Comparing the Effects of Reference-based, Orientation-based, and Turn-by-turn Navigation Guidance on Users' Independent Navigation

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ABSTRACT

Research has shown that turn-by-turn navigation guidance has made users overly reliant on such guidance, impairing their independent wayfinding ability. This paper compares the impacts of two new types of navigation guidance – reference-based and orientation-based – on their users' ability to independently navigate to the same destinations, both as compared to each other, and as compared to two types of traditional turn-by-turn guidance, i.e., map-based and augmented-reality (AR) based. The results of our within-subjects experiment indicate that, while the use of reference-based guidance led to users taking more time to navigate when first receiving it, it boosted their subsequent ability to independently navigate to the same destination in less time, via more efficient routes, and with less assistance-seeking from their phones than either map-based or AR-based turn-by-turn navigation guidance did.

CCS CONCEPTS

• Human-centered computing~Human computer interaction (HCI)~HCI theory, concepts and models

KEYWORDS

Wayfinding Performance; Navigational Guidance; Mobile Navigation Systems; Spatial Knowledge; Pedestrian Navigation

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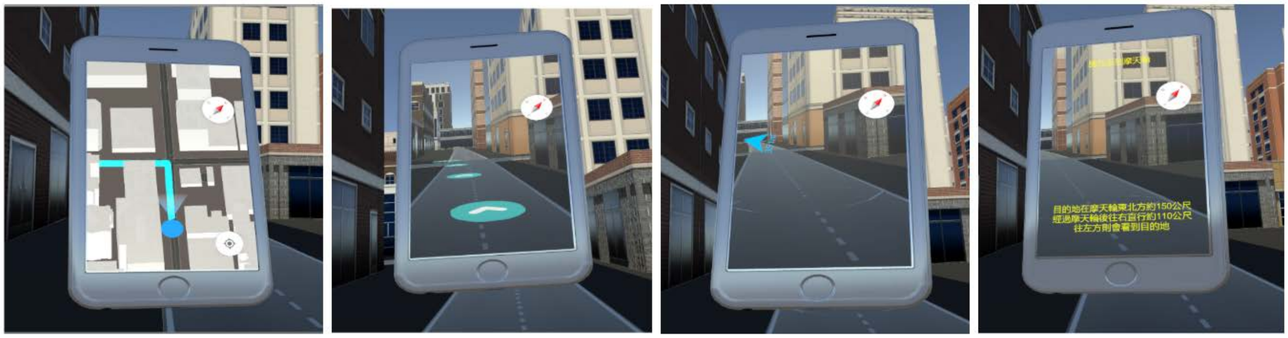
1 Introduction

Mobile navigation systems are intended to assist people to navigate to their destinations. However, research has shown that state-of-the-art systems offering turn-by-turn guidance have made users overly reliant on such guidance and impaired their independent wayfinding ability, by failing to help them acquire sufficient spatial knowledge during their navigation tasks. Ishikawa et al. [1], for example, found that users traveling with GPS-based systems acquired less survey knowledge than those who used paper maps, and thus exhibited inferior wayfinding performance. Münzer et al. [2] reported similar results.

Because learning survey knowledge during navigation guidance is likely to help users navigate on their own subsequently [3], we designed two forms of mobile navigation guidance, i.e., an Orientation-based Mode and a Reference-based Mode, and conducted an experiment to compare both of them against traditional "turn-by-turn" guidance. Since Google Maps is a well-known navigation solution, we created a similar map-navigation interface design for our systems. Also, since augmented-reality (AR) navigation technology has recently become more sophisticated, we designed an AR turn-by-turn mode for further comparison of whether either or both of our non-turn-by-turn systems were capable of reducing users' reliance on their phones when navigating, and thus improve their overall wayfinding performance.

2 Comparing Navigation-guidance Types

The comparators for our novel Reference-based and Orientation-based guidance systems, Traditional Turn-by-Turn Mode and AR Turn-by-Turn Mode, were both based on off-the-shelf mobile navigation systems that communicate the shortest path to the user's destination via turn-by-turn instructions. Both of these traditional modes support path re-planning, i.e., update the route if the user deviates from the predefined path, again in keeping with off-the-shelf navigation systems. Our two guidance systems,



(a) Map Turn-by-turn **(b) AR Turn-by-turn** **(c) Orientation-based** **(d) Reference-based**

Figure 1. The four focal navigation-guidance modes

in contrast, do not directly indicate a particular route to the destination, but instead utilize other navigation cues. Since both these latter approaches require users' active processing of spatial information, we expect them to boost users' performance on independent wayfinding tasks. Their specific features are described in more detail below.

2.1 Map Turn-by-turn Mode

We compared all four guidance modes in VR environments. As can be seen from Figure 1(a), our Map Turn-by-turn interface design is similar to that of well-known mobile navigation applications, and displays the planned route as a blue line. The user's current location is indicated by a blue point, and his/her orientation as a blue beam. Users are allowed to check the whole route by moving the map around with their hand controller; and, having done this, if they can no longer see their own location point, they can press the "My Location" button to re-center their current position.

2.2 AR Turn-by-turn Mode

AR Mode (Fig. 1(b)) was inspired by the AR Live View feature on Google Maps, in which the user can see his/her route as moving arrows on the ground through cellphone's camera view. When the user deviates from the predefined route, the system will re-plan the route and update these display arrows accordingly.

2.3 Orientation-based Mode

In the Orientation-based Mode (Fig. 1(c)), a blue arrow displayed in the camera view always points to the user's destination, and text immediately beside that arrow displays the distance between the user and the destination.

2.4 Reference-based Mode

The design of the Reference-based mode (Fig. 1(d)) was inspired by the concepts of cognitive maps and global landmarks [4]. The "Reference" alluded to its name is a landmark that the user already knows how to navigate to by him- or herself. Its guidance comprises a textual description of the user's current location relative to the reference destination, plus a short navigational description such as "The destination is 190 meters southwest of the Ferris wheel. Turn right at the first intersection after the Ferris wheel. Go straight for 110 meters. The destination is on the right-hand side." The idea is to leverage users' existing place knowledge as a reference/anchor for their learning of how to navigate to the destination in the future. We hypothesize that this mode will help users build cognitive maps by gradually expanding the geographic scope of their knowledge about relative locations, a key element of survey knowledge.

3 Method

3.1 Participants and Design

We recruited 26 participants for this study (12 men and 14 women), ranging in age from 20 to 55. Approximately four-fifths of the participants were college students aged from 20 to 25. When recruiting participants, we asked them to complete the Santa Barbara Sense-of-direction Scale [5] as a proxy for their baseline wayfinding ability. They were also asked to rate their familiarity with mobile navigation systems, from 1=very unfamiliar to 5=very familiar. We divided the participants into a 3x3 group according to whether their Santa Barbara scores were high, medium, or low and whether their familiarity with mobile navigation systems was high (i.e., 5), medium (4), or low (1-3). Our within-subjects design required each participant to be tested on four different routes with all four of the focal navigation-guidance systems. The order in which each given participant used the four guidance systems was randomly assigned to prevent learning effects; and the combinations of particular routes with particular types of guidance were also random.

3.2 Virtual Environment

We built a virtual city using the Unity game engine [Fig. 2]. The buildings in the city were designed to be roughly similar in style, and unique prominent landmarks were avoided, to prevent users' learning of such landmarks from affecting their navigation-task performance. Participants wore VR headsets (HTC VIVE pro) while exploring the virtual environment. The right VR hand controller was used to turn the cellphone on and off and to control

Figure 2. The virtual city study environment

the player's movement in the virtual world, while the left one consisted of a beam pointer that could be used to interact with the buttons and mobile interface in the virtual scene.

3.3 Navigation Task

In each navigation task, the participants had to navigate twice to the same destination (a specific shop). First, they would do so by following the designated guidance along a route equivalent to between 500 and 600 meters in the real world, varying from easy (i.e., three turns) to difficult (six turns) and planned by the system using a shortest-path policy. Next, they would navigate to the same destination independently, relying on the spatial knowledge learned when using the system previously, but were allowed to consult their phones for hints if they became lost. The performance metrics recorded during the guidance-assisted phase of each task consisted of completion time and navigation distance; and in the second, independent phase, of both those metrics plus the number of times the user checked his/her phone for hints.

3.4 Procedure

Because none of the participants could have had any prior experience of the virtual city, it was necessary to provide them with some knowledge about the reference that we would be using in the Reference-based guidance during the experiment. Therefore, all participants were asked to watch videos of navigating from two different starting points to the reference location, a Ferris wheel, and asked to memorize both those routes before commencing the experiment. At the beginning of the experiment, we asked each participant to "walk" the same routes shown in the two videos to ensure that they knew the reference location, and that they were able move about effectively in the virtual environment. After they successfully completed this trial task, the experiment *per se* began.

After they had finished each experimental task, they were asked about how difficult they had found it, and were given a 3-minute break to prevent motion sickness. We also asked them to fill out the VR sickness scale [6] so we could measure how many discomfort may have affected their navigation performance.

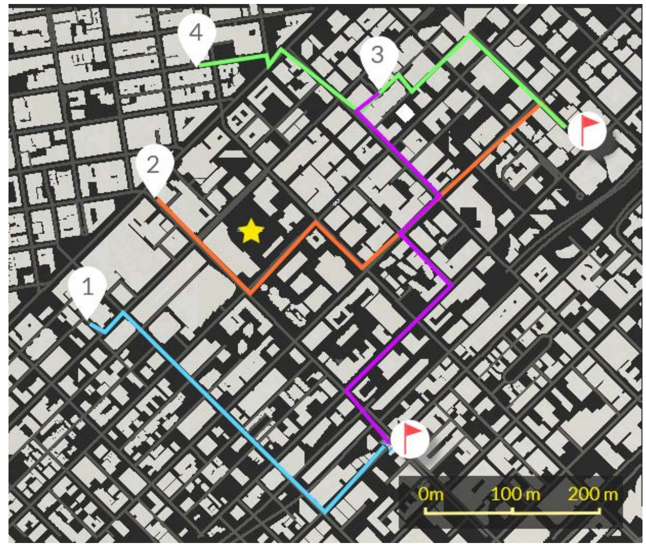


Figure 3. Map of the virtual study area, showing four wayfinding-task routes, color-coded by complexity level. (Route 1 has 3 turns; rout 2 has 4 turns; route 3 has 5 turns; route 4 has 6 turns)

4 Results

Since our study is within-subjects design, we had to consider the order of task performance. In addition, routes were a critical variable likely to affect the navigation performance. We also had to consider individual differences in sense-of-direction. Thus, we used a linear regression model to examine the experimental results. Its predictor variables were navigation guidance, task order, route and Santa Barbara score. Our specific results are described in the following subsections.

4.1 Assisted-wayfinding Task Phase

4.1.1 Completion time and distance. We recorded how much time (in seconds) it took each participant to complete each assisted wayfinding task, and the distance s/he had traveled (in meters). We found that there was a significant difference in completion

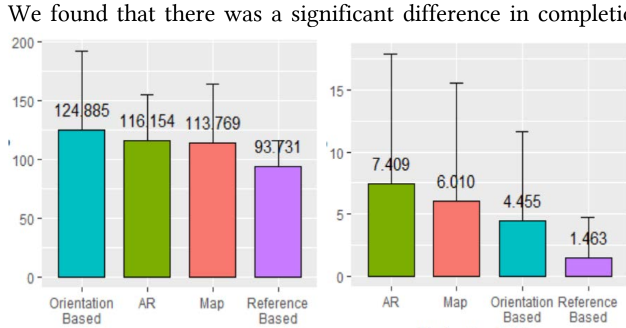


Figure 4. Bar plots that show mean and standard deviation for completion time and phone checking time in independent-wayfinding task phase

time across the four navigation-guidance modes: with the Reference-based mode taking the longest, and AR Turn-by-turn

	Map	AR	Orientation-Based	Reference-Based
Time(sec)	M=113.7 (SD=50.4)	M=116.1 (SD=39.3)	M=124.8 (SD=67.0)	M=93.7 (SD=22.2)
Distance(m)	M=639.8 (SD=140.9)	M=669.3 (SD=160.7)	M=773.3 (SD=416.3)	M=614.4 (SD=101.3)
Number of Phone-checking	M=2.4 (SD=3.3)	M=2.4 (SD=3.7)	M=1.7 (SD=2.6)	M=0.6 (SD=1.2)
Phone-checking time(sec)	M=6.0 (SD=9.5)	M=7.4 (SD=10.4)	M=4.4 (SD=7.1)	M=1.4 (SD=3.2)
Difficulty	M=2.9 (SD=1.2)	M=3.2 (SD=1.2)	M=3.1 (SD=1.3)	M=2.1 (SD=1.0)

Table 1: Means (and standard deviations) for each variable by participants in the four groups of independent wayfinding task

Mode the shortest. Reference-based mode's completion time was further found to be significantly longer than that of AR Turn-by-turn Mode (p<0.001), Map Turn-by-turn Mode (p=0.02) and Orientation Mode (p=0.002). The travel-distance results were similar.

4.2 Independent-wayfinding Task Phase

4.2.1 Completion time and distance. With regard to the performance of Reference-based mode, the independent-wayfinding task phase yielded opposite results. That is, the completion time and travel distance were both shortest among users who had previously followed Reference-based guidance, and completion time was significantly shorter among former Reference-based Mode users than among their Orientation-mode counterparts (p=0.01). Differences between Reference-based modes and the other two modes were marginal, however (see Table 1, first row). Travel-distance results were again similar to completion-time ones. Surprisingly, however, participants who had previously used Orientation-based Mode took the longest time to finish the task, and devised the longest routes.

4.2.2 Phone-checking. When participants turned on their phones to look up navigation guidance during the independent phase of each task, the time they spent looking at them was recorded by our system. This data revealed that the overall duration of phone-checking by former users of Reference-based Mode was significantly lower than for their turn-by-turn counterparts, both from Map Mode (p=0.03) and AR mode (p=0.005). However, it was not significantly different from the phone-checking duration of those who had used Orientation-based Mode (Table 1, fourth row). This indicates that the Reference-based mode was the best of the four when it came to enabling users to navigate independently without assistance from their phones.

4.2.3 Ratings of task difficulty. User-perceived task difficulty was rated on a five-point scale from 1=very easy to 5=very difficult. The perceived difficulty of completing tasks in Reference-based Mode was significantly lower than that of the other three modes (Map: p=0.02, AR: p=0.001, Orientation: p=0.02). There were no significant differences in perceived difficulty across the other three modes (Table 1, fifth row).

5 Conclusion

The results of our experimental virtual-world comparison of wayfinding performance across four different modes of navigation guidance indicate that Reference-based Mode performed the best in terms of enabling users to independently navigate after receiving guidance, despite their having taken more time while using it than when using the other three systems. This was likely because they were processing spatial information more deeply while using this guidance mode than when using the other three modes. This active processing of spatial information, in turn, reduced their dependence on the navigation system, thus boosting their performance when navigating without assistance.

It is also worth noting that only those participants who had used Reference-based Mode had shorter travel distances in independent wayfinding tasks than in assisted ones. Unexpectedly, users who had first used our novel Orientation-based Mode took the longest to reach their destinations by themselves. Before the experiment, we expected that users would be able to find the destination by orientation alone, i.e., without memorizing any specific route, thus reducing users' mental effort and improving their independent wayfinding task performance. However, observation of participants' actual behavior revealed that some of them focused on following the arrow so closely that they ended up ignoring the route they were taking. This approach sometimes resulted in complicated, hard-to-memorize, inefficient routes comprising numerous turns.

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