

<sup>1</sup> **The influence of landmark visualization style on  
expert wayfinders' visual attention during a  
real-world navigation task**

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<sup>13</sup> — **Abstract** —

<sup>14</sup> Landmarks serve to structure the environment we experience, and therefore they are also critically  
<sup>15</sup> important for our everyday movement through and knowledge acquisition about space. How to  
<sup>16</sup> effectively visualize landmarks to support spatial learning during map-assisted pedestrian navigation  
<sup>17</sup> is still an open question. We thus set out to assess how landmark visualization styles (i.e., abstract  
<sup>18</sup> 2D vs. realistic 3D) influence map-assisted spatial learning of expert wayfinders in an outdoor  
<sup>19</sup> navigation study. Below we report on how the visualization of landmarks on mobile maps might  
<sup>20</sup> influence wayfinder's gaze behavior while trying to find a set of landmarks along a given route in an  
<sup>21</sup> unfamiliar environment. We find that navigators assisted with mobile maps showing realistic-looking  
<sup>22</sup> 3D landmarks more equally share their visual attention on task-relevant information, while those  
<sup>23</sup> assisted with maps containing abstract 2D landmarks frequently switch their visual attention between  
<sup>24</sup> the visualized landmarks and the mobile map to complete the navigation task. The presented  
<sup>25</sup> analysis approach for the assessment of wayfinder's gaze patterns has the potential to contribute  
<sup>26</sup> ecologically valid insights for the understanding of human visual attention allocation during outdoor  
<sup>27</sup> navigation, and to further understand how landmark depiction styles on mobile maps might guide  
<sup>28</sup> wayfinders' visual attention back to the environment to support spatial learning during map-assisted  
<sup>29</sup> navigation.

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<sup>36</sup> **1 Introduction**

<sup>37</sup> Landmarks play a key role in humans' mobility in everyday life [10]. As anchor points in the  
<sup>38</sup> environment, landmarks serve as sources and destinations for trips, and as reference points  
<sup>39</sup> for self-localization and orientation during navigation [8]. Landmarks could be visualized on  
<sup>40</sup> maps on a graphic continuum; from highly abstract text labels to photorealistic 3D icons [1]  
<sup>41</sup> or mixed design forms [6]. How to perceptually saliently visualize landmarks on mobile maps

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

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

67

## 2 Methods

68 We designed two mobile map applications, where landmarks are displayed as abstract 2D  
69 building footprints (Figure 1.1), and photorealistic 3D building models (Figure 1.2) on an  
70 interactive 2D mobile map. We selected five buildings along a predefined route (approx.  
71 1 km; Figure 1) to serve as landmarks based on their visual and structural saliency [10].  
72 To provide a naturalistic navigation experience, participants were able to interact with the  
73 mobile map applications as desired (i.e., zoom, pan, rotate, tilt). The map applications were  
74 set to display a North-up map view at the start of the route. The study was conducted in a  
75 residential area in Brugg, Aargau, Switzerland, and was unfamiliar to participants.

76 This study was conducted in collaboration with professionals of the Swiss Armed Forces.  
77 Twenty-two expert wayfinders (2 females; age:  $M = 37.1$  yrs.,  $SD = 11.7$  yrs., range =  
78 24-58 yrs.) from the Engineer and Rescue Troops participated in our study. This sample  
79 group was deemed appropriate for our study based on their map-training, spatial abilities,  
80 and a keen interest in improving map design for more effective support in their daily work.  
81 Participants were instructed to follow a given route with the aid of a mobile map application  
82 as fast as possible, without running. They were instructed to identify five landmarks in the  
83 environment (Figure 1), by raising their hand once they were next to the landmarks and  
84 then continue towards the destination point. The ethics approval (No. 19.6.10) for this study  
85 was provided by the Ethics Committee of the University of Zurich. Participants could join  
86 the study if they had normal or corrected to normal vision, and no incentives were provided.

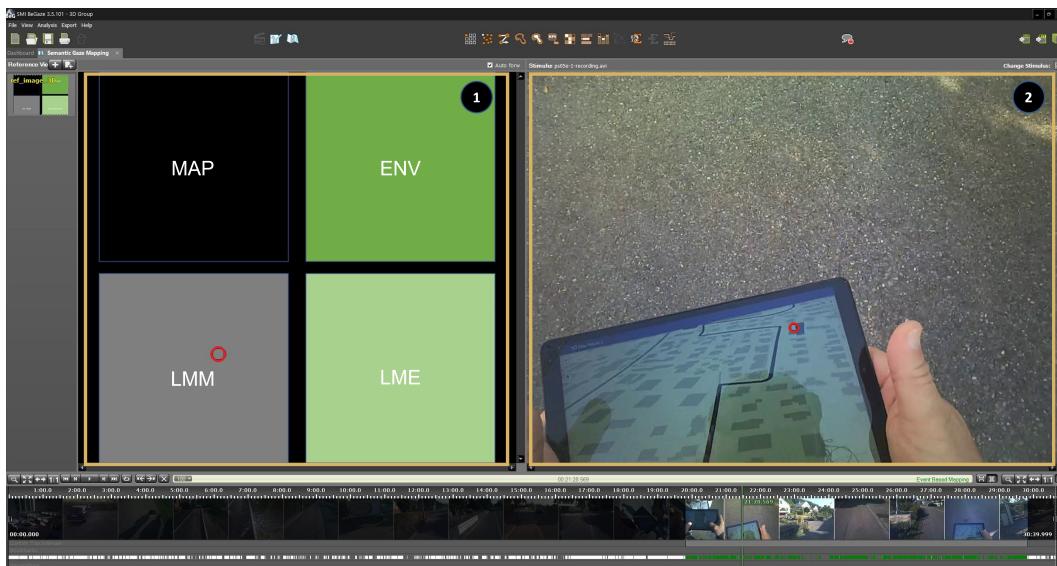
87 We used a between-subjects design with landmark visualization style (2D vs. 3D) as the

88 independent variable, and participants' eye movements collected during navigation as the  
 89 dependent variable. We controlled groups for gender, and participants' self-reported spatial  
 90 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.

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



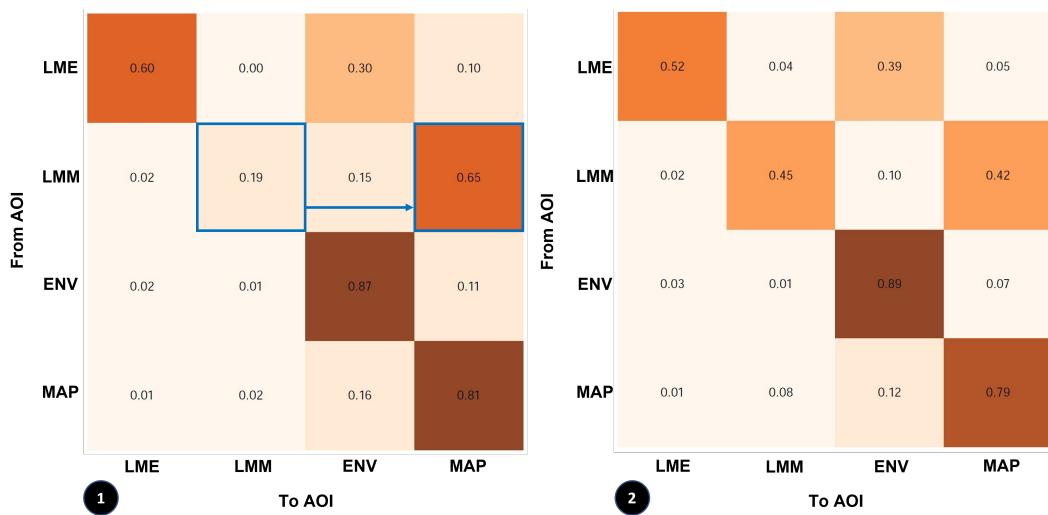
**Figure 2** BeGaze Interface. (2) Participant fixates a task-relevant landmark on the map display (red circle). (1) We manually assign this fixation to the AOI "landmark on the map" (LMM).

99 **3 Data analysis and results**

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

104 **3.1 Transition matrices**

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



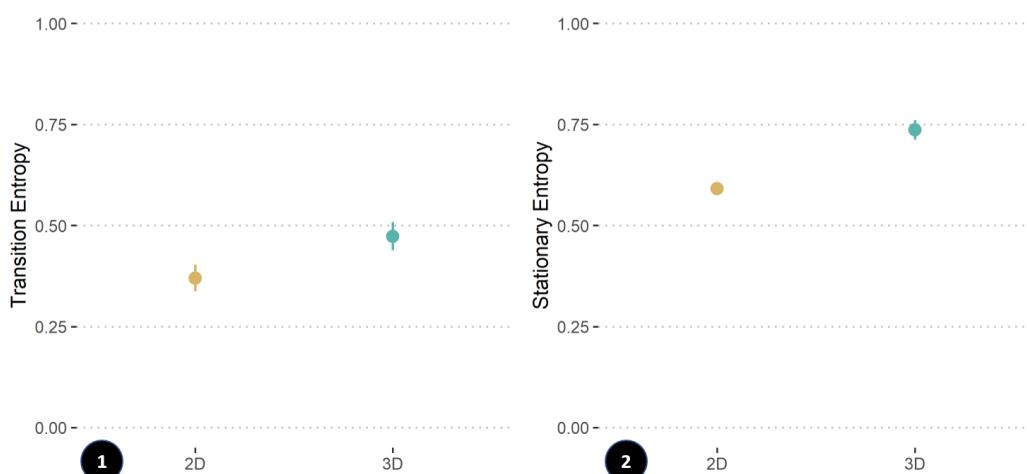
**Figure 3** Transition Matrix of the 2D (1) and 3D group (2) depicting participants' fixation transitions between and within four AOIs. Cell shading and cell values indicate the magnitude of the probability of a gaze transition, that is, the darker the shaded cell, the higher the transition probability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

108 On first glance, both TMs reveal a similar gaze pattern. The darker shaded AOIs along  
 109 the diagonal in both matrices suggest that it is most likely that a fixation in an AOI does not  
 110 move to another AOI, and this seems more pronounced for the 3D group. Specifically, when  
 111 navigators fixate the environment (ENV) there is a high probability (0.87 and 0.89) that the  
 112 next fixation is again in this AOI, similarly for the MAP AOI, but with lower probability  
 113 (0.81 and 0.79), and least for the LME AOI (0.60 and 0.52). Where the groups seem to  
 114 differ most, is a navigator's gaze transition probability pattern when looking at the LMM  
 115 AOI. The 2D group shows far fewer transitions within that task-relevant AOI on the map,  
 116 compared to the 3D group, and also the fixation transitions between LMM and MAP AOIs  
 117 seem to differ most across groups. In the 2D group, it is more likely that a fixation in the  
 118 LMM AOI will be followed by a fixation in the MAP AOI (blue squares) suggesting that  
 119 participants of this group needed to scan a larger map area surrounding the 2D landmarks.

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

### 123 3.2 Transition and stationary entropy

124 Entropy metrics allow us to characterize gaze patterns during the navigation task across  
 125 individuals and/or experimental groups, and this in turn helps us to better understand  
 126 navigators' visual attention allocation during navigation. On the one hand, high gaze  
 127 transition entropy (TE) indicates frequent fixation transitions between AOIs, suggesting a  
 128 more exploratory visual scanning [5]. On the other hand, high stationary gaze entropy (SE)  
 129 indicates a more even distribution of visual attention between AOIs, and thus suggests equal  
 130 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).

131 Even though our small sample does not warrant robust statistical analyses, we ran an  
 132 independent t-test on our normally distributed gaze data, to exploratively compare TE and  
 133 SE across experimental groups. At this stage of the ongoing research, we do not have enough  
 134 convincing evidence to suggest that the 3D group ( $M = 0.47$ ,  $SD = 0.09$ ) has a significantly  
 135 higher TE, compared to the 2D group ( $M = 0.37$ ,  $SD = 0.09$ ;  $t(11) = -2$ ,  $p = 0.05$ ), even  
 136 though the effect is medium sized ( $r = 0.55$ ). Interestingly, for the SE, though, and in line  
 137 with our working hypothesis for a more evenly distributed visual attention allocation (higher  
 138 SE) among AOIs, we have stronger evidence for a statistically significant difference ( $t(8) =$   
 139  $-5$ ,  $p < 0.001$ ) between a higher SE for the 3D group ( $M = 0.74$ ,  $SD = 0.06$ ), compared to  
 140 the 2D group ( $M = 0.59$ ,  $SD = 0.04$ ), and this is even supported by a large effect ( $r = 0.87$ ).

## 141 4 Discussion

142 We assessed how landmark visualization might influence gaze behavior of expert wayfinders'  
 143 during a map-assisted pedestrian navigation task in an unfamiliar urban environment outdoors.  
 144 In support of our working hypothesis, we preliminarily find that the visual attention of  
 145 navigators using a mobile map with 3D photorealistic landmarks is equally distributed among  
 146 the AOIs (i.e., higher stationary gaze entropy). This could mean that increased realism  
 147 and perspective viewing of landmarks on the map allow for easier visual matching, and  
 148 thus facilitated identification of the task-relevant landmarks in the environment [4]. The

149 gaze transition pattern of navigators equipped with a mobile map showing landmarks as  
 150 2D building footprints suggests a more narrowly focused visual attention on specific AOIs  
 151 (i.e., lower stationary gaze entropy). Perhaps navigators in the 2D group had more difficulty  
 152 to match the top-down view of the 2D building footprints on the mobile map with the  
 153 first-person perspective view of the task-relevant buildings in the environment. They might  
 154 have had to scan a wider area on the mobile map to gather additional visual information  
 155 for landmark matching [3]. Our gaze behavior results are consistent with previous findings  
 156 showing that low stationary gaze entropy is indicative of task difficulty [9, 11], and that  
 157 focused attention on the navigational aid limits learning of the traversed environment [2].

## 158 5 Summary and outlook

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

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