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Virtual landmark cues improve spatial learning: evidence from an augmented reality indoor navigation study

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Abstract:

Wayfinders become lost more frequently during indoor than outdoor navigation tasks (Brunner-Friedrich & Radoczky, 2006; Liu et al., 2021; Wilkening et al., 2019). This is attributed, among others, to the lack of visually salient indoor landmarks, typically only visible at short ranges (e.g., information boards, labels) in contrast to the amount and high visibility of outdoor landmarks (e.g., prominent buildings.; Dubey et al., 2019; Liu et al., 2021). To investigate this, in a related augmented reality (AR) indoor navigation study, Liu et al. (2021) enhanced the visual saliency of indoor landmarks (i.e., semantically salient offices) by augmenting them with virtual landmark icons. Their qualitative analyses showed that the augmented landmarks were the second most frequently labeled category in a landmark location task. Using a virtual reality (VR) urban environment, Zhao et al. (2023) found that adding virtual icons (i.e., 2D images) in front of landmarks facilitated spatial learning compared to when no additional virtual icons were provided. However, it is still unknown how augmenting indoor landmarks with virtual icons supports wayfinders' spatial knowledge acquisition in indoor environments. To address this research gap, we conducted an AR indoor navigation study on a university campus to assess how augmenting landmarks with virtual icons impacts wayfinders' spatial learning of indoor routes.

Wearing a Microsoft HoloLens 2, participants followed a predefined three-story indoor route (approx. 500 meters long) augmented with holographic arrows through a university campus. We selected 10 indoor features to serve as landmarks at navigation decision points, divided into two landmark types: five *freestanding* salient features with high visibility (e.g., cafeteria, plant, relief model) and five *wall installation* features with low visibility (e.g., signage, information boards). In a between-subjects design, participants followed the indoor route under either the virtual icon or control condition. In the virtual icon condition, the 10 landmarks were digitally augmented with virtual icons, whereas in the control condition, these icons were omitted. We hypothesized that landmark knowledge would improve under the virtual icon compared to the control condition (H1) and that landmark knowledge would be influenced by the interaction between landmark types and conditions (H2; Zhao et al., 2023).

A total of 41 participants with normal or corrected-to-normal vision joined the study. We assigned 21 participants to the virtual landmark condition (f = 11, M_{age} = 26.52, SD_{age} = 4.31) and 20 participants to the control condition (f = 10, M_{age} = 25.75, SD_{age} = 5.21), controlling for spatial abilities, gender, and age. Participants provided written informed consent and did not receive monetary compensation. Participants were informed that their knowledge of the environment would be assessed after the navigation task, but the type of tests was not disclosed. We assessed participants' landmark and route knowledge, focusing here on preliminary results for landmark knowledge acquisition performance.

The landmark knowledge task presented participants with 20 indoor landmark images in random order and asked them to indicate whether they had seen them on the route. Among these, 10 were the selected landmarks located at intersections where a navigation decision was required, and 10 were novel landmarks that were not encountered along the route. Due to technical AR headset failure, one wall installation landmark was excluded from the analysis. To assess the effect of condition (virtual icons vs. control) and landmark type (freestanding vs. wall installation) on wayfinders' landmark knowledge, we applied signal detection theory (SDT; Stanislaw & Todorov, 1999) using the *psycho* package (Makowski, 2018). SDT encodes correct responses as *hits* or *correct rejections* and false responses as *misses* or *false alarms.* We used the *discriminability index d prime (d'),* computed as *Z(hit) – Z(false alarm),* to assess participants' ability to differentiate between the task-relevant and novel landmarks. A value of *d'* = 3 indicates perfect landmark knowledge, whereas a value of *d'* = 0 is chance-level performance.

We used linear mixed-effects models (LME) with the *lme4* package (Bates et al., 2015) to analyze landmark knowledge performance. The model included *d'* as the response variable to assess if landmark knowledge was predicted by the fixed

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effects of the experimental condition (virtual landmarks vs. control; sum contrast-coded), landmark type (freestanding vs. wall installation; sum contrast-coded), and their two-way interaction. Although familiarity was not the primary focus of this study, 30 participants rated themselves as familiar with the route (virtual icon = 13, control = 17), and the remaining 11 were unfamiliar (virtual icon = 8, control = 3). Since familiarity can affect spatial learning (Kapaj et al., 2024), we added this as a third fixed effect in our model (familiar vs. unfamiliar; sum contrast-coded). The model included a by-subject random intercept. Post-hoc analyses on significant interactions were conducted using the *pairs()* method of the *emmeans* package (Lenth, 2023) to compare the estimated marginal means across categorical factors. The alpha level was set at 0.05, and p-values were calculated with the Satterthwaite approximation for degrees of freedom to ensure acceptable Type I error rates (Luke, 2017), utilizing the *summary()* function from the *lmerTest* package (Kuznetsova et al., 2017).

Consistent with H1, we found a main effect of condition ($\beta = 0.19$, $SE = 0.09$, $t = 2.20$, $p = .034$), indicating that landmark knowledge improved significantly when landmarks were augmented with virtual icons compared to the control condition (Figure 1a). In line with H2, we found a main effect of landmark type ($\beta = 0.64$, $SE = 0.05$, $t = 12.24$, $p < .001$), indicating that freestanding indoor landmarks are recognized better than less visible wall installations (Figure 1b). We also found a significant interaction between condition and landmark type ($\beta = -0.34$, $SE = 0.05$, $t = -6.47$, $p < .001$). Post hoc analyses revealed that the estimated marginal means differed significantly between conditions for wall installation (*emmeans* = 1.05, $SE = 0.20$, $t = 5.21$, $p < .001$) but not for freestanding landmarks (*emmeans* = −0.29, $SE = 0.20$, $t = -1.43$, $p = .157$). This means that while landmark knowledge for freestanding features was similar across conditions, it increased significantly when the less salient wall installations were augmented with virtual icons compared to the control condition (Figure 1c). Finally, we observed that environmental familiarity did not predict landmark knowledge ($\beta = 0.15$, $SE = 0.10$, $t = 1.53$, $p = .133$).

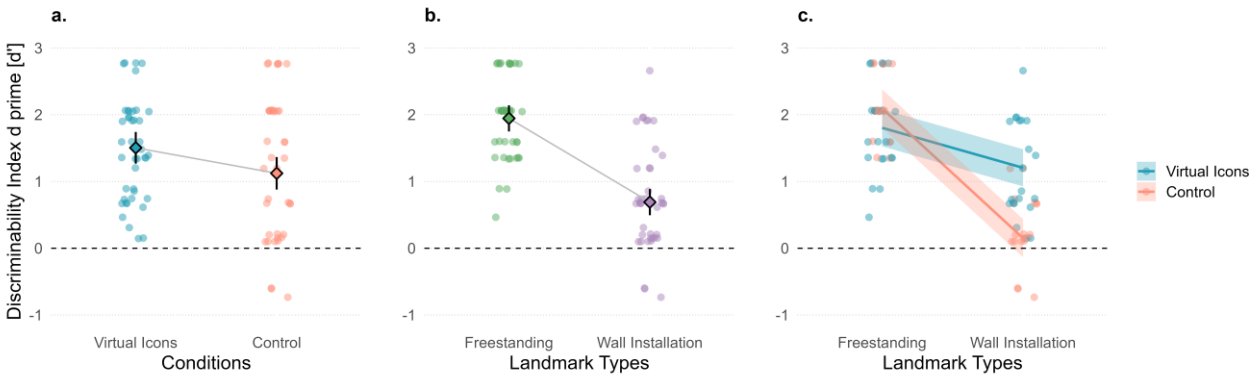

Figure 1. The LME model revealed that landmark knowledge improved in the virtual icon condition (a) was higher for freestanding features (b) and increased when wall installations were augmented with virtual icons (c). *Diamonds indicate group means with 95% confidence intervals (CIs), dots show individual data, shaded areas denote 95% CIs, and dashed black lines mark chance performance.*

Extending Zhao et al.'s (2023) research in VR, the augmentation of indoor landmarks with virtual icons in AR enhanced wayfinders' landmark knowledge acquisition compared to the control condition (Figure 1a). Consistent with real-world navigation studies (Wenczel et al., 2017), we found that landmark knowledge increased significantly for the visually salient freestanding indoor features compared to the less visually salient wall installation features visible only at short range (Figure 1b). Notably, landmark knowledge for freestanding features remained consistent across conditions (Figure 1c), likely because these features were already highly salient in the indoor environment (Dubey et al., 2019). In contrast, landmark knowledge for the less salient wall installation features improved significantly when augmented with virtual icons compared to the control condition (Figure 1c). The augmentation of wall installation with virtual icons likely increased their visual saliency and enriched the indoor environment with visually salient landmarks, which has been found to guide wayfinders' attention to task-relevant features and improve their spatial learning (Denis et al., 2014; Fine & Minnery, 2009; Kapaj et al., 2024). The improvement in landmark knowledge may be attributed to modulations in users' visual attention behavior, where salient landmarks are prioritized by users' visual encoding strategies, resulting in enhanced spatial memory (Hamid et al., 2010). Thus, AR-assisted navigation may be particularly effective in supporting spatial knowledge acquisition of task-relevant indoor landmarks that lack visual saliency. In future work, we plan to examine the role of experimental conditions in wayfinders' route knowledge acquisition.

Taken together, our findings on AR-assisted navigation contribute to the call for a perceptually salient visualization of landmarks on navigation aids (Ruginski et al., 2022), which has been shown to direct wayfinders' visual attention to task-relevant information (Kapaj et al., 2024), even in expert wayfinders (Kapaj et al., 2021, 2023), and to improve spatial learning (Kapaj et al., 2024) and cognitive processing of spatial information (Hilton et al., 2025) during map-assisted navigation tasks.

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