International Cartographic Association
Association Cartographique Internationale

User testing of reading maps with a dark background

Barbora Jančová [a,*], Stanislav Popelka [a]

[a] *Department of Geoinformatics, Palacký University Olomouc, Czechia, b.jancova03@gmail.com, stanislav.popelka@upol.cz*

* Corresponding author

Keywords: colour, dark mode, questionnaire, usability testing

Abstract:

The goal of this research is to explore whether users perceive lighter colors on maps with dark backgrounds as representing higher values. In recent years, dark mode has grown increasingly popular, and many platforms now include it. This trend has also emerged in web cartography, for example, in nighttime navigation. However, there remains a lack of empirical studies examining the usability of maps when comparing these two background options (Qiao and Wu, 2023).

Schiewe (2024) experimentally tested whether specific visual conditions, such as dark mode, alter human perception of values. His primary research question was whether the "light-is-more" principle prevails on a dark background, as light colors possess the highest contrast in this display mode and are visually the most prominent. This abstract draws inspiration from his approach to map creation.

For this work, a set of 48 map outputs was created. These outputs were generated for both light and dark backgrounds, featuring variants with and without a legend (24 maps with a legend and 24 without). To determine user preferences, four color hues were selected for the visualization: red, brown, blue, and green. Each color had 12 versions: 3 on a dark background with a legend, 3 on a dark background without a legend, 3 on a light background with a legend, and 3 on a light background without a legend. Three different tools were used to design the color scales: ColorBrewer (Harrower & Brewer, 2003), default ArcGIS Pro scales, and custom-chosen scales. Web cartography introduces specific technical challenges, such as inconsistent color rendering across different devices. According to W3C standards, web browsers should display images without an embedded ICC profile as if the standard sRGB color space were assigned to them (Brychtová, 2015). To prevent these inconsistencies and ensure accurate color reproduction, the sRGB ICC color profile was explicitly embedded into all map outputs in this thesis.

To collect user preferences, a questionnaire was created using the LimeSurvey platform. Participants were presented with maps and asked to click on the color they believed represented the highest value. Over the course of one month, 1,012 responses were collected, out of which 507 were complete and used for the analysis. Since the questionnaire alone could not reveal exactly how users visually processed the maps, eye-tracking was used to examine 20 maps selected based on statistically significant or otherwise interesting findings from the questionnaire. Furthermore, because only 39 cartographers completed the survey, this eye-tracking experiment provided a valuable supplement to the data gathered from this specific user group. A focus group was chosen as an additional qualitative research method. The main goal of using this method was to give participants more space to share their own opinions, which the previous methods (questionnaires and eye-tracking) did not allow.

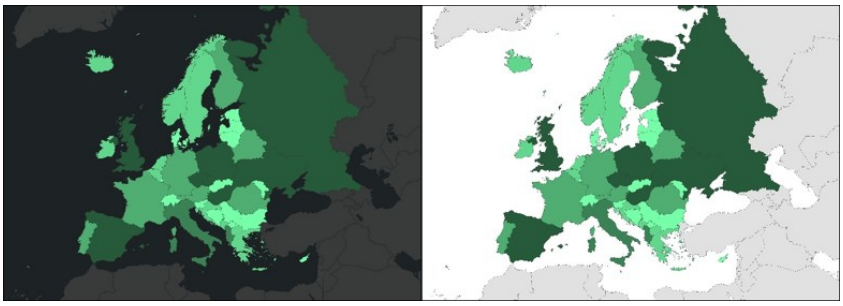

Figure 1. Green colour scale on maps with dark and light backgrounds.

The analysis of the collected data brought several important findings about how users perceive maps in different display modes. The survey confirmed clear generational differences in user preferences. While respondents under 44 preferred

https://doi.org/10.5194/ica-abs-12-49-2026

dark mode mostly for aesthetic reasons and to reduce eye strain, the over-45 age group showed a more conservative approach, mainly because they found light text on a dark background harder to read. This trend was also reflected in the use of map applications, where a permanent dark mode setting was most often reported by the 21–24 age group.

A key finding from the map interaction testing was the dominance of the intuitive "dark-is-more" principle. Although the presence of a legend demonstrably increased the proportion of correct answers, many respondents still made errors with specific color scales, even with the legend's visual aid. Furthermore, statistical testing using Pearson's chi-square test confirmed that the legend serves as a strong unifying element, effectively eliminating differences in intuitive perceptions of color hierarchy across generations.

The analysis of task completion time, with a median of 6.8 seconds, demonstrated that respondents paid sufficient attention to evaluating the maps. The observed deviations in time under 4 seconds, which occurred in 384 respondents for at least one map, are more likely due to a momentary loss of concentration from the high number of tested variants (48 maps in total) than to systematic automatic clicking. This conclusion regarding fluctuating attention and the impact of color schemes on human intuition was subsequently supported by supplementary eye-tracking testing.

The eye-tracking data provided deeper insights into users' visual behavior, confirming that participants predominantly studied the map legends at the beginning of testing or when a visual change occurred. Once they memorized the color scale, their fixations on the legend rapidly decreased. Furthermore, the analysis of gaze patterns revealed that decoding values on dark backgrounds was cognitively more demanding. Participants exhibited significantly more frequent and longer fixations on the legend in dark mode than in light mode, which correspondingly increased their overall task completion time. Interestingly, this laboratory testing group, consisting mostly of cartographers, showed an overall preference for maps on a light background, which directly contrasted with the general public's preference for dark mode observed in the online survey.

The focus group method revealed both agreement and disagreement between laypersons and cartographers. Both groups agreed that dark-mode maps are mainly useful at night to reduce eye strain, are visually appealing but unsuitable for traditional atlases, and that the brown scale performed poorly. They also noted that the darkest shades often blended into dark backgrounds, making lighter colors stand out, and accepted the inverse “light-is-more” principle for some ordinal scales (e.g., air quality). However, important differences emerged. Laypersons criticized the red scale for overly similar and aggressive shades, while experts accepted it because polygon lines remained visible. Experts instead criticized other scales for abrupt color transitions. Polygon boundaries were another point of disagreement: laypersons accepted dark boundaries, whereas cartographers considered them illegible on dark backgrounds. Laypersons focused mainly on aesthetics, while experts emphasized technical issues, optical illusions, and the complexity of dark map design. Finally, although both groups accepted the “light-is-more” principle for some ordinal data, cartographers stressed the need to preserve established conventions for standard quantitative data.

Overall, the results indicate that the intuitive ‘dark-is-more’ principle generally prevails; however, in maps with a light background, a higher proportion of respondents associated lighter colors with higher values, particularly with the green color scale. Beyond this key finding, the study also provided a range of additional qualitative insights. Based on the synthesis of these findings, specific recommendations for cartographic design in dark mode were formulated:

(1) When representing the highest value with a light color, it must clearly stand out, while the darkest color should recede into the background without blending completely; (2) Green and blue scales are the most suitable, as their lightest shades effectively "shine" on a dark background; (3) Pure white should be avoided as the lightest shade, as its extreme contrast may falsely indicate missing or zero data (4); For polygon boundaries, varying shades of gray are recommended instead of pure white (too contrasting) or black (which blends into the background); (5) The default color scales in ArcGIS Pro are not recommended for dark mode without manual contrast adjustments.

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