Investigating Smartphones and AR Glasses for Pedestrian Navigation and their Effects in Spatial Knowledge Acquisition

Aymen Lakehal, Sophie Lepreux, Christos Efstratiou, Christophe Kolski, Pavlos Nicolaou

Investigating Smartphones and AR Glasses for Pedestrian Navigation and their Effects in Spatial Knowledge Acquisition

AYMEN LAKEHAL, LAMIH, UMR CNRS 8201, Univ. Polytechnique Hauts-de-France, France
SOPHIE LEPREUX, LAMIH, UMR CNRS 8201, Univ. Polytechnique Hauts-de-France, France
CHRISTOS EFSTRATIOU, School of Engineering and Digital Arts, University of Kent, United Kingdom
CHRISTOPHE KOLSKI, LAMIH, UMR CNRS 8201, Univ. Polytechnique Hauts-de-France, France
PAVLOS NICOLAOU, School of Engineering and Digital Arts, University of Kent, United Kingdom

Abstract–Moving in a complex and changing environment (rapid expansion of cities, creation of new transport lines, etc.) requires more and more capacity for path determination and following. This paper presents a protocol of a user study under progress. Its aim is to compare an application on AR Glasses and Smartphone to help pedestrians to memorize path following recommended landmarks.

CCS Concepts: • **Human-centered computing → User studies**; *Ubiquitous and mobile devices.*

Additional Key Words and Phrases: Pedestrian navigation, AR glasses, smartphone, landmark, cognitive map

ACM Reference Format:
Aymen Lakehal, Sophie Lepreux, Christos Efstratiou, Christophe Kolski, and Pavlos Nicolaou. 2020. Investigating Smartphones and AR Glasses for Pedestrian Navigation and their Effects in Spatial Knowledge Acquisition. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '20 Extended Abstracts), October 5–8, 2020, Oldenburg, Germany*. ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3406324.3410722

1 INTRODUCTION

Smartphones equipped with navigation software are commonly used by pedestrians to navigate unfamiliar places. Although such systems serve a real user need, previous work has shown that this form of passive assistance offered by smartphones, does not help users memorize journeys or become familiar with the environment [5, 6, 8]. Way-finding using directive instructions (as is common in smartphone-based navigation software) can lead to lower navigational skills, and reduced spatial awareness [3]. These effects can have significant impact in peoples' cognitive abilities. Indeed, studies on taxi drivers [8] have shown that enhanced navigation skills are positively correlated with increased activity and gray matter in the hippocampus in people's brain. As a result, reduced navigational skills can contribute to cognitive decline during normal aging [6].

Considering the potentially negative impact of traditional smartphone navigation in cognitive abilities, in this work we aim to explore how pedestrian navigation systems can be used to help users memorise a route, and enable them to navigate without the need for navigation systems. In this short paper we report on the design, methodology, and early results of a user study focusing on mobile pedestrian navigation systems and their effects in journey memorisation. In this study we aim to investigate and compare the effects of smartphone-based navigation, against AR (augmented reality) glasses based navigation.

Fig. 1. Mobile Phone Application displaying the instruction: "Turn Left after the Phone Booth in 20 meters"

Fig. 2. AR Glasses Application displaying the instruction: "Turn Right when you see the Bus Stop in 30 meters"

Map-based automated navigation assistance can have a negative effect on spatial transformation abilities, especially with respect to changes in perspective, and environmental learning [14]. Indeed, studies have shown that navigation learning involve only visuo-spatial (and not verbal) abilities [9]. This explains why automated navigation system that don't expand the user's visuo-spatial skills, lead to degradation in spatial knowledge acquisition [12].

In the context of navigation to facilitate learning, landmark-based navigation systems can help improve the user's knowledge of the environment during way-finding tasks [16]. Landmarks, are salient entities in the environment, and they can help improve the user's survey knowledge during the way-finding task. Previous work has shown that the representation of knowledge about a specific location, goes progressively from knowing landmarks, then paths, and finally to a global survey knowledge [11]. Motivated by these findings, our aim is to study the effects of landmark-based navigation systems, deployed on smartphones or AR glasses, in helping users learn how to navigate the environment.

2 RELATED WORK

A limited number of studies have investigated the spatial knowledge acquisition in pedestrian navigation, comparing different interaction modalities or devices. In [4] the authors explored the effects of smartphone map-based navigation, through different interaction modes: visual map, voice or augmented reality (through the smartphone). They found no significant difference on spatial knowledge acquisition. Unfortunately, that work did not explore the effects of landmark-based navigation, while focusing only on the use of smartphones as interaction devices. A similar study [13], comparing the use of digital maps, voice, and augmented reality interfaces for navigation assistance, found that AR was less effective in users navigation. That work focused only on the effectiveness of the technology itself and not the effects on spatial knowledge acquisition.

These early attempts in exploring the effects of technology assisted navigation in spatial knowledge acquisition have not so far produced results that can lead to practical advise. To the best of our knowledge, there are no studies that explore the differences in spatial knowledge acquisition using AR glasses and smartphones, through the use of a landmark-based navigation system.

3 RESEARCH QUESTIONS

Although map-based smartphone navigation is the most common method for assistive pedestrian navigation, it does have negative effects in spatial knowledge acquisition. In this work, our aim is to investigate assistive navigation technologies, that have the best potential to enhance knowledge acquisition. Specifically, we aim to study systems that rely on landmarks as a navigation technique, as prior work has indicated that landmark-based navigation can facilitate better path memorisation, and survey knowledge [10, 16]. Furthermore, as prior work has highlighted the value of visuo-spatial engagement of the user with the environment during navigation [9], our aim is to investigate the effects of AR glasses as devices for assistive navigation. Previous work has explored AR only through traditional smartphones. We believe that the latest generation of AR glasses, offer a radically different experience for the user, which can potentially affect their experience with a navigation system. Therefore one of the main objectives of this study is to explore the differences between smartphone and AR glasses in terms of navigator's engagement with the environment (recognizing and memorizing landmarks, and travelling efficiently) and how this could affect the spatial knowledge acquisition.

More specifically, in order to design this study we formulate the following hypotheses that we intend to test:

(1) When using navigation technologies, **AR Glasses** based navigation is more efficient in helping recognize landmarks compared to **Smartphone** based navigation.
(2) People tend to navigate less efficiently (travel duration, number of errors, number of stops and duration) using **Smartphones** compared to **AR Glasses**.
(3) After using navigation technologies, **AR Glasses**' experience supports landmark memorisation more effectively than **Smartphones**.

We note that our work focuses solely on the study of landmark-based navigation, through different mobile devices. Indeed, we do not consider 2D map-based navigation in this work, as such traditional navigation system have been extensively studied in the past [5, 6, 8, 14], and shown to offer poor results in terms of landmark recognition and path memorisation.

4 METHODOLOGY

We conducted an experiment to investigate how technology assisted navigation can affect the memorisation of landmarks and recalling navigation paths after a period of time. Specifically, the experiment was split into two phases (Figure 3): during the first phase participants were involved in navigating an unfamiliar location using relevant technology (either smartphones or AR glasses). After 1 week participants were invited back and were asked to perform appropriate memory tests, and navigate the same path without any navigation assistive technology.

During the study a range of metrics were collected to help us address the research questions. Details on the collected datasets are discussed in a following section.

4.1 Path Definition and Landmark selection

The selection of the location for conducting the experiment can have a significant effect on the results. Our objective was to select a path that was in an area that is not visited often by people (to make participant recruitment easier), does not involve extraordinary, or very distinctive landmarks (in order to be able to observe variations in landmark memorisation), and there is some level of challenge navigating the path without technology. Following informal surveys of the authors' social network we identified a residential area, primarily occupied by university students, in a

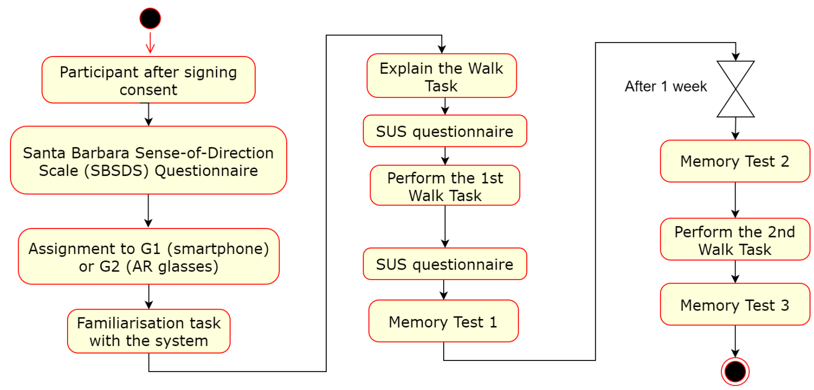

Fig. 3. Activity diagram of the protocol

Fig. 4. Footpath between the residential buildings of the study area.

Fig. 5. Main Road inside the residential area

small British town. The location is away from popular walking routes, consists of multiple, similar looking residential buildings, and is commonly described as "difficult to navigate" (see Figures 4 and 5).

In order to define the path and landmarks for navigation in the experiment, we relied on local residents. We performed a survey asking 12 local residents (6 females) to fill a questionnaire to help us define the navigation path. Questions that were asked included: "A person new to this area is asking you for guidance; what landmarks would you use to guide them?", "Please suggest a path between location A (departure) and B (destination) and highlight what landmarks you would use for guidance" (used for multiple A-B combinations).

This survey allowed us to use local knowledge in selecting a path, and defining landmarks that would make sense for a pedestrian in that area. The categories of landmarks identified by local residents are illustrated in Figure 6. Combining this information, and the suggested navigation advise by local residents, we defined the path within that area, and the relevant landmarks for navigation (Figure 7).

4.2 Navigation App

Using this information as input, we constructed a navigation mobile app that relied on landmarks to assist users finding their way through a predefined path. The application uses GPS tracking to detect the current location of the user, and

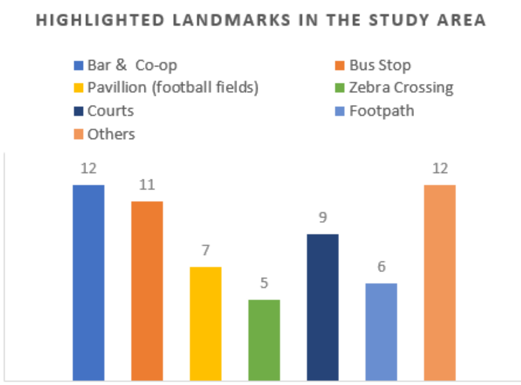

Fig. 6. Highlighted landmarks in the targeted residential area.

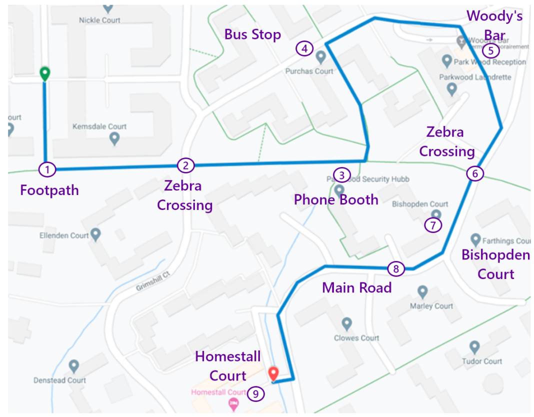

Fig. 7. Selected Path

shows appropriate navigation advise (cf. Figure 1 & 2) when the user approaches a "decision point" (Figure 8). The app was designed to offer the same type of functionality and similar visual clues on both smartphones and AR glasses.

The design of the app is driven by prior research in the areas of cognitive mapping, wayfinding and route instructions design [7, 17, 18]. Navigation routes are often explained as a sequence of turns or changes in direction during decision points, over a navigation path. The navigation app that was developed for this study, involves the delivery of precision textual guidance with an orientation indicator, which is triggered when the user approaches decision points. The aim is to reduce the cognitive load that is required for the user to engage with the app, and allow them to focus more on their surroundings, and give them the opportunity to build their own perception of the environment. Landmarks are included into the guidance instructions to give most relevant information. Further design recommendations were considered while designing the AR glasses application. For instance, the display colour was selected to be green [2], and information was positioned at the bottom center of the in-glass screen, to support the highest comprehension [15] and to ensure a clear view of the walking path.

For the purposes of this study, the navigation app involved the manual construction of navigation paths that offered navigation advise using landmarks. As described in the previous section, both the paths and landmarks were identified through surveys of local people. That information was then encoded into the app as a connected graph of decision points, where the user is expected to decide when they should change their direction. The app offered relevant prompts, with references to local landmarks, visible at each decision point. Figure 9 illustrates a sequence of instructions displayed on the AR glasses when the user is approaching a decision point. The described process is the same on the smartphone. When the user is within a short distance of a decision point, the system displays an instruction highlighting the selected landmark for the decision point (cf. number (3)). Through GPS tracking, the system updates the targeted decision point with the next point, after confirming that the user took the correct decision.

4.3 Data capture

As described in the protocol, each participant was asked to walk through the same path twice. Once, using a navigation assistive app (either through a smartphone or through AR glasses), and after 1 week, without any technology. The study involved the collection of a number of datasets that would help us address the defined research questions.

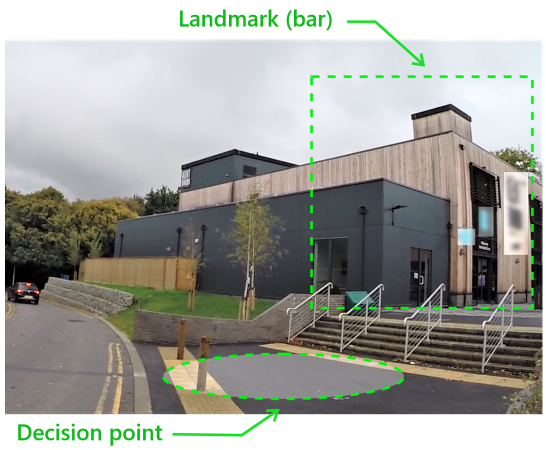

Fig. 8. Decision Point illustrating a landmark (Bar)

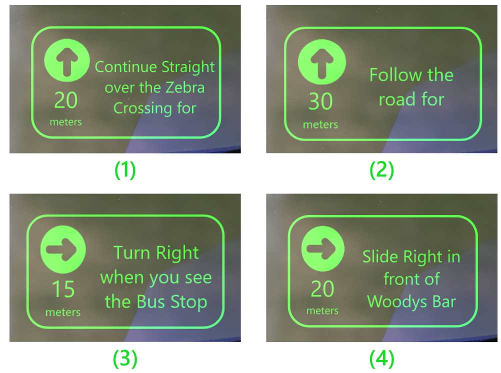

Fig. 9. Sequence of instructions displayed when the user is approaching a decision point.

4.3.1 Quantitative: GPS traces were captured during both walks. Through these we can calculate a number of measurements including: walk duration, speed log, number of stops and stop duration, errors in navigation (following the wrong path). Moreover, each participant was asked to complete the SUS [1] questionnaire before and after using the navigation technology, in order to capture their subjective assessment of the technology. This metric could help us explore correlations between the participants' perception of the technology, and the effects in spatial knowledge acquisition.

4.3.2 Qualitative: The Santa Barbara Sense of Direction Scale (SBSDS) survey offers an indication on the inherent sense of direction of each participant. The SBSDS questionnaire is used to evaluate the spatial abilities of the participants. Based on these results, participants were allocated to the two groups to ensure a balanced representation of abilities. During the walking tasks participants were asked to "think aloud", describing what they are doing, and commenting on the identification of landmarks, and possible hesitation during their walk. A key dataset in this experiment involve a number of memory tests that participants were asked to perform after the first walk, and a week later before and after they performed the walk without any technology. The aim of the memory test is to capture the participant's recall of landmarks, and to test their abilities in spatial transformation as an indication of spatial knowledge acquisition [14]. Specifically, participants were asked to plot their walk on a map, as way of mentally changing their perspective of the environment (transformation), and to indicate the location and type of landmarks along the path (see Figure 10).

5 THE STUDY

The study was conducted in Autumn 2019. The study included 20 participants (10 females), age range 21-39 (median: 25.5). The participants were split into two groups: G1 group was given the smartphone version of the navigation system to use during their first walk, and G2 group was given the AR glasses version. When splitting the groups we aimed to keep a similar distribution of SBSDS scores for both groups. Each participant was allowed 3-4 minutes of becoming familiar with the technology. We understand that AR glasses are a novel technology, and this can affect the perception and interaction of the user with them. Although the familiarisation task may not be sufficient to avoid the novelty factor completely, we believe that it would at least ensure that participants feel comfortable with them.

Fig. 10. Memory test (2nd walk)

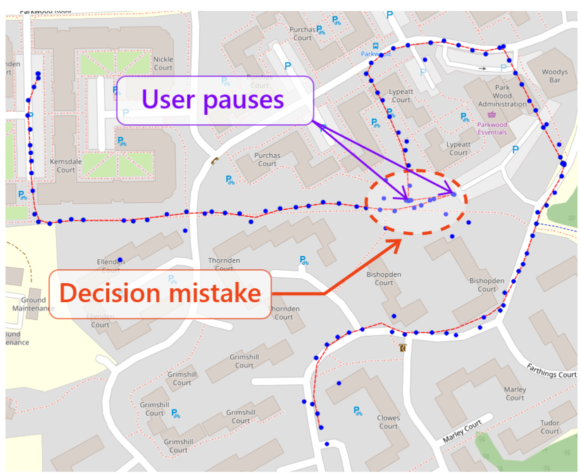

Fig. 11. GPS log - Participant ARG9

Preliminary results collected through the study, demonstrate promising findings, which can allow us to identify differences in users' experience with each technology. For example, GPS traces as seen in Figure 11 can be used to identify errors where users have accidentally followed the wrong path; speed logs (Figure 12) demonstrate times of indecision where the participant had to stop to identify the direction they have to follow, or potentially stops they made to help identify landmarks. We intend to combine the analysis of such quantitative data, with findings extracted from the transcripts of voice records produced by the participants during their walks. Finally, the memory tests (Figure 10)

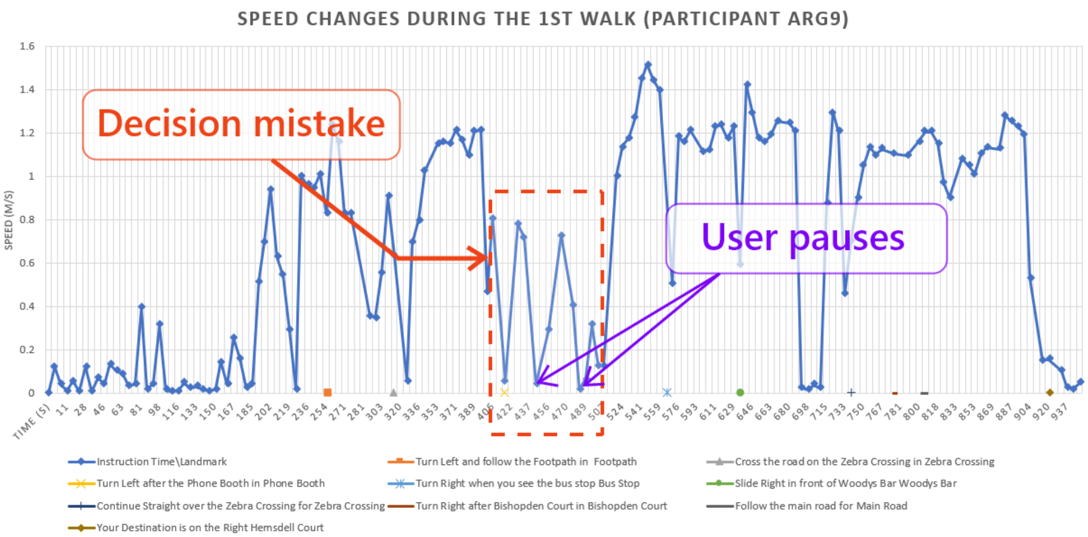

Fig. 12. Speed log - Participant ARG9

performed a week after the experiment, demonstrate differences in memorisation of landmarks, as well as their relative location on the map. Such features will help us evaluate the acquisition of spatial knowledge and the comparative difference of the effects of the two technologies.

6 SUMMARY AND FUTURE WORK

The methodology proposed in this short paper aims to compare two navigation technologies that can facilitate path memorisation. The 3 hypotheses associated with the study are formed to test (h1) the efficiency to recognize landmarks with the AR Glasses during the navigation compared to Smartphone,(h2) to compare the efficiency to navigate (travel duration, number of errors, number of stops and duration), and (h3) after using navigation technologies, whether AR Glasses offer better support for landmark and path memorisation than Smartphones. Raw data collected during the study will be analysed as part of our future work, in order to test our research questions. The detailed description of this protocol, aims to facilitate reproducibility of the experiment, and to extend this approach to other technologies or interaction modalities if necessary.

ACKNOWLEDGMENTS

The authors thank the Département du Nord and the Agence Nationale pour la Rénovation Urbaine (ANRU) for their financial support within the framework of the ValMobile project as well as the PRIMOH research pole. They also thank the I-SITE Univ. Lille-Europe (mobility grants: EWAID & Go-Smart).

REFERENCES

[1] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *J. Usability Studies* 4, 3 (5 2009), 114–123. http://dl.acm.org.ins2i.bib.cnrs.fr/citation.cfm?id=2835587.2835589

[2] Joseph L Gabbard, J Edward Swan, and Deborah Hix. 2006. The effects of text drawing styles, background textures, and natural lighting on text legibility in outdoor augmented reality. *Presence: Teleoperators & Virtual Environments* 15, 1 (2006), 16–32.

[3] Aaron L. Gardony, Tad T. Brunyé, Caroline R. Mahoney, and Holly A. Taylor. 2013. How Navigational Aids Impair Spatial Memory: Evidence for Divided Attention. *Spatial Cognition and Computation* 13, 4 (2013), 319–350. https://doi.org/10.1080/13875868.2013.792821

[4] Haosheng Huang, Manuela Schmidt, and Georg Gartner. 2012. Spatial Knowledge Acquisition with Mobile Maps, Augmented Reality and Voice in the Context of GPS-based Pedestrian Navigation: Results from a Field Test. *Cartography and Geographic Information Science* 39, 2 (2012), 107–116. https://doi.org/10.1559/15230406392107

[5] Toru Ishikawa, Hiromichi Fujiwara, Osamu Imai, and Atsuyuki Okabe. 2008. Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology* 28, 1 (2008), 74–82. https://doi.org/10.1016/j.jenvp.2007.09.002

[6] Kyoko Konishi and Véronique D. Bohbot. 2013. Spatial navigational strategies correlate with gray matter in the hippocampus of healthy older adults tested in a virtual maze. *Frontiers in Aging Neuroscience* 5, FEB (2013), 1–8. https://doi.org/10.3389/fnagi.2013.00001

[7] Christian Kray, Katri Laakso, Christian Elting, and Volker Coors. 2003. Presenting route instructions on mobile devices. *International Conference on Intelligent User Interfaces, Proceedings IUI* (2003), 117–124. https://doi.org/10.1016/b978-008044531-1/50445-0

[8] Eleanor A. Maguire, David G. Gadian, Ingrid S. Johnsrude, Catriona D. Good, John Ashburner, Richard S.J. Frackowiak, and Christopher D. Frith. 2000. Navigation-related structural change in the hippocampi of taxi drivers. *PNAS USA* 97, 8 (2000), 4398–4403. https://doi.org/10.1073/pnas.070039597

[9] Chiara Meneghetti, Clara Zancada-menéndez, Patricia Sampedro-piquero, Laudino Lopez, Massimiliano Martinelli, Lucia Ronconi, and Barbara Rossi. 2016. Mental representations derived from navigation : The role of visuo-spatial abilities and working memory. *Learning and Individual Diff.* 49 (2016), 314–322. https://doi.org/10.1016/j.lindif.2016.07.002

[10] Alexandra Millonig and Katja Schechtner. 2007. Developing landmark-based pedestrian-navigation systems. *IEEE Transactions on Intelligent Transportation Systems* 8, 1 (2007), 43–49. https://doi.org/10.1109/TITS.2006.889439

[11] Daniel R Montello. 2005. Navigation. In *The Cambridge Handbook of Visuospatial Thinking*, A. Miyake P. Shah (Ed.). Cambridge Univ. Press, 257–294.

[12] Avi Parush, Shir Ahuvia, and Ido Erev. 2007. Degradation in Spatial Knowledge Acquisition When Using Automatic Navigation Systems. *Knowledge Acquisition* (2007), 238–254.

[13] Karl Rehrl, Elisabeth Häusler, Sven Leitinger, and Daniel Bell. 2014. Pedestrian navigation with augmented reality, voice and digital map: final results from an in situ field study assessing performance and user experience. *J. Locat. Based Serv.* 8, 2 (2014), 75–96. https://doi.org/10.1080/17489725.2014.946975

[14] Ian T Ruginski, Sarah H Creem-regehr, Jeanine K Stefanucci, and Elizabeth Cashdan. 2019. GPS use negatively affects environmental learning through spatial transformation abilities. *Journal of Environmental Psychology* 64, May (2019), 12–20. https://doi.org/10.1016/j.jenvp.2019.05.001

[15] Rufat Rzayev, Paweł W Woźniak, Tilman Dingler, and Niels Henze. 2018. Reading on smart glasses: The effect of text position, presentation type and walking. In *CHI 2018, ACM*. 1–9.

[16] Alexander W Siegel and Sheldon H White. 1975. Advances in Child Development and Behavior Volume 10. *Adv. Child. Dev. Behav.* 10 (1975), 9–55. https://doi.org/10.1016/S0065-2407(08)60007-5

[17] Barbara Tversky. 1992. Distortions in cognitive maps. *Geoforum* 23, 2 (1992), 131–138.

[18] Denis Wood. 1992. How Maps Work. *Cartographica: The International Journal for Geographic Information and Geovisualization* 29, 3-4 (10 1992), 66–74. https://doi.org/10.3138/H314-J2NG-Q543-5633