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From maps in the head to maps in the hand: how does environmental familiarity influence pedestrian navigators' mobile map use behavior?

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Abstract:

Mobile maps designed and adapted in response to navigators' dynamically changing use context have been attracting great interest from cartographers. This is because map users have different individual preferences and needs for mobile maps, depending on changing map use situations (Bartling et al., 2022), for example, traversed environments of different familiarity to navigators. However, today's mobile map applications are primarily designed to facilitate effective wayfinding in unfamiliar environments, where users mostly follow navigation instructions on the mobile map to find their desired destinations. Current mobile map applications do not consider users' past environmental experience. They are agnostic about navigators' available environmental knowledge. This knowledge, also known as a "cognitive map" (Behrens et al., 2018; Weisberg & Newcombe, 2016), plays a critical role in self-localization, orientation, planning, and the execution of the navigation process, especially in the absence of external navigational aids (Griesbauer et al., 2022; Spiers & Maguire, 2008). Environmental familiarity thus plays an important role in the development of spatial knowledge. It influences wayfinders' navigation strategies and respective behavior (Muffato & Meneghetti, 2020), spatial learning performance (Kapaj et al., 2024), and when and how navigation assistance is needed (Golab et al., 2022). However, it is still unclear how environmental familiarity interacts with the use of a mobile map-aid during wayfinding. This is why we set out to investigate how pedestrian navigators develop their spatial knowledge through repeated mobile map-assisted exposure to the same traversed environment, and how this acquired spatial knowledge, in turn, affects their use of mobile maps. We hypothesized that as the familiarity of the traversed environment increases, navigators' visual interactions with the mobile map will decrease, accordingly.

To examine this, we conducted an outdoor navigation experiment in a residential area in Zurich, Switzerland, which was initially unknown to participants. Forty-six healthy adults (f = 26, M_{age} = 27.3 yrs., m = 20, M_{age} = 26.4 yrs.) participated in the experiment. They completed two route-following tasks shown in Figure 1 (Route A and Route B, the sequence of navigating the two routes was counterbalanced across both sessions and participants) repeatedly over three separate days within one week, either assisted with a mobile map or not. The mobile map, adapted from OpenStreetMap, was presented on a 10.10-inch Samsung Galaxy tablet (1920 x 1200 pixels resolution). It displayed the route to be followed, including the navigation start and end locations, and participants' current location on the route. An example image of the mobile map is available at this link: https://doi.org/10.17605/OSF.IO/SJYZH. Participants could zoom, pan, and rotate with the map. We tracked participants' map-assisted movement trajectories with GPS fixes at 500-millisecond intervals. In the no-map condition, participants followed the experimenter without any access to a mobile map, which will not be discussed further. The assignment of the two navigation conditions to each route was counterbalanced between participants. Technical difficulties resulted in incomplete trajectory data for 8 participants who were excluded from this analysis. Data from 8 participants are still being processed at the time of submission. The results reported below are thus based on 30 participants (15 participants on each route, f = 14, M_{age} = 26.2 yrs).

We recorded participants' eye movements and their scene videos using the mobile Pupil Labs eye-tracking glasses (https://pupil-labs.com/products/neon/). We extracted eye fixations from the raw gaze data with the I-VT algorithm (Salvucci & Goldberg, 2000), available in the Pupil Labs software. To semantically annotate participants' eye fixations automatically, we extracted scene video frame segments bounded by the start and end timestamps for each fixation. These segments were then processed using the YOLOv5 instance segmentation model (Chen et al., 2018). We trained the model to segment the mobile map appearances in the extracted video frames (Ying et al., 2024). Fixations that were located on the mobile map in the scene video sequences were geolocated with participants' movement trajectories and then imported

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into ArcGIS Pro 3.3 (Esri, CA, USA; https://www.esri.com/en-us/arcgis/products/arcgis-pro) for kernel density computation. We applied the Planar method using the default settings for cell size and search radius.

The kernel density patterns in Figure 1 suggest that as participants got more familiar with the traversed environment over time, they checked the mobile map less frequently across navigation sessions. We confirmed this observation using paired t-tests, which revealed a significant reduction in map fixations between the first two navigation sessions ($M_{session\ 1} = 214.3$, $M_{session\ 2} = 130.4$, $t(29) = 3.36$, $p = .007$), but no significant difference in map fixations between sessions 2 and 3 ($M_{session\ 3} = 101.1$, $t(29) = 1.32$, $p = .597$). This suggests that after only one single exposure to an initially unfamiliar environment, participants acquired already sufficient spatial knowledge to navigate the same route, relying significantly less on the mobile map. The high-density fixation clusters appearing across sessions in Figure 1 indicate that as environmental familiarity increased, participants mostly checked the map when approaching navigation decision points (i.e., a street intersection), which has also been found in prior related work in unfamiliar environments (Brügger et al., 2019). Indeed, general control of visual attention shows unique patterns at decision points when navigating a route and changes over exposures during non-map assisted navigation (Hilton et al., 2020).

Figure 1 The kernel density pattern revealed overall that participants checked the map less frequently with increased environmental familiarity, and as familiarity increased, participants relied on the map mainly when approaching the intersections.

Mobile map applications have been reported to limit users' ability to acquire spatial knowledge from the environment during navigation, primarily due to a lack of navigators' engagement with their surroundings (Hejtmánek et al., 2018; Ishikawa et al., 2008). Our preliminary findings suggest that mobile map-assisted navigators were already able to learn from the unfamiliar environment on their first exposure, and they appeared to use this new knowledge efficiently for their navigation decisions. They chose to check the map only at relevant decision points as they became more familiar with the route, and thus were able to rely on the mobile map less after only one trial. Also, in the third trial, participants preferred to continue to check the map, particularly at decision points. Perhaps they lacked the confidence to take advantage of their newly acquired spatial knowledge or used the mobile map less for wayfinding, but rather for progress monitoring and confirmation purposes. Nonetheless, a visual examination of Figure 1 shows that map fixations at intersections also reduced substantially as familiarity increased, showing that reduced reliance on the map occurred even at key decision making parts of the navigation process.

The future design of a context-adaptive mobile map that considers navigators' current state of environmental familiarity could thus 1) effectively support spatial learning by minimizing the displayed information and highlighting navigation-relevant features in the environment between navigation decision points (Kapaj et al., 2024), and 2) visually prepare users when approaching intersections with navigation decision-relevant information to facilitate wayfinding decisions and to support spatial learning further. Our first qualitative findings will be further quantitatively examined in future work, considering additional factors that may influence mobile map use behavior, such as participants' acquired spatial knowledge of the surrounding environment (i.e., landmark, route, and survey knowledge), their spatial abilities, and other relevant factors.

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