test images:
1 Highly connected street network, zoom level 7, original color scheme;
2 Single street segment, zoom level 10, adjusted color scheme;
3 Unconnected combination of streets A, zoom level 13, original color scheme;
4 Unconnected combination of streets B, zoom level 17, adjusted color scheme.

A simple legend was displayed showing the relevant street classes. Selected streets in the images were labeled with letters and the user was asked to pick the corresponding street class number from the legend. The user could also choose the option “I cannot identify the class of the street reliably”. The zoom level was not displayed so the user had no indication of the map's scale. See *Figure 7* for an example.

Participants were asked to participate in the survey under usual working conditions.

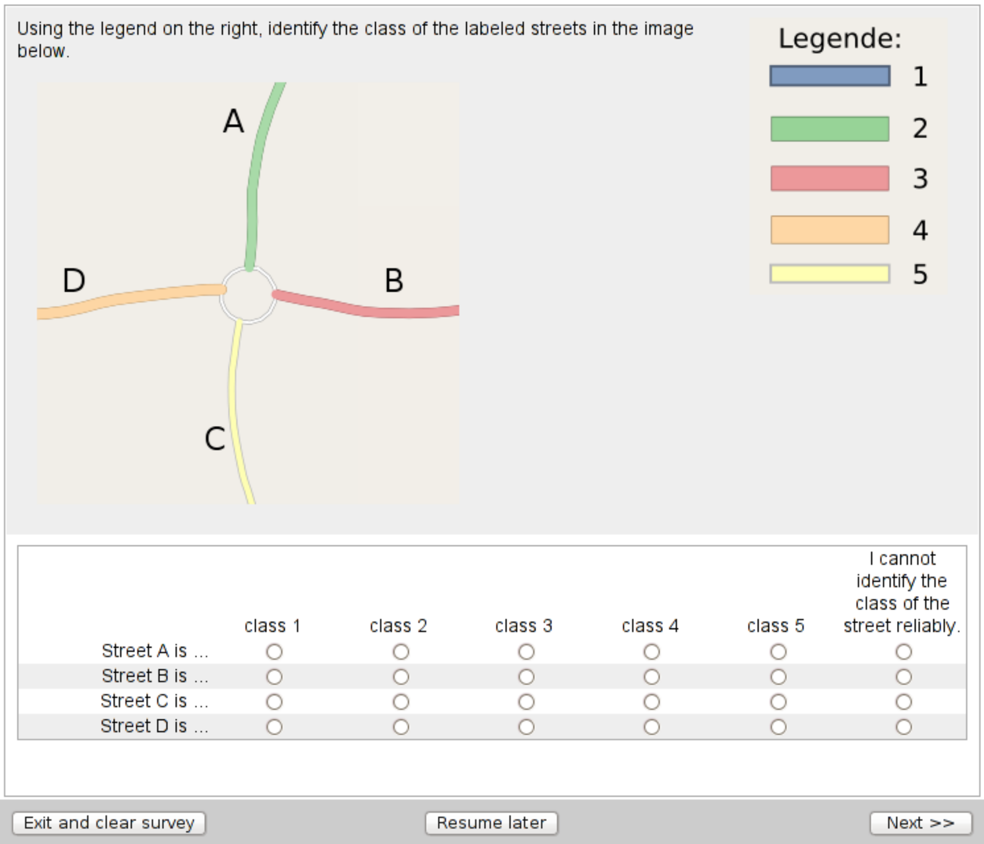

Figure 7. Example of a question in the survey.

6. Results and Analysis

6.1. Participants

We recruited participants online in CVD communities as well as the OSM community. 129 self-assessed CVD affected participants completed the survey. One third of the users stated a deuteranopic CVD: 21 % a deuteranomaly, 9 % deuteranopia. 10 % stated to be affected by a protanomaly, 5 % by protanopia. One user specified a tritanopic CVD (a tritanomaly). 3 % of the participants said to be completely color blind. 37 % chose the option "(...) red-green deficiency (I cannot specify)".

75 % of the participants rated their ability to read maps to be good or better, 17 % as average. One third of the users stated never to have used openstreetmap.org before. The remaining 67 % were evenly distributed between the remaining options from "rarely" to "all the time".

6.2. Street Class Identification

Using the adjusted color scheme the identification rates generally improved, in some cases dramatically. With the adjusted color scheme 90 % of the answers were correct compared to 76 % with the original scheme. Below the results are presented grouped by street class. *Figures 8* to *10* show the results and the absolute change in identification rate in diagrams.

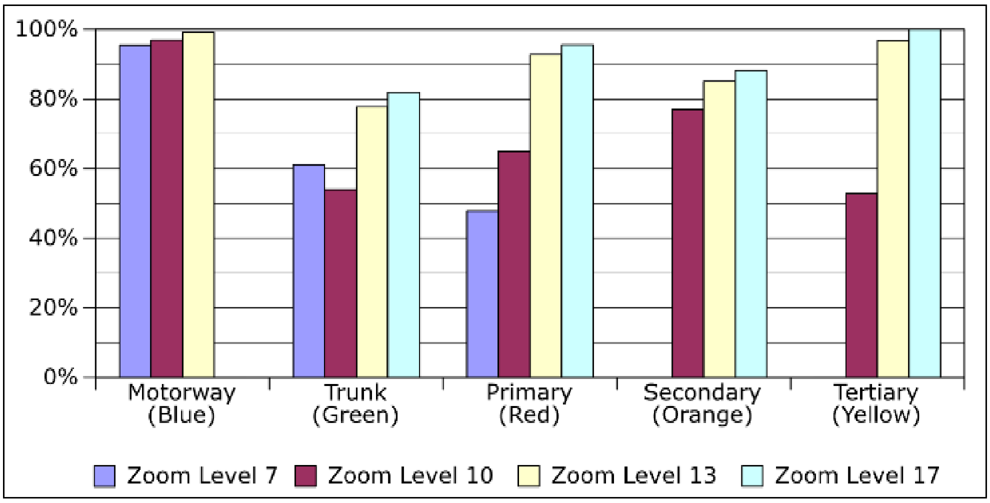

Figure 8. Identification rates using the original color scheme, grouped by class and zoom level.

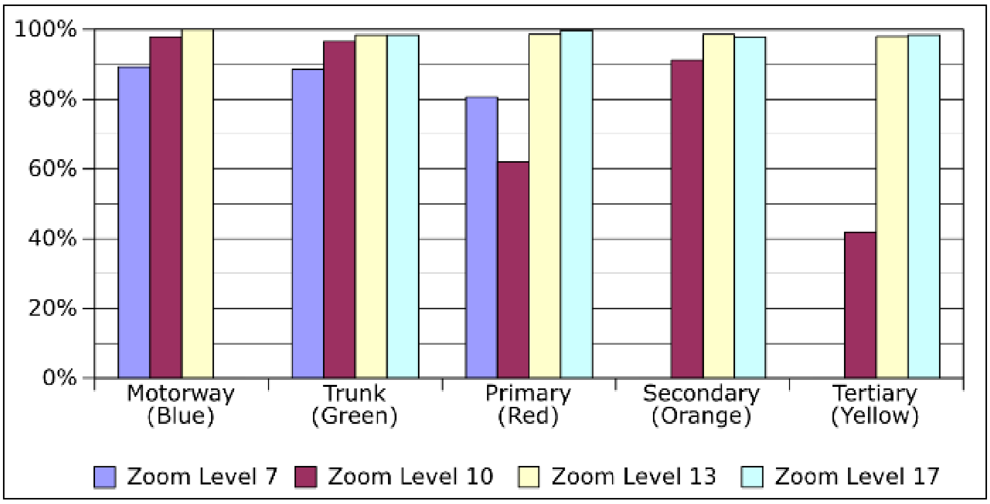

Figure 9. Identification rates using the adjusted color scheme, grouped by class and zoom level.

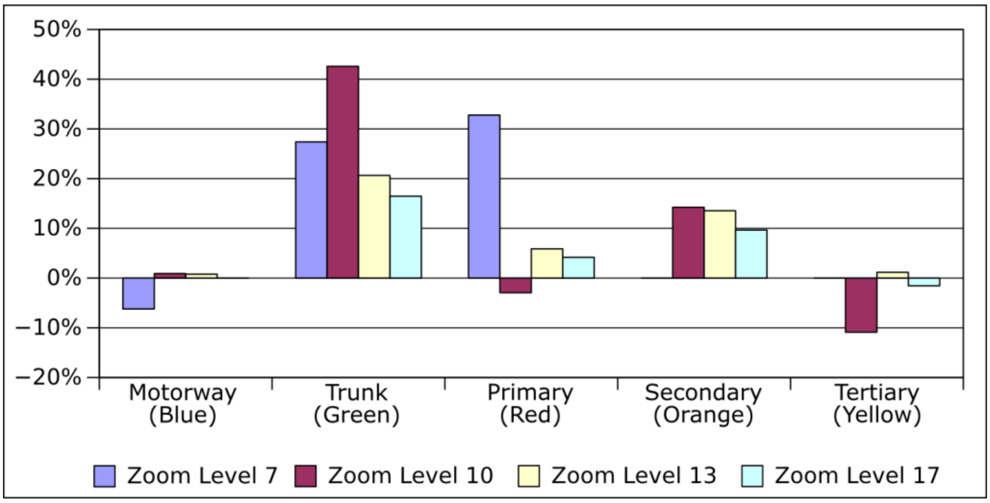

Figure 10. Absolute change in identification rate per class and zoom level between original and adjusted color scheme.

The identification rate of the ***Blue*** class ranked 94 % and higher with no significant changes between color schemes except for zoom level 7. On this zoom level the identification rate deteriorated from a near perfect 91 % to 74 %. 16 % of the participants now falsely identified the class as *Red*. Another less severe decline was observed for the street network on the same zoom level. Here the identification rate of a *Blue* instance decreased from 98 % to 92 %.

The identification rate of the **Green** class was significantly improved. All but one test resulted in identification rates of 91 % and higher. The exception being the single street segment at zoom level 7 with only 78 % (18 % up from 60 % with the original color scheme).

Overall the **Red** class was slightly improved. While its identification rates on the higher zoom levels 13 and 17 were already 93 % and higher with the original color scheme (which was improved to 98 % and higher), the lower zoom levels remain problematic. At zoom level 7 rates of 43-53 % were improved to 73-87%. At zoom level 10 identification rates stagnated or worsened as much as 8 % to values between 51 % and 71 %. Here *Red* was often confused with the gray of the *Yellow* class in the legend. Confusions with *Green* were mostly eliminated.

Interestingly a difference of up to 18 % identification rate for **Red** occurred between the two tested variations of unconnected street combinations at zoom level 10. In a combination of *Blue*, *Green*, *Red* and *Orange*, 69 % correctly identified *Red*, while in a combination of *Green*, *Red*, *Red* and *Orange*, only 58 % respectively 51 % identified it correctly. As only the significant difference between the images is the addition of an instance of *Blue*, this hints at the *Blue* class being used for comparative identification of *Red*.

The **Orange** class was identified without major problems (98-100 %) in most cases. As with Red zoom level 10 turned out problematic. While improved to an average of 94 % (+14 % from 80 %) in the combination images, for the single segment this change occurred at a lower point: 67% in the original color scheme to 81 % in the new one. The street network improved similarly to 89-91 % in the adjusted color scheme.

The **Yellow** class was expected to be unproblematic and thus not tested well. It was tested in the combination images at zoom levels 13 and 17 plus as single segment at zoom level 10. On the higher zoom levels the class was displayed in its main color and was correctly identified by 95-100 % of participants in both color schemes. At zoom level 10 however the identification rate was only 53 % in the original color scheme and worsened to 42 % in the new one. Here it was displayed in gray as defined in the original color scheme. At this zoom level confusion with *Red* by 5 % of the participants with the original scheme increased to 12% with the new one. With the misidentification of *Red* as *Yellow* (as mentioned above) it is safe to say that the new Red color is too similar the light gray of the Yellow class on zoom level 10.

6.3. Time Measurements

In addition to the improved identification rates with the adjusted color scheme, we also measured a decrease in the times participants took to answer the questions. Overall the median times were reduced by 10 % from the original to the adjusted color scheme. Single street segments were identified 9 % faster, the combinations 6 % and the networks 13 % faster. The only deterioration happened on zoom level 7 where *Blue* in the adjusted color scheme took the participants 17 % longer than with the original scheme. The largest improvements were recorded for the single *Green* class on the zoom levels 10-17 where we observed a 26-27 % faster identification.

7. Discussion and Outlook

Given the results of the survey, adjusting an existing color scheme to better accommodate CVD affected users showed to be very well possible, albeit complex. The remaining problems on the lower zoom levels could be solved in the future by adjusting colors only on and especially for these zoom levels.

The test's distinction between the combination of street instances both connected and unconnected showed to have been redundant for the most part. The results for zoom level 13 and 17 showed to be very similar with a slightly higher average identification rate for zoom level 17. Testing zoom level 17 in addition to 13 can be considered redundant based on this.

The low scores for some of the single street segments should not be overstated. It is not likely for streets to be shown isolated in the map. In hindsight these questions might have been an unrealistic case in a complex street map.

The results for neither OSM users nor participants from the United Kingdom show a significant difference to the rest, so a bias from being previously exposed to the original color scheme or a similar one can be ruled out. In future studies these demographic information would not need to be asked for.

The research was limited to color changes. Several participants mentioned using the street's widths in their decision making. Adjusting these to be more distinct might be a simple step towards easier identification, especially on the lower zoom levels.

The OSM map style is an organically grown style with a wide selection of displayed features such as differently colored kinds of rural and urban land use. In our case only few selected feature classes of a highly complex map style were analyzed in an isolated environment, ignoring the multitude of different possible background colors and occurring contrast. The so-called effect of simultaneous contrast has been described by Albers (1970), Monmonier (1996), Brewer (1997) and Lyons (2000) and could give further insights for the adaption of the colors.

Utilizing the concept of confusion lines (as done by Olson and Brewer 1997) would allow for better identification of problematic color combinations and appropriate color adjustments. Using a perceptually uniform color space like CIE L*a*b would allow to maximize contrast between colors by measuring color distances. Another approach by Steinrücken et al. (2013) maximizes the minimal distance between colors by formulating an optimization model that considers cartographic guidelines. The authors state that thereby it is possible to select clearly distinguishable colors.

Designing a completely new color scheme for OSM focused on color vision and accessibility might be easier than carefully adjusting colors to suit the needs of CVD affected users whilst not significantly changing the overall appearance of an existing scheme. Also the visual appeal to normal sighted observers could be neglected.

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