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Ahmadpoor, N

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SPATIAL KNOWLEDGE ACQUISITION AND MOBILE MAPS: THE ROLE OF ENVIRONMENTAL LEGIBILITY

Negar Ahmadpoor[a, b]

Alastair D. Smith[c]

[a] Department of Architecture and Built Environment, University of Nottingham, UK

[b] Department of Engineering and Built Environment, Anglia Ruskin University, UK

[c.] School of Psychology, University of Plymouth, UK

Abstract

The legibility of an environment (i.e. the ease with which a navigator can comprehend its structure) is a fundamental component of urban design, and is related to navigational success in the users of a space. The ascendency of mobile mapping solutions, however, means that legibility could potentially play an increasingly smaller role, where navigators may no longer be required to attend to their surroundings in order to make navigational decisions. To address whether legibility might also modulate the environmental knowledge of mobile map users, we conducted a real-world navigation study where participants were required to navigate to a series of key landmarks in a novel urban city centre. One group navigated using mobile mapping technology, whereas the other group planned their own routes on the basis of the information present in the environment. Participants were then required to produce a sketch map of their route as an assay of their topographical mental representation of the space. Confirming previous findings by other researchers, our quantitative analyses revealed that mobile map users had a poorer mental representation of the environment, compared to the self-experience group. However, further analysis revealed that mobile map users were nevertheless affected by environmental legibility, and experienced greater difficulty with path and nodes (i.e. intersections) that were of greater complexity. This may reflect the demands of relating map information to its real-world referents, and carries implications for urban design that can mitigate against the variety of navigational experiences that take place within it.

Keywords: Spatial knowledge, navigation, mobile maps, spatial factors, sketch map accuracy, urban design

1. Introduction

Research across the fields of environmental psychology, urban planning, and design, has shown that people's understanding of the spatial properties of the physical environment is moderated by its physical attributes (e.g. see: Arthur & Passini, 1992; Montello, 1998; Dogu & Erkip, 2000; Golledge, Jacobson, Kitchin, & Blades, 2000; Dalton, Hölscher, & Turner, 2012). This relationship between the form of a place and our abilities to build an accurate mental representation of it was captured by Lynch (1960) in the concept of 'legibility', which refers to the qualities of a physical environment that make it easy to comprehend. Accordingly, along a spectrum of legibility, some places (urban or otherwise) facilitate spatial understanding whereas others can be downright challenging. At the core of this is general complexity – environments with lower legibility will be less likely to possess a clear spatial organisation and, therefore, less likely to be comprehended accurately (Weisman, 1981). So, if an environment is to be understood, then the principles underlying its spatial organisation must be clearly conveyed to users (Arthur and Passini, 1992). This has given rise to a fundamental premise in urban planning and design that has reigned during the 60 years since Lynch's (1960) theory, which states that urban places should be legible in order to be well understood and navigated easily. For example, Evans et al. (1982) suggested that legibility should be considered a "criterion for useable habitats" (p94), for all users. Passini (1980) and O'Neill (1991) also argued that legibility should be an active design criterion for the built environment and, indeed, this has been clearly demonstrated in modern design (e.g. see: Urban Design Compendium (Davies, 2000); By design (Britain, 2000); Responsive environments: A manual for designers (Bentley, 1985)).

Whilst the concept of legibility has fundamentally affected how urban planners account for the navigational needs of people using an environment, the advent of mobile navigation systems has heralded unexpected changes to people's exploration in recent years. Mobile navigation tools based on the Global Positioning System (GPS), which we henceforth refer to as 'mobile maps', can now guide users successfully to their destination, seemingly regardless of the complexity, or legibility, of the environment. This begs the question of whether environmental legibility is as essential as it was previously thought to be, at least for people navigating a novel environment using a mobile map. In the present report we, therefore, describe an investigation of whether the legibility of the physical environment moderates the spatial understanding of mobile map users, or whether its influence is more pronounced for those that navigate without assistance (i.e. route planning that is based upon the visible contents of the environment). The practical considerations of such a question are as apparent as the theoretical ones: since people are increasingly using navigation systems in their everyday lives (Speake, 2015), it is important to understand how legibility, which has been a design principle in built environment for decades, should be considered in (re)designing our future cities for modern users. Knowing this, we might also be able to predict people's spatial understanding of a built environment when they use mobile maps for navigation.

Of central importance to this question is the effect that mobile map use may have on spatial knowledge acquisition, since several empirical studies have clearly demonstrated that mobile navigation systems can have a negative impact on people's mental representation of environmental and navigational information. Some reports have compared spatial knowledge in people using mobile navigation systems to participants using other types of assistance, such as physical maps (e.g. see: Aslan et al., 2006; Ishikawa et al., 2008; Krüger et al., 2004; Münzer et al., 2006; Willis et al., 2009; Ahmadpoor and Heath, 2018; Ruginski et al., 2019). Although such studies report a general pattern of poorer quality environmental knowledge in mobile map users, compared to people using other navigational strategies, it is yet to be established whether this is moderated by the nature of the physical environment. For example, one might expect to observe little difference between mobile map users and people navigating without assistance in a very legible environment, but a much larger difference between them in a less legible environment. The functional basis of this difference might be that environments with less legibility require greater effort to 'read' on the part of the navigator, and so focus on a mobile map might reduce the likelihood of an accurate encoding of one's surroundings.

Our present enquiry had two core objectives. The first was to compare the spatial knowledge acquisition of pedestrians who used mobile maps[1] (MM group) for navigation in an unfamiliar urban environment to those who navigated the same environment without assistance (i.e. through Direct Experience: DE group). The second objective was to identify how environmental legibility moderated mobile map users' spatial knowledge acquisition. We used the sketch map method (Kim, 2001) to gather the participants' spatial knowledge of the environment navigated, and then coded that data so that it could be subjected to quantitative analysis. In this report, we first review previous research projects that have assessed the effects of using mobile maps on people's navigation within the built environment, and also introduce the legibility factors that were tested in the present study. We then describe the underlying methodology of our empirical study and report our analyses of the data collected. Finally, we discuss the results of the study in relation to previous studies, and consider how the findings might affect design principles in future.

2. Literature review

2.1. Spatial knowledge acquisition and mobile maps

Since the advent of mobile mapping solutions, a number of studies have assessed whether they result in a poorer mental representation of the navigated space than other types of navigation aid that rely on greater awareness of the surrounding environment, such as physical maps (e.g. see: Krüger et al., 2004; Münzer et al., 2006; Aslan et al., 2006; Ishikawa et al., 2008; Willis et al., 2009).

[1] The information provided by mobile navigation systems can be in different formats such as texts, audio services, maps, pictures, etc. These formats affect differently the acquisition of spatial knowledge and success of way finding LI, C. 2006. User preferences, information transactions and location-based services: A study of urban pedestrian wayfinding. *Computers, Environment and Urban Systems,* 30**,** 726-740. In this research, we focused on using the 'mobile map format' such as Google maps, as this widely used in pedestrian navigation KALIN, J. & FRITH, J. 2016. Wearing the city: Memory p (a) laces, smartphones, and the rhetorical invention of embodied space. *Rhetoric Society Quarterly,* 46**,** 222-235..

Such studies have measured differences across psychological factors such as the accuracy of memory for the location of discrete environmental features (e.g. landmarks, and their allocentric spatial organisation), and the estimation of distance and heading between two locations. Münzer et al. (2006), for example, required participants to navigate a zoo, and compared performance between participants using a hand-held computer-based assistant to those who used a physical map. Following the navigation task, the researchers examined both the route and survey knowledge of their participants. Route knowledge describes sequentially-ordered representations of places/landmarks encountered, and the egocentric directional information that connect them, whilst survey knowledge specifies an understanding of the spatial relationships between locations that is unrelated to the viewer. They examined route knowledge by presenting participants with images of junctions that they had previously navigated and requiring them to report which direction they had turned. Survey knowledge was tested by a spatial relocation task, where participants were required to place the same pictures of intersections at their correct locations on a map of the zoo (which depicted no landmarks). Route knowledge was determined by the accuracy of direction judgements, whereas survey knowledge was measured in terms of Euclidean placement error (in pixels). They found that those who used physical maps presented perfect route knowledge and good survey knowledge. In contrast, participants that had computer assistance had good route knowledge, but poor survey knowledge. In a similar zoo setting (and experimental procedure), Krüger et al. (2004) compared the effects of mobile pedestrian navigation systems and physical maps on the development of route and survey knowledge. They found the similar results to Münzer et al. (2006), and concluded that whilst mobile navigation systems can potentially support landmark knowledge, they fail to adequately support survey knowledge (i.e. an allocentric cognitive representation of an environment).

Other studies have made use of sketch-map drawing as a means to gain a more detailed assay of spatial learning in participants. This is considered an informationally-rich, and relatively naturalistic method for recovering information about the way people represent the environment and has been used (individually, or in combination with other measures) for many spatial cognition research studies (Evans, 1980, Weisman, 1981, Evans et al., 1984a, Tu Huynh and Doherty, 2007, Montello et al., 2004, Aram et al., 2019, Ahmadpoor and Shahab, 2019). For example, Ishikawa et al. (2008) required participants to navigate six separate routes in search of specified goals, and compared mobile map users, physical map users, and people navigating through self-experience (i.e. finding their destinations without any representational assistance). At the end of the experiment, participants were required to draw the paths that they had walked, and the topological accuracy of their sketch maps was analysed by counting the number of routes that depicted all the turns in the correct directions and sequences. The comparisons showed a significant difference in topological accuracy between the three groups, in which GPS users had the lowest topological accuracy for the study area. In another study, Willis et al. (2009) compared spatial knowledge between participants who had learned the environment from a physical map and those who had learned it using a mobile map. They noted that those navigating with mobile maps were less accurate in drawing sketch maps of the study area, in comparison to the physical map users. In addition, they found that mobile map users were poor in estimating the distance travelled or the cardinal directions of landmarks from their start point.

2.2. Quantifying legibility

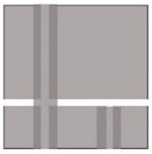
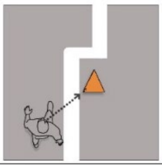
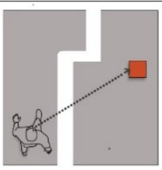
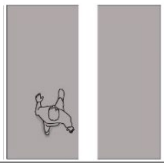
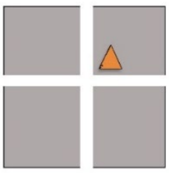
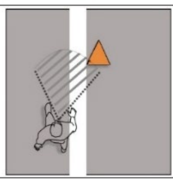
Although there have been demonstrations, such as those described above, that mobile map use can impact negatively on spatial knowledge acquisition, it is yet to be ascertained how this effect relates to the nature of the environment itself – i.e. whether the legibility of the environment moderates the supposedly deleterious influence of mobile map usage. In order to formally investigate this issue, we sought guidance from traditional planning theory of urban legibility and navigation to quantify legibility.

Environmental legibility has been considered as a core urban planning and design objective (e.g. see: Building Legible Cities 1 & 2 (Kelly & Kelly, 2001, 2003); The Councillor's Guide to Urban Design (Britain, 2003); UK National design guide (Great Britain. Ministry of Housing, 2019)), since it moderates the user's knowledge of the built environment and facilitates their wayfinding (Evans et al., 1982; Passini et al., 2000; Taylor, 2009; Dalton et al., 2012; Carmona et al., 2012). In order to quantify legibility, and to determine whether it moderates the experiences of mobile map users, we undertook a review of the extant literature in environmental psychology, urban planning and design. This revealed three key environmental elements that underlie legibility: landmarks, paths, and nodes (Golledge, 1978; Golledge et al., 2000; Slone et al., 2015; Lynch, 1960; Appleyard, 1970; Gärling et al., 1983; Passini, 1984; Haq, 2003).

Multiple research papers on the topic of landmarks have sought to formalize the concept from architectural and perceptual perspectives, (e.g. see: Lynch, 1960 Appleyard, 1969; Siegel and White, 1975; Evans et al., 1981; Couclelis et al., 1987; Presson and Montello, 1988; Denis, 1997; Evans and McCoy, 1998; Raubal and Winter, 2002; Nothegger et al., 2004,; Winter et al., 2005; Klippel and Winter, 2005; Westerbeek and Maes, 2013). A common factor amongst all these studies is that landmarks are reference points for the navigator, with distinctive visual or semantic characteristics that contrast with background information (i.e. their physical context). Objects with these characteristics are more likely to appear in people's cognitive representation of the place and, hence, in their sketch map drawing of the environment. Paths are the channels through which the navigator moves, or has the potential to move (e.g. streets, walkways, canals, or railroads) (e.g. see: Lynch, 1960; Evans et al., 1984b; Herzog and Kropscott, 2004; Ahmadpoor and Shahab, 2019). Finally, nodes are decision points within the physical setting that the navigator can enter into, and are the foci to and from which people travel. They are mainly junctions, where there is a break in transportation, a crossing, or a convergence of a number of paths (e.g. see: Haq, 2003, Haque et al., 2006; Farr et al., 2012; Klippel and Winter, 2005).

These environmental components of legibility can themselves be subdivided into different types, and the results of our review are summarised in Table 1. One can see that the most frequently examined factors relating to paths are length, the number of turns along a path, and the presence of internal (i.e. proximal) or external (i.e. distal) landmarks along a path. For nodes, the effects of number of paths entering the node, and the placement of a landmark at a node, have attracted significant attention. Finally, in the case of landmarks, visibility is a crucial factor that appears to moderate people's spatial knowledge. Together, these factors provide something of a taxonomy that we capitalised upon in the present study.

Table 1. A taxonomy of the underlying attributes of paths, nodes, and landmarks that were focused upon in the present study

	Factors	Diagram	Description
Paths	Length		Length of the path is a factor that can influence people's spatial knowledege acquisition (Evans et al., 1984b; Haque et al., 2006,Guérard and Tremblay, 2012).
	Number of turns		Number of turns along a path (can occur at an intersection as well) (Evans et al., 1984b; Haque et al., 2006; Jansen-Osmann and Wiedenbauer, 2004).
	Route with internal landmark		Paths containing inernal landmarks (i.e. landmarks in the immediate context of the path) (Westerbeek and Maes, 2013; Klippel and Winter, 2005).
	Route with external landmark		Paths with visual access to extenal landmarks (i.e. landmarks which are not located in the immediate context of the path, but visible to people as they walk along the path) (Westerbeek and Maes, 2013; Klippel and Winter, 2005).
	No landmark		Paths without internal and external landmarks (Westerbeek and Maes, 2013; Klippel and Winter, 2005).
Nodes	Number of legs (paths)		Number of equivalent choices (paths) that one has at a decision point on the way to a destination (Richter and Klippel, 2004; Haque et al., 2006; Richter, 2009)
	Nodes with landmark(s)		Placement of landmark(s) at a node. (e.g an intersection containing historic buildings at its corner(s)) (Klippel and Winter, 2005). Hunt (1984) found that elderly people could make the most robust mental image of an environment, when main decision points (i.e. intersections) are accompanied by landmarks.
Landmark	Visibility to the landmarks		The degree of visual access from the origin to the landmarks and the extension of the visual field towards the landmarks (Janzen et al., 2001; Turner et al., 2001; Jiang, 2006; Shah and Miyake, 2005; Omer and Goldblatt, 2007).
Internal Landmark, External Landmark			

By identifying and quantifying the factors that account for legibility in the built environment, we were then able to design a protocol to empirically address our research objectives. Participants (i.e. either in the DE Group or the MM Group) were required to navigate a novel urban environment by visiting eight locations in the environmental setting of this study. To interrogate their spatial knowledge of the environment (i.e. our first objective), we used sketch map drawing (see Kim, 2001) as a method to examine their mental representations of landmarks, paths, and nodes. We then compared the placement accuracy of these elements on the maps across both groups. In order to assess the impact of legibility factors on users' spatial knowledge (i.e. our second objective), we tested the placement accuracy of these elements on the maps, in relation to legibility factors present in the environment that was explored. The Method section below details the data collection paradigm, and is followed by a Results section that describes statistical analysis of our data.

3. Research methods

3.1.Materials

Participants. 76 participants (38 female, 38 male) aged between 18-28 years (M= 22.86, SD=3.36) were recruited. They were opportunistically sampled from the first year of students attending the University of Nottingham, according to the following criteria: (a) they were born and raised in the UK, to increase the likelihood that they were familiar with the general culture of the neighbourhood; (b) they had no prior exposure to the study area; (c) they had previously used mobile maps self-sufficiently in an urban area; (d) they were all right-handed. Participants were evenly and quasi-randomly allocated to one of two experimental groups: Mobile Map (MM), and Direct Experience (DE). Group allocation was controlled according to two factors. First, there was an even allocated of males and females to each group. We also ensured that self-reported evaluations of sense of direction were similar across groups, with DE group (M = 4.632, SD = 0.492) and MM group (M =

4.710, SD = 0.465): t = 0.725, df = 74, p =0.156, in order to equate general spatial abilities across samples

Sense of direction was measured using the Santa Barbara Sense-of- Direction Scale (SBSOD: Hegarty et al., 2002), which was emailed to participants and returned before the experiment took place. The scale consists of 15 statements, to which participants express their degree of agreement on a 7-point Likert scale. Seven of the questions are positive (e.g. "I am very good at giving directions") and the other eight are negative (e.g. "I very easily get lost in a new city"). Respondents answer the questions by giving 1 (strongly agree) to 7 (strongly disagree) to each question. In our study, for each participant, the mean of their answers to the 15 sense-of-direction questions was calculated. Negatively oriented questions were reverse-coded to that a higher score reflected a better self-reported sense of direction, ranging from 1 to 7. This then allowed us to assign participants to groups in a manner that equated the distribution of SBSOD scores between them. The SBSOD test has largely been used as a measure of individual differences in spatial cognition, and the validity of this test has been demonstrated in other research projects (Hegarty et al., 2002, Wen et al., 2011). For instance, Hegarty et al. (2002) showed that people who have a better SBSOD score are more accurate at using self-motion to update their orientation and location in space.

The study was approved by the University of Nottingham Ethics Committee for human-based research and all of the participants provided written informed consent. All participants were presented with gift vouchers in return for their participation.

Environmental setting. The environmental setting chosen for this research was a 14 hectare area of the city centre of Nottingham, which is a medium-sized city in the centre of England with a greater urban population of around 730,000. The study area includes both modern and historic architecture with over 350 buildings and it retains a medieval historic morphological pattern, with 20 streets and

18 key street junctions. Figure 1 A & B illustrate the eight target locations used in the procedure, along with the order in which participants were asked to visit them.

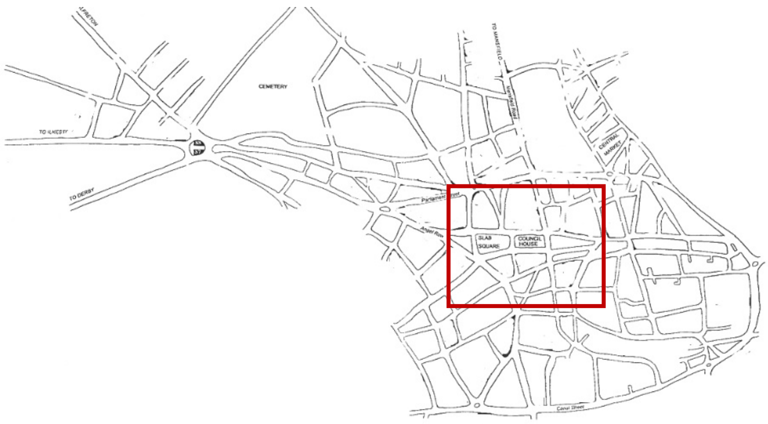


Figure 1 A: Study site in relation to Nottingham City

Figure 1B: Map illustrating the eight locations and the order in which they were to be visited: 1) Broadmarsh shopping centre, 2) St Nicholas' Church, 3) Nottingham Castle, 4) St Peter's church, 5) Nottingham Central Library, 6) Council House, 7) Pelham Street House, 8) Nottingham Contemporary art gallery. Source: Authors' drawing

Mobile Map. MM participants were asked to navigate using the Google Map application (version 3.26), running on an iPhone 6 mobile phone, in order to navigate to the target locations. In the configuration used in the application, the position of the participants was marked on the map, and this was continuously updated as they moved through the environment. The interface also conveyed the direction in which way they were facing, by placing a cone of vision icon on the location marker that updated as participants rotated.

3.2. Design

In the first phase of the experiment, both the MM and DE participants were individually exposed to the environmental setting. Based on the paradigm reported by Willis et al. (2009), MM participants were instructed to explore the study area by sequentially navigating to a series of proposed locations with the assistance of a mobile map. In contrast, DE participants were required to find the same locations by relying on urban features and any directional signs within the study area. In this way, the experiment was designed to closely approximate everyday navigational behaviour, which might sometimes rely on a mobile map, and other times occur without any external assistance. After finishing the exposure phase, participants were asked to draw a sketch map of the area that they had been through. We analysed the sketch maps on the basis of depiction accuracy of paths, nodes, and landmarks. We then tested the depiction accuracy of these elements in relation to their physical-spatial features in the real environment.

3.3. Procedure

The experiment took place in late September 2017, across two weeks, and all of the sessions were conducted during weekday mornings. On the day of experiment, participants were taken individually to the start point of the experimental route (illustrated in Figure 1B) using a path that avoided the study site. MM participants were then provided with an iPhone 6 mobile device that was running the Google Maps application. They were asked to practice using the application on the phone before undertaking the task. The map on the phone could be scaled in and out, but was fixed in a north-up orientation throughout the task. Participants were then given a written briefing to take with them during the journey, which included the names of eight locations within the site, and order that the locations should be found. These locations were selected to represent eight buildings that have distinctive architectural features, distinctive function, and were each located on a single street. MM participants were told to find the eight locations by using the Google Maps application on the phone (i.e. simply inserting the name of the location and following the guide provided to them to get to the location) in the order they were given in the briefing. In the entire journey, participants were followed by two researchers who remained at a distance of about 20-30 metres. Participants were required to point at the building when they found it – once the researchers had confirmed to them that this was the correct building, they could carry on to finding the next location. Consistent with the methods of Ishikawa et al. (2008), participants that moved beyond the boundaries of the study area for longer than 10 minutes were guided by the researchers to the routes that were part of the study.

DE participants were given the same general briefing as MM participants, although they were asked to find the same locations by relying solely on urban features and using guiding signs in the city. The eight target locations in this study were key tourist destinations for the city and the guiding signs in the city referred to them specifically (e.g. Nottingham Castle; Nottingham Contemporary gallery; St. Peter's Church). The guiding signs were located at the main decision points along participants' routes to the destinations. Although in real-world experiments it is not possible to fully control people's movements in the site, we attempted to guide participants from both groups to move through the same study routes, and sequence of buildings, by implementing the following steps. First, the locations of the eight buildings within the site, and the order that participants were asked to find them, were selected in a way that meant that both groups were likely to walk through the same routes in the same sequence (see Figure 1B). This had been tested in a pilot study by manipulating the order of landmarks to make sure that both groups for moving from one location to the next one would go through the same route. Second, MM participants were encouraged to choose the shortest route that the mobile map suggested, which would be more likely to produce the same route that DE participants would follow. Figure 2 illustrates the experimental context with photographs that were taken during the sessions.

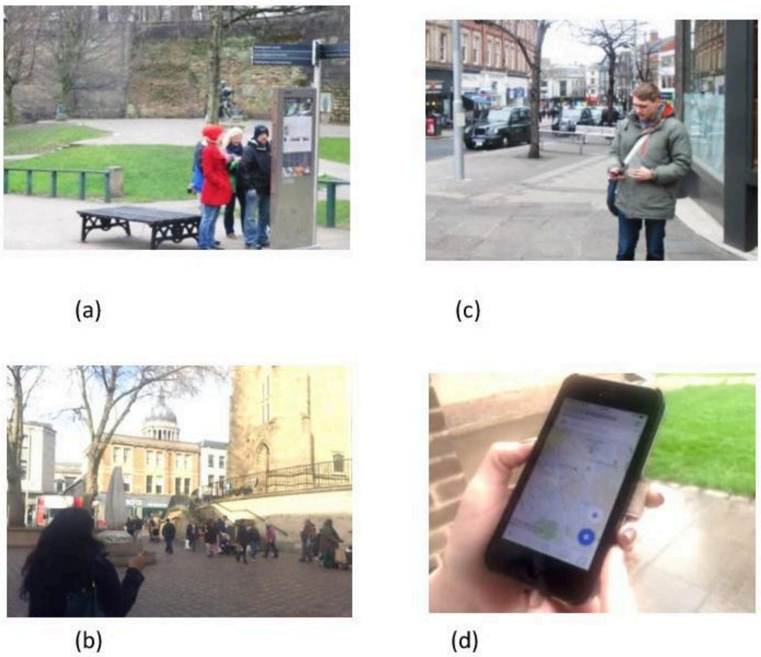


Figure 2. Illustrations of the experiment procedure: (a) a direct experience participant is using the directional signs to find the destinations; (b) a Mobile Map user pointing at one of the destinations; (c) and (d) Mobile Map participants using the mobile map to find the destinations.

After the exposure phase, participants were led to a seating area near to the concluding location, but with no view of the area that they had explored, and asked to draw a sketch map of the area that they had navigated on a blank sheet of A4 paper. There was no time limit for this task and they were instructed to draw all the buildings, spaces, streets and details of the area as accurately as they could remember. A sample of sketch maps developed by participants in the two groups is illustrated in Figures 3 and 4.

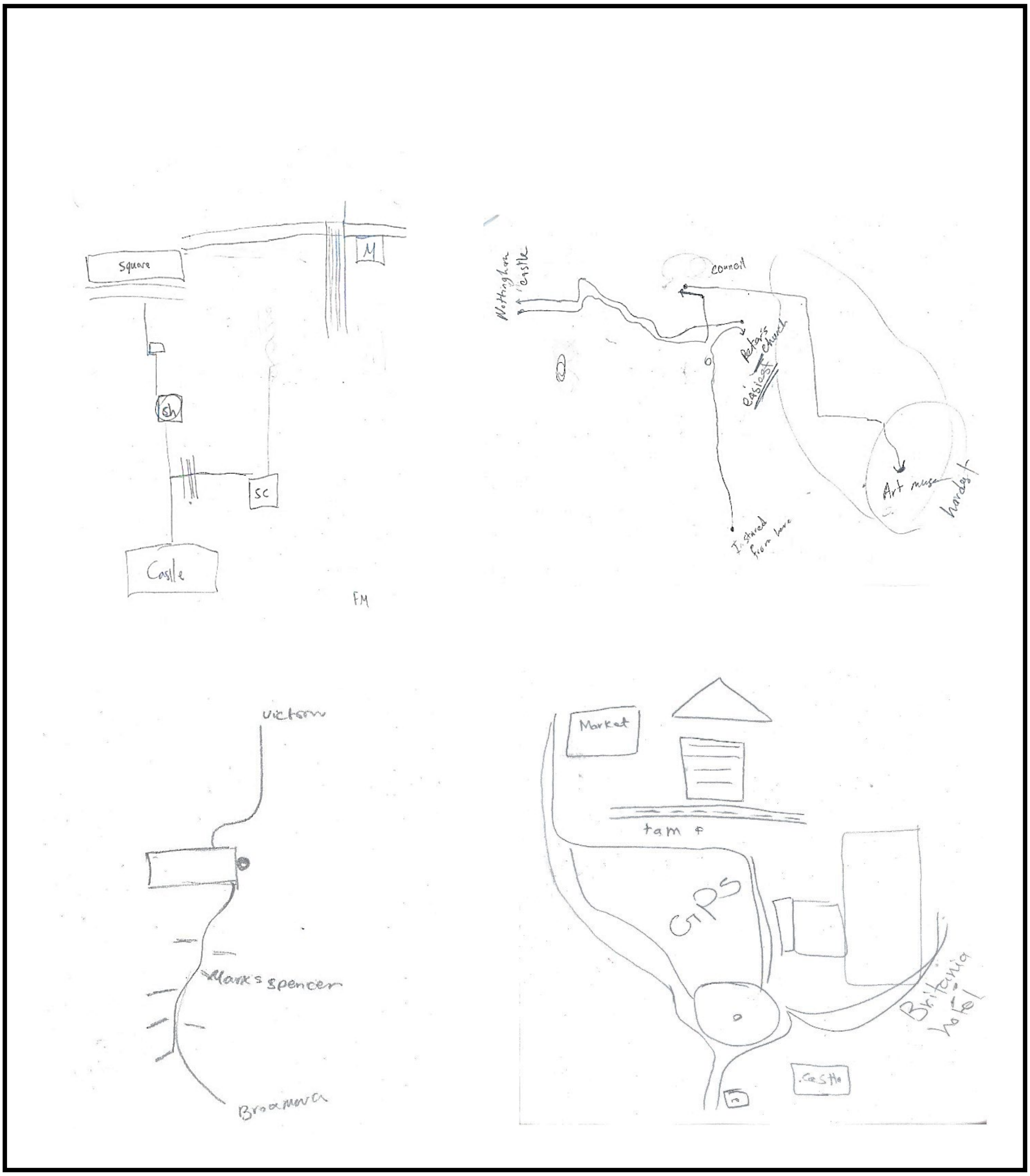


Figure3. Examples of sketch maps produced by Mobile Map (MM) participants

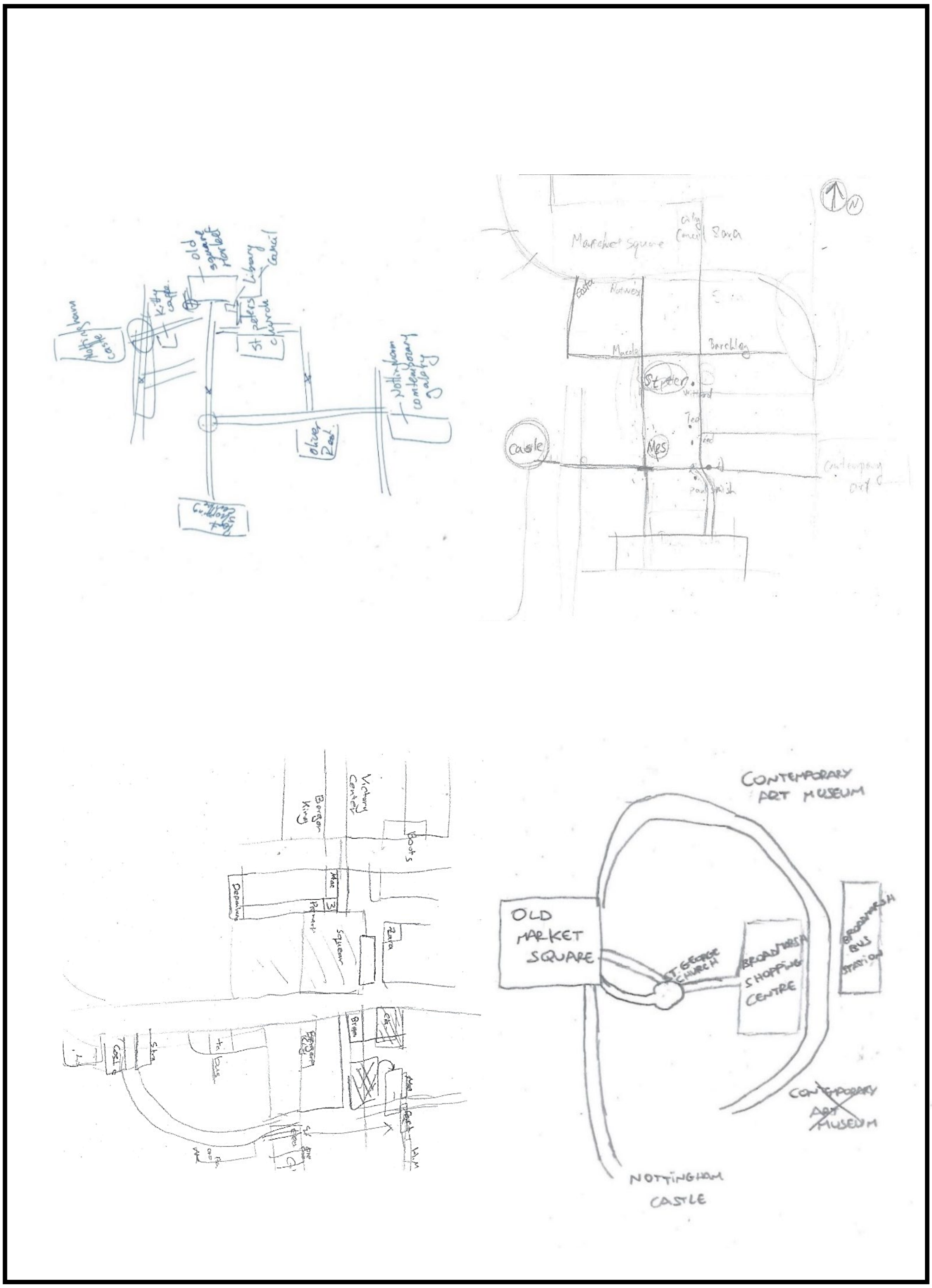


Figure 4. Examples of sketch maps produced by Direct Experience (DE) participants

4. Results

4.1 Group comparisons

The analyses reported in this initial section address the first objective of the study – i.e. whether there were any differences in sketch map accuracy according to whether participants used a mobile map (MM group) or navigated using direct experience of the environment (DE group). In particular, we focused on three core components of map representations: paths, nodes, and landmarks, as discussed in Section 2.2.

Sketch map accuracy was gauged according to the method of Long and Baran (2012). First, a list of all the paths and nodes that the participants traversed was constructed. In the case of landmarks, a list of buildings included in all sketch maps (not only the eight locations the participant found in the site) was developed, and this was considered to represent all of the potential landmarks that could be included. Paths were scored on a 4-point scale, ranging from 0 to 3, and included the following path/street categories: 0 = street did not exist in the sketch map; 1 = incorrectly drawn (wrong location or direction); 2 = partly correctly drawn (distortions in curve, and/or angle, and/or number of turns, and/or length); and, 3 = correctly drawn. Nodes were scored similarly, using a 4-point scale that included the following categories: 0 = nodes did not exist in the sketch maps; 1 = incorrectly drawn (wrong location); 2 = partly correctly drawn (along a right path/street, but in a wrong location, and/or having wrong number of paths forming the node); and, 3 = correctly drawn. Finally, the schema for scoring landmarks utilised the following scale: 0 = landmark not drawn on the sketch map; 1 = incorrectly located; 2 = partly correctly located (along the right path/street, but in a wrong location); and, 3 = correctly drawn.

Following this coding, separate total scores for Path, Node, and Landmark, were calculated for each participant by summing the respective scores. These data are illustrated in Figure 5. An independent samples t-test revealed that Path scores were significantly higher for the DE group (M = 14.526, SD = 10.253) than for the MM group (M = 6.763, SD = 5.645): t = -4.089, df = 74, p < .001. A similar analysis showed that Node scores were significantly higher for the DE group (M = 12.184, SD = 7.450) than for the MM group (M = 5.974, SD = 4.493): t = -4.400, df = 74, p < .001. Finally, we found that Landmark scores were also significantly higher for the DE group (M = 16.816, SD = 11.453) than for the MM group (M = 7.816, SD = 4.770): t = -4.472, df = 74, p < .001 .

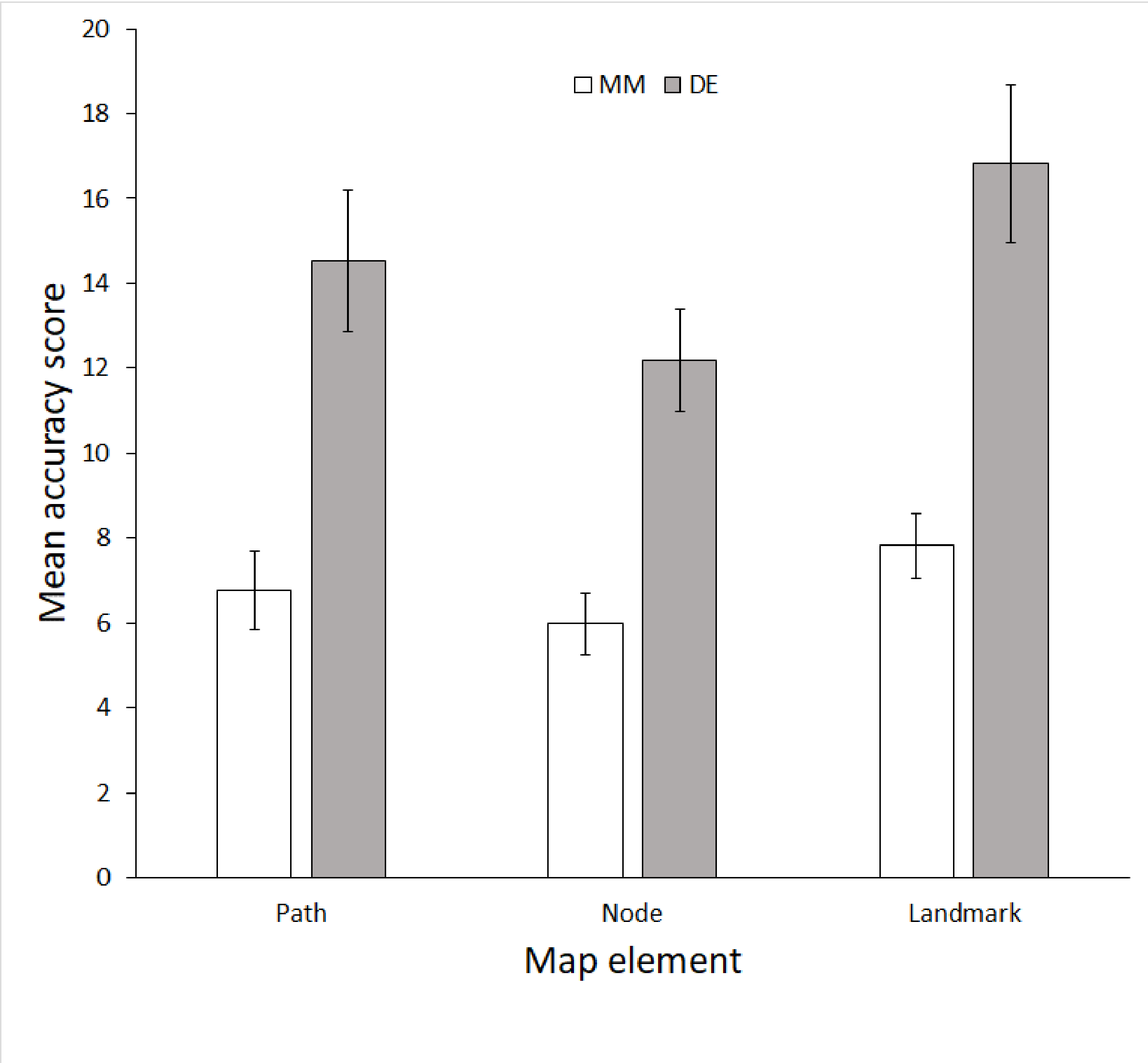


Figure 5. Mean accuracy scores for Path, Node, and Landmark, plotted according to experimental group. Error bars represent standard error of the mean.

4.2. Route comparisons

Our remaining analyses were based on comparisons between different route components, in order to ascertain whether participant performance was moderated by environmental factors. In these analyses, comparisons were made between route components on the basis of mean participant scores, for all paths, using the schema-based analyses described in the previous section. Analyses were separately conducted for MM and DE groups and, in some cases, we also addressed correlations between the quantity of a particular feature and accuracy (separately for each experimental group).

Number of turns. Some paths along the routes followed by participants had more turns (i.e. junctions at which the navigator would be required to make a navigational decision) than others – these ranged from no turns to six turns ($M = 2.20$, $SD = 1.881$). In order to certify whether the number of turns was related to participants' accuracy at representing them, we conducted a Pearson's correlation between the number of turns (for each street) and the mean path scores (i.e. the mean of participants' scores for each path, using the schema-based analyses). Analysis for the MM group revealed a significant negative correlation between the number of turns and accuracy ($r = -.846$, $p < .001$), and the same relationship was apparent for the DE group ($r = -.806$, $p < .001$). This suggests that, for both groups, a greater number of turns was associated with lower (i.e. less accurate) path scores .

Street length. Similarly to the number of turns, some streets along routes followed by participants were longer than others, with street length ranging between 110 – 800 metres ($M = 339.150$, $SD = 189.689$). In order to gauge whether street length was related to participants' accuracy at representing them, we conducted a Pearson's correlation between the length of each street and the mean path scores. Analysis for the MM group revealed no relationship between length and accuracy (r = -.266, p = .257), and there was no relationship between these variables for the DE group either (r = -.258, p = .272).

Internal landmarks. Some streets along participants' routes contained internal landmarks, defined on the basis of landmarks that have distinctive visual or semantic characteristics that contrast with background information, and are located in the immediate context of the path (Klippel and Winter, 2005). In contrast, other streets did not feature any landmarks that fitted this definition. For example, Long Row Street contained the Council House building, which is architecturally distinctive and visually salient in its context, whereas Castle Gate Street consists of buildings with a high level of visual similarity. To find out whether the presence of these internal landmarks affected depiction accuracy of the streets, we compared the mean path scores of the streets with internal landmark to the streets without internal landmarks. An independent samples t-test for the DE group showed that the mean path scores were significantly higher in streets with internal landmarks (M= 2.00, SD= 0.632) in comparison to the streets without internal landmarks (M= 1.20, SD= 0.351), t (18) =-3.00, p<0.01. However, for the MM group, there was no significant difference in the mean path scores between the streets with internal landmarks (M= 1.20, SD= 0.551) and the streets without internal landmarks (M= 0.750, SD= 0.252), t (18) =-1.90, p = 0.070.

External Landmarks. Some streets along the routes included salient external landmarks, defined on the basis of landmarks that were not located in the immediate context of the path but visible to people as they walked along the path (Klippel and Winter, 2005), whereas other streets did not have any external landmarks. Independent samples t-tests revealed that, for the MM participants, there was no significant difference in the mean path scores between the paths with external landmarks (M= 1.20, SD= 0.701), compared to the streets without external landmarks (M= 1.00, SD= 0.503), t (18) =-0.60, p = 0.231. The result was similar for DE group, with no difference between the paths with external landmarks ($M= 1.80$, $SD= 0.700$) and those without external landmarks ($M= 1.70$, $SD= 0.552$), $t(18) =-0.25$, $p = 0.132$.

4.3 Node Comparisons

This part of our analysis focused on comparison between node components on the basis of the mean participant score for each node, using the schema-based analysis described previously. Analyses were separately conducted for MM and DE groups and, in some cases, we also addressed correlations between the quantity of a particular feature and accuracy (separately for each experimental group).

Number of Node-legs. Nodes had different numbers of streets entering them, termed as node-legs, and these ranged from three to six legs ($M = 3.750$, $SD = 1.020$). In order to measure whether the number of node-legs was related to participants' accuracy at representing nodes, we conducted a Pearson's correlation between the number of node-legs (for each node) and the mean node scores (i.e. mean of participants' scores for each node, using the schema-based analyses). Analysis for the MM group revealed a significant negative correlation between the number of node-legs and accuracy ($r = -.625$, $p < 0.01$), and a moderate relationship was also apparent for the DE group ($r = -.501$, $p < 0.01$). Therefore, for both groups, a greater number of node legs was associated with a reduction in accuracy .

Landmark and nodes. Some of the nodes had landmarks (according to our previous definition) located at their junctions (i.e. on a street corner) while others did not. To ascertain whether the presence of landmarks at the nodes affected accuracy of node depiction in the sketch maps, we compared the mean node scores between the nodes with landmark and the nodes without landmarks. An independent samples t-test for DE data revealed that the mean path scores were significantly higher in nodes with landmarks ($M= 2.00$, $SD= 0.401$) in comparison to the nodes without landmarks (M= 1.251, SD= 0.602); t (18) =-2.900, $p < 0.01$. For the MM group, there was a similar difference between the nodes with landmarks (M= 1.652, SD= 1.300) and the nodes without landmarks (M= 1.00, SD= 0.903) was evident: t (18) =-2.654, $p < 0.01$.

4.4 Landmark comparisons

This final component of our analyses focused on the comparison between landmarks on the basis of their visibility. To evaluate the visibility for each landmark, an adapted version of the scale used by Appleyard (1969) was adopted. Accordingly, the visibility of the landmarks listed in this study were rated according to three attributes: a) immediacy - the landmark's measure of distance and centrality to the line of view; b) proximity to the main decision points - the landmark's presence at important decision points and points of transitions; and c) significance of viewpoint - an estimate of the number of people who might see the landmark regularly from its most commonly used viewpoint. This final attribute was measured by estimating the number of pedestrians during a typical day that are likely to pass by the viewpoint of the landmarks that our participants passed by in the experiment. This was an approximate measure, as accurate flow data did not exist (Hassan, 1965, Appleyard, 1969). The landmarks were then rated from low to high on a three-point Likert scale.

In order to measure if the degree of visibility for landmarks affected the accuracy of their depiction, we employed a Pearson's correlation between the visibility attributes (for each landmark) and the mean landmark scores (i.e. mean of participants scores for each landmark, using the schema-based analyses). Analysis showed a medium, positive correlation between the immediacy of a landmark and its mean score for DE group, which was statically significant (r=0.681, N=23, p=0.001). However, the analysis did not show any correlation between the immediacy of a landmark and its mean score for MM group (r=0.362, N=23, p=0.082). Analysis also revealed a positive correlation between the significance of the viewpoint to a landmark and its mean score for the DE group, which was statically significant (r=0.673, N=23, p<0.001). There was, however, no correlation between these two factors for the MM users (r=0.37, N=23, p=0.072). Finally, positive correlations were revealed between landmark proximity to the main decision points and mean landmarks scores, in both DE (r=0.672, N=23, p=0.001) and MM groups. (r=0.652, N=23, p=0.001). The table below summaries the sketch map analysis and indicates the influence of the factors (analysed above) on depiction correctness of paths, nodes, and landmarks in the sketch maps.

Table 2. Summary of results

Elements	Factors	The influence of factors on depiction correctness of elements in the sketch maps		Description
		MM	DE	
Paths	Number of Turns	✓	✓	When the number of turns along a path increases, the mental representation of path becomes poorer
	Length	×	×	Length of the path did not show any significant influence on the mental representation of path
	Containing internal landmarks	×	✓	The paths with internal landmarks were drawn correctly more often than the paths without internal landmarks only for DE, not MM
	Containing external landmarks	×	×	The paths with external landmarks did not have a significant influence on depiction correctness of the paths for both DE and MM
Nodes	Number of Node-Legs	✓	✓	When the number of legs increases at a node, the nodes are more likely to be inaccurately depicted by both DE and MM
	Containing landmarks	✓	✓	Nodes with landmarks are more likely to be depicted correctly than the nodes without landmarks, by both DE and MM
Landmarks	Immediacy	×	✓	The landmarks that are placed at the vision line of travellers are depicted correctly more often by DE, but it did not have a significant effect on MM
	Proximity to the decision points	✓	✓	The landmarks that are placed close to the decision points are more likely to be depicted correctly by both DE and MM
	Significant of viewpoint	×	✓	The landmarks which were at the main paths are more likely to be depicted correctly by DE, but not by MM

5. Discussion

The present study was conducted with two core objectives. The first was to compare the accuracy of spatial knowledge in participants that navigated the environment using mobile maps (the MM group) to those who navigated the environment directly (the DE group). The second was to investigate whether the legibility of discrete components of the physical environment (comprising: landmarks, nodes, and paths) would moderate the spatial knowledge of MM users. The physical-spatial attributes of the components that contribute to legibility (see Table 1) were examined in relation to the participants' acquired spatial knowledge.

In line with our hypotheses, the findings of this experimental task indicated that participants in the MM group gained less accurate spatial knowledge of the site, in comparison to participants in the DE group. This was evident in the sketch maps produced by participants, and our analyses revealed that paths, landmarks, and nodes of the site were all represented significantly less accurately by MM participants than they were by those in the DE group. This is consistent with the results of previous studies by Aslan et al. (2006), Ishikawa et al. (2008), Krüger et al. (2004), Münzer et al. (2006), and Willis et al. (2009), which have all reported relative impairments of environmental knowledge when comparing the experiences of mobile map users to people navigating by other means. Together, these findings reinforce the conclusion that individuals navigating using positional technology (e.g. mobile maps that utilise GPS) are less likely to encode a detailed configural mental representation of their surroundings, compared to people that have more actively planned their route by other means.

We investigated this issue in greater detail by examining whether environmental legibility affected the quality of the spatial knowledge acquired by MM and DE groups. Whilst we expected that it would affect the quality of knowledge for DE participants, in line with previous empirical demonstrations (e.g. Klippel & Winter, 2005; Westerbeek & Maes, 2013), it has not been established whether it would be likely to affect MM participants. By analysing different components of legibility, and comparing routes with greater and fewer instances of these features, our data showed that the number of turns along a path, the number of streets entering a node, and the existence of a landmark at a node can moderate spatial knowledge of not only DE participants, but also MM participants.

According to previous research, the number of turns along a path are likely to moderate its complexity, with increasingly adverse effects on its environmental legibility and the accuracy of people's spatial knowledge acquisition (Evans et al., 1984b, Jansen-Osmann and Wiedenbauer, 2004). Other reports (Richter et al., 2004, Haque et al., 2006, Richter, 2009) have also shown that a greater number of paths meeting at an intersection is associated with increased complexity and ambiguity, resulting in greater navigational difficulty. Similarly, our results show that when the number of streets entering a junction (here termed as node legs) increased, both DE and MM participants demonstrated less accurate spatial knowledge. For example, when the intersections in the site were only made of three paths, like a 'T junction' (two directional choices), participants from both groups showed more accurate spatial understanding of them in comparison to the intersections that were made of more than three paths. One possible reason that spatial knowledge of mobile map users was affected by the number of paths at an intersection is that they were still required to relate their graphical representation to the real world at these locations, in order to make a successful navigational decision. Although mobile map users were provided with the correct path to their destination at each intersection, they still needed to relate the information they received on their phones to the actual environment to be able take the correct path to walk through. So, when the number of choices they were presented with at an intersection (i.e. the number of streets) increased, they might have still struggled to spatially comprehend the intersection, and to identify the correct path that matched the suggested pathway on their mobile map.

According to Haque et al. (2006) and Sorrows and Hirtle (1999), the presence of a landmark at an intersection decreases the ambiguity level of the intersection and, therefore, increases people's spatial understanding of the intersection. Our analysis showed that intersections with landmarks were more likely to be accurately represented by both the MM and DE groups, compared to intersections without landmarks. A reason for this factor to affect MM participants may be that the landmarks at the intersections, which were of architectural and structural significance to the urban environment, were marked also on the mobile maps. This could help those participants to relate the information on their mobile map easier to the actual environment, and to then understand it better. Interestingly, the presence of landmarks at nodes not only improved knowledge for the node itself, but those landmarks were also more likely to be accurately represented by participants on their sketch maps. In a study by Daniel and Denis (2004), participants describing a route were more likely to include landmarks that were placed at intersections, compared to those that appeared elsewhere along the route. Again, the reason that MM participants were also affected by this factor may be that relating the map to the actual environment at intersections required them to visually inspect their surroundings, rather than only focusing on their mobile screens. This would allow them to spatially comprehend those better, and to relate them to the graphical representations on their map.

In accordance with the relative primacy of landmarks at intersections, our analyses revealed that the existence of external landmarks along a path did not affect spatial knowledge in either group, nor did the length of the paths themselves. This may be owing to the complexity of the testing site, since streets with similar metric length were not necessarily topologically similar. Some shorter streets had more turns and were more complicated than the longer streets, which had fewer number of turns and, as discussed earlier, the number of turns along the streets appeared to moderate participants' spatial knowledge. External landmarks (i.e. the landmarks that were visible to the navigators, but not located at the immediate context of the path) are not necessarily considered in the same terms as internal landmarks (i.e. landmarks in the immediate context of the path), and previous studies have indicated that internal landmarks are more associated with environmental comprehension (Lynch, 1960, Klippel et al., 2005, Westerbeek and Maes, 2013). In line with this distinction, our results also revealed that external landmarks of the site did not have a significant influence on spatial knowledge acquisition of either participant group.

In contrast to this finding, the presence of an internal landmark along a path, the immediacy of a landmark to the viewer's line of view, and the significance of the viewpoint (i.e. significant landmarks are likely to be located along major thoroughfares and passed by a greater number of people), had a substantial effect on the spatial knowledge of DE users, but not MM participants. This echoes previous research that has demonstrated the utility of internal landmarks, even when they are along a path, rather than at an intersection. For example, Westerbeek and Maes (2013) showed that people tend to use internal landmarks to describe a route, and this may be because they serve the purpose of reassuring the navigator that they are following the correct path (Herrmann et al., 1998). Our results also showed that DE participants depicted the streets that had internal landmarks significantly more accurately than the streets that did not have internal landmarks. However, MM users' spatial knowledge did not appear to be moderated by internal landmarks. This may be explained by MM users' relative inattention to their surroundings at certain point along their route, and that they were more likely to attend to landmarks at intersections rather than landmarks along the paths. When people use navigational systems (such as mobile maps), they are more likely to receive egocentric direction-based instructions, thus requiring less attention to the structural features of the environment, and perhaps leading to a more response-based representation of their environment (see Hartley et al., 2003). Interestingly, our visual analysis also showed that even the immediacy of a landmark to the navigator's line of view (e.g. the landmarks were on the line of vision on the streets, where the navigators were walking), and the significance of visibility (e.g. the landmarks placed at main streets that so many people pass by them) did not affect mobile map users' spatial knowledge of those landmarks. This may also result from the same relative inattention to structural features when planning a route under mobile map guidance.

In summary, our findings reveal that some environmental factors related to legibility can moderate the spatial knowledge of mobile map users, despite the fact that they are not required to attend to their surroundings in the same way as people navigating through direct experience. Environmental complexity, both along paths and at intersections, therefore does appear to affect the ability of mobile map users to build a mental representation of their route. This may be due to the calculations required at intersections, where MM navigators need to relate their graphical representation to the real world, in order to make a successful navigational decision and follow their prescribed path further.

Our results support the position that designing intersections are of central importance to navigational and legibility design. Spatial understanding of both MM and DE users was strongly affected by the design of the intersections (i.e. number of streets entering them and landmark location at their corners). This is in line with other research, such as that of Janzen and Van Turennout (2004), which has identified the primacy of intersections in neural representation of the built environment when learning routes. Designing intersections in urban design has been also an important asset for increasing legibility and memorability for the built environment (Carmona, 2014, Burton and Mitchell, 2006, Brantingham and Brantingham, 1993, Crookston, 2001, Evans et al., 1984a, Haque et al., 2006).

Review of urban design guidelines regarding the design of junctions reveals a standard recommendation that legible junctions should be components of a grid network of streets (Guide, 2018, Britain, 2003, Council, 2016, Council, 2004). Having a simple grid system may be the easiest and most cost-effective way for designing and developing legibility in the city. However, it may not be the best option for provision of other urban design assets that can let people experience joy, excitement, serendipity, etc. in the city. Moreover, it does not necessarily allow for a sensitive or conservatory approach in the re-design of historical urban spaces. Our findings certainly suggest that junctions should simple in their design, which means that there could be a threshold to the number of paths that should be allowed to enter them. They also provide evidence-based support that the placement of a landmark at a junction can reduce the complexity of the junction for both mobile map users and users navigating by direct experience. Designing urban intersections can be discussed in two different scenarios: a) new urban development and b) regeneration projects. In new urban development, from the design stage, it is easier to ensure that the main junctions in the site are not complex (i.e. do not have so many streets building up them and those junctions can be emphasised by key buildings or groups of buildings). However, in older neighbourhoods within cities, junctions are often configured with curvilinear streets, and the complexity is increased by having many streets entering a junction. Therefore, modification of these junctions in a regeneration project, either by closing a street or adding a unique landmark, could increase the legibility of the junction (and, equally, the neighbourhood) for all users, irrespective of their navigational process.

6. Conclusion

Mobile navigational systems are becoming more advanced, more accessible, and more embedded into people's everyday navigational experiences. Although navigation from one location to another has never been easier, it is important to consider that everyday wayfinding is more complex than simply 'finding your way', since understanding of one's environment depends upon a variety of factors beyond a simple route. It is, therefore, essential for urban designers and planners to understand how differently the built environment can be understood and experienced by people who are equipped with these devices, especially when slavishly following a specified path. Our study has revealed that the spatial knowledge of people that navigated a novel urban environment with the use of mobile maps was not simply worse than that of direct experience users, but it was, in fact, moderated by environmental legibility factors. This reveals that knowledge of the built environment is not uniformly attenuated when people do not rely upon it to make navigational decisions, as previous studies might imply. However, the influence of environmental legibility might, perhaps, be confined a little more to points at which the navigator is required to make a decision. In the case of MM users, that decision might simply be how best to co-register a map with the real-world, and to verify an externally-generated directive, but it further reinforces the primacy of the decision point for building a meaningful and enduring mental representation of navigated space.

The present findings suggest that greater simplicity in urban design, especially at intersections, will increase legibility for all users of an environment, irrespective of the attention they might be allocating to their surroundings. More research is still needed to test the influence of environmental legibility factors on people's spatial knowledge acquisition in different environments. As a result, our next empirical step will be to ascertain whether other components of legibility, such as spatial organisation of an environment, also affect the quality of navigational knowledge. Together, these data will provide a foundation upon which we might more accurately predict which aspects of an environment might pose problems for the greatest variety of navigators, and to mitigate against those difficulties.

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