The Effect of Abstract vs. Realistic 3D Visualization on Landmark and Route Knowledge Acquisition

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Abstract

Even though humans perform it daily, navigation is a cognitively challenging process. Landmarks have been shown to facilitate navigation by scaffolding humans' mental representation of space. However, how landmarks can be effectively communicated to pedestrians to support spatial learning of the traversed environment remains an open question. Therefore, we assessed how the visualization of landmarks on a mobile map (i.e., abstract 3D vs. realistic 3D symbols) influences participants' spatial learning, visual attention allocation, and cognitive load during an outdoor map-assisted navigation task. We report initial results on how exposing pedestrians to different landmark visualization styles on mobile maps while navigating along a given route in an urban environment can have differing effects on how they remember landmarks and routes. Specifically, we find that navigators better remember landmarks visualized as 3D realistic-looking symbols compared to 3D abstract landmark symbols on the mobile map. The pattern of results shows that displaying realistic 3D landmark symbols at intersections potentially helps participants to remember route directions better than with landmarks depicted as abstract 3D symbols. The presented methodological approach contributes ecologically valid insights to further understand how the design of landmarks on mobile maps could support wayfinders' spatial learning during map-assisted navigation.

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1 Introduction

Imagine you are in a new town and are meeting new friends at a café in the historic downtown area. As you live in a spatially enabled society, you most likely rely on your trusted mobile navigation service to get you there [4]. Once you approach the narrow medieval streets of the downtown area, you realize it is getting harder for you to make destination-relevant navigation decisions. You are standing at an intersection and wondering which way to go. You rotate your navigation device and look around to guess the correct direction. You notice historic buildings with unique facades, but these are only indicated as plain gray footprints on your mobile map. You wished you saw some of these beautiful building facades on your mobile map to facilitate your wayfinding, especially at street intersections.

Unique buildings serve as landmarks during navigation and facilitate the challenging wayfinding process [1]. Landmarks are geographic features that help structure humans' mental representation of space, and when placed on a mobile map, they support the matching of information on the mobile map display with what is seen in the environment [12]. Hence, landmarks play a key role in humans' everyday spatial mobility [11]. Despite their acknowledged importance for navigation, landmarks are not communicated effectively on most mobile wayfinding services. They are either omitted entirely and shown only as building footprints or substituted with commercial points of interest [9]. Aside from GPS reliance for localization, the omission of relevant landmarks on GPS-enabled maps might also explain navigators' deteriorated spatial learning [4]. This is because GPS reliance increasingly shifts navigators' visual attention to the mobile map display [3, 6] without offering additional navigation-relevant information.

Past research has shown that landmarks can be depicted on a visual abstraction (geometric symbol vs. photorealistic symbol) and dimensionality continuum (2D vs. 3D symbols) on mobile maps, ranging from abstract text labels to realistic 3D building models with different levels of realism [2, 10]. However, how landmarks can be communicated on mobile map services for pedestrian navigation to help shift users' attention away from the map and back to the environment, thus improving spatial learning, has not been explored systematically.

Our research program aims to identify cartographic design solutions for landmark visualization by including first-person perspective viewing of 3D landmarks on planar mobile maps, with the goal of increasing the visual saliency of relevant landmarks while inhibiting irrelevant features in mobile maps [7]. We propose that a closer visual match between information on the mobile map display and the physical environment would increase wayfinders' engagement with their surroundings. Consequently, navigators' spatial learning would improve without increasing cognitive load. In this article, we are particularly interested in assessing how landmark visualization style (3D abstract vs. 3D realistic symbols) might influence participants' landmark and route knowledge acquisition. We hypothesize that participants can recall landmarks and route directions better when navigating with realistic 3D landmark symbols on the mobile map than with abstract 3D landmarks. Next, we detail our empirical approach that emphasizes ecological validity while assessing wayfinders' spatial learning in situ.

2 Methodology

We conducted an outdoor navigation experiment in a residential area in Zurich, Switzerland, on days without precipitation, in December 2021. We used a within-subject experimental design with landmark visualization style as the independent variable and landmark and route knowledge as the dependent variables. We designed a mobile map application containing the route depicted as a black line and ten landmarks (five depicted as realistic 3D symbols and five as abstract 3D symbols) on a 2D basemap (Figure 1). We counterbalanced the order of the landmark symbol style, starting with landmarks visualized as realistic 3D symbols (Figure 1.A) and then as abstract 3D symbols (Figure 1.B) or vice versa. Prior to developing the mobile map, we conducted a pilot survey ($N = 9$) to select prominent buildings along the route that would serve as landmark candidates. Participants in the survey rated the most prominent buildings and the buildings they would use to give directions [9].

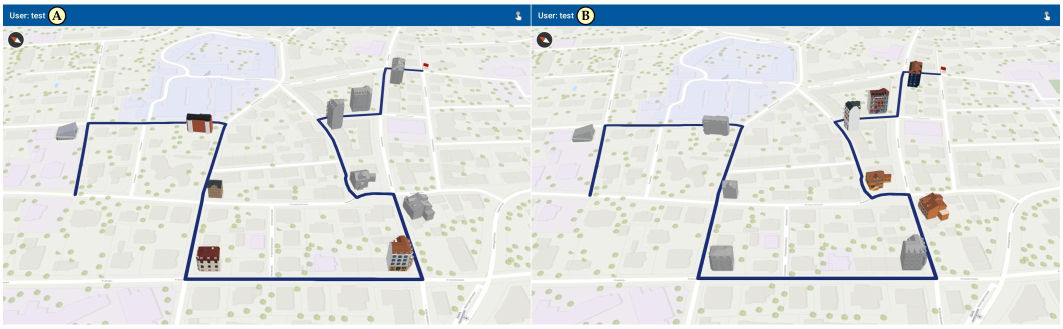

Figure 1 Mobile map stimuli with counterbalanced order of landmark visualization, either with realistic 3D (A) or abstract 3D landmark symbols (B) shown first.

2.1 Participants and procedure

Forty-six (22 females; avg. age = 27.5 yrs., range = 21–46 yrs.) healthy adults with normal or corrected-to-normal vision (i.e., contact lenses only) participated in the study. The experimental task consisted of following a given route for approximately 1 km with the help of a mobile map (Figure 1) in an urban environment (77% of participants were unfamiliar with the study area). Participants were asked to identify the ten visualized landmarks on the mobile map in the environment by raising a hand while passing the given landmarks on the predefined route on their way to the set destination. We followed participants at a safe distance and corrected their direction if a wrong navigation decision was made. To provide a naturalistic navigation experience, we asked participants to walk as they would when exploring a new environment. Additionally, they could interact (i.e., zoom, pan, rotate, and tilt) with the mobile map application as desired. To control for intentionality in learning, we informed participants that they would be tested on their newly acquired environmental knowledge at the end of the navigation task. After arriving at the destination, participants completed a questionnaire (see subsection 2.2) designed to assess their spatial learning.

2.2 Post-navigation questionnaires

The landmark and route questionnaire presented 30 images in random order, with ten images each for 1) relevant, 2) irrelevant, and 3) novel landmarks as seen from participants' perspective during navigation. Relevant landmarks (REL) refer to landmarks that participants saw along the route where a navigation decision was required and which were presented as either realistic or abstract 3D symbols on the mobile map (Figure 1). Irrelevant landmarks (IRL) refer to buildings located along the route but not depicted on the mobile map and where no navigation decision was required (i.e., participants continued straight when passing an IRL). Novel landmarks (NOL) were buildings similar in style to the buildings in the study area but that were neither along the route nor visualized on the map. We asked participants if they remembered seeing a given building during navigation for each of the 30 building images. If they answered yes, we asked participants whether they saw the building visualized on the mobile map **and** in the environment or **only** in the environment to distinguish between REL and IRL landmarks. If participants classified the building as a REL landmark, they were asked to provide the navigation direction they took after seeing it.

3 Data analyses and results

To assess the effect of landmark visualization style on wayfinders' acquired landmark knowledge, we employed analyses according to signal detection theory (SDT) using the *psycho* package in R (v.4.1.2).

3.1 Data analyses

SDT distinguishes response accuracy (i.e., stimulus, signal, or target) from background noise or distractors [13]. SDT encodes participants' correct responses as "Hit" or "Correct Rejection", and false responses are recorded as "Miss" or "False Alarm" [13]. To statistically compare landmark recall accuracy, we used the discriminability index d' (d prime), computed as *Z(Hit) − Z(False Alarm)*. Additionally, we used criterion location (c) computed as *−0.5 * [Z(Hit) + Z(False Alarm)]* to assess participants' response bias against zero (no bias). We ran SDT analyses in two ways. Firstly, we analyzed whether participants remembered seeing landmarks that could be seen in the environment during navigation (i.e., REL and IRL) or were not present at all (i.e., NOL). Secondly, we analyzed whether participants remembered seeing landmarks visualized on the mobile map display and in the environment (REL) or only in the environment (IRL).

We additionally ran multilevel regression analyses to compare landmark and route knowledge recall performance by landmark visualization condition. Multilevel models were executed using the *lme4* package, with the significance threshold set at $p < .05$. Analyses outcomes are detailed next.

3.2 Results

3.2.1 Results on recall of landmarks seen in the environment

First, we turn to the landmark recall analyses by visualization condition using SDT (Figure 2).

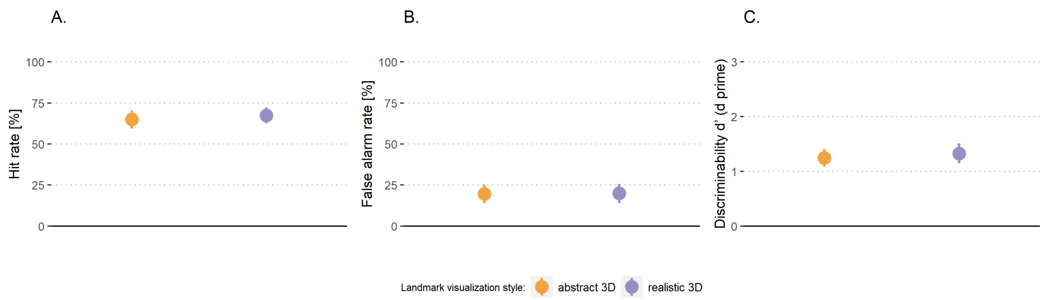

Figure 2 Participants' hit (A) and false alarm rates (B), and (C) recall performance of landmarks seen in the environment by visualization style (dots indicate means; bars indicate 95% CIs).

The average hit rate of approximately 75% together with the average false alarm rate of approximately 25% equates to a moderate discriminability between signal and noise, with a d' score of 1.23 ($SD = 0.68$) for 3D realistic landmarks compared to a d' score of 1.19 ($SD = 0.61$) for abstract 3D landmarks. This difference is not statistically significant ($p = 0.74$, $r = 0.06$). Additionally, we find that participants' response bias is significantly higher than zero for both conditions (abstract 3D: $M = 0.19$, $t(45) = 2.8$, $p = 0.007$; realistic 3D: $M = 0.17$, $t(45) = 2.7$, $p = 0.009$), indicating that participants were more likely to respond that they did not see the landmark in the environment. The difference in response bias is not significant between conditions ($t(45) = 0.29$, $p = 0.77$).

3.2.2 Results on recall of landmarks seen on the mobile map

Figure 3 illustrates the results on participants' recall of landmarks seen in the mobile map. Specifically, participants had both higher hit rates ($M = 74.3\%$, $SD = 23.7\%$) and lower false alarm rates ($M = 5.7\%$, $SD = 10.8\%$) for realistic 3D landmarks compared to abstract 3D landmarks (hit rate: $M = 66.5\%$, $SD = 25.3\%$, and false alarm rate: $M = 8.3\%$, $SD = 15.5\%$). In line with our hypothesis, the d' prime analysis reveals significantly better recall ($p = 0.03$, $r = 0.4$) for the realistic 3D landmarks ($M = 1.81$, $SD = 0.74$) compared to the abstract 3D landmarks ($M = 1.54$, $SD = 0.79$). Results revealed that participants' response bias is significantly higher than zero for both conditions (abstract 3D: $M = 0.35$, $t(45) = 6.02$, $p < 0.001$; realistic 3D: $M = 0.29$, $t(45) = 5.3$, $p < 0.001$), indicating that participants were more likely to respond that they did not see the landmark on the mobile map display. The difference for response bias between conditions is not significant ($t(45) = 0.93$, $p = 0.36$).

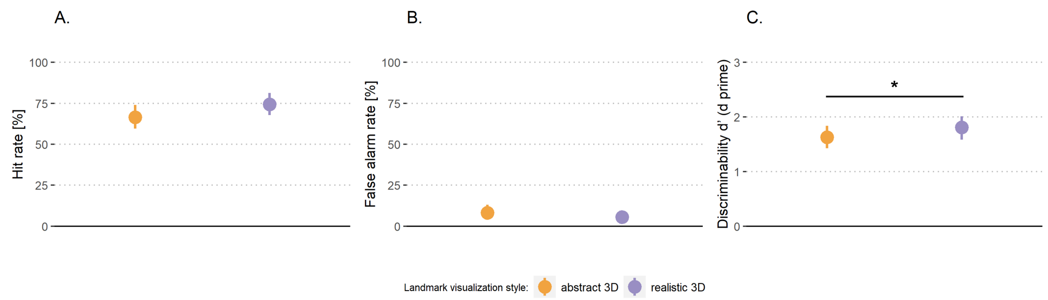

Figure 3 Participants' hit (A) and false alarm rates (B), and (C) recall performance of landmarks seen on the mobile map by visualization style (dots indicate means; bars indicate 95% CIs, $*p < .05$).

3.2.3 Results on route direction recall

Finally, the analysis of route direction recall accuracy (Figure 4) reveals that both groups performed significantly better (abstract 3D: $t(45) = 4.8$, $p < 0.001$; realistic 3D: $t(45) = 7.7$, $p < 0.001$) than chance level (green line) at 33.3% (three possible route directions: straight, left, and right). Participants, on average, seem to remember route directions better when navigating with realistic 3D landmarks ($M = 59.56\%$, $SD = 23.3\%$) on the mobile map compared to abstract 3D landmarks ($M = 52.17\%$, $SD = 26.5\%$). Contrary to our hypothesis, this difference is not statistically significant ($p = 0.09$). However, this difference shows a medium effect size ($r = 0.3$).

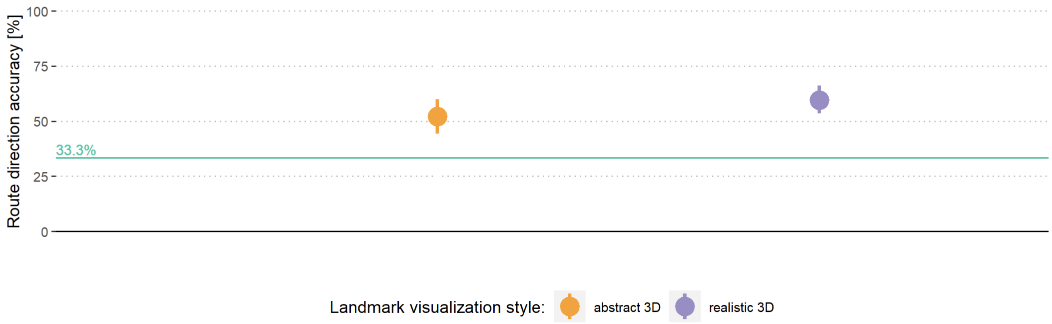

Figure 4 Accuracy of route direction recall by landmark visualization condition (dots indicate means; bars indicate 95% CIs; green line indicates performance at chance level).

4 Discussion

We conducted a map-assisted navigation experiment outdoors in an urban area to assess how landmark visualization style (i.e., 3D abstract vs. 3D realistic symbols) on a mobile map influences participants' recall of landmarks and route direction along the traversed environment. Our first results show that participants better remembered landmarks shown as 3D realistic symbols on the mobile map than 3D abstract landmark symbols (Figure 3). In support of our hypothesis, adding more details to the 3D landmarks (realistic) on the mobile map display could have made them more memorable compared to 3D landmarks with fewer details (abstract) and thus made it easier for participants to recall these symbols [7]. Our results on landmark recall are consistent with previous findings showing that 3D realistic landmarks on mobile maps facilitate the matching of navigation-relevant information with proximal features in the environment [6], and in doing so, facilitate landmark learning [7]. Although participants' response biases were significantly higher than zero, they did not differ between landmark visualization conditions and thus do not affect our interpretation of this result.

Contrary to our hypothesis, the results did not reveal any significant differences in recalling landmarks seen in the environment (Figure 2) and route direction accuracy (Figure 4). The lack of differences between landmark visualization styles could be because having 3D landmarks in general (regardless of the level of detail) could have already provided the necessary visual information to help participants recognize these buildings and the associated navigation decisions [2, 10]. This result is consistent with previous studies showing that participants do not necessarily perform better with increased realism [10, 15]. Another possible explanation could be that participants were explicitly told that their acquired knowledge of the environment would be tested [14], which might have motivated them to pay more attention to task-relevant features and directions along the navigation route, or use other spatial-learning strategies, reducing the benefits of depicting landmarks on the mobile map [8].

5 Implications and future directions

This navigation study revealed promising results on how the design of landmarks on mobile maps can support spatial learning during navigation. We conducted the study in an urban residential environment of a European city; thus, it remains to be seen whether our results can be applied to other types of environments. On the one hand, a close visual match between the mobile map display and the environment could have directed participants' visual attention away from the display and toward the environment, thus helping participants to learn the environment while mitigating cognitive load. On the other hand, the increased visual information on the realistic 3D landmarks might have increased participants' cognitive load due to the higher amount of visual information to be processed [5]. Therefore, examining participants' cognitive load (i.e., recorded with electroencephalography) and visual attention allocation (i.e., by using mobile eye-tracking) could complement the interpretation of these behavioral results. Even though we did not find differences in the landmarks seen in the environment and route direction knowledge, there might be differences between the conditions regarding survey knowledge acquisition. Specifically, viewing the route from a bird's-eye view and remembering 3D realistic landmarks on the mobile map display better could mean that participants' survey knowledge is better with the realistic 3D compared to the abstract 3D landmarks. Therefore, for the next steps in our research program, we are interested in analyzing the relationships between participants' map interactions, familiarity with the study area, survey knowledge acquisition, visual attention allocation, and cognitive load during this real-world navigation task.

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