

UNDERSTANDING MOBILE SPATIAL INTERACTION IN URBAN ENVIRONMENTS

K.S. Willis*, C. Hoelscher[†], G. Wilbertz[†]

*MEDIACITY Project, Bauhaus University of Weimar, Germany
katharine.willis@achit.uni-weimar.de

[†] Centre for Cognitive Science, Institute of Computer Science and Social Research University of Freiburg, Germany,
hoelsch@cognition.uni-freiburg.de, gregor.wilbertz@cognition.uni-freiburg.de

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Abstract

In order to act in urban environments an individual access various types of knowledge, such as memories, spatial strategies and also information from the environment in order to develop plans and make decisions. This paper will investigate the nature of spatial knowledge acquisition by comparing performance in a task where the subjects learnt the environment using spatial assistance; either from a map or from a mobile map. It outlines the early results of an empirical experiment which evaluated subjects spatial knowledge acquisition in a large scale environmental setting for orientation and distance estimation tasks. The initial findings of the experiment highlight the fact that mobile map subjects performed worse in distance estimation tasks than map subjects, and that their errors for complex routes were high. We will conclude by analyzing the results of this experiment in terms of the specific types of knowledge afforded by mobile maps and the implications for spatial learning in urban environments.

1 Introduction

We learn about the spatial environment through a process referred to as cognitive mapping, which is a series of psychological transformations by which an individual acquires, codes, recalls and decodes information about relative locations and attributes in a spatial environment [4]. It is a dynamic process and occurs following successive experiences of sequential routes, where knowledge about the environment is integrated into configurational survey representations [15]. At a global level we use overview type knowledge that distinguishes between here and there and regions around and between them. We use this information to determine a plan for traveling between one place and another. Once we set out on a path, we need local representations of our surroundings to help us make decisions at key points. All of these types of knowledge are used to try to prevent us from losing our way and arriving at our destination.

However we also use spatial assistance of many kinds to augment the knowledge in our heads, these include maps and also more recently developed mobile maps of navigation assistance supported by GPS. Mobile maps seem to provide an ideal solution to the problem of getting local information on where to go whilst completing a wayfinding task; this information is incremental since it is delivered in stages, rather than a paper map source which provides all the information in a stable format and is usually studied primarily in the planning stage of a task. But recent empirical studies found that subjects who used mobile maps to navigate an environment had significantly poorer survey knowledge acquisition when compared to subjects who used paper maps in the same task [2]. In order to investigate this further we will first propose how people acquire knowledge about urban space, and the role of representations in this process. In order to better understand the nature of spatial knowledge acquisition with mobile maps we then describe an empirical experiment which evaluated subjects spatial knowledge acquisition in a large-scale environmental setting by comparing subjects who had learned the environment from a map and those who had learned it using a mobile map.

2 Approach and Hypothesis

2.1 Spatial Knowledge Acquisition in Urban Environments

In a large-scale environment the structure and features are revealed by integrating local observations over time, rather than being perceived from one vantage point [8]. This means that the acquisition of spatial knowledge of urban space depends not just on direct perception but on learning experience. One of the key elements of this experience of an environment in motion is the paths along which we move. People observe the environment whilst moving through it on the path, and environmental elements are perceived as arranged and related along these paths [10]. The behavioral pattern or movement, performed by moving along a path is called a route. When moving along a path an individual experiences an organised sequence in which phases follow each other meaningfully in an order. Consequently studies [5, 6, 11]

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have found that the route sequence affects learning. For instance in the Golledge study subjects who undertook a wayfinding task within a very simple regular environment performed significantly worse when they took one route, as when they took another, even where the routes on plan were very similar. Thus the difference in the way the environment was experienced as a certain sequence of events and features significantly affected the degree of error with which the individual completed the task. This can be explained simply with the example we have all experienced, of a route or path, which when walked in one direction is familiar and legible, but often completely unrecognisable when walked in the opposite direction. The difference in the dynamic, or sequential experience of the environment and therefore its configuration affects comprehension.

2.3 Knowledge from Maps and Mobile Maps

Studies of spatial knowledge acquired through maps and through navigation have found that when people learnt the environment from a map they had different knowledge about it to those who had experienced it only through navigation [16]. Maps offer a different frame of reference to an egocentric viewpoint; map users acquire a bird's eye view of the environment whereas individuals who have acquired knowledge through navigation have a configurational knowledge where features and structure have been integrated over time [15]. So far, few studies have looked at the knowledge acquired from mobile maps, which present incremental information during navigation of an environment. However we propose here that mobile maps support the acquisition of route type knowledge, because the individual learns the environment in a procedural egocentric manner. Route knowledge is structured around decision points along the path, which are remembered in a sequential and 'chunked' manner, and the path is characterized by the location of landmarks along it. There are many open questions however, as to whether the dynamic presentation of route directions, such as those in a mobile map, supports spatial knowledge acquisition or whether it merely succeeds in guiding an individual from a start point to a destination, but without them learning anything about the environment.

2.3 Perception and Memory in Spatial Tasks

A good deal of the time we proceed in wayfinding tasks based on piecemeal spatial information in unfamiliar or semi-familiar environments where we do not have access to learned configurational structures. In these cases we often adopt strategies based on our previous experience of similar environments; a form of hard-wired background knowledge [13, 14] or 'image schemata' [7, 12], which by means of imagination are used to help us relate to the world and categorize it. These schemata are the recurrent mental patterns that help people structure space. For example when we approach a new city for the first time and arrive at the central station, we will attempt to formulate a travel plan based on our experience of all the other cities and the various possible positions of the

central station. We will make assumptions about the structure and features of the city, and mentally update our schematic framework, and as we move through the city we encounter information that either confirms or rejects our suppositions. In addition to the schemata there are 'cues' [10, 3] or salient features of the environment, which tend to be located at decision points and comprise Lynchian structures such as landmarks, nodes, paths, edges and districts. These features do not necessarily need to have strong visible features or shape, as one might expect a typical landmark to be, instead it is the way in which they work in conjunction with the organisation of the space, and thus they degree to which they are perceived as salient or legible as the individual moves through this environment. However legibility is also intertwined with the way an individual perceives the world when one studies task based activities, such as finding one's way from A to B, where perception and memory process occur in simultaneously. In these situations, environments are perceptually complex and always provide more information than can possibly be processed. Peripheral, as well as central, information is always present, peripheral in a mechanical sense - the area behind one is no less a part of the environment than that in front- and peripheral in the sense of being outside the focus of attention. As a consequence the individual cannot be separated from the environment, and is part of the system they are perceiving, to the extent that the strategies chosen become part of the perceived environment.

3 Learning from Field Studies

In order to understand how individuals acquire spatial knowledge about the environment when they use mobile devices, a field study was undertaken which recreated critical features of the seminal study by Thorndyke and Hayes Roth [16]. This study evaluated spatial knowledge acquisition by comparing subjects who had navigation experience with those who had map experience of an environmental setting. The analysis found that map subjects made good estimations of direct distances between two points, whereas navigation subjects had better orientation abilities and performed well in route distance estimations. This paper presents early results from an experiment, in which we compared maps and mobile maps, instead of comparing maps and navigation we. The experiment also differed from the original study in that it took place in an external environmental setting, rather than a building. However the structure, layout, location of features and scale of the setting was directly comparable to that of the original study.

3.1 Experiment Method

The environmental setting chosen was an allotment area located near to the University of Bremen Campus, Germany, approx. 400m x 300m (see Fig. 1).



Fig. 1 View of path in the experiment environment

The setting is outside and in an urban area, although somewhat removed from a standard urban environment. The setting comprises a rectilinear grid path structure (indicated by white blocks with dotted lines in Fig 2.), with several prominent landmarks (indicated by black rectangles) and numerous repetitive allotment gardens in rows.

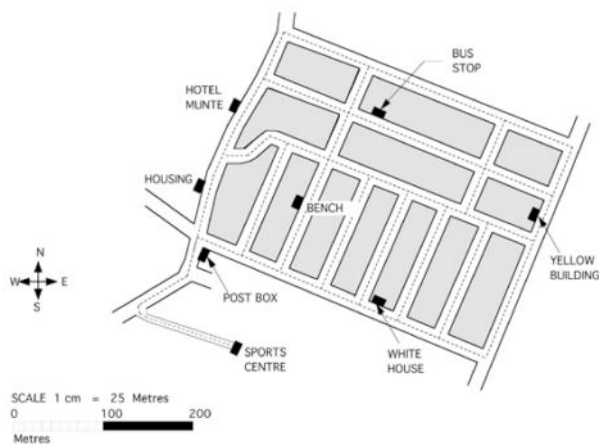


Fig. 2 Map of the environment used in the map condition

There are no visual clues or landmarks that enable global orientation, and most landmarks were not visible from one location to another.

3.2 Subjects

Twenty four participants participated for an honorarium of 7,50 Euro per hour. There were twelve female and twelve male subjects. Subjects had a range of academic and non-academic backgrounds and ages.

3.3 Experiment Design

The experiment comprised of two training conditions with approx. twelve subjects per condition. None of the subjects had any prior exposure to the environmental setting. In the first condition map subjects were seated in an office not connected to the environmental setting and asked to learn a map of the environmental setting. In the

second condition mobile map subjects learnt the map through navigation with the mobile device in the environmental setting itself. Once both groups of subjects had completed the learning task they were then asked to complete a series of estimation tasks in the environment. For each item the subjects performed three estimates: orientation (pointing to the destination from the start point along the paths), route distance (the distance from start point to destination) and Euclidean distance (the straight line distance from start point to destination).

3.4 Procedure

Subjects were tested individually. Each map-learning subject was told that he or she was to learn the map of the environmental setting (shown in Fig. 2), including the layout of the paths, and the names and locations of the landmarks. Each subject studied the map on a series of study—recall trials, where the subjects were given the map to study and were then asked to redraw the features of the map on a sheet of A4 paper. This was repeated until the subject had depicted the topological properties of the map and labeled it correctly.

In the second condition the mobile map the subjects learnt the map in environmental setting. The map was presented on a Nokia 6630 mobile phone (see Fig. 3 and 4) running a mobile mapping software application running.



Fig. 3 and 4 Screenshot of the map of the environment used in the mobile map condition

A GPS tracking device indicated the participants real-time location on the map with a moving dot. Once they had learnt the environment, the subjects were asked to complete the same study-recall task as completed by the map subjects, but completed this task in the environmental setting.

For the estimation task, the experimenter took each subject to the first Start point, the Post Box. The experimenter then informed the subject that she would read to him/her a succession of locations within the environmental setting in a random order. For each location, the subject was to perform three estimates. First, the subject indicated to the nearest degree the direction to the destination, using the compass (i.e. the orientation). Second, the subject estimated the distance in metres to the destination along the ray indicated by the previous judgment (i.e., the Euclidean distance). Third, the subject estimated the distance in metres to the destination along

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the shortest path (i.e. route distance). When the subject had performed the eight sets of estimates from the Post Box the experimenter led the subject to the next start point, Housing. The order of the positions from which subjects made their estimates was varied, so that half of the subjects completed a clockwise route and the other half of the subjects an anti-clockwise route in the test phase.

4 Results

4.1 Learning Phase

The map subjects took an average of 18.3 mins to learn the paper map in the office setting. The mobile map subjects, who undertook the learning task in the environment, spent an average of 46.8 minutes learning the mobile map in the environment (access to mobile map varied with each subject). From the maps in Fig. 5 and Fig. 6, it is clear that the basic knowledge acquired by the two groups in the learning task is different.

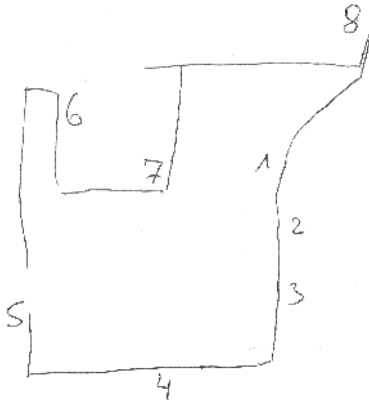


Fig 5. Example of 1st map drawn by mobile map subject in learning task



Fig 6. Example of 1st map drawn by map subject in learning task

The mobile map subject indicates a route, with a series of sequential landmarks. In this case the configuration of the environment is not shown, and no features are indicated which were not on route. Also, the maps drawn were not consistently drawn 'north-up'. This is despite the fact that

the mobile map group had accessed a map representation of the environment, which was orientated 'north up', throughout the learning task. Whereas the map subject shows a clear survey structure onto which landmarks and features are placed.

4.2 Orientation Estimates

We tested the predictions for the orientation task by contrasting the average angular error between the true and estimated orientation of destinations for the map and mobile map subjects. Generally the performance was very good, with the difference between real and estimated distance being generally small. The average angle of error for map subjects was 16.31 degrees, and for mobile map subjects was 16.58 degrees – see Table 1. There errors were not symmetrically distributed around the average value, with the majority of the subjects having lower value differences (map 11 degrees, mobile map 14 degrees). There was no difference in the systematic distribution (with the distribution to the right for map being 53% and mobile map 51 %). In the median there was a slight tendency for the differences to be lower for map user subjects, although this difference was not significant, whether tested parametrically (t-test) or non parametrically (Mann-Whitney -test). There was no effect on the results of the destination being visible to the subject, compared to when the destination was not visible.

Type of experience	Angle error
map	16.31
m. map	16.58
Thorndyke and Hayes Roth (hereafter T&HR) map	40
Thorndyke and Hayes Roth (hereafter T&HR) navigation	19

Table 1: Angular error for orientation judgments

4.3 Euclidean Estimates

The difference between the estimated and actual distances is large (map: 70,17m, mobile map: 94,57m) – see Table 2. There is also indication of an uneven distribution around the median (map: 55, mobile map: 68). Both groups underestimated the actual distance more frequently (map 65%, mobile map 73%) as they overestimated (correspondingly 35%, 27%). The systematic differences averaged with the map -12,43, and mobile map -22,99. Between the two groups the relative differences were compared, and were found to be non significant (map: 0,33, mobile map: 0,40, $p=.222$, $d=.52$).

Type of experience	Euclidean distance error
map	33
m. map	40
T&HR map	32.8
T&HR navigation	32.3

Table 2: Average error in Euclidean estimates

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Looking at individual tasks separately, only 2 of 42 tasks showed significant differences (largely due to high inter-individual variance). Yet in the majority of the tasks the map users performed better (with an average effect size of $d=0.46$), whilst the mobile map users were only better with one-quarter of the tasks and for these the differences are much less pronounced (average effect size: $d=.20$). The correlation between estimated and actual differences is equally high in the both groups (map: $r=.78$, mobile map: $r=.79$). This pattern is independent of the testing method, whether parametric or non-parametric, and also independent of whether the destination was visible from the start point

4.4 Route Distance Estimates

The difference between the estimated and actual distances is larger than that for Euclidean distance (map: 97,56m, mobile map: 135,29m). There is also indication of an uneven distribution around the median (map: 77, mobile map: 99). Both groups underestimated the actual distance more frequently (map 71%, mobile map 72%) than they overestimated (correspondingly 29%, 28%). The average of the systematic differences was for the map $-43,55$, and for mobile map $-50,27$. The relative differences were tested between the groups. The difference (with individual tests) is significant (map: 0,32, mobile map: 0,42, $p=.067$, $d=.82$)- see Table 3. However the non-parametric test was not significant. Looking at individual tasks separately, we observe statistically significant differences for only 2 of 42 tasks. But again a clear tendency becomes visible: in 90% of the tasks the map users numerically outperform the mobile map users, confirming the parametric test above.

Type of experience	Route distance error
map	32
mobile map	42
T&HR map	35.8
T&HR navigation	26.2

Table 3: Average error in Route Distance estimates

4.5 Comparison between Distance Estimates

The difference Euclidean and route distance estimates is very small, and is only significant with mobile map-users (0,40 vs. 0,42, $p=.083$) – see Table 4.

Type of experience	Euclidean Error	Route Distance Error
map	33	32
mobile map	40	42

Table 4: Percent Relative error in Distance Estimates

4.5 Dependence of the number of legs

Generally the relative deviation increases with increase in

number of legs – see Table 5.

Type of experience	1-2 legs	3-6 legs
map	30	33
mobile map	39	47

Table 5: Percent Relative error in Route Distance estimates

5 Discussion**5.1 Orientation and Environmental regularity**

Map and mobile map subjects seemed to acquire a similar level of orientational knowledge of the environment, which when compared to the original study by T&HR has results similar to the navigation subjects. The reason for this may be the benefit of the environmental setting. The setting for the T&HR study was one floor of an office building where subjects were required to make estimates whilst in a closed room, i.e. they were isolated from any visual cues about the environment for which they were estimating. It seems that having visual access to the environment to match the mental representation and the real setting is very useful for making estimations. This is despite the fact that there was no effect of the visibility of the destination. Both map and mobile map subjects registered salient visual cues in the environment and used these to match against salient aspects of their internal representation in order to make orientation estimations. In this study the map users orientated themselves very quickly at the beginning of the task, and used environmental cues to match their internal map to the environment structure, despite the fact that they had learned the map without any prior experience of the setting. Additionally both groups repeatedly verbally reported problems in making the estimation to destination D2 Bench, since it was on a path which was not part of the either the primary survey or route framework of the environment, and thus was often spatially 'lost' by the subjects. In general the regularity of the environment would have an affect on the overall success in completing the task. In extremely regular environments, i.e. those with a clear grid structure it is easier to acquire survey knowledge. In a more irregular environment this process might be much more error prone.

5.2 Types of Knowledge

The accuracy of metric knowledge between the two groups was different, with mobile map users making more pronounced errors. At first these results seems strange; how can an individual acquire knowledge about spatial relations, but have such poor metric knowledge? The orientation data would suggest that mobile map subjects they had acquired a similar level of configurational knowledge about the environment as the map users, but the analysis of the Euclidean and route distance estimates disproves this. Map learners acquired a bird's eye view of the environment which enables them, despite a very short period of learning, to demonstrate good spatial knowledge

acquisition. The map subjects in a sense mentally envisaged a layer of their internal map laid or stretched over the environment, and used this to frame their estimations. The attention of the mobile map subjects during the learning task was on a series of landmarks, which they learned along a route. It enabled the mobile map subjects to identify and estimate the eight main destinations, but when they were required to make estimations of Euclidean or route distances with many legs, performance declined more than map subjects, indicating that the route knowledge was confined to the route they had navigated in the learning task. Conversely map subjects performance did not change with route complexity with either Euclidean or route distance, indicating the broader, configurational nature of their knowledge. When we compare the results back to the original T&HR experiment it seems fair to assume that navigation subjects would have better route distance estimation than map subjects. From this experiment this would suggest that navigation subjects would perform best, followed by map subjects and then mobile map in route distance estimation. For Euclidean estimates, map and navigation subjects were fairly similar, but mobile map subjects performed worse.

Although the map representation learned by the two groups had similar features, it is clear that the way that it was presented and delivered to the subjects fundamentally affected the spatial knowledge acquired. For map subjects, the learned knowledge acted like a configurational framework, which enabled the individual to locate landmarks within the schemata (see Fig 9) and make fairly consistent orientation and distance estimates for all destinations.

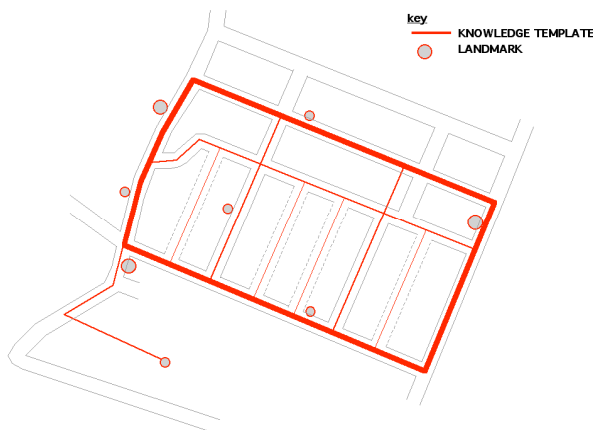


Fig 9. Map knowledge schemata

Mobile map subjects acquired a schemata based on procedural route knowledge structured into 'chunks' or sections of learned route centred on the salient landmarks (see Fig 10). This enabled them to make good estimates of spatial relations, but was fragmented and sequential in nature. This would explain why mobile map subjects made greater errors with routes with greater complexity, because these legs would tend to lie outside the main route knowledge of the subjects.

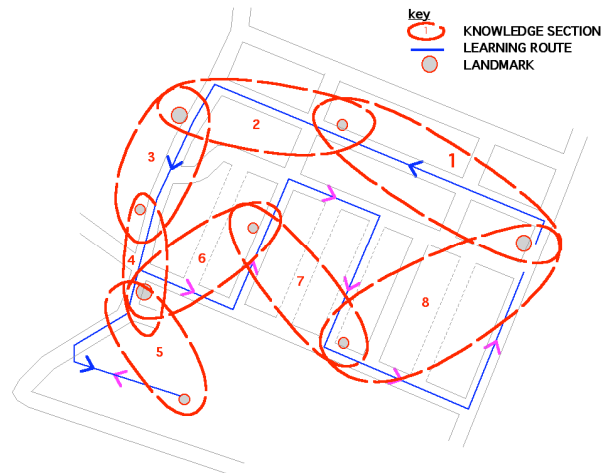


Fig 10. Mobile map knowledge schemata

The schemata frameworks which the two groups used to make estimates was therefore generally different, with mobile map users trying to reconfigure sequential route sections structured around landmark cues, and map users attempting to match their locate landmarks within a structured template-like schemata, which was mentally mapped onto the environment through rotation of the image.

5.3 Attention

Mobile maps require attention from the individual whilst they are in the environment because the information is both automatically changing and updating, and also because the individual can interact with the information (e.g. by changing the scale of the map interface). Interestingly, it is not the graphic representation of the mobile map that distinguishes it from a cartographic map in the effect on performance, but rather the delivery and attention it requires of the individual. For example a study by Gaerling and Lindberg found that when participants were engaged in a secondary task whilst navigating a route were less able to keep track of where the learned locations were, than a groups who did not have a concurrent task [9]. With a mobile map the fact that it constantly updates the users position on the map itself, thus effectively offering a dynamic, constantly changing set of information seems to create a very sequential form of spatial knowledge. This meant their attention was being divided between the device and the environmental setting, which affected their memory. In addition since the user had the ability to change the scale of the map, meaning that they did not consistently view the same map representation throughout the task, this created a type of focused 'keyhole' information acquisition. Rather than the mobile map interface disappearing into the background it seems to have the opposite affect; creating a conflict, with attention to the features of the real environment being divided and shared with attention to the interface. Since both offered different forms of information; the mobile map a survey type representation, and the environment an egocentric perspective, the subjects were in a constant process of trying to resolve the information from the map

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and the information from their view environment, and this was cognitively demanding. The map subjects also had to translate the two perspectives to make their judgments, but paradoxically the learned map representation did not demand their attention because since it offered a single static clear representation it enabled more cognitive offloading where the individual could focus on matching cues in the environment to their internal map in a more cognitively adequate manner.

6 Interacting and Learning with Representations of the Urban Environment

If the city is what we perceive it to be and is formed by our memories of it, then the city is different when perceived with mobile maps, through navigation or through the use of cartographic paper maps. The knowledge acquired through mobile maps is route-like in nature suggesting that survey knowledge has not been acquired, with the consequence that qualities such as linkage, connectivity and scale would be missing. We can relate this work back to that of Kevin Lynch where he identified a series of key elements in urban space that help individuals to structure their knowledge; landmarks, nodes, edges, districts and paths that structure our understanding of urban space. Following field studies in Venezuela, Appleyard further clarified these elements as being either sequential or spatial in nature [1]. Due to the strong sequential nature of learning with mobile maps, this would mean that people who used this type of spatial assistance will have less developed concepts of spatial elements such as edges and districts, and instead sequential elements such as landmark and path learning will be dominant. Additionally they will have more incremental knowledge, where sections of learned configurations are placed together in the sequence in which they were learned. But if we work under the assumption that our knowledge about the city is never independent of the way it is perceived and remembered, then the city encountered through such mobile mapping support will be perceived as having different structural characteristics and in many cases individuals will have poorer memory for environments where they have used mobile map assistance to find their way.

7 Summary

When we move and act in the urban environment in a motivated manner, we acquire knowledge about it which is transformed into mental representations. These representations can be retrieved to make decisions during navigation, but we also use graphic representations such as maps and mobile maps to assist us. In this paper we introduced an experiment which looked at the types of knowledge acquired by an individual, depending on whether they used a map or mobile map to assist them. The study found that mobile map users performed worse than map users, particularly on Euclidean and route distance estimation, and that this was a consequence of the format and presentation of the spatial information. We examined the reasons for these differences, and stated that

mobile map users acquire a fragmented set of knowledge about spatial features, whereas map users act on a framework within which features are located. The paper concluded that this has implications for how people will perceive and act in urban environments, and that they may develop less well-formed spatial representations as a result of the type of spatial knowledge they have acquired from mobile map assistance.

7 Future Work

This paper presented the early results and analysis of an empirical study. Further work is planned in order to provide a more detailed analysis of the experiment results. This will include an investigation of the effect of both route sequence (in the learning phase of the experiment), and the number of route legs between start and destination on the performance in the estimation task. Additionally a study will be carried out that will reconstruct subject's cognitive maps of the various locations using combinations of estimates for each location. It is also intended to develop the outcomes of the experiment into a series of suggestions for how the design of mobile map interfaces could be improved to better support spatial knowledge acquisition in urban space. These will be tested with comparative field studies in the original experiment environment.

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