



Spatial Knowledge Acquisition with Mobile Maps, Augmented Reality and Voice in the Context of GPS-based Pedestrian Navigation: Results from a Field Test

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ABSTRACT: GPS-based pedestrian navigation systems have become increasingly popular. Different interface technologies can be used to communicate/convey route directions to pedestrians. This paper aims to empirically study the influence of different interface technologies on spatial knowledge acquisition in the context of GPS-based pedestrian navigation. A field experiment was implemented to address this concern. Firstly, the suitability of the evaluation methods in assessing spatial knowledge acquisition was analyzed empirically (focusing on the ability of differentiating “familiar” and “unfamiliar” participants). The suitable methods were then used to compare the influence of mobile maps, augmented reality, and voice on spatial learning. The field test showed that in terms of spatial knowledge acquisition, the three interface technologies led to comparable results, which were not significantly different from each other. The results bring some challenging issues for consideration when designing mobile pedestrian navigation systems.

KEYWORDS: field study, spatial knowledge acquisition, GPS-based pedestrian navigation, mobile map, augmented reality, voice

1. Introduction

Recent years have seen raising interests in using mobile phones to assist pedestrian wayfinding. Mobile pedestrian navigation systems are designed for this purpose. They often employ Global Positioning System (GPS) or other positioning methods for continuously tracking of mobile users, and thus provide users with real-time and in-situ route information (directions). Different interface technologies can be used to communicate/convey route information to pedestrians, such as mobile maps, voice, 3D, and images. Recently, mobile augmented reality (AR), which augments the real world camera view with virtual information overlays, is considered as another promising technology for conveying route information.

There are many field tests studying the effectiveness of different interface technologies in supporting pedestrian navigation (Rehrl et al. 2010; Walther-Franks 2007). In many tests, subjects’ wayfinding performance was often evaluated and compared, such as how many errors they made during wayfinding, and how much time they took to finish the route. In contrast to these field tests, this article aims at studying the influence of different interface technologies on spatial knowledge acquisition. Spatial knowledge acquisition is needed to build a mental representation of space, which is essential for wayfinding and other spatial tasks. With sufficient spatial knowledge about an environment, people can still find their way when navigation systems fail (e.g., out of battery). Currently, more and more people are relying (or even over-relying) on navigation systems to find ways. Therefore, it is important to investigate how these systems affect the acquisition of spatial knowledge during navigation.

The goal of this article is to empirically study the influence of mobile maps, AR, and voice on spatial knowledge acquisition in the context of GPS-based pedestrian navigation. Three navigation prototypes, implementing mobile map-based, AR-based, and voice-based guidance respectively, were developed based on recent findings in literature. Subjects were asked to use the interfaces to solve some real-world navigation tasks in the city center of Salzburg (Austria).

The rest of this article is structured as follows. Section 2 outlines related work. In section 3, the three navigation prototypes are implemented by integrating recent findings in literature. The study design is

presented in section 4. Section 5 analyzes and discusses the results, focusing on two issues: the suitability of the evaluation methods in assessing spatial knowledge acquisition, and the influence of the three interface technologies on spatial knowledge acquisition. Finally, we draw conclusions and present future work.

2. Related Work

In this section, we describe related work on spatial knowledge acquisition, and empirical studies investigating spatial knowledge acquisition in pedestrian navigation.

2.1 Spatial Knowledge Acquisition

Three levels of spatial knowledge can be distinguished (Siegel and White 1975): 1) Landmark knowledge comprises salient points of reference in the environment, 2) Route knowledge puts landmarks into sequence (e.g., navigation paths), and 3) Survey knowledge allows people to locate landmarks and routes with a general frame of reference. Spatial knowledge, or mental representation of space, is essential for wayfinding. During wayfinding (especially without any external route aids), humans make route decisions to find a connection between a start point and an end point. Therefore, sequences connecting decision points are planned. When moving, this plan is monitored permanently by referring to objects of the real world and comparing them with the mental representation for route confirmation (Gartner and Hiller 2009). Spatial knowledge acquisition, or spatial learning, can help to build this kind of mental representation. Various methods can be used to acquire spatial knowledge, including sensual perception of the real world as well as acquisition from models of the real world, such as maps, 3D, AR and verbal description.

When analyzing mental maps (the results of spatial knowledge acquisition), the method of sketch map is often used. Byrne (1979) demonstrated distorted distances and angles in sketch maps. Tversky (1981) and Thorndyke et al. (1982) pointed out that the skills of drawing correct angles and finding a way were not significantly correlated. It is therefore useful to stick to topological interpretation of sketch maps only (Lynch 1960). In contrast to the method of sketch map, Münzer et al. (2006) employed a route recognition task (ask participants to recall how they turned at each intersection) and a spatial relocation task (ask participant to place pictures, representing landmarks and intersections, at their correct locations on a map showing the test area) to assess acquisition of route knowledge and survey knowledge respectively.

In this article, the methods provided by Münzer et al. (2006) will be employed in the field experiment. Firstly, the suitability of these methods in assessing spatial knowledge acquisition will be partially evaluated. The suitable methods will be then used to compare the influence of mobile maps, AR, and voice on spatial knowledge acquisition.

2.2 Related Empirical Studies

There are some studies empirically investigating the acquisition of spatial knowledge in the context of pedestrian navigation. Gartner and Hiller (2009) investigated maps with different display sizes and showed that display size influenced spatial knowledge acquisition during navigation. Ortag (2005) studied the differences of spatial knowledge acquisition with mobile maps and verbal instructions during navigation. Krüger et al. (2004) compared the impact of different modalities (i.e., audio and graphics; route directions were indicated on images) on spatial knowledge acquisition during navigating in a zoo, and concluded that the acquisition of route knowledge was much better than that of survey knowledge. Münzer et al. (2006) empirically compared paper maps with three electronic navigation systems, and found that navigation system users showed good route knowledge and poor survey knowledge, in contrast, paper map users showed better survey knowledge and nearly perfect route knowledge. Münzer et al. (2006) also showed that variations of information presentation within electronic navigation systems did not lead to significant differences in spatial knowledge acquisition.

It is important to note that most of the above studies employed the ‘Wizard of Oz’ prototyping (e.g., without using the GPS) (Wikipedia 2011). In contrast, Ishikawa et al. (2008) compared the acquisition of spatial knowledge with a map-based GPS navigation system, paper maps and direct experience of travelling, and showed a poorer performance of subjects using the GPS-based system. However, it is

important to note that the maps used in the navigation system showed the surrounding area with a ‘north-up’ allocentric perspective; also relevant landmarks were missing or not purposely highlighted. To the best of our knowledge, none of the field test compares the influence of mobile maps, AR, and voice on spatial knowledge acquisition in the context of GPS-based pedestrian navigation.

3. Conveying Route Information with Mobile Maps, AR, and Voice

For studying spatial knowledge acquisition with different interface technologies, we used three self-implemented mobile navigation systems running on Apple’s iPhone 4. These systems used map-based, AR-based, and voice-based interfaces respectively. Recent findings on pedestrian navigation from literature were integrated and considered when developing these systems.

Research on cognitive mapping and wayfinding has shown that routes are often thought as a sequence of turns (Tversky 1992; MacEachren 1995). Tversky and Lee (1999) showed that both route maps and route directions maintained a similar structure in schematizing information, and focused on communicating turn directions at each turning point (decision point). Therefore, in order to effectively support wayfinding, route guidance must convey turning point information in a clear and easy-to-understand manner, and the supplementary information (local context and overview context) should ‘only be included when it does not reduce the clarity of the turning point information’ (Agrawala 2001, p. 27). We applied this consideration when designing the three navigation systems.

3.1 Map-based Interface

The main factor that has to be considered when designing map-based navigation systems is the small size of mobile screens. Literature provides some useful suggestions for route map design (Radoczky 2004; Gartner and Radoczky 2005): 1) providing an overview of the whole route at the beginning of wayfinding and also during route following, 2) automatically adapting the map view to the position of the user, 3) providing a ‘track-up’ egocentric map view, 4) supporting scale changes, 5) clearly distinguishing the past and the future paths. Related research on landmarks was also considered when designing route maps (Michon and Denis 2001; Elias and Paelka 2007).



Figure 1. A screenshot of the map-based interface, with an egocentric view, distinction between the past and future paths, automatic adaptation to real-time location, zooming and panning functions, etc. (© Salzburg Research, Map data: OpenStreetMap and Contributors, CC-BY-SA).

A screenshot of the map-based interface is shown in Figure 1. The route is visualized as a red line filled with small white arrows pointing the forward direction. The past path is dyed in a lighter color to be clearly separated from the future one. The current position is determined by GPS, improved by a route matching algorithm. A 'track-up' egocentric map view is provided. In order to provide a better readability, the orientation of street names is changed accordingly. For visualizing relevant landmarks, the last three abstraction levels (i.e., words, symbol and icon) suggested by Elias and Paelka (2007) are used. Finally, some functions are also provided. Users can press the button in the middle of the header to fade out the route for a better readability of street names on the map tiles. Zooming and panning functions are also provided.

3.2 AR-based Interface

In the AR-based route guidance, route information is overlaid on the real world camera view. The GPS module, magnetometer, and tilt sensor on the mobile devices are used to calculate the position of the overlay information. The information includes a green virtual path showing the route to be followed. Also street names of the route and relevant landmarks along the route are designed as overlay information. In addition to the graphic interface, a vibration alarm alerts when a decision point is reached. Figure 2 shows a screenshot of the AR-based interface.

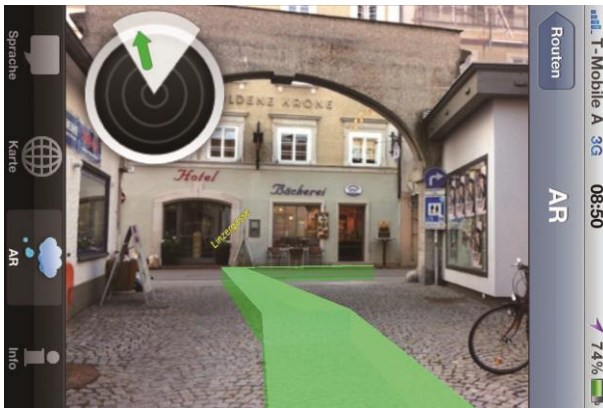


Figure 2. A screenshot of the AR-based interface, with a real world camera view, route overlay, street names and relevant landmarks (© Salzburg Research).

3.3 Voice-based Interface

The development of the voice-based interface was based on the findings of the previous project SemWay. The project studied how people describe the world and routes, and designed a formal model of navigation language. Three sets of particles forming route instructions were extracted and modeled (Rehrl et al. 2009): motion concepts (a set of re-occurring verbs describing motion patterns, such as turn, walk, pass and cross), direction concepts (a set of re-occurring spatial relations which can be used to anchor motion with landmarks, such as along, in, out, direction of, to, through, and through between), and landmark concepts (reference entities along different route segments). With the model, semantic-based route instructions instead of metric-based instructions can be provided, for example, 'walk straight, pass the theatre, and walk to the crossing' instead of 'walk straight for 103 m'. Voice instructions for each decision point of the test route were automatically generated by using this semantic-based model (Rehrl et al. 2010).

The user interface of the voice-based guidance includes a single screen with a slider for controlling the sound volume and a button for repeating the last instruction. When a user gets close to a decision point, the mobile device vibrates, and plays the voice instruction describing the actions from this decision point to the next.

4. Study Design

4.1 Study Routes and Participants

A route in the city center of Salzburg was selected for the test. It was divided into three sub-routes, each with 9 decision points (e.g., interactions where multiple outgoing choices exist). The surroundings of these sub-routes were characterized by residential and business areas.

Twenty four participants took part in the study (12 female and 12 male). The mean age was about 42 years (range 21-73). They were paid for their participation. All of them were German-speaking people.

4.2 Tasks for Assessing Spatial Knowledge Acquisition

At the end of each sub-route, participants were asked to give an approximate direction to the starting point of the current sub-route ('pointing task'). In addition, they had to finish the following tasks assessing their acquisition of spatial knowledge. For each sub-route, a corresponding photo album containing 11 randomly numbered pictures was given to them. Seven of the pictures were taken along the current sub-route (5 at intersections and 2 within route segments), using the perspective of route following. The other four pictures taken at other off-route places (2 at intersections) were introduced as 'fake' pictures. For pictures taken at intersections, all possible outgoing choices (branches) were labeled ('A', 'B', 'C' ...). Participants were then asked to write down the IDs of all pictures that they thought were along the current sub-route ('landmark recognition task'). In addition, for the chosen pictures that were at intersections, participants should indicate the turn ('A', 'B', 'C' ...) they had taken at each of them ('route direction task'). Landmark recognition task and route direction task were used to assess the acquisition of landmark knowledge and route knowledge respectively. Finally, participants were asked to place/write the IDs of the chosen pictures on an A4 paper, which showed a simple map of the current area, with the start point and the end point marked on the map (the sub-route was not indicated, and street and building names were erased). This 'landmark placement task' helped to assess the acquisition of survey knowledge.

4.3 Design and Procedure

Participants were randomly divided into three groups, each with 8 participants (4 female and 4 male). A within-subject design and a counterbalancing consideration were used for the test, i.e., for each sub-route, these three groups each used one of the navigation prototypes (mobile maps, AR, and voice). When they reached the next sub-route, they switched to another prototype. Each participant was accompanied by two researchers. One observed the test run and guided through the interviews and the other collected quantitative and qualitative performance measurements (e.g., stops, and reasons for them). Participants' movement, interaction with the navigation prototypes, task completion time, and GPS accuracy were logged on mobile phones.

At the beginning of each test, participants had to complete the Santa Barbara Sense of Direction test (Hegarty et al. 2002) to measure their spatial abilities. After that, we explained the basic usage of the pedestrian navigation systems and gave a short demonstration of the prototypes.

After a brief training session, the participants were led to the starting point of the first sub-route. Their task was to navigate to the end of the sub-route. If participants decided wrongly at a decision point, the observing researcher used gestures to indicate the correct choice. No other assistance was given during navigation. In order to keep the influence on participants to a minimum, the researchers walked several meters behind them. When reaching the end of the sub-route, participants were asked to answer questionnaires assessing usability and task load, and give some further qualitative feedback and comments. In addition, they were asked to do the following tasks one by one: indicating their familiarity with the current sub-route before the test, solving the pointing task, the landmark recognition task, the route direction task, and the landmark placement task. None of the tasks had a time limit for answering. Only accuracy performance was measured.

When finishing all these tasks, participants switched to another prototype, and the same procedure was repeated for the next sub-route. Each test was completed within 1.5 hours in total.

5. Results and Discussion

The field experiment was completed in July 2011. All participants successfully completed the navigation tasks. The results of the experiment included two parts: wayfinding performance and user experience, and spatial knowledge acquisition. In this article, we report the results of spatial knowledge acquisition.

As mentioned above, the spatial knowledge acquisition test was conducted within a framework including many other empirical tests, in which familiarity with the area was not the only criterion in selecting participants. Therefore, not all participants were unfamiliar with the sub-routes. In total, 32 participant/sub-route pairs were marked with ‘unfamiliar’ⁱ (10 for mobile maps, 13 for AR, and 9 for voice), and the other 40 participant/sub-route pairs were ‘familiar’ⁱⁱ (14 for mobile maps, 11 for AR, and 15 for voice). The coexistence of ‘unfamiliar’ and ‘familiar’ pairs gives us a good opportunity to investigate the suitability of the proposed tasks in assessing spatial knowledge acquisition.

In this section, we firstly investigate the suitability of the tasks, mainly focusing on their ability in differentiating “familiar” and “unfamiliar” participants. The suitable tasks will then be used to compare the influence of mobile maps, AR, and voice on spatial knowledge acquisition. The analysis of the latter issue will only use the results from the 32 ‘unfamiliar’ participant/sub-route pairs.

5.1 The Suitability of the Employed Tasks in Assessing Spatial Knowledge Acquisition

5.1.1 Results

The pointing task, the landmark recognition task, the route direction task, and the landmark placement task were used in the experiment to assess the acquisition of spatial knowledge. This section analyzes the results of these tasks, comparing participants who were familiar and participants who were unfamiliar with the sub-routes. We aim to study whether these tasks can differentiate ‘familiar’ and ‘unfamiliar’ participants.

In the *pointing task*, participants were asked to give an approximate direction to the starting point of the sub-routes. Their performances were measured as the deviation between actual directions and pointed directions. The deviations were measured in degrees. The results of the pointing task are given in Figure 3. On average, participants who were familiar with the sub-routes performed slightly better than participants who were unfamiliar (25° versus 29° deviation). A two-way analysis of variance (ANOVA) showed that the interaction between sub-routes and familiarity was not significant [$F(2,66) = 0.079$, $p=0.924$]. There was also no significant difference found between ‘familiar’ and ‘unfamiliar’ participants [$F(1,70) = 0.124$, $p=0.727$].

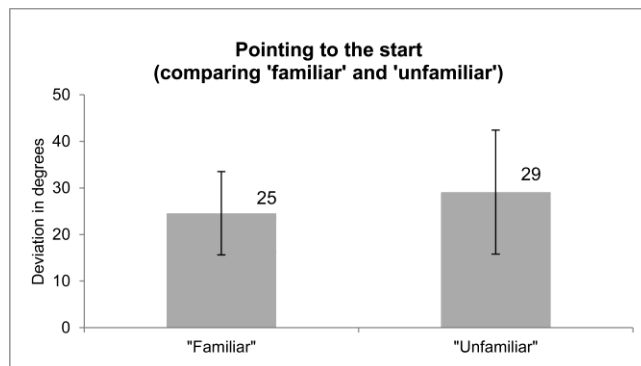


Figure 3. Results of the pointing task (deviation in degrees). Vertical error bars denote 95% confidence intervals.

In the *landmark recognition task*, participants were asked to choose pictures that they thought were along the sub-routes. Their performances were measured by counting the number of correctly chosen pictures. Figure 4 shows the results. On average, participants who were familiar with the sub-routes performed much better than participants who were unfamiliar (13% versus 34% errors). The interaction between sub-routes and familiarity was not significant [$F(2,66) = 1.544$, $p=0.221$]. However, the difference between ‘familiar’ and ‘unfamiliar’ participants was very significant [$F(1,70)= 19.556$, $p<0.001$].

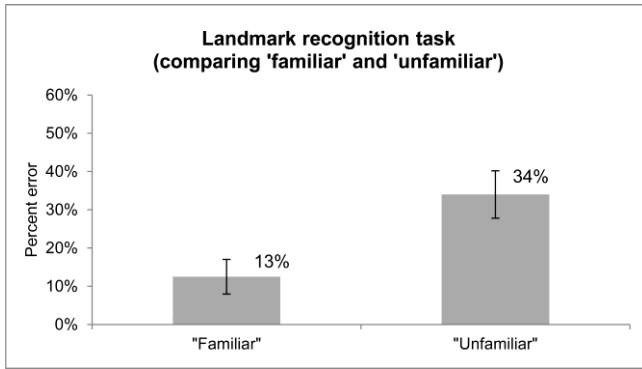


Figure 4. Results of the landmark recognition task (mean percent error). Vertical error bars denote 95% confidence intervals.

The *route direction task* was designed to assess the route knowledge acquisition during navigation. The score was calculated by counting the number of wrong turning directions in participants' responses to the route direction task. If the participants did not remember how they turned at an intersection shown on a picture, we counted an error as well. Figure 5 shows the mean percent error in the route direction task. Participants who were familiar with the sub-routes performed much better than participants who were unfamiliar (18% versus 42% errors). The interaction between sub-routes and familiarity was not significant [$F(2,66) = 2.528, p=0.087$]. However, the difference between 'familiar' and 'unfamiliar' participants was very significant [$F(1,70) = 22.725, p<0.001$].

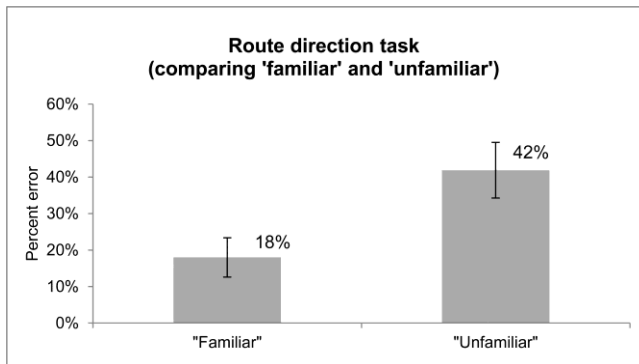


Figure 5. Results of the route direction task (mean percent error). Vertical error bars denote 95% confidence intervals.

In the *landmark placement task*, participants had to write/place the IDs of the chosen pictures on an A4 size map of the area. For assessing the acquisition of spatial knowledge, the distance (deviation) between the placed position and the correct place on the paper map was measured in centimeters, and then transformed to meters in a real world scale. If a picture was missing, its deviation was set as the length of the corresponding sub-route. For each participant, the averaged deviation was taken as his/her score. The results are presented in Figure 6. Again, participants who were familiar with the sub-routes performed much better than participants who were unfamiliar (76 m versus 214 m). The interaction between sub-routes and familiarity was not significant [$F(2,66) = 0.393$, $p=0.677$]. However, the difference between ‘familiar’ and ‘unfamiliar’ participants was very significant [$F(1,70)= 15.649$, $p<0.001$].

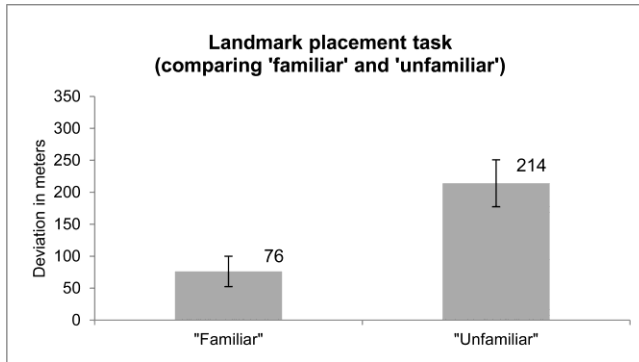


Figure 6. Results of the landmark placement task (mean deviation in meters). Vertical error bars denote 95% confidence intervals.

In summary, the results show that for all four tasks, people familiar with the sub-routes performed better than people who were unfamiliar with the sub-routes. The difference in the pointing task was not significant. However, the differences in the landmark recognition task, the route direction task, and the landmark placement task were all significant.

5.1.2 Discussion

The underlying hypothesis of a suitable task for assessing spatial knowledge acquisition is that: People with more spatial knowledge about an environment perform better in the task. In the experiment, participants had two kinds of familiarities with the sub-routes: 'familiar' and 'unfamiliar'. It is obvious that people who were familiar with the sub-routes had more knowledge about the environment, compared to people who were unfamiliar. Therefore, by comparing the performance of 'familiar' and 'unfamiliar' pairs, we can investigate whether these proposed tasks can differentiate 'familiar' and 'unfamiliar' participants, which can then be used to judge the suitability of the tasks.

The results of the pointing task showed no significant difference between 'familiar' and 'unfamiliar' participants. Two possible explanations can be argued for this result. In the first case, the pointing task has a poor ability in differentiating 'familiar' and 'unfamiliar' participants, and is therefore not suitable for assessing spatial knowledge acquisition. However, the results might also mean that, 'unfamiliar' participants learnt a lot during navigation, and were therefore as good as participants who were 'familiar' with the test environment. The current experiment did not provide additional information to favor one of the above two cases. Therefore, no clear conclusion about the suitability of the pointing task in assessing spatial knowledge acquisition can be made.

In contrast, in the landmark recognition task, route direction task, and landmark placement task, significant differences were found between 'familiar' and 'unfamiliar' participants (with all p-values smaller than 0.001). In all three tasks, people who were familiar with the sub-routes performed much better than people who were unfamiliar. In other words, for all three tasks, people with more knowledge about the sub-routes will perform considerably better than people with less spatial knowledge. This suggests that the above three tasks can differentiate 'familiar' and 'unfamiliar' participants.

5.2 The Influence of Mobile Maps, AR, and Voice on Spatial Knowledge Acquisition

5.2.1 Results

Results from section 5.1 show that the landmark recognition task, the route direction task, and the landmark placement task can differentiate 'familiar' and 'unfamiliar' participants. Therefore, the three tasks will be used to compare the influence of mobile maps, AR, and voice on spatial knowledge acquisition. As mentioned above, we only considered the results from participants who were unfamiliar with the sub-routes. In total, we had 32 participant/sub-route pairs (10 for mobile maps, 13 for AR, and 9 for voice). The male-female ratios were similar in the three interface technologies. Figure 7 shows the results.

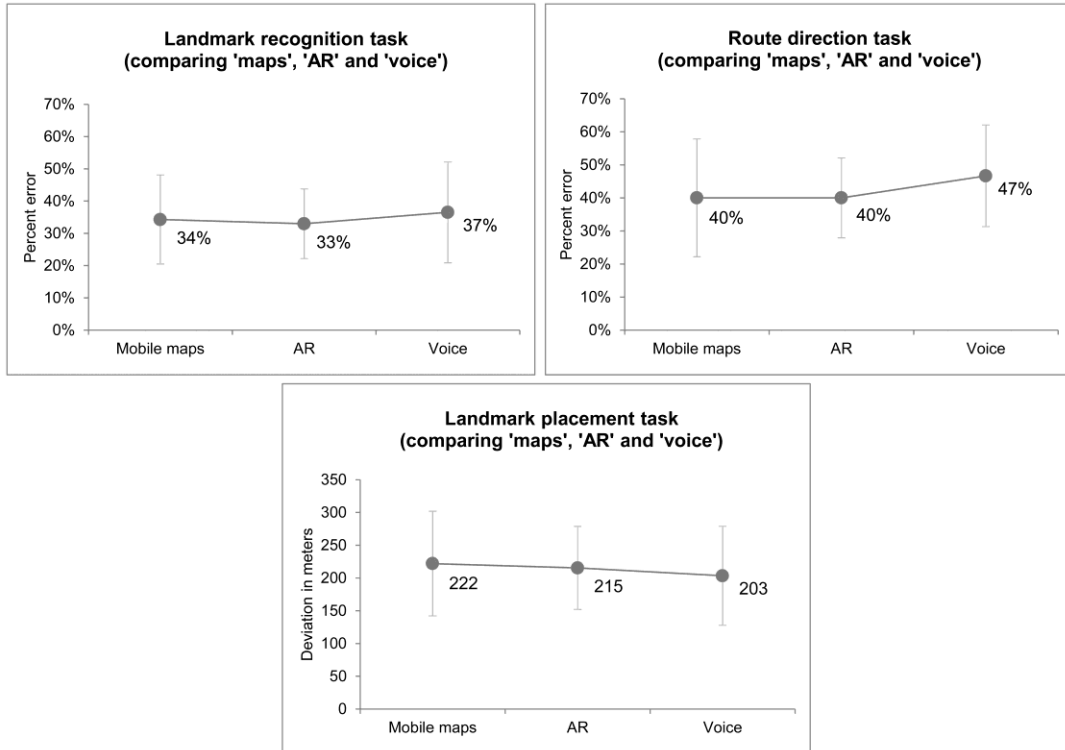


Figure 7. Comparison of the influence of mobile maps, AR, and voice on spatial knowledge acquisition: the landmark recognition task (mean percentage error), the route direction task (mean percentage error), and the landmark placement task (mean deviation in meters). Vertical bars denote 95% confidence intervals.

In the *landmark recognition task*, AR users performed best with 33% errors, followed by map users with 34% errors, and voice users with 37% errors. The interaction between sub-routes and interface technologies was not significant [$F(4,23) = 1.405, p=0.264$]ⁱⁱⁱ. No significant difference was obtained among the three interface technologies [$F(2,29) = 0.097, p=0.908$].

In terms of the *route direction task*, map users and AR users performed best with 40% errors, followed by voice users with 47% errors. The interaction between sub-routes and interface technologies was not significant [$F(4,23) = 0.740, p=0.575$]. No significant difference was obtained among the three interface technologies [$F(2,29) = 0.659, p=0.527$].

For the *landmark placement task*, voice users performed best with a mean deviation of 203 m, followed by AR users with 215 m, and map users with 222 m. The interaction between sub-routes and technologies was not significant [$F(4,23) = 1.069, p=0.485$]. No significant difference was obtained among the three interface technologies [$F(2,29) = 0.609, p=0.394$].

To sum up, for all three tasks, the differences among the three interface technologies were not significant at the 5% level. It is also worth noting that, in all three interface technologies, participants did not perform so well in either of the three tasks (about 33%-47% errors in the first two tasks, about 42%-46% of the route length in the last task).

5.2.2 Discussion

In our field test, difference among mobile maps, AR, and voice was not significant in terms of spatial knowledge acquisition. All three technologies led to comparable poor results. These non-significant results are consistent with the findings of Münzer et al. (2006), in which they compared paper maps with three electronic navigation systems, and showed that the three navigation systems did not lead to significant differences in spatial knowledge acquisition.

One of the possible interpretations of the above results can be the effect of the ‘active encoding principle’ (Münzer et al. 2006): Only information that is ‘actively’ processed during the primary wayfinding activity is learnt and remembered. The design of the three navigation prototypes integrated recent findings of pedestrian navigation, most of which aimed to reduce pedestrians’ cognitive workload during wayfinding. Communication of route directions in all of the prototypes was optimized to make navigation as easy as possible. For example, with the help of GPS, users were free from the mental effort of continuously maintaining the sense of where they were. In addition, a mental spatial transformation was not needed as an egocentric frame of reference was employed in all three interface technologies (egocentric map views in the map-based interface, view-based live camera pictures with overlays in the AR-based interface, and ‘turn right/left’ like instructions in the voice-based interface). In short, for all three interface technologies, participants did not need much active mental effort to derive direction information; they could just ‘passively’ follow the readily available ‘turn by turn’ information to reach the destination. As spatial learning is an effortful process (Aginsky and Rensink 1997; Münzer et al. 2006; Parush et al. 2007), all three interface technologies led to poor results in spatial knowledge acquisition, which were also not significant from each other. However, in order to draw a clear conclusion, more empirical studies should be done on this aspect.

6. Conclusions and Future Work

Recent years have witnessed an increased interest in GPS-based pedestrian navigation systems. More and more people are relying (or even over-relying) on pedestrian navigation systems to find ways. Therefore, it is essential to study how these systems affect the acquisition of spatial knowledge, which is required when navigation systems fail.

This article studied the influence of different interface technologies (mobile maps, AR, and voice) on spatial knowledge acquisition in a field test in an urban environment. The field test showed that the landmark recognition task, route direction task and landmark placement task can differentiate ‘familiar’ and ‘unfamiliar’ participants. The field test also showed that in terms of spatial knowledge acquisition, the difference among the three interface technologies was not significant. Some possible interpretations of the results were discussed.

In the future, we will analyze more aspects of the evaluation methods, such as the ability to identify smaller differences of the performances of spatial learning. In addition, a more in-depth analysis of the influence of different interface technologies on spatial knowledge acquisition will be done.

The results of the field test also brought some considerations for designing mobile pedestrian navigation systems: Do users care about spatial learning during navigation? If yes, how can we design navigation systems, which not only guide users from A to B efficiently, but also support them to acquire spatial knowledge during navigation? Related findings of spatial cognition and human wayfinding together with cartographic communication and usability studies should be integrated to address these challenges.

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REFERENCES

- Aginsky, V., C. Harris, R. Rensink and J. Beusmans. 1997. Two strategies for learning a route in a driving simulator. *Journal of Environmental Psychology* 17: 317–331.
- Agrawala, M. 2001. *Visualizing Route Maps*. PhD thesis, Stanford University.
- Byrne, R. 1979. Memory for urban geography. *Quarterly journal of experimental psychology* 31: 147-154.
- Elias, B. and V. Paelke. 2007. User-centered Design of Landmark Visualization. In: *Map-based Mobile Services: Design, Interaction, and Usability*, ed. by Meng, M., A. Zipf and S. Winter, pp. 33-56, Springer.
- Gartner, G. and W. Hiller. 2009. Impact of restricted display size on spatial knowledge acquisition in the context of pedestrian navigation. In: *Location Based Services and TeleCartography II*, ed. by Gartner, G. and K. Rehrl, pp. 155-166, Springer.
- Gartner, G. and V. Radoczky. 2005. Schematic vs. Topographic Maps in Pedestrian Navigation: How Much Map Detail is Necessary to Support Wayfinding. In: *Proceedings of AAAI 2005 Spring Symposia*.
- Hegarty, M., A.E. Richardson, D.R. Montello, K. Lovelace and I. Subbiah. 2002. Development of a self-report measure of environmental spatial ability. *Intelligence* 30: 425-447.
- Ishikawa, T., H. Fujiwara, O. Imai and A. Okabe. 2008. Wayfinding with a GPS-based mobile navigation system: a comparison with maps and direct experience. *Journal of Environmental Psychology* 28(1): 74–82.
- Lynch, K. 1960. *The image of the city*, MIT Press, Cambridge, MA.
- Krüger, A., I. Aslan and H. Zimmer. 2004. The Effects of Mobile Pedestrian Navigation Systems on the Concurrent Acquisition of Route and Survey Knowledge. In: *Proceedings of Mobile HCI 2004*, ed. by Brewster, S. and M. Dunlop, pp. 446-450, Springer.
- MacEachren, A.M. 1995. *How Maps Work*. The Guilford Press.
- Michon, P.E. and M. Denis. 2001. When and why are visual landmarks used in giving directions. In: *Spatial Information Theory*, ed. by Montello, D.R., pp. 243-259, Springer.
- Münzer, S., H. Zimmer, M. Schwalm, J. Baus and I. Aslan. 2006. Computer Assisted Navigation and the Acquisition of Route and Survey Knowledge. *Journal of Environmental Psychology* 26: 300-308.
- Ortag, F. 2005. *Sprachausgabe vs. Kartendarstellung in der Fußgängernavigation*. Master thesis, Vienna University of Technology.
- Parush, A., S. Ahuvia and I. Erev. 2007. Degradation in spatial knowledge acquisition when using automatic navigation systems. In: *COSIT 2007*, ed. by Winter, S., pp. 238-254, Springer.
- Radoczky, V. 2004. *Literature Review and Analysis about Various Multimedia Presentation Forms*. Technical report, unpublished, Vienna University of Technology.
- Rehrl, K., E. Häusler and S. Leitinger. 2010. Comparing the effectiveness of GPS-enhanced voice guidance for pedestrians with metric- and landmark-based instruction sets. In: *GIScience 2010*, ed. by Fabrikant, S.I., T. Reichenbacher, M. van Kreveld and C. Schlieder, pp. 189-203, Springer.
- Rehrl, K., S. Leitinger, G. Gartner and F. Orttag. 2009. An analysis of direction and motion concepts in verbal descriptions of route choices. In: *COSIT 2009*, ed. by Stewart Hornsby, K., C. Claramunt, M. Denis and G. Ligozat, pp. 471-488, Springer.

- Siegel, A. and S. White. 1975. The development of spatial representations of large scale environments. In: *Advances in child development and behavior 10*, ed. by Reese, H., pp. 9-55, Academic Press, New York.
- Thorndyke, P. and B. Hayes-Roth. 1982. Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology* 14 (4): 560-589.
- Tversky, B. 1981. Distortions in memory for maps. *Cognitive Psychology* 13 (3): 407-433.
- Tversky, B. 1992. Distortions in cognitive maps. *Geoforum* 23(2): 131-138.
- Tversky, B. and P. Lee. 1999. Pictorial and verbal tools for conveying routes. In: *COSIT 1999*, ed. by Freska, C. and D.M. Mark, pp. 51-64, Springer.
- Walther-Franks, B. 2007. *Augmented reality on handhelds for pedestrian navigation*, Master thesis, University of Bremen.
- Wikipedia, 2011. Wizard of Oz experiment. http://en.wikipedia.org/wiki/Wizard_of_Oz_experiment (accessed on 31.August.2011).

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ⁱ 'unfamiliar': participants who were new to the sub-routes

ⁱⁱ 'familiar': participants who had been to the sub-routes before.

ⁱⁱⁱ As suggested by many statistic textbooks, if the interaction is not significant, we can then examine each factor without needing to qualify the effects because of the interaction.