The influence of landmark visualization style on expert wayfinders' visual attention during a real-world navigation task

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Abstract

Landmarks serve to structure the environment we experience, and therefore they are also critically important for our everyday movement through and knowledge acquisition about space. How to effectively visualize landmarks to support spatial learning during map-assisted pedestrian navigation is still an open question. We thus set out to assess how landmark visualization styles (i.e., abstract 2D vs. realistic 3D) influence map-assisted spatial learning of expert wayfinders in an outdoor navigation study. Below we report on how the visualization of landmarks on mobile maps might influence wayfinder's gaze behavior while trying to find a set of landmarks along a given route in an unfamiliar environment. We find that navigators assisted with mobile maps showing realistic-looking 3D landmarks more equally share their visual attention on task-relevant information, while those assisted with maps containing abstract 2D landmarks frequently switch their visual attention between the visualized landmarks and the mobile map to complete the navigation task. The presented analysis approach for the assessment of wayfinder's gaze patterns has the potential to contribute ecologically valid insights for the understanding of human visual attention allocation during outdoor navigation, and to further understand how landmark depiction styles on mobile maps might guide wayfinders' visual attention back to the environment to support spatial learning during map-assisted navigation.

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1 Introduction

Landmarks play a key role in humans' mobility in everyday life [10]. As anchor points in the environment, landmarks serve as sources and destinations for trips, and as reference points for self-localization and orientation during navigation [8]. Landmarks could be visualized on maps on a graphic continuum; from highly abstract text labels to photorealistic 3D icons [1] or mixed design forms [6]. How to perceptually saliently visualize landmarks on mobile maps

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to effectively and efficiently direct wayfinders' visual attention to key cognitive anchors in space, and to thus facilitate spatial learning during navigation is still little explored. Our research program aims to identify a cartographic design solution for landmarks that matches their cognitive and conceptual importance as key environmental anchors for navigation, e.g., by increasing their visual saliency using photorealistic texturing, and allowing for perspective viewing changes, while visually demoting other less relevant spatial information that may be shown on mobile maps. We contend that this might facilitate spatial learning in map-assisted navigation because it keeps navigators engaged with their traversed surroundings and thus helps to scaffold spatial learning, rather than passively following automated directions of a GPS-enabled navigation device [2].

In the following, we present a quantitative analysis approach to assess wayfinder's gaze patterns collected in-situ during a pilot navigation study with a small sample of expert wayfinders. We asked them to follow a given route in an unfamiliar environment outdoors, and to identify given landmarks on a mobile map. We were interested to systematically analyze navigators' gaze behavior during this map-assisted navigation, to better understand how landmark visualization style (i.e., abstract 2D building footprints or 3D photorealistic buildings) might interact with navigators' visual attention allocation during navigation. In line with past research, our working hypothesis is that participants' gaze behavior will be different, as a result of the landmark visualization style on the map [6]. We expect that more realistic-looking landmark symbols on a mobile map will facilitate the visual matching process with the landmarks seen in the environment. We thus expect the 3D landmark group to exhibit less gaze switches from the landmarks visualized on the map to other areas on the map—and possibly be distracted by the additional task-irrelevant spatial information on it—but more equally distribute their visual attention to task-relevant information, in support of spatial learning.

2 Methods

We designed two mobile map applications, where landmarks are displayed as abstract 2D building footprints (Figure 1.1), and photorealistic 3D building models (Figure 1.2) on an interactive 2D mobile map. We selected five buildings along a predefined route (approx. 1 km; Figure 1) to serve as landmarks based on their visual and structural saliency [10]. To provide a naturalistic navigation experience, participants were able to interact with the mobile map applications as desired (i.e., zoom, pan, rotate, tilt). The map applications were set to display a North-up map view at the start of the route. The study was conducted in a residential area in Brugg, Aargau, Switzerland, and was unfamiliar to participants.

This study was conducted in collaboration with professionals of the Swiss Armed Forces. Twenty-two expert wayfinders (2 females; age: $M = 37.1$ yrs., $SD = 11.7$ yrs., range = 24-58 yrs.) from the Engineer and Rescue Troops participated in our study. This sample group was deemed appropriate for our study based on their map-training, spatial abilities, and a keen interest in improving map design for more effective support in their daily work. Participants were instructed to follow a given route with the aid of a mobile map application as fast as possible, without running. They were instructed to identify five landmarks in the environment (Figure 1), by raising their hand once they were next to the landmarks and then continue towards the destination point. The ethics approval (No. 19.6.10) for this study was provided by the Ethics Committee of the University of Zurich. Participants could join the study if they had normal or corrected to normal vision, and no incentives were provided.

We used a between-subjects design with landmark visualization style (2D vs. 3D) as the independent variable, and participants' eye movements collected during navigation as the dependent variable. We controlled groups for gender, and participants' self-reported spatial strategies skills measured with the questionnaire on spatial strategies [7].

Figure 1 Landmark visualization on the interactive mobile map applications as (1) abstract 2D building footprints, and (2) realistic 3D buildings. The inset offers a zoomed-in view of one 3D landmark.

Participants' eye movements were recorded at a 60 Hz sampling rate using SensoMotoric Instrument (SMI) Mobile Eye-Tracking (MET) glasses. Due to technical and data quality issues, we were able to analyze only 13 out of 22 participant MET recordings (2D group, n=7; 3D group, n=6). We used the SMI BeGaze 3.5 software to group participants' eye fixations into four areas of interest (AOI): (1) the mobile map (MAP), (2) the environment (ENV), (3) the five landmarks visualized on the map (LMM), and (4) the corresponding landmarks in the environment (LME). We manually assigned participants' gaze data from the MET recordings to the respective AOI (Figure 2).

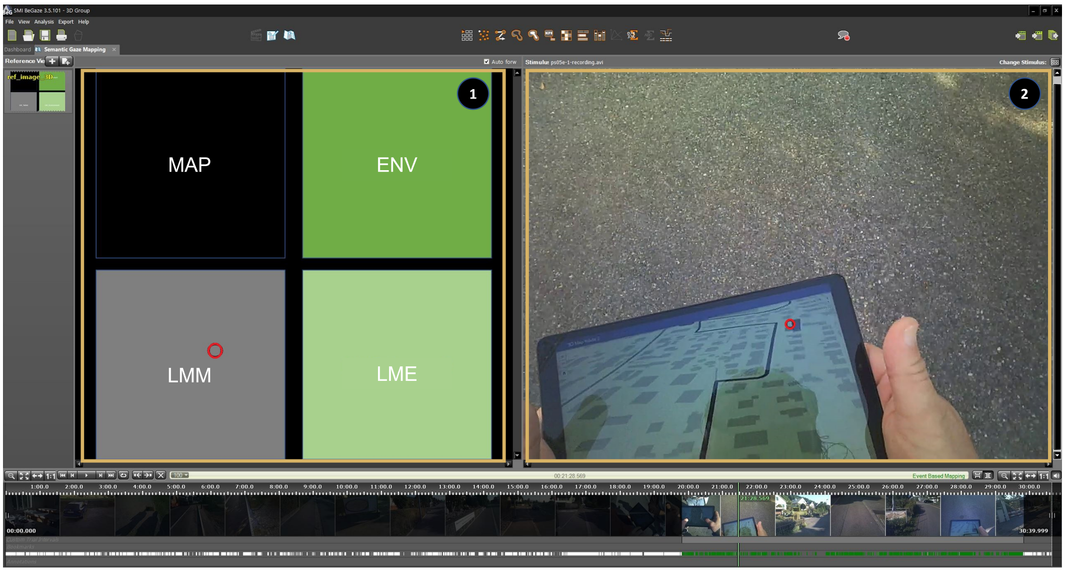

Figure 2 BeGaze Interface. (2) Participant fixates a task-relevant landmark on the map display (red circle). (1) We manually assign this fixation to the AOI "landmark on the map" (LMM).

3 Data analysis and results

To assess the potential influence of landmark visualization style on participants' gaze behavior we employ gaze transition matrices (TMs) and gaze entropy measures as indicators of the predictability of eye movement sequences using a script developed by Krejtz et al. [5] and run in R (version 4.0).

3.1 Transition matrices

Transition matrices (TMs) show the probability of eye movement transitions between AOIs, and within an AOI [5], as in Figure 3 below to allow us to gain first insights into participants" gaze behaviors.

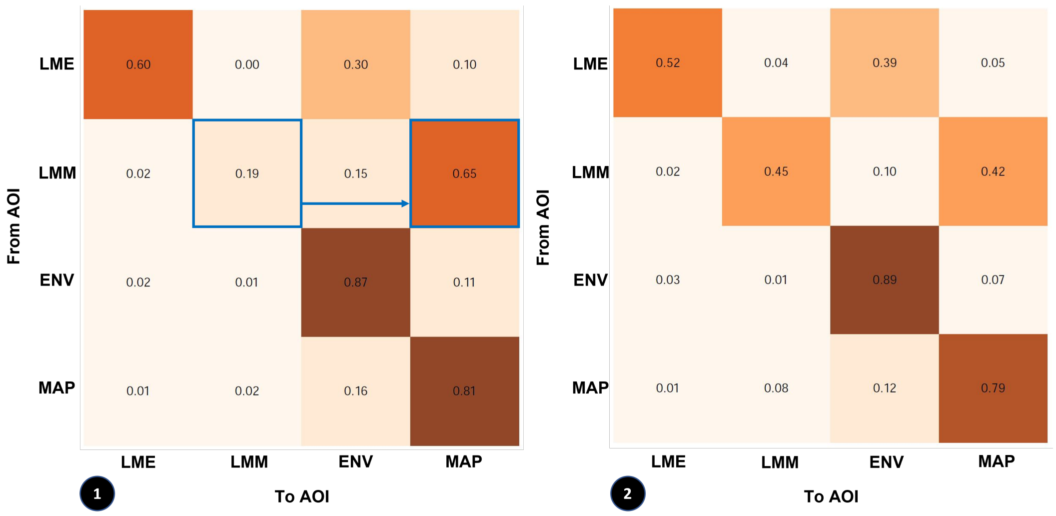

Figure 3 Transition Matrix of the 2D (1) and 3D group (2) depicting participants' fixation transitions between and within four AOIs. Cell shading and cell values indicate the magnitude of the probability of a gaze transition, that is, the darker the shaded cell, the higher the transition probability for that cell.

On first glance, both TMs reveal a similar gaze pattern. The darker shaded AOIs along the diagonal in both matrices suggest that it is most likely that a fixation in an AOI does not move to another AOI, and this seems more pronounced for the 3D group. Specifically, when navigators fixate the environment (ENV) there is a high probability (0.87 and 0.89) that the next fixation is again in this AOI, similarly for the MAP AOI, but with lower probability (0.81 and 0.79), and least for the LME AOI (0.60 and 0.52). Where the groups seem to differ most, is a navigator's gaze transition probability pattern when looking at the LMM AOI. The 2D group shows far fewer transitions within that task-relevant AOI on the map, compared to the 3D group, and also the fixation transitions between LMM and MAP AOIs seem to differ most across groups. In the 2D group, it is more likely that a fixation in the LMM AOI will be followed by a fixation in the MAP AOI (blue squares) suggesting that participants of this group needed to scan a larger map area surrounding the 2D landmarks.

Next, we report on preliminary results to further summarize the fixation transition pattern revealed in the TMs (Figure 3), using gaze transition entropy (between AOIs) and stationary gaze entropy (within an AOI) [5].

3.2 Transition and stationary entropy

Entropy metrics allow us to characterize gaze patterns during the navigation task across individuals and/or experimental groups, and this in turn helps us to better understand navigators' visual attention allocation during navigation. On the one hand, high gaze transition entropy (TE) indicates frequent fixation transitions between AOIs, suggesting a more exploratory visual scanning [5]. On the other hand, high stationary gaze entropy (SE) indicates a more even distribution of visual attention between AOIs, and thus suggests equal interest to viewers [5], as we hypothesized for the 3D group.

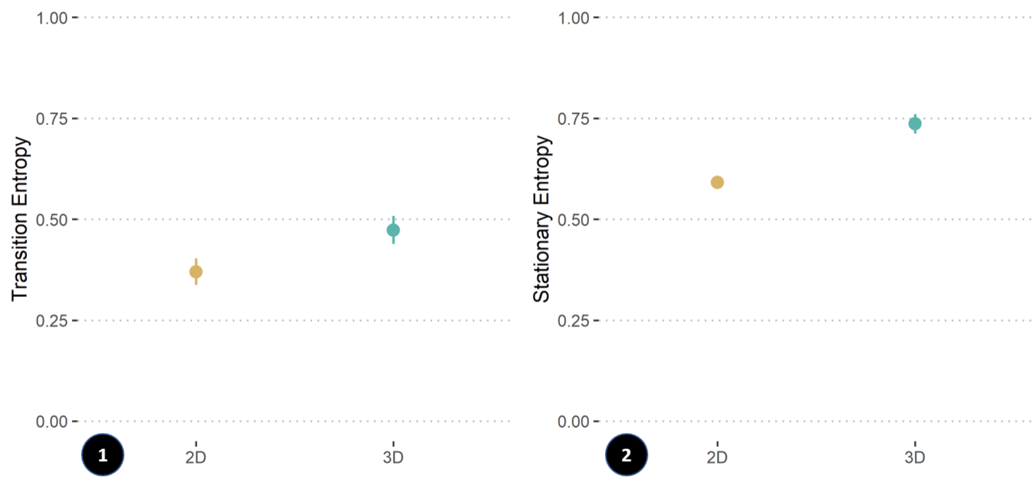

Figure 4 The 3D group shows higher TE (4.1), and higher SE (4.2) compared to the 2D group (dots represent the entropy mean, and bars indicate 95% confidence intervals).

Even though our small sample does not warrant robust statistical analyses, we ran an independent t-test on our normally distributed gaze data, to exploratively compare TE and SE across experimental groups. At this stage of the ongoing research, we do not have enough convincing evidence to suggest that the 3D group (M = 0.47, SD = 0.09) has a significantly higher TE, compared to the 2D group (M = 0.37, SD = 0.09; $t(11)$ = -2, p = 0.05), even though the effect is medium sized (r = 0.55). Interestingly, for the SE, though, and in line with our working hypothesis for a more evenly distributed visual attention allocation (higher SE) among AOIs, we have stronger evidence for a statistically significant difference ($t(8)$ = -5, $p < 0.001$) between a higher SE for the 3D group (M = 0.74, SD = 0.06), compared to the 2D group (M = 0.59, SD = 0.04), and this is even supported by a large effect (r = 0.87).

4 Discussion

We assessed how landmark visualization might influence gaze behavior of expert wayfinders' during a map-assisted pedestrian navigation task in an unfamiliar urban environment outdoors. In support of our working hypothesis, we preliminarily find that the visual attention of navigators using a mobile map with 3D photorealistic landmarks is equally distributed among the AOIs (i.e., higher stationary gaze entropy). This could mean that increased realism and perspective viewing of landmarks on the map allow for easier visual matching, and thus facilitated identification of the task-relevant landmarks in the environment [4]. The gaze transition pattern of navigators equipped with a mobile map showing landmarks as 2D building footprints suggests a more narrowly focused visual attention on specific AOIs (i.e., lower stationary gaze entropy). Perhaps navigators in the 2D group had more difficulty to match the top-down view of the 2D building footprints on the mobile map with the first-person perspective view of the task-relevant buildings in the environment. They might have had to scan a wider area on the mobile map to gather additional visual information for landmark matching [3]. Our gaze behavior results are consistent with previous findings showing that low stationary gaze entropy is indicative of task difficulty [9, 11], and that focused attention on the navigational aid limits learning of the traversed environment [2].

5 Summary and outlook

In this pilot study with only a small participant sample, we are already able to discover meaningful gaze patterns suggestive of visual attention processes, likely induced by different landmark visualization styles. These encouraging preliminary results on quantitative gaze pattern behavior analysis with expert wayfinders suggest us to further assess the influence of landmark visualization styles by increasing the participant sample, and also by including non-expert navigators. We also wish to further analyze participants' AOI gaze transitions with other commonly used eye-tracking metrics such as, fixation count, dwell time etc.. Overall, our findings could have important implications for designing mobile maps that cue users' visual attention to salient landmarks in the environment and thus to increase navigators' spatial awareness, both shown to be critically relevant for navigation success and increased spatial learning.

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