Small differences: Limits of Legibility of Cartographic Symbols on High- and Ultra-High-Resolution Mobile Displays

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Abstract. This paper reports on a lab study that attempts to experimentally establish the limits of legibility of fundamental cartographic symbology on modern smartphone screens. Participants were presented six classes of stimuli on four different displays of varying pixel densities, and were asked to identify the cartographic symbol shown among a set of choices. The results of the experiment should help to develop updated guidelines for minimal dimensions of cartographic symbology for use on mobile phones and other high resolution digital displays.

Keywords. Map perception, map symbols, user study, cognition, controlled experiment

1. Introduction and Problem Statement

Cartographic design guidelines usually demand that maps presented on screens use larger and coarser symbology than paper-based maps, due to the reduced fidelity of the display medium (Neudeck, 2001; Lobben & Patton, 2003; Jenny et al., 2008). However, such recommendations were generally derived from the state of development of display hardware around the turn of the millennium, when desktop monitors were limited at pixel densities around 100 pixels per inch (ppi) (Malić, 1998). In recent years, screens of mobile devices have become available with ever higher pixel densities. Today, there are virtually no technical limitations in manufacturing displays of ultra-high pixel densities (Katsui et al., 2019), and the highest pixel density for commercially available mobile phones currently lies at 801ppi (Sony Xperia Z5 Premium). However, guidelines for the dimensions of cartographic symbology have not been updated to reflect those developments. Does the increased fidelity of digital displays mean that cartographers can now revert

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to the minimum dimensions that have been traditionally used for printed maps? Can even smaller symbol sizes be used for smartphones due to the increased contrast ratio and the reduced viewing distance? Or does the recommendation to use larger symbology for presentation on screens still hold, even for displays of the highest resolutions?

2. Study Design, Apparatus and Stimuli

Figure 1. Lab setup for the study. Top: viewing stations with mobile phones of varying pixel densities mounted behind bezels, rail to ensure constant viewing distance, curtain to minimize reflections. Bottom left: mobile phone mounting fixture. Bottom right: Bezel covering mounting fixture to reveal an area of identical size for each station.

This paper reports findings of a lab study that attempts to experimentally establish the limits of legibility for fundamental cartographic symbology on modern smartphone screens of varying pixel densities. For the experiment, four mobile phones with screens of varying pixel densities (228 / 342 / 522 / 801 ppi) were mounted behind bezels, revealing only a square portion of 48 x 48mm of each phone display (as mandated by the smallest screen size used in the study). In front of these viewing stations, a rail was mounted to ensure equal viewing distance of approximately 30cm (see Fig. 1). Participants were presented a sequence of stimuli on each display, and were asked to select the symbol best matching each stimulus by pressing the corresponding on-screen button on a separate response device. Stimulus size was specified in millimeters and adjusted using a staircase procedure, which upon three consecutive correct responses decreased the stimulus size, and upon one incorrect response increased the stimulus size. Using this procedure, the limit at which stimuli could still be reliably discriminated was established for each participant, display and stimulus class.

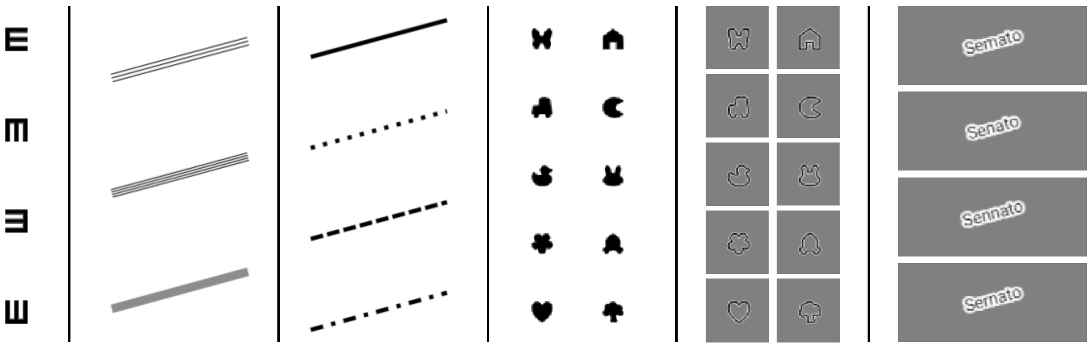

Figure 1. Types of stimuli which participants were asked to distinguish in the experiment. (1) Tumbling E's (2) parallel lines (3) dashed/dotted lines (4) "Auckland Optotypes" symbols (5) "vanishing" symbols (6) word variants. (The orientation of stimuli for tasks 2,3 and 6 was randomized for each trial in the experiment)

Each participant would perform all tasks of the experiment on all four display stations, in randomized order. At each station, the identical sequence of tasks was run, each representing a specific class of stimuli related to cartographic symbology (see Fig. 2) – (1) "tumbling E's", which are established as a standard test for visual acuity; (2) three / four parallel lines or a grey line, random orientation; (3) dotted, dashed, dot-dash and solid lines, random orientation; (4) point symbols taken from the "Auckland Optotypes" symbol set (Hamm et al., 2018); (5) Point symbols, drawn with a white-black-white outline against a grey background ("vanishing" into grey when beyond legibility) ; (6) Short words, made up to look plausible as a toponym without being a dictionary word or a well-known toponym, with a white outline against grey background, rotated randomly ±90°.

The experiment was implemented using our in-house framework for running distributed experiments, stimsrv (Ledermann & Gartner, 2021), and run with 28 participants recruited among student volunteers.

3. Results and Conclusions

In line with our hypotheses, the display with lowest pixel density (228ppi) was outperformed significantly by the one of next higher pixel density (342ppi) in five out of six tasks. The display of yet higher density (522ppi) outperformed this display significantly in three tasks (2,4,5), while, surprisingly, performing significantly *worse* in the tumbling E task (1). The display with highest pixel density (801ppi) outperformed the 522ppi display significantly only in the tumbling E tasks (with no significant improvement over the 342ppi display in that task). Although a plateau for further improving the legibility of most cartographic symbols seems to have been reached with the 522ppi display, the display of highest pixel density was the only display on which participants did not perform significantly worse in any task than on any other display. Surprisingly, no significant difference in performance has been found for any pair of devices for the text legibility task (6).

Further analysis of these results lets us conclude that for high-resolution devices (> 500ppi), which are now commonly available, and near viewing distance (≈30cm), cartographic symbology can be differentiated at significantly smaller sizes than conventionally recommended for screen-based maps. Point symbols were reliably identified at a size of 0.6mm on the two highest-resolution displays, and dash patterns of lines could be reliably discriminated at a line width of 0.12mm – both of these values are approaching the minimum dimensions conventionally recommended for printed maps (0.6mm and 0.1mm, respectively) (Imhof, 1972; Schweizerische Gesellschaft für Kartografie, 1980). The viewing conditions of the presented experiment approximated ideal contrast, so these findings would need to be adapted for less-than-ideal viewing conditions and more complex cartographic symbology.

It is important to note that this is clearly not a recommendation to use such minimal dimensions to depict important information on a map. However, these minimum dimensions may establish the foundation of the visual hierarchy of cartographic symbols of a map (Dent et al., 2008), from which the dimensions of the symbols at higher importance or the parameters for cartographic generalization may be derived. Lines and point symbols of the smallest size may be used for purely optional or contextual information, such as graticules or contour lines.

Two results of our study stand out as going against our intuitive expectations: the poor performance of the 522ppi device in the "Tumbling E's" task, and the virtually identical performance of all devices in the text legibility task. Closer inspection of the stimuli presented of the tumbling E's tasks reveals that this stimulus was subject to strong aliasing effects due to its intensity gradients being aligned with the pixel grid. This caused the stimulus to appear enlarged on the 228ppi display, leading to better performance than the physical pixel resolution should allow on this device, while degrading the stimulus in an unfortunate way for the 522ppi display, leading to worse-than-expected performance. Only the device with the highest resolution (801ppi) was not affected by such sampling artefacts for this task. While this result serves as a reminder that sampling artefacts must be taken into account for some classes of stimuli on digital displays, in real-world cartographic applications such high-frequency stimuli in perfect alignment with the pixel grid would rarely be encountered.

A detailed report on the findings of the presented study and a table of guidelines for cartographic symbology derived from the results can be found in a forthcoming publication (Ledermann, forthcoming).

In the future, we are planning to investigate whether novel techniques could be deployed to make use of the highest resolutions available and further increase user's map reading performance on those devices. Furthermore, we want to verify the findings of our lab study in real-world cartographic applications, potentially in collaboration with institutions for which detailed maps are important and which could deploy high-resolution devices to their staff, such as emergency services in alpine areas.

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