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Spatial Knowledge Acquisition for Pedestrian Navigation: A Comparative Study between Smartphones and AR Glasses †

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Abstract: Smartphone map-based pedestrian navigation is known to have a negative effect on the long-term acquisition of spatial knowledge and memorisation of landmarks. Landmark-based navigation has been proposed as an approach that can overcome such limitations. In this work, we investigate how different interaction technologies, namely smartphones and augmented reality (AR) glasses, can affect the acquisition of spatial knowledge when used to support landmark-based pedestrian navigation. We conducted a study involving 20 participants, using smartphones or augmented reality glasses for pedestrian navigation. We studied the effects of these systems on landmark memorisation and spatial knowledge acquisition over a period of time. Our results show statistically significant differences in spatial knowledge acquisition between the two technologies, with the augmented reality glasses enabling better memorisation of landmarks and paths.

Keywords: spatial knowledge; pedestrian navigation; augmented reality glasses; smartphone; landmark; cognitive map; navigation assistance

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1. Introduction

Mobile interactive systems have become common tools in assisting pedestrian mobility. For example, more and more pedestrians are using smartphones equipped with navigation software, particularly to navigate unfamiliar places. Moreover, continuous research in the area of pedestrian navigation explores novel ways that navigation guidance is conveyed to the users in order to improve usability [1–7]. Although, such tools are considered very useful, several studies have shown that this form of passive assistance does not help pedestrians memorise journeys nor does it help them become familiar with the environment [8–10]. Indeed, on smartphones, common navigation systems support wayfinding using directive instructions [11]. As shown by Gardony and colleagues, such systems do not provide opportunities to develop spatial skills, and they tend to reduce spatial awareness [12,13]. These effects can have a broader negative impact on the cognitive abilities of users, especially when they are used frequently. Studies involving taxi drivers [10] have demonstrated that enhanced navigation skills are positively correlated with increased activity and gray matter in the hippocampus in people's brains. Konishi and Bohbot also showed that reduced navigational skills can contribute to cognitive decline during normal aging [9].

Considering the potentially negative impact of traditional smartphone navigation in cognitive abilities [14], our aim is to explore how pedestrian navigation systems, operated either through smartphones or augmented reality (AR) glasses, can be used to help users memorise a route and enable them to navigate without the need for navigation systems. This paper reports on the design, methodology, and results of a user study with 20 participants focusing on mobile pedestrian navigation systems and their effects in journey memorisation. In this study, we investigate and compare the effects of smartphone-based navigation vs. AR (augmented reality)-glasses-based navigation.

As reported by Ruginski and their colleagues [15], traditional map-based automated navigation assistance can have a negative effect on spatial transformation abilities. They observed a negative impact in the case of changes in perspective and on environmental learning [15]. Indeed, a study by Meneghetti and colleagues has shown that navigation learning involves only visuospatial abilities, and not verbal ones [16]. This important result explains why automated navigation systems that do not expand the user's visuospatial skills lead to degradation in spatial knowledge acquisition [17].

For several years, researchers have been interested in how to integrate landmarks into the design of navigation systems. It is considered that landmark-based navigation systems can help improve the user's knowledge of the environment during wayfinding tasks [18]. Work from Montello [19] showed that landmarks are salient entities in the environment, and they can help improve the user's survey knowledge during wayfinding tasks: the representation of knowledge about a specific location goes progressively from knowing landmarks, then paths, and finally to a global survey knowledge. Our work is 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 without the need for wayfinding technology, ultimately.

The spatial knowledge acquisition in pedestrian navigation has been investigated by a limited number of studies, comparing different interaction modalities or devices.

1.1. Comparative Studies of Pedestrian Navigation Technologies

Several studies have attempted to compare alternative navigation systems for pedestrian navigation but without exploring their impact on path memorisation. A study by Rehrl et al. [20] compared the use of digital maps, voice, and augmented reality interfaces implemented through smartphones for navigation assistance. They found that AR (through smartphones) was less effective in users' navigation demonstrating that the physical characteristics of smartphones can have a negative effect on the usability of AR interfaces for navigation assistance. Exploring image-based navigation, the work in [21] proposed the design of an augmented photograph-based application on a smartphone and contrasted it to a traditional map-based mobile application. This work showed that the users experienced a lower demand to constantly look at the image-based system, helped by an alert mechanism that notified them when a new photo message was triggered. This approach highlights the value of applying less distracting designs for pedestrian navigation, offering more time to the users to focus on the environment. The role of photography in navigation was also studied in [22]. The work by Wen et al. [23] explored the effects of five different navigation visualisation approaches on wayfinding: traditional north-up maps, forward-up maps, compass, augmented reality, and radar. Their study explored interface performance and effectiveness for pedestrian navigation. Unfortunately, the work did not investigate how the different visualisation approaches affected the route memorisation for the users.

1.2. Spatial Knowledge Acquisition with Pedestrian Navigation Technologies

In [24], the authors compared four navigation system variations implemented on tablets, that differed in their level of automation and attention demand. Automation in that context considered notifications on path finding, being triggered automatically by the application or triggered manually on user request. The authors explained that "participants using systems with higher levels of automation seemed not to acquire enough spatial knowledge to reverse the route without navigation errors". Amirian et al. [25] designed a tablet-based AR navigation system that relied on automated landmark recognition, with superimposition of navigational signage (orientation arrows and distance information). This system was compared to turn-by-turn map-based navigation system. Their system demonstrated significant improvements in acquiring local knowledge. These results further highlight the limited effects of map-based navigation with respect to spatial knowledge acquisition. More recently, a number of studies have explored the use of landmarks for pedestrian navigation, coupled with different interaction modalities, aiming to improve the acquisition of road knowledge and thus promote autonomy in orientation [26,27].

The work by Liu et al. [28] focused on the use of landmarks in an indoor environment. In that work, they explored the use of iconic holograms in a mixed-reality environment supported by hololens glasses. Augmented landmarks were employed to address the challenge that in indoor environments, corridors and rooms may look alike, making it difficult for people to find physical landmarks to help them navigate. The results showed that virtual semantic landmarks assisted the acquisition of corresponding knowledge, as these landmarks were the second most often labelled in the landmark locating task [28].

A number of studies explored the effects of user interaction with the navigation system and their impact on spatial knowledge acquisition. In [29], the findings suggested that higher user engagement with the navigation system correlated with better spatial knowledge acquisition. Huang and colleagues [30] explored the effects of smartphone map-based navigation through different interaction modes: (1) visual map, (2) voice, or (3) augmented reality (through the smartphone). They found no significant difference in spatial knowledge acquisition in the context of map-based navigation.

Kamilakis and colleagues [31] proposed a mobile application, which addressed the practical requirements of public transport users (visualisation of nearby transit stops along with the timetable information of transit services passing by those stops). In their paper, they studied the utility and experience perceived by users interacting with mobile augmented reality (MAR) vs. map-based mobile application interfaces. MAR has been shown to offer an enjoyable intuitive interaction model. This demonstrated its potential for directly linking digital content with the user's physical environment, thereby enabling the experiential exploration of the surrounding elements. The offering of an improved sense of orienteering relatively to surrounding physical elements (e.g., unambiguous interpretation of the direction towards a Point of Interest) should be regarded as another strong aspect of sensor-based MAR applications. The authors concluded that MAR interfaces still need to resolve major usability issues until they can be regarded as an indisputable substitute for traditional map-based interfaces. Most likely, emerging devices such as smart glasses (which involve principally different methods for interacting with digital content) would affect the quality of the experience perceived by the users. In the study [8], GPS (Global Positioning System) users traveled longer distances and made more stops during a walk than map users and direct-experience participants. Moreover, GPS users traveled more slowly, made larger direction errors, drew sketch maps with poorer topological accuracy, and rated wayfinding tasks as more difficult than direct-experience participants. In another study [32], the authors proposed a novel system for pedestrian navigation assistance that included global landmarks (for example, the Eiffel Tower) in navigation instructions. They found a better performance, as compared to turn-by-turn navigation systems, in terms of navigating the environment and building a more accurate mental map.

Reflecting on the existing research on pedestrian navigation systems, we can observe that there has been extensive work on map-based systems and their negative effects on spatial knowledge acquisition. With respect to AR systems, the current work focuses primarily on AR through smartphones or tablets. Although these studies demonstrate that landmark-based navigation can improve the acquisition of spatial knowledge, there is no work that has explored the effects of AR glasses as the interaction medium for navigation. To the best of our knowledge, no studies have addressed the spatial knowledge acquisition using AR glasses and smartphones with a landmark-based navigation system. Furthermore, when considering the approaches for assessing spatial knowledge, there is limited work regarding the effects in spatial transformations (i.e., the ability to mentally change the perspective of space), which is positively correlated with environmental learning during memory tests.

The next section presents the methodology we followed for the study, including the navigation path definition, the navigation system design, and the data capture. The results concerning the memory tests are presented in Section 3. The paper ends with a discussion of the obtained results and a conclusion.

2. Materials and Methods

2.1. Path Definition and Landmark Selection

The selection of the location for conducting the experiment can have a significant effect on the results. Our goal was to select a path in an area unfamiliar to the participants, without very distinctive landmarks. It should present a level of challenge for people to navigate through without technology. A residential area was identified following informal surveys of the authors' social network. The location is within Canterbury, a small British town, away from popular walking routes. This area is described as "difficult to navigate" by local residents. It consists of similar looking residential buildings (Figures 1 and 2).

Figure 1. Footpath between the residential buildings of the study area.

Figure 2. Residential buildings.

By relying on local knowledge, 12 residents (6 females) were asked to fill out a questionnaire in order to identify the relevant landmarks in their local area and thus to help define a landmark-based 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 using local knowledge to select a path and define the landmarks that would make sense for a pedestrian in that area. The categories of landmarks identified by local residents are illustrated in Figure 3. Combining this information with the suggested navigation advice by local residents, the path was defined within that area, along with the relevant landmarks for navigation (Figure 4).

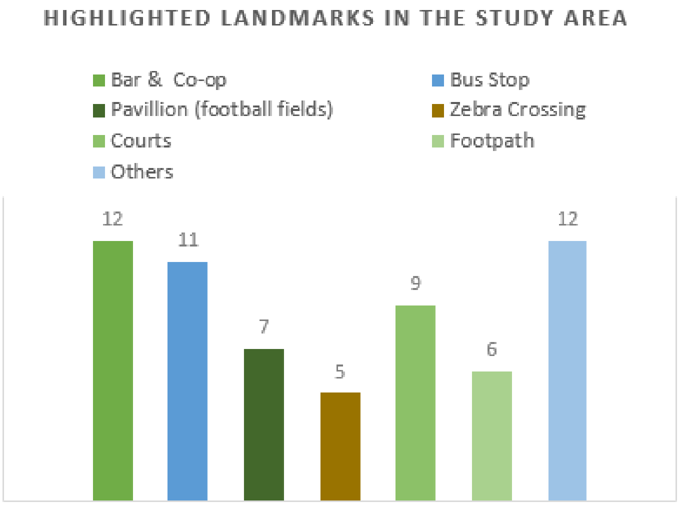

Figure 3. Highlighted landmarks in the targeted residential area.

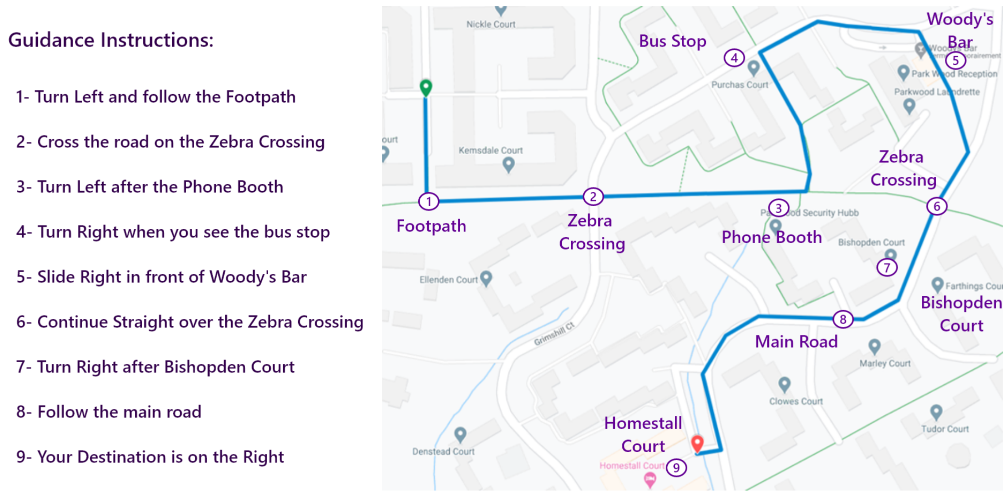

Figure 4. Selected path with different landmarks and guidance instructions.

2.2. Navigation App

Relying on the collected information including identified landmarks, a navigation mobile application was constructed to provide assistance for users finding their way through the defined path. The application was designed to offer the same type of functionality and similar visual clues on both smartphones and AR glasses (see Figures 5 and 6). The application displayed suitable navigation advice when a user approached a decision point (Figure 7); it was based on the current location of the user retrieved through GPS tracking.

Figure 5. Mobile phone application displaying the instruction: "Turn Left after the Phone Booth in 20 meters".

Figure 6. AR glasses application displaying the instruction: "Turn Right when you see the Bus Stop in 30 meters".

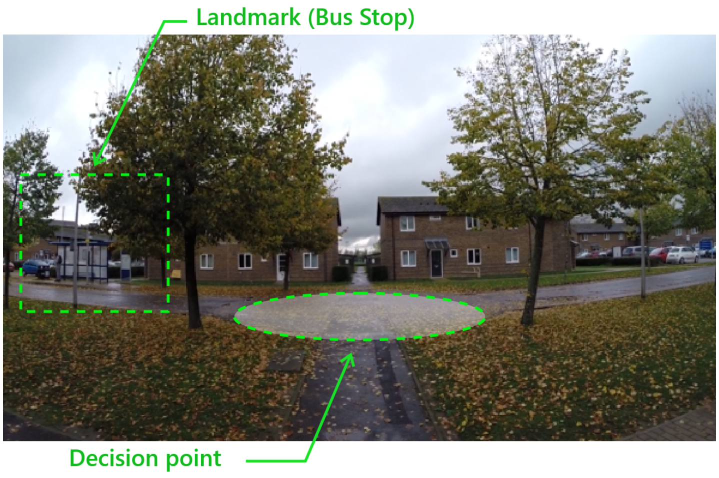

Figure 7. Decision point illustrating a landmark (Bus Stop).

The design of the application was driven by prior research in the areas of cognitive mapping, wayfinding, and route instructions design [33–35]. Navigation routes are often explained as a sequence of turns or changes in direction during decision points in a navigation path. The navigation application that was developed for this study involved the delivery of precision textual guidance with an orientation indicator, which was triggered when the user approached decision points. Landmarks were included in the guidance instructions to give the most relevant information. The aim was to reduce the cognitive load that was required for the user to engage with the application, allowing them to focus more on their surroundings and giving them the opportunity to build their own perception of the environment. Further design recommendations were considered while designing the AR glasses application. For instance, the display colour was selected to be green [36], and information was positioned at the bottom center of the in-glass screen, to support the highest comprehension [37] and to ensure a clear view of the walking path.

The navigation assistance was manually constructed by including navigation advice using landmarks. Different decision points from the navigation path were connected and encoded into the application from the previous information. These points consisted of where the user was expected to decide on any changes in their direction. The application offered relevant prompts, with references to local landmarks, visible at each decision point. Figure 8 illustrates a sequence of instructions displayed on the AR glasses when the user was approaching a decision point. The described process was the same on the smartphone.

Figure 8. Sequence of instructions displayed when the user is approaching a decision point.

The system showed navigation advice highlighting the selected landmark when the user approached a decision point (see Figure 8, number 3). After confirming that the user took the correct decision using GPS tracking, the system updated the targeted decision point with the next point.

2.3. Study Design

The study included 20 participants (10 females) with an age range of 21–39 (median: 25.5). The experiment procedure is illustrated in Figure 9 (adapted from [38]). The participants were split into two groups: the SP (Smartphone) group was given the smartphone version of the navigation system to use during their first walk, and the ARG (Augmented Reality Glasses) group was given the AR glasses version. All participants were asked to take the Santa Barbara Sense of Direction Scale (SBSOD) test [39]. When splitting the groups, a similar distribution of SBSOD scores for both groups was ensured. First, each participant was allowed 3–4 min of becoming familiar with the technology. 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 have been sufficient to avoid the novelty factor completely, it ensured that participants felt comfortable with them.

Each participant navigated through the path following the guidance provided by the system. They were asked to fill out a usability questionnaire, the SUS (System Usability Scale) [40,41], before and after performing the first walk.

At the end, they answered a memory test by plotting the path and marking the memorised landmarks (see Figure 10). On the left-hand side of the map shown in Figure 10, we intentionally made visible a list of examples of landmarks, so that the notion of a landmark was clear and illustrated for each participant. This list of 10 examples did not include the nine landmarks used in this study. For example, the Woody's Bar or Phone Booth on our path were not mentioned in this list. Conversely, our path did not include, for example, a stream, river, or nursery.

A second walk was planned after one week, and it involved two memory tests, before and after the walk. Participants were not given an explicit interdiction for visiting the area between both walks. However, they were made aware of the importance of avoiding the area during the entire duration of the study and how it might affect the memorisation results.

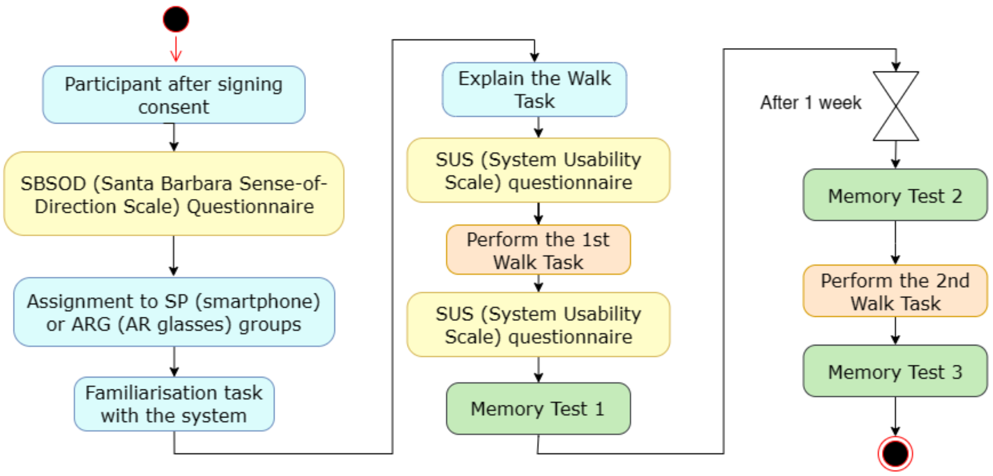

Figure 9. Activity diagram of the protocol.

2.4. Data Capture

The experimental protocol, as described earlier, consisted of asking each participant to walk through the same path twice: the first time, using navigation assistance (an application installed on a smartphone or AR glasses) and the second time, without using any device. Several datasets were collected during the study to address the defined research questions.

Each participant was asked to answer the SUS questionnaire, before and after using the technology for the walk. This subjective assessment of the technology could help to explore the correlations with the effects of spatial knowledge acquisition.

The Santa Barbara Sense of Direction Scale (SBSOD) survey offers an indication of the inherent sense of direction of each participant. The SBSOD questionnaire was 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. The findings, using a Welch's t test, showed no significant difference between the two groups in terms of the spatial navigation and sense of orientation abilities.

A key dataset in this experiment involved a number of memory tests that participants were asked to perform after the first walk and a week later, both before and after they performed the walk without any technology. The aim of the memory test was to capture the participant's recall of the landmarks and to test their abilities in spatial transformation as an indication of spatial knowledge acquisition [15]. Specifically, participants were asked to plot their walk on a map, as a 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).

Figure 10. Memory test 1 for participant SP8.

3. Results

The primary objective of this study was to test the hypothesis: "After using landmark-based navigation technologies, the AR Glasses' experience supports landmark memorisation more effectively than Smartphones".

3.1. Santa Barbara Sense of Direction Scale (SBSOD)

The SBSOD is a 15-item attitude Likert scale [39]. For each item, there are seven possible responses that range from Strongly agree to Strongly disagree. The fifteen items are shown in Table 1. The SBSOD provides a score from 1 to 7 for each statement, and the highest score that can be reached is 105 (7×15 statements). Following previous work [8,42], we reversed the positively stated questions to negatively stated ones so that a higher score meant a better sense of direction.

Table 1. The SBSOD items [39].

No	Item
1	I am very good at giving directions.
2	I have a poor memory for where I left things.
3	I am very good at judging distances.
4	My "sense of direction" is very good.
5	I tend to think of my environment in terms of cardinal directions (N, S, E, W).
6	I very easily get lost in a new city.
7	I enjoy reading maps.
8	I have trouble understanding directions.
9	I am very good at reading maps.
10	I don't remember routes very well while riding as a passenger in a car.
11	I don't enjoy giving directions.
12	It's not important to me to know where I am.
13	I usually let someone else do the navigational planning for long trips.
14	I can usually remember a new route after I have traveled it only once.
15	I don't have a very good "mental map" of my environment.

Tables 2 and 3 present the results of the SBSOD questionnaire. By using the Welch's *t* test on this data, no significant difference was found between both groups (t = 1.7,

$p > 0.0991$), where the SBSOD score for the ARG group was (M = 69, SD = 8.1976), and the SBSOD score for the SP group was (M = 61.5, SD = 9.9725).

Table 2. The SBSOD score for the ARG group.

Participant	**ARG1**	**ARG2**	**ARG3**	**ARG4**	**ARG5**	**ARG6**	**ARG7**	**ARG8**	**ARG9**	**ARG10**
SBSOD	81	63	67	76	83	57	72	62	65	64

Due to technical issues, the ARG8 participant did not manage to complete the memorisation task, and in the current circumstances, it was impossible to add a new participant. With the statistical Welch's *t* test, it was possible to proceed with the analysis despite having two different groups in terms of size.

Table 3. The SBSOD score for the SP group.

Participant	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**	**SP8**	**SP9**	**SP10**
SBSOD	68	64	80	65	58	57	47	44	65	67

3.2. System Usability Scale (SUS)

This questionnaire helps to obtain a subjective estimation of the system's usability. The SUS is a ten-item attitude Likert scale [40,41]. For each item, there are five possible responses that range from Strongly agree to Strongly disagree. The ten items are shown in Table 4. The SUS provides a score from 0 to 100.

Table 4. System Usability Scale (SUS) items [41].

No	**Item**
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very cumbersome to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system.

Table 5 illustrates the descriptive statistics of the SUS results for both groups before and after the use of the navigation system. It shows that participants in both group gave a better score after using the technology.

Our aim was also to detect whether the usability problems, expressed via the SUS questionnaire (or noted through direct observation), could be disruptive or even blocking for some users, with either of the two devices. Although the scores varied from one user to another, no such problems were detected.

Table 5. The SUS score summary for the ARG and SP groups.

Group	ARG (Before)	ARG (After)	SP (Before)	SP (After)
M	66.25	73.50	68.25	75.25
Med	62.50	76.25	67.50	77.50
Min	32.50	37.50	52.50	50.00
Max	92.50	92.50	92.50	92.50
SD	21.87	16.72	9.93	11.81

3.3. Memory Tests

In this section, the memorisation results are analysed following three steps: (1) landmarks, (2) path segments, and (3) the global memorisation score including the landmarks and path segments.

3.3.1. Landmark Memorisation

Figure 10 illustrates the results of one memory test with a plotted path and the landmarks located along this path. To evaluate the performance of the participants, a memorisation score for the landmarks (MS_L) was calculated based on the identified landmarks; three values were possible for each landmark (0: not located at all, 1: incorrectly located, and 2: correctly located). For example, Table 6 shows the results of participant SP8 (using a smartphone), who succeeded in recalling four landmarks out of nine, in the first test, where two of the landmarks were positioned correctly on the map. The complete results are illustrated in Tables 7 and 8.

Table 6. Evaluation of the memorisation of landmarks (Participant SP8).

Landmark	Footpath	Zebra Crossing	Phone Booth	Bus Stop	Woody's Bar	Zebra Crossing	Bishopden Court	Main Road	Hemsdell Court
Notation	L1	L2	L3	L4	L5	L6	L7	L8	L9
M. Test 1	0	2	0	1	2	1	0	0	0
M. Test 2	0	2	0	1	2	0	0	0	0
M. Test 3	0	2	0	1	1	0	0	0	0

Legend: 0: not located at all, 1: incorrectly located, 2: correctly located.

Table 7. Memory tests: landmarks results for the ARG group (the score is in the range of 0 to 18).

Participant	ARG1	ARG2	ARG3	ARG4	ARG5	ARG6	ARG7	ARG8	ARG9	ARG10
ARG M. Test 1	8	12	9	10	11	12	5	NA	12	7
ARG M. Test 2	8	13	8	9	11	8	4	NA	10	6
ARG M. Test 3	9	13	8	8	13	2	7	NA	12	10

Due to technical issues, The ARG8 participant did not manage to complete the memorisation task, and in the current circumstances, it was impossible to add a new participant. With the statistical Welch's t test, it was possible to proceed with the analysis despite having two different groups in term of size.

Table 8. Memory tests: landmarks results for the SP group (the score is in the range of 0 to 18).

Participant	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10
SP M. Test 1	10	6	7	4	12	8	7	6	2	11
SP M. Test 2	6	7	7	7	6	8	9	5	1	5
SP M. Test 3	6	7	2	7	6	10	11	4	3	8

With the Welch's *t* test, no significant difference was found between both groups except for the second test (t = 2.1897, $p < 0.0442$), where the score of the located landmarks for the ARG group (M = 8.6, SD = 2.4994) was higher than the score of the located landmarks for the SP group (M = 6.1, SD = 2.0712).

Figure 11 illustrates the results of the landmark memorisation analysis. It shows that the participants in the ARG group performed better in terms of memorisation compared to the SP group. Thus, the AR glasses supported landmark memorisation more effectively than smartphones.

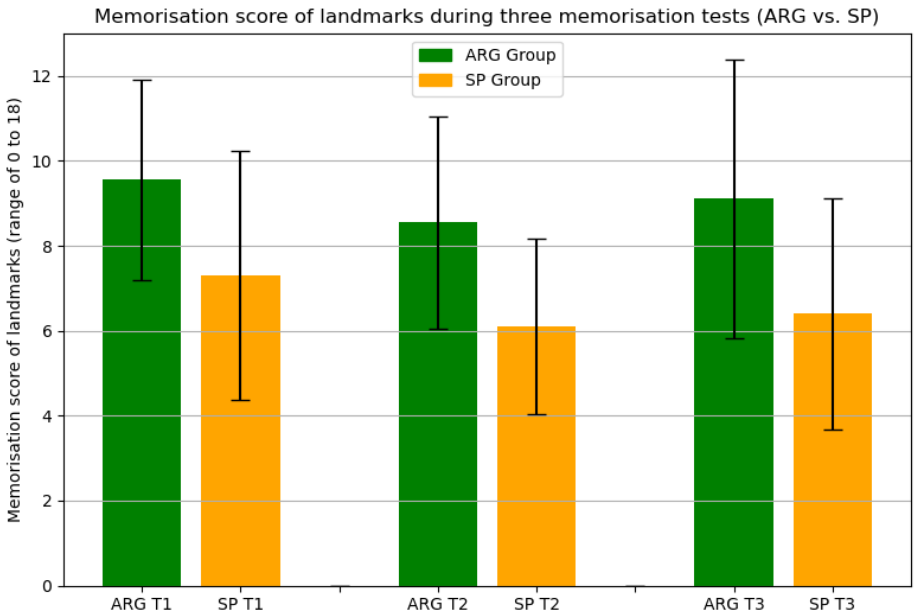

Figure 11. Memorisation score analysis (landmarks).

3.3.2. Path Segment Memorisation

The next step was to consider the accuracy of the plotted path by calculating a memorisation score MS_S of recalled segments (each segment was located between two decision points, i.e., between two landmarks). Table 9 illustrates the corresponding score for participant SP8 (1: correct segment, 0: incorrect segment). Tables 10 and 11 illustrate the results of both groups. By using the Welch's *t* test on these data, no significant difference was found between both groups in terms of memorising the path segments. Figure 12 illustrates these results that show no significant difference between both devices in supporting the path segment memorisation.

Table 9. Evaluation of segment memorisation (Participant SP8).

Segment	Departure - L1	L1 - L2	L2 - L3	L3 - L4	L4 - L5	L5 - L6	L6 - L7	L7 - L8	L8 - L9	Score MS_S
M. Test 1	1	1	1	1	1	1	0	0	0	6
M. Test 2	1	1	1	1	1	1	1	0	0	7
M. Test 3	1	1	1	0	1	1	1	0	0	6

Table 10. Memory tests: segment results for the ARG group (the score is in the range of 0 to 9).

Participant	ARG1	ARG2	ARG3	ARG4	ARG5	ARG6	ARG7	ARG8	ARG9	ARG10
ARG M. Test 1	8	9	8	7	9	9	3	nan	9	7
ARG M. Test 2	9	9	9	7	9	9	3	nan	9	8
ARG M. Test 3	9	9	9	7	9	9	5	nan	9	9

Table 11. Memory tests: segments results for the SP group (the score is in the range of 0 to 9).

Participant	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10
SP M. Test 1	7	6	4	4	7	8	5	6	7	8
SP M. Test 2	7	6	4	4	7	8	7	7	4	8
SP M. Test 3	7	6	6	5	7	8	7	6	8	9

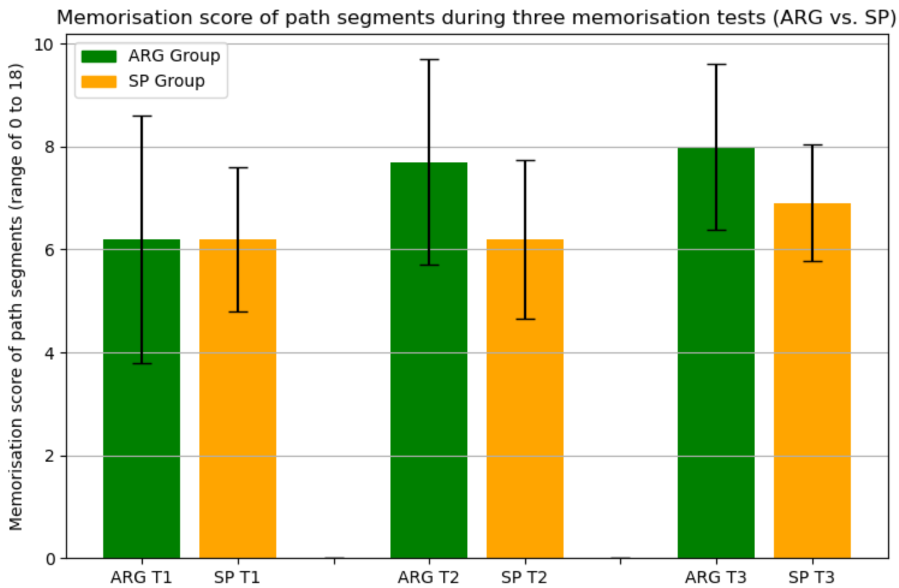

Figure 12. Memorisation score analysis (path segments).

3.3.3. Landmark and Path Segment Memorisation Combined

Both results obtained from the previous analyses (landmarks and segments) were combined to calculate a global memorisation score, MS. (see Tables 12 and 13). The scaling method, described below, was used to bring the results to the same range between 0 and 5. Then, the MS was calculated by aggregating the scaled scores, and thus, the MS was in the range of 0 to 10 (lowest and highest score of global memorisation, respectively).

- r_{min}, r_{max} denote the minimum and the maximum of the range of the measurement, respectively;
- t_{min}, t_{max} denote the minimum and the maximum of the range of the desired target scaling, respectively.

$$scaled\_score = \frac{score - r_{min}}{r_{max} - r_{min}} (t_{max} - t_{min}) + t_{min}$$

Table 12. Memory tests: global score results for the ARG group (the score is on a scale out of 10).

Participant	**ARG1**	**ARG2**	**ARG3**	**ARG4**	**ARG5**	**ARG6**	**ARG7**	**ARG8**	**ARG9**	**ARG10**
ARG M. Test 1	6.67	8.33	6.94	6.67	8.06	8.33	3.06	nan	8.33	5.83
ARG M. Test 2	7.22	8.61	7.22	6.39	8.06	7.22	2.78	nan	7.78	6.11
ARG M. Test 3	7.5	8.61	7.22	6.11	8.61	5.56	4.72	nan	8.33	7.78

Table 13. Memory tests: global score results for the SP group (the score is on a scale out of 10).

Participant	**SP1**	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**	**SP8**	**SP9**	**SP10**
SP M. Test 1	6.67	5.0	4.17	3.33	7.22	6.67	4.72	5.0	4.44	7.5
SP M. Test 2	5.56	5.28	4.17	4.17	5.56	6.67	6.39	5.28	2.5	5.83
SP M. Test 3	5.56	5.28	3.89	4.72	5.56	7.22	6.94	4.44	5.28	7.22

By using the Welch's *t* test, a significant difference was found between both groups for the second and third memory tests. The obtained results for these two tests were (M.Test 2: t = 2.4, $p < 0.0279$) and (M. Test 3: t = 2.6, $p < 0.0195$), respectively , where the global MS for the ARG group (M. Test 2: M = 6.821, SD = 1.6039) and (M. Test 3: M = 7.16, SD = 1.3205) was larger than the global score for the SP group (M. Test 2: M = 5.141, SD = 1.1672) and (M. Test 3: M = 5.611, SD = 1.1088).

Figure 13 illustrates the results of the memorisation score (MS). It shows that the participants in the ARG group performed better in terms of path memorisation compared to the SP group. Thus, the AR glasses supported the path (landmarks + segments) memorisation more effectively than the smartphones.

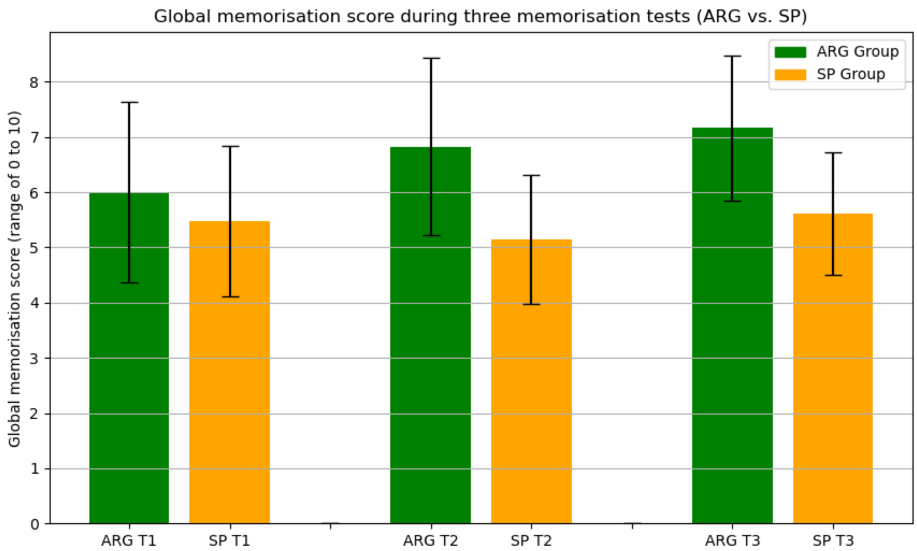

Figure 13. Memorisation score analysis (landmarks + path segments).

4. Discussion

Traditional navigation aid systems are known for being less efficient when it comes to spatial knowledge acquisition. This paper aimed to explore the use of landmark-based assistance, as stated by other researchers [18,43], and determine its benefit for memorising paths and survey knowledge. Its objective was to investigate AR glasses and smartphones for pedestrian navigation and their effects on spatial knowledge acquisition. The results indicated that people using AR glasses, performed better in terms of landmark memorisation, compared to those using smartphones. These results are promising.

Concerning the methodology, Liu and colleagues [28] investigated the effects of spatial knowledge acquisition derived from sketch maps and landmark locating tasks. Their study involved testing the ability of participants to successfully navigate to a specific destination and return back, without the support of technology, relying mainly on landmarks. Our methodology was influenced by this work, involving tasks of positioning landmarks and guidance information on a map.

With respect to memorisation, Lu et al. compared the memorisation of participants in three conditions [27]. During the experiment within a VR environment, participants were expected to memorise landmarks. Immediately after, memory tests were performed using photos taken within the VR environment. Effectively, in their experiments, they assessed the short-term memory acquisition immediately after the activity. In our study, we extended our approach to assessing memorisation, by including an analysis of memorisation tests one week later. This involved the physical repetition of the trip without navigation guidance followed by related memorisation tests. We believe that our approach delivers more robust evidence of the memorisation of landmarks over longer periods of time.

The work by Afrooz et al. focused on the comparison between active navigation and passive navigation to assess their effects on spatial and visual memory during wayfinding [44]. In this work, the authors asked participants to navigate through a predefined route within a university campus, either by following the experimenter (passive navigation) or by leading them (active navigation). The authors did not employ a virtual environment to investigate wayfinding (as commonly performed in other similar works) in order to ensure the direct response of any findings to the real physical environment [45]. A university campus rather than a city was selected to control confounding variables and avoid factors affecting the data collection process, such as crowds and noise. Knowledge acquisition was assessed through a range of tests involving scene recognition, recollection of the left–right orientation of scenes (mirror image discrimination), and route recollection (sketch maps). However, all the memory tests were performed immediately after the navigation tasks, allowing the analysis of short-term memory acquisition. In our work, we explicitly attempted to assess both the short-term and longer-term (a week later) effects of landmark memorisation following the use of wayfinding technologies.

Reflecting on the original hypothesis for this study: "After using navigation technologies, the AR Glasses' experience supports landmark memorisation more effectively than Smartphones", the memory tests analysis showed that AR glasses offered better support for landmark memorisation and also for survey knowledge acquisition after combining both memorisation scores. We acknowledge that the results of this study are based on a limited scale experiment, performed within a single location. In that respect, we consider that further studies can potentially allow for a deeper understanding and more thorough comparison of the effects of the two modalities under different conditions.

Based on the outcomes of our study, we can hypothesise about the factors that may have led to these results. One clear advantage of connected glasses may be that the user is able to constantly look at their surroundings during their walk (therefore, also landmarks), without being severely disrupted by any digital information that may be displayed via augmented reality. With a smartphone, on the other hand, the user's gaze often shifts from the environment to the smartphone. One hypothesis, therefore, is that being able to perceive the environment along the way makes it easier to memorise the environment and its constituent elements (landmarks). In a complementary study involving users with intellectual disabilities, various participants expressed such a view. For instance, one participant explained: "I rather choose to use these AR Glasses than my smartphone with Google Maps. At least, these glasses are in front of my eyes and wouldn't need to look down. If I look all the time at my smartphone, I won't be able to see the street. They will serve when I go to unfamiliar places." [46].

Comparison with Previous Work and Contribution. The main contribution of this work was to investigate the effects of AR glasses compared to smartphones on spatial knowledge acquisition. This research question has not been addressed before using a similar approach. Previous studies have compared navigation devices without evaluating the memorisation task, and for those who did, the AR experience was limited to smartphone support.

Our results show that AR glasses can be a suitable support to provide active landmark-based assistance for pedestrian navigation. It offers a better experience favouring spatial knowledge acquisition. It is legitimate to expect that using similar systems will help people to gain improved spatial awareness and create more autonomy for their mobility.

Limitations and Future Studies. The generalisability of the results is limited by having two groups with different sizes for the memory test. In addition, our study considered navigating two groups of people through one single path. Despite these limitations, the obtained results are valid to answer the research question and support our hypothesis. The statistical method used was insensitive to the difference in group sizes. Moreover, the navigation path was identified following a rigorous method based on local residents' knowledge and expertise in the area.

5. Conclusions

Regarding the negative effects of passive assistance offered by most of the current navigation systems, the use of landmarks by future systems lets us envisage new perspectives for pedestrians. With this aim, new types of technologies have to be designed and evaluated.

This paper has described our contribution through a comparative study, conducted at the University of Kent, of two navigation technologies (smartphones and AR glasses) that can facilitate path memorisation. The participants of each of the two groups were asked to walk through the same path twice, the first one using navigation assistance installed on one of the devices and the second time without any device. The SBSOD questionnaire was initially used to evaluate the spatial abilities of the participants, who were equally allocated to the two groups. Each participant had to perform memory tests about the landmarks used and the pathway followed after the first walk and a week later, before and after they performed the walk without any assistance. The results obtained showed that the performance of the participants was better in terms of path memorisation using AR glasses rather than smartphones.

These promising results can open up opportunities for further research in this area. Specifically, we consider expanding this work with larger-scale studies involving more participants, while diversifying the physical settings for our experiments (i.e., longer paths with more decision points). Furthermore, user demographics can have a significant effect, including age and occupation (e.g., delivery person or taxi driver). Finally, the way information is presented to users would require further studies to identify the most appropriate visualisation mode to maximise memorisation.

A direction of particular importance includes the study of the effects of such systems on people with certain physical or cognitive disabilities both in outdoor environments (considered for instance in [5,7,47]) and also in indoor contexts (see, for instance, [7,48–50]. For instance, people with intellectual disabilities could take advantage of these landmark-centered systems to move around with more autonomy [51,52].

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