Supporting navigation using different types of spatial information: an experimental human factors study

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Thesis submitted to the University of Nottingham

for the degree of Doctor of Philosophy

September 2008

Contents

Abstract

This thesis presents research which examines how the display of location-based information on a mobile device affects navigation. The research was informed by current literature and user research conducted with Nottinghamshire Fire and Rescue Services.

Experimental results are explained in terms of Passini's (1980) model of wayfinding. Design guidelines and a human-factors framework for mobile location-based services are also presented.

Cognitive task analysis and semi-structured interviews were used to conduct a user requirement study with firefighters from Nottinghamshire Fire and Rescue Services. Following this study, an experimental programme was developed to test how different methods of presenting information and displaying different types of information affected navigation. Measurements included time taken to navigate a route, workload, perceived usability and perceived navigational ability. A small scale observational study examined user behaviour while navigating with GPS enabled information. Finally, a focus group was used to evaluate the results from the experimental work with Nottinghamshire Fire and Rescue Services.

Qualitative studies suggest that firefighters could use mobile, location based information to enhance navigation in large incidents. This information should be easy to understand and act on, incurring the minimum of cognitive demand. To achieve these requirements, the type of information presented on a paper map should not simply be transferred directly to a mobile device but must be adapted. The type of information displayed must also take into account the environment to maximise navigation efficiency and minimise cognitive demand. In the inside environment, simplified information showing only main features such as staircases and route changes should be displayed. In the outside environment paths and a

selection of large, permanent features such as buildings support navigation most effectively. Evaluation with the fire service indicates that firefighters concur with the results of the experimental program.

Major areas of further research include collaborative designs involving multiple mobile services and further experimental work examining how the presentation of specific features affects navigation in the outside environment.

Acknowledgements

Thanks must go to all the participants and the firefighters who took part in the research. Without their generous contributions this kind of research would never be possible. Thanks also to the EPSRC who sponsored this work.

Thanks of course go to my supervisors Dr. Sarah Sharples and Prof. Mike Jackson for their support, friendship and advice throughout this degree. And to Dr. Christine Haslegrave who had the knack of asking all the questions I most dreaded and as such, was of great help in making me look critically at the focus of the research. Thanks also to Dr. Sue Cobb for all her help and support when conducting experiment two.

A big thank you to Tim Birkin and Jenny Scapens, who both helped me greatly through that difficult first year. And to the gang: Andy Cook, Duncan Cheshire, Dave Allan, John Tullis and especially to Lauren Gough.

Special thanks are due to Dr. Suzanne McGowan and Dr. Bob Abrahart for all your valuable advice and support, it really is appreciated.

To Iain ‘Croβ’ Cross and Tom Wainwright (Note alphabetical order) it’s been hilarious, and I hope the start of a long friendship. Here’s to our friends at Staff Club, Beeston Tandoori and Premium Beverages Ltd.

Heartfelt thanks to Mum, Dad, Tom, Harry, Judith and Paul for everything and for always knowing when not to ask how the research is going. Extra special thanks to Judith for chapter reading and making this thesis a much better place to be.

Publications

(Chapter 3)

NIXON, J., SHARPLES, S. & JACKSON, M. (In Preparation) A Human-Factors Led Approach to Designing Location-Based Services for the Fire Service. *Journal of Location Based Services*.

NIXON, J., SHARPLES, S. & JACKSON, M. (2007a) Ask the Expert: The Potential for Location-Based Support in the Fire Service. IN WINSTANLEY, A. C. (Ed.) Proceedings of Geographical Information Science UK (GISRUK) 2007, Maynooth, Ireland, 11th - 13th April pp. 231 - 235.

(Chapter 5)

NIXON, J., SHARPLES, S. & JACKSON, M. (2007b) Navigating with a mobile device: Differences in participant behaviour using four different representations IN The Proceedings of The Royal Geographical Society (RGS) Annual International Conference, London, 29th - 31st August.

NIXON, J., SHARPLES, S. & JACKSON, M. (2007c) Presenting spatial information on a mobile device: Differences in workload and performance. IN Proceedings of The Human Factors and Ergonomics Society (HFES) 51st Annual Meeting, Baltimore, USA, 1st - 5th October.

(Chapter 6)

NIXON, J., SHARPLES, S. & JACKSON, M. (2008b) Less is More? Navigating with different types of information on a small-screen device. IN Proceedings of The Human Factors and Ergonomics Society (HFES) 52nd Annual Meeting, New York, USA, 21st - 26th September.

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List of Abbreviations

Abbreviation	Definition
A-GPS	Augmented Global Positioning System
BA	Breathing Apparatus
BBC	British Broadcasting Corporation
BNG	British National Grid
CDM	Critical Decision Method
CTA	Cognitive Task Analysis
D-GPS	Differential Global Positioning System
ECO	Entry Control Officer
E-GPS	Enhanced GPS
ESRI	Environmental Systems Research Institute
GI	Geographical Information
GIS	Geographical Information System
GLONASS	Global Navigation Satellite System (Russian)
GNSS	Global Navigation Satellite System (Generic)
GPS	Global Positioning System
HCI	Human Computer Interaction
HTA	Hierarchical task Analysis
INQ	Integrated Navigation Questionnaire
INS	Inertial Navigation Systems.
LBS	Location-Based Service
LCD	Liquid Crystal Display
MDT	Mobile Data Terminal
MWL	Mental Workload
NASA	National Aeronautics and Space Administration
NMEA	National Marine Electronics Association
OGC	Open Geospatial Consortium
OPT	Object Perspective Taking Test
OS	Ordnance Survey
PCA	Principal Components Analysis
PDA	Personal Digital Assistant
RAM	Random Access Memory
RFID	Radio Frequency Identification Device
SDS	Santa Barbara Sense of Direction Scale
SME	Subject Matter Expert
SPSS	Statistical Package for Social Sciences
TDoA	Time Difference of Arrival
TLX	Task Load Index
ToA	Time of Arrival
TOID	Topographic Identifier
UWB	Ultra Wide Band
VE	Virtual Environment
WLAN	Wireless Local Area Network
Ws	Shaprio - Wilks statistic
YAH	You Are Here

Chapter 1 Introduction

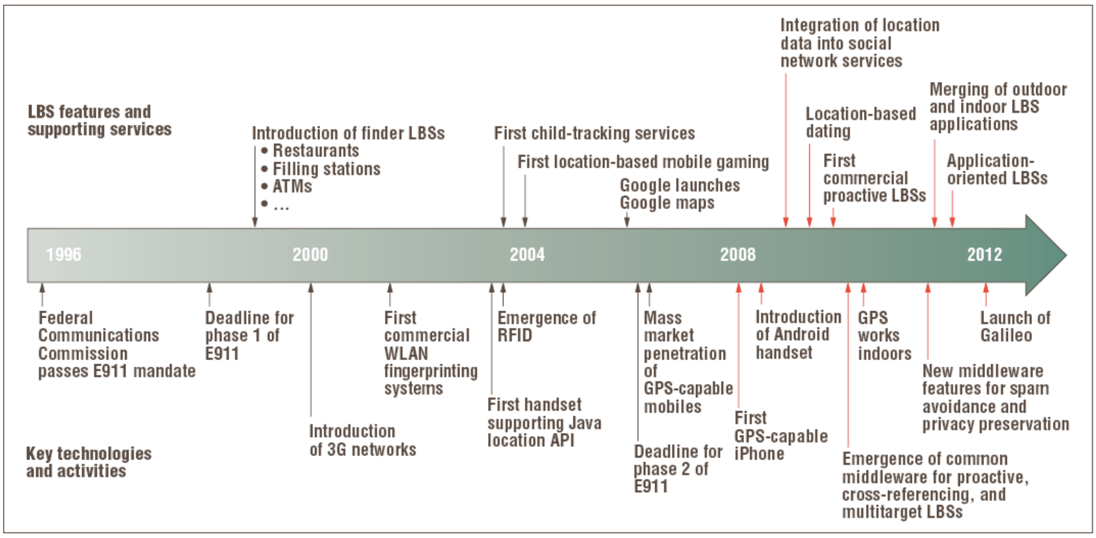
1.1 Background

The mobile computer is experiencing a surge in popularity, use and functionality at the moment. Once plagued by inadequate processing power and memory, poor software and variable operating systems it has come a long way. Technological advances mean that mobile computers are viewed less as the weaker sibling of the desktop system (Luo, 2007). This is reflected in the increased availability of applications; calendars, personal organisers, navigation tools on a wide variety of platforms including personal digital assistants (PDAs), mobile phones and tablet PCs.

Even greater functionality in mobile computing has been achieved by using positioning systems such as GPS to locate an individual and use this information to deliver specific and contextually relevant information to that user, a location-based service (LBS). Many different definitions of LBS are present in the literature. A broad definition of the term is used in this thesis. An LBS is a service that uses the individual's position to deliver contextually relevant information to that user. The information could be delivered in any form or modality but is constrained by the user's position. In this thesis, visual information is delivered to support navigation on foot.

A timeline which charts the development of LBS is shown in Figure 1.1 (Bellavista et al., 2008). Delivering location-specific information to the user on a mobile device presents both exciting possibilities and significant human factors challenges.

Figure 1.1 Timeline charting the development of LBS



(After Bellavista et al., 2008)

The research presented in this thesis examines human factors and navigation with an LBS. The research is inspired by and framed by the requirements of Nottinghamshire Fire and Rescue Services. Larger incidents attended by the fire service are often geographically distributed, changing rapidly and sometimes unpredictably. In these circumstances, an LBS provides the ideal platform on which to deliver relevant information about location to inform navigation. The information could be updated in real time and delivered by a variety of methods to many users simultaneously.

Mobile devices frequently have limited screen size and many different types of interaction are available making the selection of information to portray on the screen of critical importance (Brewster, 2002). Kray and Baus (2003) neatly summarise these challenges by suggesting that the limited technical resources available to the device, together with the limited psychological resources of the user, conspire to generate a formidable array of human-factors challenges in creating usable and useful LBS. New research is needed to understand how information can be best presented to support navigation using LBS.

The seven studies presented in this thesis are shown in Table 1.1.

Table 1.1 Summary of studies in the thesis

Chapter	Study
3	Real World Context
5	Experiment One
6	Experiment Two
7	Experiment Three
8	Quantitative Meta Analysis
9	Adding GPS
10	Returning To the Context

Firstly, an in-depth understanding of the application domain is described, identifying key tasks and user requirements. Experiments are then conducted on different types of spatial information presented in different ways, in different environments. Using novel methodologies, fundamental knowledge is developed about the way in which the method of presentation and type of spatial information affect navigation. Finally, the impact of positioning systems when using location-based spatial information is investigated and a final evaluation of the different types of spatial information by the target user group used is presented.

1.2 Aims of research

The research has four major aims:

1. To examine how mobile LBS could be used in a real-world context and to evaluate experimental findings in conjunction with that context.

The research presented in this thesis is grounded in a real-world context. At the start of the research period, strong links were formed with Nottinghamshire Fire and Rescue Services. Chapter 3 describes a cognitive task-analysis conducted with a senior member of Nottingham Fire and Rescue. As a result of this study a number of tasks that could benefit from LBS were identified. Navigation was selected as a key task and further interviews with practising firefighters identified the challenges involved while navigating during incidents and how elements of the navigation tasks could be supported by an LBS. Critical dependent variables used in Experiments One, Two and Three were identified from the interviews in order to generate knowledge useful to the application. The experimental findings are related back to the real world application in two ways. Chapter 9 describes issues involved when positioning technologies are used to automatically present spatial information according to location. Chapter 10 describes the results of an evaluation of the different types of information used in experiments one, two and three. Practising firefighters performed this evaluation. Limitations of using the different types of information in different ways are explored with the fire-service and further avenues for research are identified.

2. To investigate how different ways of presenting spatial information and how different types of spatial information affect navigation

Novel methodologies described in Chapter 4 are applied to the experimental work used to meet this aim of the thesis. Three major experiments described in Chapters 5, 6 and 7 provide empirical evidence for how different methods of presentation and different types of information used to navigate in different environments impact on navigation supported by a mobile LBS. A quantitative meta-analysis combining data from Experiments One, Two and Three is presented in Chapter 8.

3. To suggest human factors guidelines that could be used in the development of mobile, location-based navigation support.

Human factors guidelines and considerations are presented in Chapter 11, derived entirely from the studies conducted in this thesis.

4. To develop experimental methods for human factors research into mobile LBS

The literature relating to the technological and cognitive aspects of navigation are reviewed in detail in Chapter 2. Synthesis of these areas with human factors literature identifies that further research into the best ways of displaying information on a mobile device for pedestrian navigation is required. Chapter 4 describes in detail the measurement of variables used in the experiments and the development of custom software required by the experimental work. In Chapter 11 an overview of key methodological guidelines are presented

1.3 Organisation of thesis

The organisation of this thesis is presented in Figure 1.2. The focus of the different research conducted is presented in Figure 1.3.

Figure 1.2 Structure of the thesis

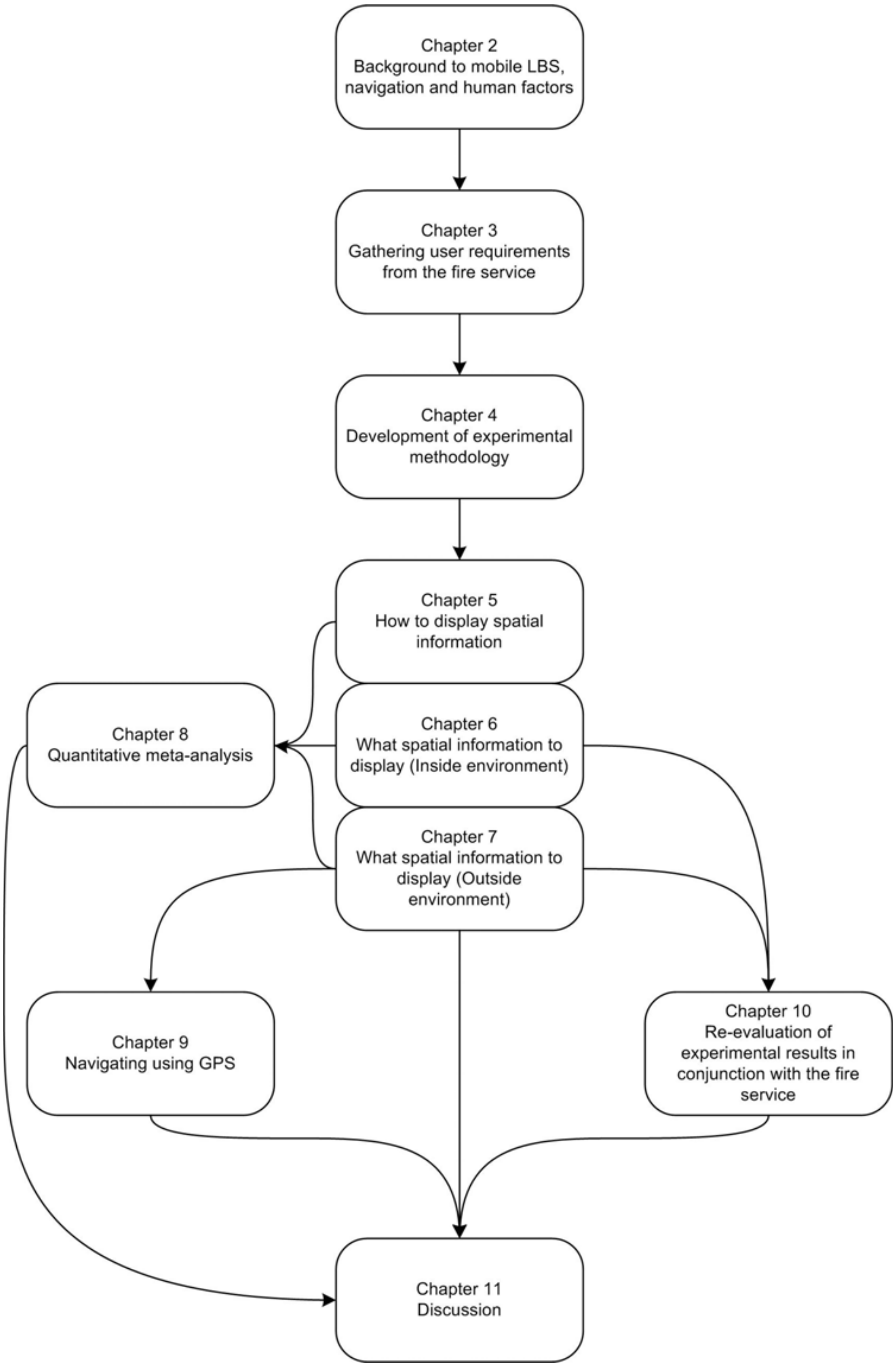
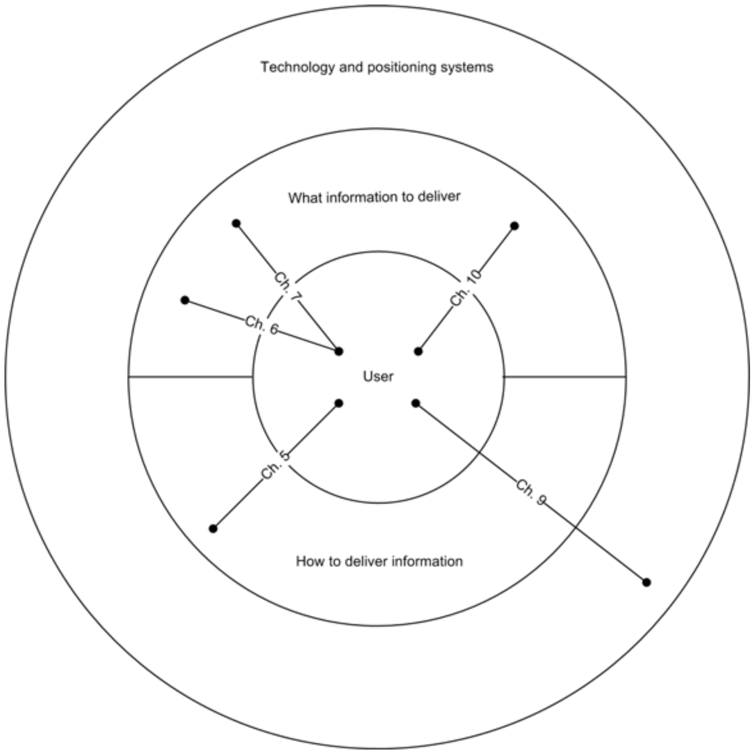


Figure 1.3 Focus of research in the thesis



Chapter 2: Literature Review

This chapter explores and synthesises a diverse body of literature relating to mobile LBS in the context of this thesis. Both the technological aspects and human factors aspects of supporting navigation through LBS are described. In addition, a review of the psychological literature on relevant aspects of spatial cognition is presented and synthesised with the human factors literature.

Chapter 3: Real World Context

Using cognitive task-analysis, an understanding of the real-world application is developed and the potential for a variety of location-based support within the fire service are identified. The task of navigation was identified as critical and further interviews with practising firefighters were used to identify key task requirements and to inform selection of dependent variables used in the experimental work

Chapter 4: Experimental Methods

The experimental work conducted and described in this thesis required development of custom software. This software forms the basis of the methodology and its development is described in detail. In addition to other published questionnaires, a questionnaire was developed by the author to probe the experience of navigation using the handheld device. Since these subjective measures are common to all experimental work, they are described in this section. Methods specific to an individual experiment are described in the appropriate method section for that experiment.

Chapter 5: Experiment One

Identical representations were presented in different ways to examine differences in task performance, workload and subjective experience of navigation. Three different methods of presenting spatial information in a location-based context were compared to presentation on a paper map.

Chapter 6: Experiment Two

Three different types of spatial information required for navigation were used by participants. Location-based information was presented on a mobile device and used by participants to navigate inside a building. Differences in task performance, workload and subjective experience of navigation were examined in this experiment.

Chapter 7: Experiment Three

The same types of spatial information used in experiment two were used in a different location. Participants navigated a complex, outside environment. Similar dependent variables to previous experiments were used. A new experimental design was employed to investigate differences in navigation. As in experiment two, spatial information was location-based and presented on a mobile device.

Chapter 8: Quantitative Meta analysis

Experiments one, two and three, although different individually, all share a common core of dependent variables. In this chapter, a meta analysis is conducted across the entire data set where appropriate. A factor analysis of the questionnaire developed by the author is also conducted at this stage. The larger number of completed questionnaires across the entire research period allows this method of analysis to be used hence its inclusion in this chapter.

Chapter 9: Adding GPS

A small study was conducted using GPS to add true location-based functionality to the mobile device. Based on the results of experiment two and experiment three, two representations were used for inside and outside navigation. The challenges of using automatic positioning to select information for display on a mobile device are discussed.

Chapter 10: Returning To the Context

The representations used in the experimental work and the results found were presented back to practising firefighters in a focus group to elicit opinions. Potential operational problems when using the different representations are discussed.

Chapter 11: Discussion

A discussion of the complete research project is presented in this chapter, framed by the original aims of the work, and how they have been met by the research conducted. The theoretical issues discussed in the literature review are considered in the light of the experimental results. Finally, a number of guidelines developed from the research are presented. and opportunities for future research are identified.

Chapter 2 Literature Review

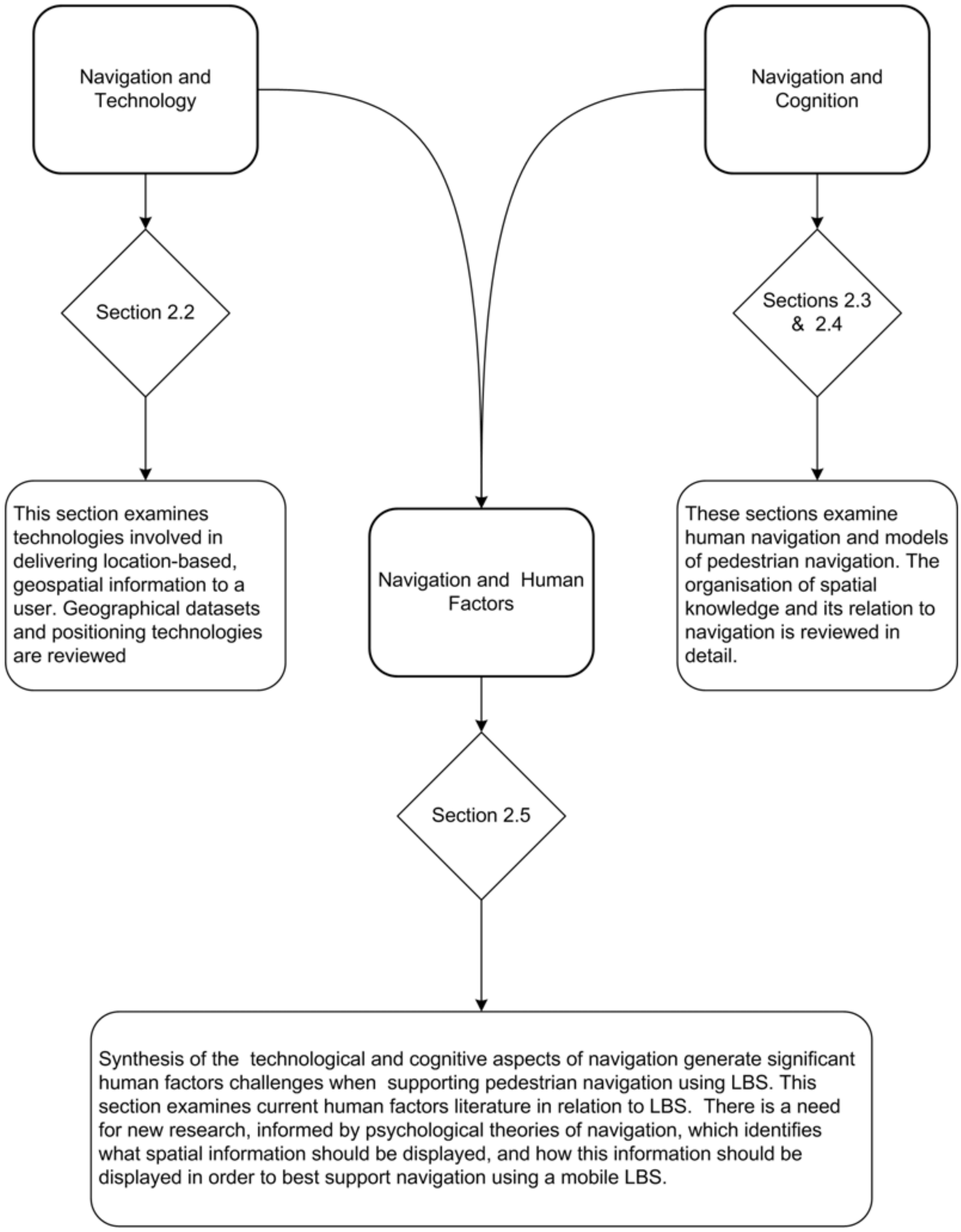
2.1 Introduction

The review is divided into five sections. In Section 2.2, an overview is given of the technology involved in delivering location specific information to a user through a location-based service (LBS). A generic system architecture is shown and the critical components of the system, geospatial data and positioning technologies are discussed in detail.

Section 2.3 reviews current perspectives on navigation and the processes that may be involved when navigating. A selection of models of navigation which seek to explain these basic processes are critically evaluated. Section 2.4 reviews theories on how spatial knowledge is stored and encoded, to be used for navigation.

Finally, Section 2.5 examines current human factors research into LBS and identifies the need for new research into the optimum type of spatial information to display, and how this information can be presented to effectively support navigation. Figure 2.1 shows the overall structure of this review.

Figure 2.1 Structure and overall content of this review



2.2 Location-based services

2.2.1 Introduction to LBS

LBS can use the position of a user to communicate specific and contextually relevant information to that user (Paay and Kjeldskov, 2007).

Applying this facility to mobile services is a natural extension since services specific to location, for example, wayfinding in a shopping centre or locating a group of friends, can deliver information to the ever-increasing array of mobile devices available to the consumer. Indeed commercially successful LBS other than in-car navigation have been slow to emerge and frequently the number of services and data providers required to deliver other successful applications is cited as a barrier to widespread use and development of services (see Rao and Minakakis, 2003;Williams, 2003).

Figure 2.2 shows a representation of an LBS at the most basic level. A variety of content can be delivered to the LBS which is then presented to the user. The user responds to information displayed on the device and interacts with the device. Information about the position of a user is delivered to the LBS which then ‘requests’ relevant information from the content servers depending on the user’s position.

Figure 2.2 High level representation of an LBS

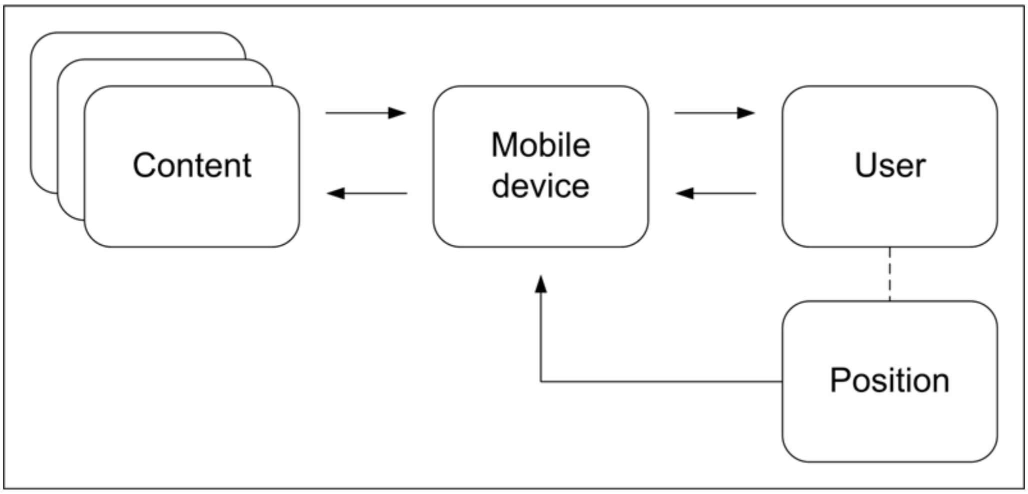
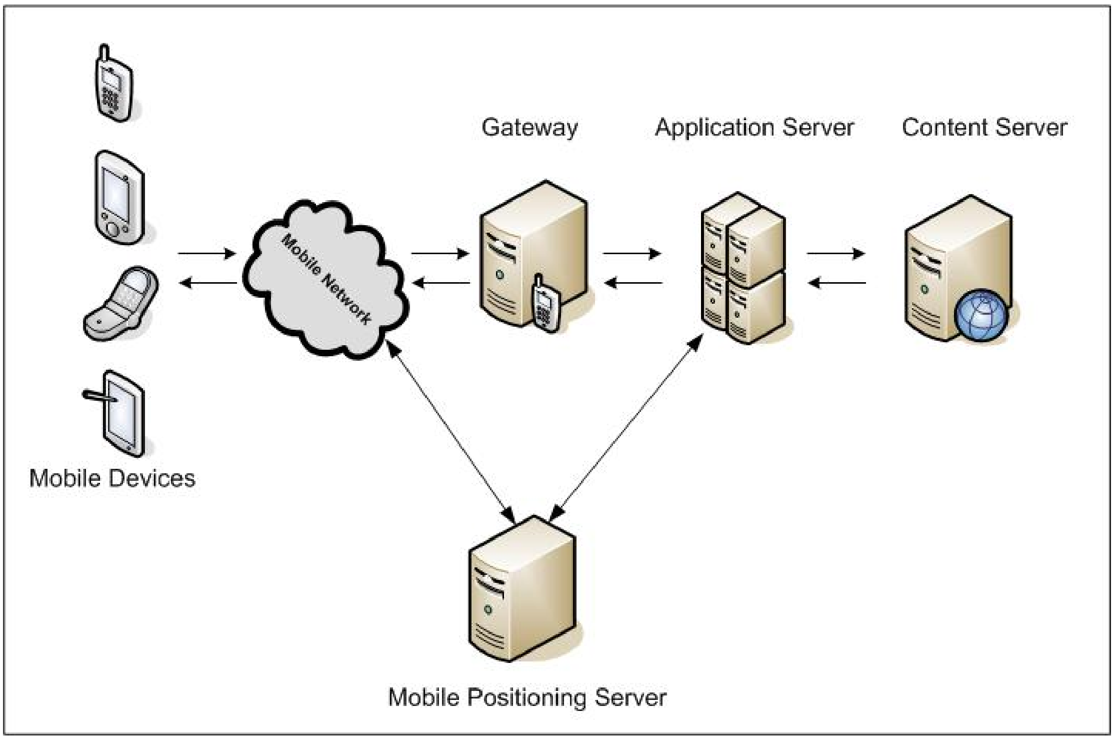


Figure 2.3 shows one general system architecture for any number of mobile LBS (Lopez, 2004). Other system architectures may rely more on locally cached information or content, improving the speed of service delivery. With increasing computing power this approach may be used more often in the future. The definition of each stage of the diagram is shown in Table 2.1.

Figure 2.3 General system architecture for an LBS



(Adapted from Lopez, 2004)

Table 2.1 Definition of stages in LBS system architecture

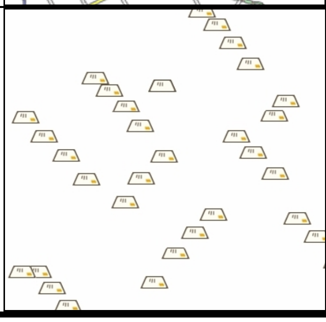
Stage	Description
Mobile Devices	Any mobile device with software to receive and send signals to and from an appropriate mobile network. Although physical mobile devices are shown, wearable custom systems may also use a similar architecture
Mobile Network	Handles the secure transmission of data between the mobile device and the system
Mobile Positioning Server	Calculates the position of the device using methods available to the service, for example GNSS or cell-ID
Gateway	Manages smooth transmission between the different web-based information delivered by the servers and the wireless, mobile network
Application Server	Retrieves and processes required data from a large array of data delivered by the content servers in order to satisfy user demands from the mobile device.
Content Server	A large database often managed and owned by a third party. In Great Britain, OS is a key supplier of geographical data.

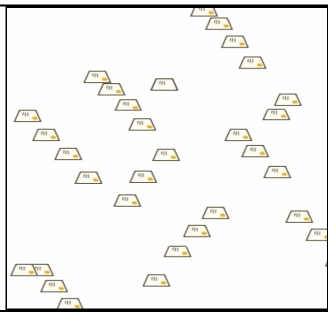
The technological limitations of mobile hardware when compared to desktop-based hardware become of critical importance in any area, but especially so when considering location-based services owing to the complexity of geospatial data and the demanding mobile user.

2.2.2 Geospatial information

Many different sources of geospatial information exist. The Ordnance Survey (OS) is a key supplier of geospatial information (GI) in Great Britain. Its main product, MasterMap, holds the most complete picture of Great Britain and is one of the most detailed geospatial datasets in the world (Ordnance Survey, 2007b). All geographic features are contained in layers within MasterMap and are identified by Topographic Object Identifiers or TOIDS. TOIDS are unique sixteen digit identifiers which are assigned to features in Great Britain. For example Kings Cross station would be made up of a large number of features such as the buildings, pavements, railway tracks and platforms. Each feature or in many cases part of the feature would have a separate TOID. In this way, applications are able to interact with the TOIDs allowing extensive processing of geographic data for a range of applications. Table 2.2 shows the five major layers contained within OS MasterMap. The examples show an area of Basingstoke in Great Britain.

Table 2.2 The five major layers contained within OS MasterMap

Layer Name	Description	Example	Size for whole of Great Britain dataset (Compressed)
Topographic Layer	Vector based data containing all land based features and objects		32 Gb
Integrated Transport Network (ITN) Layer	Routing and network information for Great Britain road and rail transport links		2 Gb
Address Layer 1	Contains all postcode information about addresses in Great Britain		0.44 Gb

Layer Name	Description	Example	Size for whole of Great Britain dataset (Compressed)
Address Layer 2	Enhanced version of Address Layer 1. Contains additional information in property being built and objects without postal codes		(Included in Address Layer 1)
Imagery Layer	Seamless aerial photography of the whole of Great Britain		11300 Gb

(Data and layers structure from Ordnance Survey, 2007b;Ordnance Survey, 2007c)

Other major providers of GI do exist, for example Experian, Google or the AA, however the OS supplies the most comprehensive map data for Great Britain.

Data Interoperability

Although geospatial data is critical to LBS, in order to provide useful and desirable services to consumers, other data sources must be combined with the base map data. A hypothetical LBS for an incident commander in the fire service would potentially use any number of different data sources. For example:

- MasterMap data on road networks and local topography
- Local Authority data on vulnerable individuals
- Utilities data concerning the location of hydrants or gas pipelines
- Aerial thermal imaging data to view and possibly predict the spread of fire
- Data from other fire officers at the site

These data sources may be held by different companies in different formats. For example, local authority data may be simply stored in spreadsheets, utilities data may be geo-referenced and XML coded, ready to integrate with similar data. Frequently, data sources are stored in different formats in different locations and may not be available on demand. Another example would be a consumer service that located local tourist attractions. An exhaustive database of attractions and their attributes would need to be created and made available in conjunction with the GI in order to develop a realistic service that could be relied upon by users.

A key theme demonstrated by these simple, hypothetical examples is the need for data interoperability. In order for a service to be delivered the data must exist and interact in a form accessible by the service. These requirements are far more difficult to meet in reality than in theory and data interoperability remains a challenging issue for LBS development and delivery (Goodchild et al., 1999;Jiang and Yao, 2006). The range of standards, protocols, hardware, software and users mean that an overwhelming array of useful applications can be dreamed up but arranging for all stakeholders to agree on standards and share data is far more taxing. The Open Geospatial Consortium (OGC) leads in the area of interoperability. When data meets OGC standards it is possible to use the data on a variety of different platforms for a variety of applications without the need for highly specialised software to mediate between different formats. The OGC provides freely available standards which are responsive to the needs of both business and consumers. OGC members include many leading companies (for example Google, ESRI, Microsoft) involved in the development of LBS (Open Geospatial Consortium, 2007).

In summary, LBS require interaction between multiple data sources and hardware. The information demanded by the user must be fed though the system and the appropriate, location specific information must then be delivered in a form that can be understood and acted upon by the user.

2.2.3 Positioning technologies

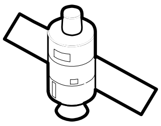
The backbone of any mobile LBS is the positioning technology or technologies that are used in order to fix position and communicate the appropriate information to the user in that specific location. Each positioning technology has its own strengths and weaknesses. Often, technologies are used together in order to ensure that a reasonable fix on position can be achieved in a range of environment.

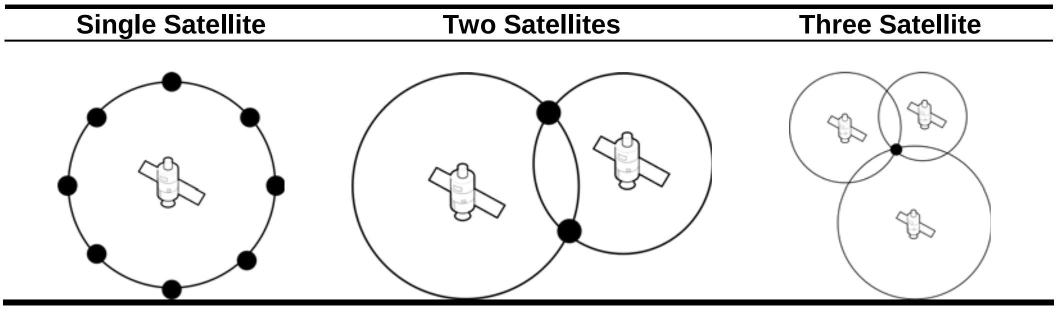
Global Navigation Satellite Systems

Global Navigation Satellite Systems or GNSS are the most familiar form of positioning technology, especially the American Global Positioning System (GPS). GNSS uses satellites in geostationary orbit in order to allow the GNSS receiver on the earth to compute its position.

GNSS works by trilateration. A GNSS receiver works by receiving signals from multiple, orbiting satellites. The satellites send a very accurate time signal derived from an onboard atomic clock (Rizos, 2002). The signal is sent in the ultra-high frequency range and is assumed to travel at the speed of light, approximately $3 \times 10^{8} ms^{-1}$. Given a time and a speed, the distance from the satellite to the object on earth can be calculated (Thurston et al., 2003, Rizos, 2002). Figure 2.4 shows simplified representations of single, double and triple satellite configurations. Calculating the distance between the satellite and the object placed on the edge of the circle would give an infinite range of positions, along the edge of the circle shown in Figure 2.4. Introducing another satellite would reduce the range of positions to two, where the two circles cross. The positions are shown in as black circles. Addition of a third satellite reduces the number of possible positions to one in an ideal scenario. The minimum number of satellites to fix an x, y position on the earth is three. To fix an x, y, z position four satellites are required. Increasing the number of satellites reduces uncertainty in the position leading to a more accurate fix (Thurston et al., 2003).

Figure 2.4 Schematics to show how GNSS derives position from distance for a one, two and three satellite case.


- Satellite



As of 2008, there are two functional GNSS signals available, that of the American Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS). Currently GLONASS has a reduced number of operational satellites (Ordnance Survey, 2007a) but further improvements are expected and GLONASS does emit a usable signal albeit at reduced accuracy. The European system, Galileo, due to come online in 2014, promises a wide variety of services aimed at both consumers and safety-critical applications. A comparison of these systems is shown in Figure 2.5.

Figure 2.5 A comparison of the three major GNSS

	GPS	GLONASS	Galileo
Number of Operational Satellites (Predicted Availability)	24	18(24)	1(30)
Horizontal Accuracy	5-10m	Unpublished	<1m – 6.5m
Vertical Accuracy	15-20 m	Unpublished	8-12m
Sources	Ordnance Survey, 2007a U.S. Coast Guard Navigation Center, 2007	Russian Space Agency, 2007	European Commission, 2007

The desire for greater accuracy of positioning has led to a number of developments. Assisted GPS (A-GPS) uses terrestrial infrastructure to improve, sometimes dramatically, the accuracy of the position recorded by a GPS receiver. The Ordnance Survey maintains a country-wide network of fixed base-stations for a form of A-GPS called Differential GPS (DGPS) (Thurston et al., 2003;Ordnance Survey, 2007a). The fixed base-stations broadcast very accurate position information which can identify and therefore correct for errors in the GPS signal.

Greater communication between the system designers has led to increased interoperability between the systems (Beatty, 2002). The potential exists for a GNSS receiver to operate using over 60 satellites when all three GNSS are fully operational (European Commission, 2007). Increases in the number of satellites visible to the receiver mean higher accuracy of positioning information. Already, GNSS receivers which exploit GLONASS and GPS are available (Bruyninx, 2007). Improvements to accuracy from interoperability between GPS and Galileo also show excellent potential (Ochieng et al., 2001).

Other Positioning Technologies

Although satellite based systems are improving constantly and promise much as new systems come online, they are not the answer to all positioning problems. One major problem is receiving signals in built up areas where satellite visibility is low. Tall buildings, tree canopies and other environmental structures cause multipath effects; the GNSS receiver receives two or more reflected signals from the satellite rather than a single direct signal from satellite to GNSS receiver (Abidin, 2002). This causes a reduction in the integrity and therefore the accuracy of the signal. Electronic jamming of the signal can occur when attempting to derive a position close to sources of microwave radiation such as TV broadcasting towers or mobile phone masts. Significantly, GNSS systems do not work well, if at all, inside buildings or under water. Increasingly, an approach has been taken where by GPS signals are enhanced or even replaced by other positioning technologies. Many of these technologies allow a location to be attained indoors, something which remains fraught with difficulty for satellite based positioning.

Mobile Phone Positioning

Mobile phone networks locate the user in order that a signal can be routed to the nearest transmitter. Under mobile phone networks, an area is divided into a number of cells, usually hexagonal. An individual user is located in a cell. Using timing information, the position can be defined more accurately. The cells vary in size, being much larger in open countryside and smaller in urban areas. Therefore, positioning accuracy is typically at its best where GNSS performs worst, in built up, urban areas (Mountain and Raper, 2001). Proposals for enhanced GPS (E-GPS) have been discussed where the mobile-phone networks would augment GPS signals. However, this would require substantial co-operation between phone networks and significant infrastructure upgrades and at the present time, these changes have not been achieved (Retscher and Kealy, 2006).

Wireless Local Area Networks (WLAN)

WLAN systems consist of fixed beacons creating ‘hotspots’, generally enabling wireless internet access. Location can be determined by recording signal strength from a receiver to a specific beacon. Signal strength changes with distance from the beacon. Reference to a database with the appropriate signal strength - location pairings would then give an individual’s location. More than one beacon could be used in order to improve positioning accuracy by delivering many different signal strengths and processing the results (Retscher and Kealy, 2006, Pahlavan et al., 2002).

Ultra Wideband (UWB)

UWB positioning systems use time-of-arrival (ToA) or time-difference-of-arrival (TDoA) to fix location. Similar to WLAN, beacons are fixed throughout an area. Following calibration, the difference in time between signals sent to a receiver and received back from a beacon is used to position a user. This method of positioning is very similar to GNSS where time is used to derive distance which then gives location. Although UWB systems are effective at fixing position, they require expert installation and calibration unlike WLAN. Each installation is unique to a particular space (Retscher and Kealy, 2006).

Radio Frequency Identification (RFID) & Bluetooth

RFID and Bluetooth installations operate in a very different way. Fixed landmarks are assigned transmitters which broadcast a unique signal. The accuracy of the position fix is proportional to the density of transmitters in a given space. Fewer transmitters will mean lower accuracy, all things being equal. A receiver will interpret each individual transmitter’s signal as corresponding to a fixed location (Retscher and Kealy, 2006). This kind of technology is used in retail security systems to establish whether goods (and hence individuals) are inside or outside the store.

Dead Reckoning

Dead reckoning is a technique which estimates a user's location given an initial position. For example, if an object travels a distance from a known position at a specific heading the new position can be estimated from these parameters. A variety of technologies exist in order to achieve this, deriving position in difficult locations such as in tunnels. Inertial navigation sensors (INS) which detect the movement of a device carried by an individual and heading sensors which detect and report the direction travelled can be worn on the body or mounted in shoes (Retscher, 2004;Stirling et al., 2005;Ojeda and Borenstein, 2007). This process becomes even more straightforward when considering vehicles, where heading can be derived from the steering wheel and distance can be calculated from the number of wheel revolutions. As long as an initial position can be fixed, dead reckoning can be used to update position until a further fix can be achieved.

All technologies have their own advantages and disadvantages. Beatty (2002) argues strongly for synthesis of technologies through interoperability. In this way, deficiencies in one technology can be overcome by the strengths of another. Most recently Soehren and Hawkinson (2008) have developed a geo-locating system for soldiers for personal navigation which combines a variety of dead reckoning technologies with GPS to deliver position information under a range of circumstances. Positioning technologies are briefly summarised in Figure 2.6.

Figure 2.6 Comparison of positioning technologies

Method	Accuracy (+/-)	Outdoors	Indoors
GNSS	6 -10 m	✓	×
D-GNSS	1 - 4 m	✓	×
Mobile phone network	150 m - 35 km	✓	✓
WLAN	1 - 3 m	✓	✓
UWB	0.2 - 1 m	✓	✓
RFID	6 m	✓	✓
Bluetooth	10 m	✓	✓
Dead-reckoning (INS)	20 - 50 m per 1 km	✓	✓
Dead-reckoning (Heading)	0.5º	✓	✓

(Accuracy of specific technology taken directly from Retscher and Kealy, 2006)

2.2.4 Classifying positioning technologies

As the number of ways of deriving an individual's position increase, it becomes more difficult to assess the applicability of a certain technology to a specific application. Hightower and Borriello (2001) propose a comprehensive taxonomy for classifying positioning systems for use in LBS. This taxonomy will be examined in some detail.

Physical vs. Symbolic Position

In a physical positioning system, an object has a specific location in space. For example the author's office is located at 52º 56' 23.70" N, 1º 11' 42.02" W at an altitude of 57 metres above sea level. This location corresponds to an actual location on the earth. All GNSS are physical positioning systems.

In a symbolic system the office might be described as 'at The University of Nottingham', or 'near the Student Union'. An RFID tag security system would use a symbolic positioning system to establish whether goods leaving a shop had been paid for or not. The system requires information as to whether goods have left the shop. The specific, physical location of the goods themselves is of no consequence. Clearly a symbolic position can be derived from a physical position given appropriate interoperable databases containing such symbolic locations and relations.

Absolute vs. Relative Data

Closely related to the physical/symbol dichotomy is the concept of absolute and relative locations. Physical positioning systems generate absolute data. Position is recorded on an agreed upon frame of reference, frequently latitude/longitude. In relative positioning objects have their own frame of reference in relation to other objects. This distinction is subtle since frequently a mixture of absolute and relative positions are required.

For example, in a rescue scenario, an absolute position is required to guide a crew to the scene of a rescue. A relative position may be required for an individual crew-member to locate a survivor wearing a locating-beacon. The spatial relationship of interest is where the survivor is in relation to the crew-member. The physical location of the survivor is not required to complete the task of finding the survivor

Local vs. Remote Computation

In a GNSS based device, the device itself computes position locally from the differences in time of signals sent to and received from the satellites. In this device-centred approach, only the device has access to its position. Transmitting this position to a network requires separate processing and transmission of the signal.

In a network-centred system, the network or system computes position. Returning to the example of the RFID security tag, the tag transmits a signal to a beacon. The network then takes into account a number of factors such as which beacon or beacons have detected the signal and the strength of the signal. From this information, the network computes the relative position of the RFID in relation to the beacon. The network has access to the position and identity of the RFID tag and further seamless processing can be carried out.

Accuracy

As discussed in previous sections, different positioning technologies have very different profiles in terms of accuracy and precision. Depending on the nature of the task, different accuracies will be required.

Extent

The nature of the application will dictate on what scale the positioning technology must operate. For example, a museum tour guide would only be required to fix positions inside a specific museum. A city guide would require a larger extent of information. Positioning technologies used in international aviation would require a world-wide extent.

Recognition

Hightower and Borriello (2001) use an example of airport baggage handling to illustrate the importance of recognition in certain LBS. In baggage handling, the location of the baggage must be known in addition to the destination to which the baggage is routed. GNSS systems are not suited to this kind of task since there is at present no mechanism or standard to identify the precise receiver that is being located.

2.2.5 Section summary

A wide range of technologies exist in order to locate a user in a specific position on the earth and deliver useful, contextual information to that individual. The selection of a positioning technology for a handheld device is not trivial. Different tasks require different combinations of technologies. Often, the requirements of a task rely on different capabilities of the positioning systems. A system may require physical location inside a building. As yet, no satellite positioning system can achieve this. Systems do exist whereby a physical location can be derived inside a building from the reprocessing of satellite data, but the issues of cost and complexity often preclude widespread adoption of such systems.

Mobile LBS present challenges. The complex data required by many services and interoperability issues demand high levels of processing power and memory. Users demand local computing on limited devices at the speed of remote computing on large servers. The issue of response time becomes especially critical when using geospatial information which is often extremely complex to process and deliver to a PDA or mobile phone with limited processing power and memory. GNSS position fixes can take significant time to achieve especially when a limited number of satellites are viewable by the device. Users may not be prepared to wait for good position fixes, reducing the credibility of the information displayed.

Developing an understanding of how users respond and perform using different types of information would inform design trade-offs. For example, if less information were required with which to navigate, this may have a positive effect on speed of service-delivery. This would have critical importance since the fire service requires delivery of fast, easy-to-understand information. In a consumer application more data may be required to make a decision but the speed of delivery may not be so critical. These considerations would affect the choice of positioning technology and system architecture for an LBS.

2.3 Navigation

2.3.1 Introduction to navigation

The ability to navigate is central to the survival of humans and other animals. An animal with limited physical resources requires the ability to efficiently locate food and water or to return to important locations (Montello, 2005b) A varied array of explanations, terms and models for this persistent and necessary form of behaviour exist. Sometimes navigation is used as a metaphor, for example, navigating through a website or navigating information (for example Spence, 1999). Discussion here is restricted to the 'getting from A to B' type of navigation. This thesis will frame navigation in terms of the structure suggested by Montello (2005). Montello defines navigations as:

"[a] co-ordinated and goal-directed movement through the environment by organisms or intelligent machines"

This clear definition encompasses much of the current literature on how navigation takes place. Two components of navigation are defined by Montello - locomotion and wayfinding. Locomotion is incorporated into the idea of navigation being a co-ordinated movement. The mode of locomotion is critical in understanding how information is acquired, processed and used by the individual. If an individual is navigating across open terrain, the types of environmental features and information being attended to in order to navigate are very different to an individual driving into work. When driving, the environment is often structured in a consistent way, affording certain types of locomotion and preventing others. Empirical evidence shows that self directed locomotion through an environment tends to generate the most comprehensive and enduring knowledge of that environment. Feldman and Acredolo (1979) showed that children show improved recall after walking a route rather than imagining it. More recent research (Waller and Greenauer, 2007) indicates that the situation may be more complex, involving contributions from different sensory systems to different representations. Nevertheless, Waller and Greenauer show that locomotion is an important part of creating enduring spatial representations from which to navigate.

The second component of navigation, wayfinding, reflects the goal-directed part of the definition. Wayfinding is a purposeful movement through an environment, including planning routes or decision making at route intersections. Wayfinding can be proximal involving only the immediate environment available to the senses, or distal, using knowledge beyond the senses. This knowledge could include using wayfinding or navigation aids such as maps or plans, or information stored in memory.

Wayfinding is further differentiated into orientation and updating. Geographic orientation is knowledge of one's position within a certain reference system. This reference system is frequently a function of environmental scale. For example, an individual may be able to navigate using the layout of a building as a reference system but may not know where the building is located in terms of some other reference point, for example, a county or city. Hart and Moore (1973) provide a general framework of reference systems. The first level of differentiation is whether the system is egocentric or allocentric. An egocentric frame or reference uses the body as a reference point. In an egocentric frame of reference objects in the environment could be described as 'in front of me' or 'to the right of me' (see Levinson, 1996 for review of linguistic concepts associated with frames of reference). In an allocentric frame of reference something other than the position of the body is used as a frame. Hart and Moore (1973) subdivide the allocentric frame of reference into concrete and abstract. An example of a concrete frame of reference would be when a landmark or other feature of the environment was being used to orient. The latitude/longitude co-ordinate system is an example of an abstract co-ordinate system which is applied to, rather than grounded in, the physical world.

The second component of wayfinding is updating. As individuals moves through the environment they must have the ability to maintain orientation with respect to a frame of reference and proceed in the correct direction. This process of updating may be active, using spatial knowledge from memory or external, cartographic information. Updating can also be sensory and automatic, for example navigating a very familiar route. (Montello, 2005b). Updating and orienting are critical processes in correct navigation. Basic processes involved in spatial updating and orienting are discussed in Section 2.3.2. More complex, cognitive processes using spatial knowledge stored in memory are reviewed in Section 2.4.

2.3.2 Basic processes in navigation

Many experimental studies which reveal the nature of basic processes involved in navigation derive from studies of animal behaviour. These studies often demonstrate that complex cognition or mental representations are not prerequisite for effective navigation. Wang and Spelke (2002) review the basic processes that have been shown experimentally to exist in both humans and animals. These basic navigational processes give insight into the strategies which humans may use when navigating:

- Path Integration
- View-dependent place recognition
- Reorientation

Path integration is the most transient of navigation strategies, operating rather like following a homing beacon. It has been demonstrated in insects (for example Etienne and Jeffery, 2004, Collet and Collet, 2000, Gallistel, 1993), rats (McGregor et al., 2004) and humans (Kearns et al., 2002, Klatzky et al., 1990;Loomis et al., 1993;Kearns et al., 2002). In this mode of navigation the position of the animal relative to a significant location of the environment, for example a nest or food source, is continually updated as the animal moves. This type of navigation does not necessarily involve the use of visual landmarks, being wholly sensory in nature. The process of path integration relies on a bearing, a distance conception of origin and destination. These two parameters are continually updated as the animal moves in relation to a frame of reference, maintaining orientation. The limitation of this kind of navigation strategy is that it is error prone. Small errors in either direction or distance can propagate until the animal is unable to navigate towards the intended target. Wang and Spelke suggest that the other types of navigation act in harmony with path integration so that effective error correction and subsequent correct navigation can take place.

View-dependent place recognition has been found in insects (Judd and Collet, 1998). Visual landmark information to train navigation and then to change the position of landmarks. was used to test for this. Evidence that insects create egocentric, view-dependent ‘snap-shots’ to navigate comes from navigational errors when the orientation of landmark information is changed. Recognition of familiar configurations of landmarks assists navigation (for examples see Timberlake et al., 2007,Roberts and Pearce, 1999,Prados and Trobalan, 1998). Sadalla and Montello (1989) showed experimentally that humans rely on egocentric memory of the environment suggesting that memories of spatial layouts are encoded on axes orthogonal to the body.

The third and final aspect of animal navigation that Wang and Spelke review is a system of re-orientation available to the animal. They suggest that reorientation takes place through a combination of the above strategies, overseen by an overall geometry of an area. A form of triangulation takes place whereby the overall layout of the area is encoded and vectors are set up between the animal and the environment. These vectors inform path integration and can correct for errors

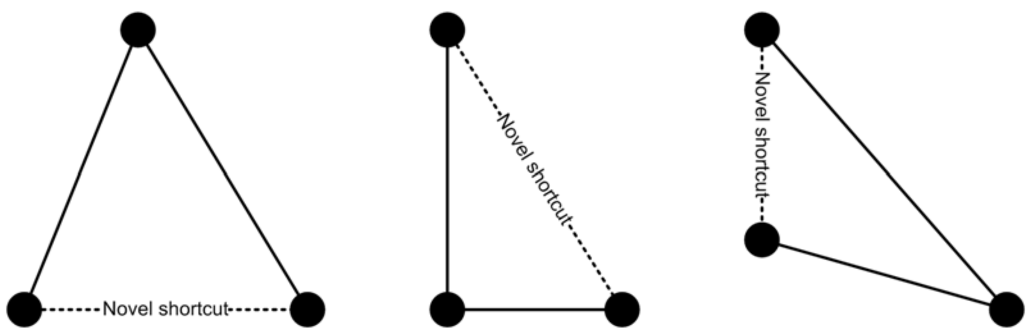
These processes closely mirror the overall framework proposed by Montello (2005). Basic mechanisms that involve the use of both subcomponents of navigation, locomotion and wayfinding are explained by these processes. The mechanism by which these processes are executed is fundamentally sensory and vestibular in nature. The processes assist navigation by generating a transient, egocentric representation of space that can be used to orient and update spatial information, maintaining navigation.

Although there is strong evidence to suggest that humans use these strategies, humans are capable of other navigational phenomena that suggest long-term knowledge about geographic space that can be acquired, accessed and most importantly acted upon to inform navigation. Examples of activities that imply enduring cognitive representations of space are communicating directions to a third party from memory, creating external representations of space or navigating with external representations of space (Cohen, 2004).

Foo et al. (2005) present a range of experiments that seek to define the extent of the cognitive element when being asked to take novel shortcuts in a virtual environment. Foo et al. suggest that navigation strategies which require cognitive resources such as following a landmark or navigating from memory are brought online when other sensory processes do not provide sufficient information with which to navigate. Sufficiency is the thrust of their argument since top-down processes impose greater cognitive demand on limited cognitive resources such as attention or memory. They classify navigation strategies in three stages. Firstly the locomotor stage which encompass all the basic sensory strategies reviewed by Wang and Spelke (2002). This strategy incurs the lowest demand on the cognitive system (Nadel, 1990) Secondly, the route stage integrates knowledge of turn sequences and direction changes. Finally, the map-stage is composed of detailed information about geographic space in memory within an allocentric frame of reference. One way of forcing engagement of top-down processes is requiring participants to take novel shortcuts across previously learned routes. The ability to navigate a new path is consistently regarded as an indicator of a cognitive representation of space as opposed to navigation guided by the sensory strategies discussed above (Bennett, 1996;Foo et al., 2005).

The high level of experimental control achieved in these experiments was possible due to a virtual environment (VE) being used. The VE ensures that each participant has a very similar experience during the experiment, free from the uncontrolled and stimuli-rich external environment. Faith in the conclusions of this experiment must lie in the validity of transfer between a VE and the real environment. Both Darkin et al. (1998) and Waller et al. (1998) suggest that valid information about wayfinding and navigation can be generated from VEs, however no attempt is made to engage with this debate here since it is beyond the scope of this thesis. The experimental tasks themselves, although using different environments were straightforward. Participants were required to complete a novel shortcut, the third leg of a triangle in the experiments. Figure 2.7 shows examples of three triangles where participants must navigate two legs between landmarks. The landmarks are shown as black circles. To complete the task, participants must navigate a new route back to the origin. This navigation may use previously learned knowledge or be informed by the landmarks themselves. Many different kinds of triangle were used in the experiments themselves. In order to engage different strategies, the environment was changed. For example, to force navigation from memory landmarks were removed or randomised. In some trials, landmarks were intentionally changed revealing whether participants were navigating from memory or whether they would continue incorrect navigation on the basis of the new configuration of landmarks.

Figure 2.7 Examples of the novel shortcut method



Foo et al. (2005) found that participants in their experiments were able to estimate heading and distance of the novel shortcut but these judgements were error prone.

Their conclusion was that individuals use a range of strategies depending on the type of environment, the features within that environment and prior knowledge in memory of the environment. Higher level strategies such as integrating path knowledge into a new route are engaged only when participants realise that the current strategy, incurring a lower cognitive demand, begins to fail. Whether the findings transfer when more complex routes are used remains to be explored.

Garden et al. (2002) provide experimental evidence for a cognitive component in navigation, supporting the research conducted by Foo et al. (2005). Unlike Foo et al, their research is grounded in the real environment. Participants were required to follow an experimenter on a route around the city of Venice or learn a route from segments of a map. Participants then had to navigate the learned route while the experimenter noted errors in navigation. Their experimental design used a dual-task paradigm, directly analogous to the kind of secondary task used to measure workload in human factors research (see Meshkati et al., 2005). Various spatial and sensory secondary tasks were used to distract from the primary task of learning a route or navigating a route, for example reading nonsense words or tapping a rhythm in order to load onto different components of working memory. Results indicate that in both actual navigation and route learning, performance was impaired by the secondary tasks that load primarily onto the visuospatial part of working memory. This results suggests that visuospatial ability and visuospatial resource availability is critical for efficient navigation.

Other supporting experimental evidence shows impaired route recall in mountaineers when required to recall a climb while performing spatial, kinaesthetic and visual secondary tasks (Smyth and Waller, 1998). Most recently, Coluccia et al. (2007) have replicated the results found by Garden et al.(2002). Their research also employed a dual task paradigm during map learning. Participants were required to learn a map while exposed to different forms of task interference. One group was required to say aloud nonsense syllables, loading onto the phonological aspect of working memory. The second group performed a spatial task being required to tap target keys in different locations. The third group was not exposed to any task interference and functioned as the control. They found that the spatial secondary task adversely affected learning and memory for maps, reflected in poorer recall and map drawing. These results again suggest a role for the visuospatial element of working memory when processing and learning spatial information.

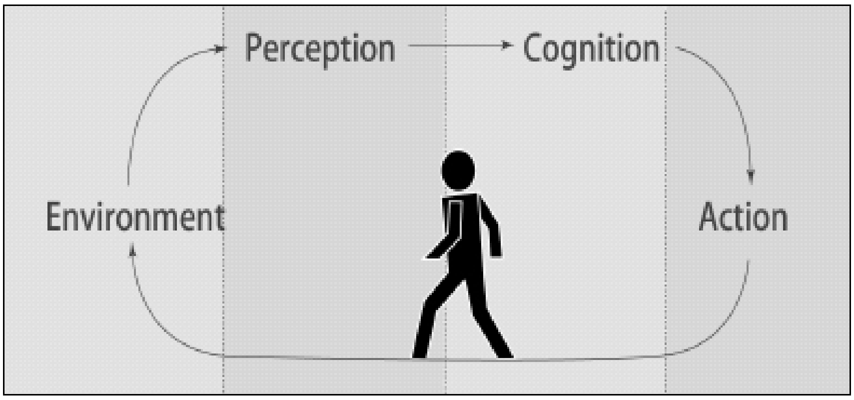
Working memory can be employed as the theoretical framework with which to understand these empirical results. All experiments discussed suggest that working memory is a critical component of route learning and navigation from learned material. Increasingly, working memory is viewed as having a critical role in executive, decision making tasks (Baddeley and Logie, 1999) and evidence points to its possible role in navigation in coordinating representation and action (Logie et al., 2001). Garden et al. characterise these functions as maintaining a cache of visual images which concur with the view dependent place recognition discussed by Wang and Spelke (2002). Access to these images is under the control of the individual. Other functionality may be the ability to retrieve sequences of turns or route directions, closely mirroring the route and map stages suggested by Foo et al. (2005). These results indicate that cognition is significantly involved in navigation. Collectively, this research raises the possibility that workload may be an important variable when considering navigation and strongly suggests a cognitive element in navigation.

2.3.3 Models of navigation

This section describes models of navigation. No single model has been widely accepted and used to inform research. Many of the models described have been developed for a specific application, for example wayfinding in buildings or navigation in a VE. Since navigation is often considered specific to a task it is difficult to develop a model which is detailed enough to be able to inform and predict navigation performance, whilst being general enough to be applied to different modes of locomotion or environments.

The first, most recent and most basic model considered is proposed by Ichikawa and Nakatani (2007). Their model is a global overview of the essential components that drive human navigation. Perception of the environment, followed by processing of the environment (cognition) ending with action on the basis of the incoming information. One very common navigational phenomenon not shown well by the model is automatic navigation where the sensory and perceptual components take over and top-down processes are minimised. Since the model is proposed as general and application-free, all other models described in this section can, to a greater extent, be framed well within this model.

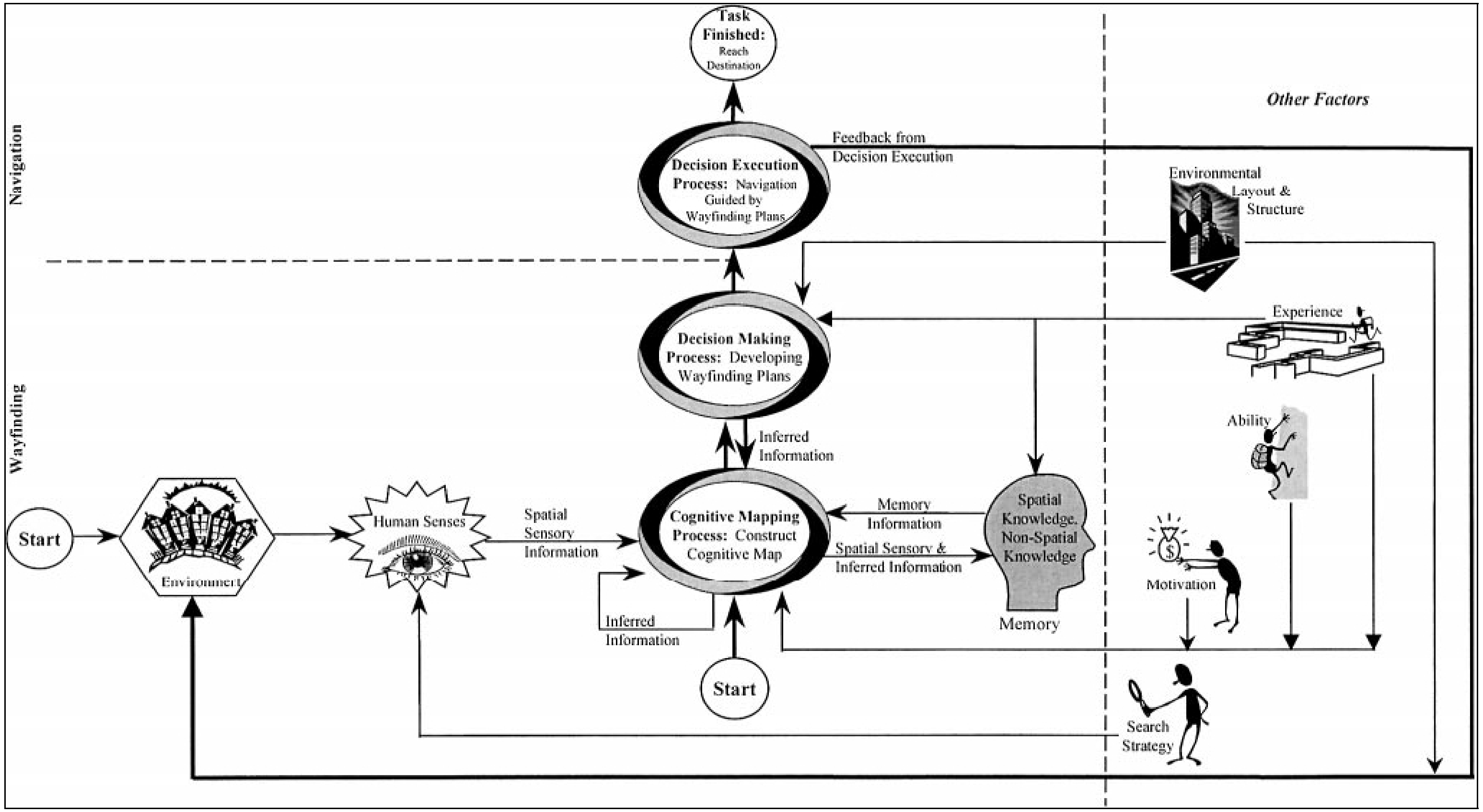
Figure 2.8 Generic model of navigation



(After Ichikawa and Nakatani, 2007)

Figure 2.9 shows a framework developed by Chen and Stanney (1999). This model was developed in order to model navigation in virtual environments. The model takes into account a variety of theories on spatial knowledge while making explicit the relationship between the individual and the environment. The model shows information flow between the sensory system and the environment which may, or may not, be modified by cognition depending on the individual. Unlike the other models, factors such as motivation and ability are included. Feedback loops are also included between the decision functions specified and the environment. The model also divides wayfinding and navigation into separate tasks suggesting that navigation is the decision execution and environment feedback process that emerges out of wayfinding. The model in particular takes into account concepts and structures suggested in other models such as decision making and information processing. One criticism of this model is its generality. It is applicable to many situations without being explanatory about the links between processes. Many processes are not represented effectively by directional arrows, for example environmental layout is an intrinsic part of the environment yet is sidelined to feeding decision making and to a single feedback loop. It is also unlikely that the serial nature of the information flows implied by the model are strictly warranted since many parallel processes may be executed simultaneously in support of changing workload or environments. The model is closer to a ‘rich-picture’ of navigation rather than a testable model given the range of factors considered. Significantly, external representations of space are not considered a factor in this model of navigation.

Figure 2.9 Generic model of navigation based on VEs



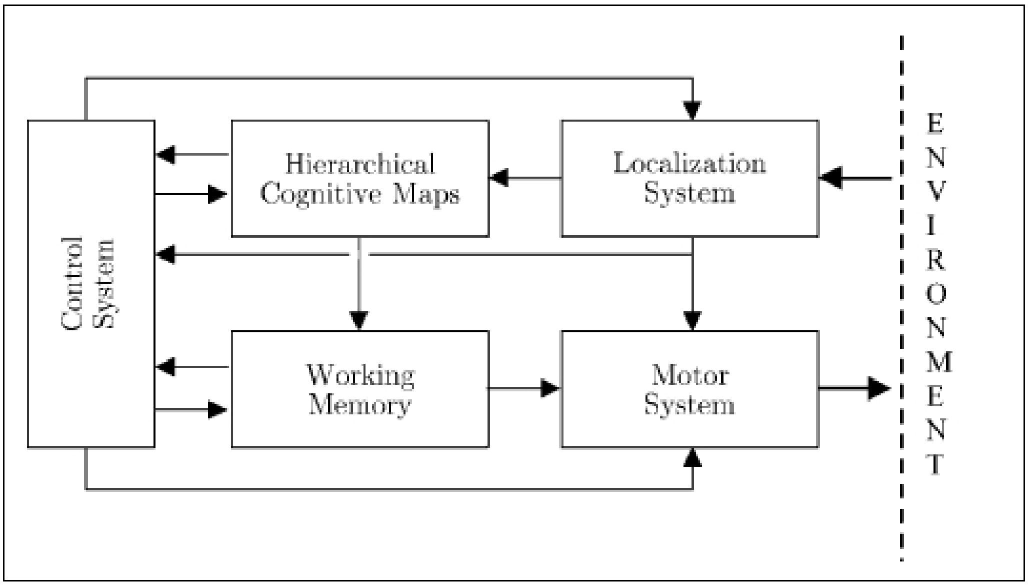
(After Chen and Stanney, 1999)

Voicu (2003) propose a far more parsimonious, computational model of navigation, shown in Figure 2.10. This model suggests that navigation is subject to flows of information between the environment and the individual, making explicit the cognitive component of navigation. The model shows information flow between the motor control system and the environment. In the case of automatic navigation, for example navigating a very familiar route, the connection is direct, implying low cognitive demand. In more unfamiliar environments, spatial knowledge is required to mediate between locomotion and wayfinding in the environment. In the model, the form of this spatial knowledge is named 'hierarchical cognitive maps'. Engaging these subsystems would necessarily incur varying degrees of cognitive demand depending on the circumstances and familiarity of the individual with a given environment. This relationship is made explicit by the inclusion of working memory in the model.

The model neatly embeds the concepts of locomotion, orienting and updating and points to the interaction between the environment and the individual when navigating. The specificity of the model could be problematic when making predictions about real world navigation. The authors argue that the computational model mimics human navigation within specific environments, for example landmarks vs. no landmarks, but makes no claim to predict performance given the range of environments encountered by an individual.

The model was validated using individuals recall of spatial information. When the reported information matched that of the output of the model, validation was successful. One problem with this approach is that essentially this is a model of spatial knowledge rather than of navigation, and that is reinforced by the method of validation selected. Cartographic representations would be referred to as part of the environment in this model.

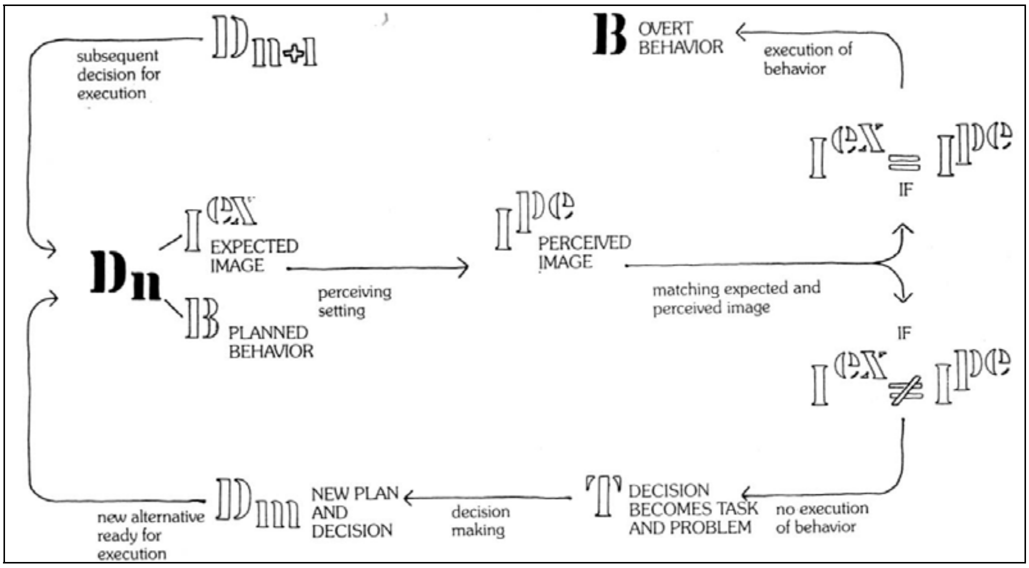
Figure 2.10 Generic computational model of navigation



(After Voicu, 2003)

One of the most cited models of human wayfinding is that proposed by Romedi Passini (Passini, 1980;Passini, 1984;Passini, 1992). Passini's model is shown in Figure 2.11. The model centres on the individual making a number (n) of decisions (D) in order to generate behaviour appropriate to navigation (B). The model centres on the perception of environmental information (I). When the environmental information perceived (I^{pe}) matches the information expected by the individual (I^{ex}), the uppermost loop is completed and successful navigation takes place. Since navigation is a continuous process, many decisions are made in any navigation process; subsequent decisions are denoted Dn+1. The lower loop of the model is activated when I^{pe} does not match I^{ex}. Passini suggests that the individual is then engaged in a task (T) or spatial problem. Information from memory is engaged (D_m) in order to rematch I^{pe} with I^{ex}. This process continues until a match takes place and successful navigation then continues. This model has influenced the development of most of the models described in this section. Navigation is reduced to a set of decisions made consciously or automatically. When a mismatch between perceived and expected environmental information is detected, higher cognitive processes are brought online, implying an increase in cognitive demand. The model restricts the sensory input to the visual modality and gives no indication of the nature of the spatial knowledge being processed restricting it to 'memory' given the debates concerning the structure of spatial knowledge this may be a realistic appraisal. It is straightforward to introduce cartographic, external representations into the model; they would be referred to at D_m.

Figure 2.11 Decision model of navigation



(After Passini, 1992)

Summary

All the models presented in this section have a common theme: navigation is a behavioural interaction between the environment and spatial knowledge which leads to spatial decisions. Despite their differences, all models suggest that effective knowledge about the world, either in the head, or represented externally such as on a map, are central to confirming location, heading or orientation and forming further, correct decisions.

The usefulness of these models in designing for LBS depends on the question being asked of them. The type of model is summarised in Table 2.3.

Table 2.3 Classification of the navigation models

Author	Model Type	Description
Ichikawa and Nakatani, 2007	Overview	High level system overview of navigation placing the user in the context of the cognitive system and the environment
Chen and Stanney, 1999	Factors	A rich picture of the factors which may affect navigation in a variety of different contexts
Voicu, 2003	Process	A flow diagram of the processes involved when navigating and their relation to the environment and cognitive system
Passini, 1980	Mechanism	A proposed mechanism for navigation involving the matching of knowledge informed by knowledge in the head or in the world with the perceived environment leading to a navigation decision

All the model types examine navigation as a concept. On the basis of the models it is difficult to derive a strong sense of what should be presented on a static paper map, let alone the wide range of display configurations and options available on an electronic, mobile device. Passini's model presents the most promising mechanism for navigation. One prediction that could be made from Passini's model is that the more closely the perception of the environment is to the expected image informed by the spatial information displayed, the more efficient navigation will be, using fewer cognitive resources. This prediction will be examined in the light of the experimental results in the overall thesis discussion (Chapter 11).

2.3.4 Section summary

Human navigation is both sensory and cognitive. Depending on the decision making requirements of the individual, either one or both systems are engaged by the individual when navigating. The sensory and cognitive levels of navigation are not mutually exclusive. The most economical strategy, incurring the least cognitive demand is the strategy engaged. Successful navigation can take place with incomplete transient, local spatial knowledge of an area.

Critical components of navigation are updating knowledge of locations and maintaining orientation with respect to a frame of reference, proceeding in the correct heading. Decisions made on the basis of this information will determine the success or failure of navigational behaviour. Decisions may be made by matching perception of the environment with previously stored spatial knowledge or an external representation such as a map. The mechanisms by which this is achieved are intrinsically connected to the mode of locomotion.

The models of navigation primarily structure the concept of navigation around environmental and cognitive factors and although interesting cannot inform the design of displays for mobile LBS. The question of what spatial information to present is not answered by any of the models described. Certainly, the models suggest cognitive and environmental elements to navigation and Passini's model suggest a 'matching mechanism' to explain how knowledge about the environment is matched with bottom-up perception of the environment to inform spatial decision making and ultimately navigation.

2.4 Spatial knowledge

2.4.1 Introduction to spatial knowledge

Spatial knowledge is information in memory about orientation, distances, organisation of space and directions which is encoded and available to the individual through a variety of cognitive processes (Cohen, 2004). Spatial knowledge is a key component of navigation and is included to varying extent in all of the models described in Section 2.3.3.

Lynch (1960) made a critical contribution to understanding the way in which people develop and partition knowledge about space. Lynch found that individuals divided space in cities consistently proposing a model of spatial knowledge for cities consisting of nodes, points and edges. This model was neither explicitly psychological nor geographical since Lynch was an architect and developed the model in order to build better cities. However, abstracting from the model, the suggestion is that the individual's knowledge about space is organised, consistent with other individual's knowledge about the same space and accessible to reason. The model also strongly suggests that the knowledge about space is hierarchical; each component is nested within other, higher order components. This is a key debate in the area of the organisation of spatial knowledge and memory.

A central concept within the cognitive science community is the distinction between declarative and procedural knowledge. Rumelhart and Norman (1985, p50) provide a comprehensive overview of these two types of knowledge. Declarative knowledge is primarily concerned with facts. This type of knowledge is accessible to reason and can be transformed, propagated and interpreted through the cognitive system. An example of a prototypical declarative statement would be 'take the first turning on the right next to the shop'.

Procedural knowledge is less accessible to consciousness, being more concerned with sequences of actions. An example of this knowledge would be navigating automatically on a very familiar route. This kind of knowledge often allows an individual to perform a task. The two types of knowledge can be used separately or together when navigating, reflecting the varying levels of task demand incurred by the individual. For example, when navigating a familiar route the individual may not be directly aware of the unique and numerous cognitive and perceptual processes that allow us to, for example, proceed in the correct direction, but they are present nonetheless, informing navigation. The sense of walking home automatically may be a result of navigation taking place using procedural knowledge, this knowledge being inextricably linked to the action of walking home. Procedural knowledge allows the individual to perform a task automatically, incurring less cognitive demand. Explicit declarative knowledge gained from route directions, memory or an external cartographic representation can be used to actively navigate in an unfamiliar space or area. Mark (1993) makes this distinction explicitly in geographical terms referring to declarative and procedural geographic knowledge. Declarative geographical knowledge consists of facts about location, direction or heading. This kind of knowledge also includes spatial knowledge derived from maps or plans. Mark suggests that procedural geographic knowledge may consist of the basic processes that allow us to navigate or wayfind; processes such as view-dependent place recognition described in section 2.3.2 may rely on procedural geographical knowledge. These basic processes (for example see Foo et al., 2005) are often difficult to verbalise or reason by the individual, but still take place, underlying the many overt spatial behaviours associated with navigation and wayfinding.

2.4.2 The LRS model

The dominant framework for understanding the levels and structure of spatial knowledge is the Landmark-Route-Survey model (LRS). The LRS model emerged from the work of Shemyakin (1962) who suggested that the structure of spatial knowledge was hierarchical. Early experimental work also suggests a strong hierarchical structure in spatial memory using distance estimation and spatial layout recall tasks (McNamara et al., 1989;McNamara et al., 1992). Within this hierarchy, increasing exposure to the environment generated more detailed and more flexible spatial knowledge that could be used to inform navigation. This nascent theory owed much to the stage model of child development developed by Piaget at this time (Golledge and Stimson, 1997). Siegel and White (1975) propose a strongly hierarchical structure, defining the three different levels of knowledge that are encompassed within the framework. More recently the original model has been revised and updated (Montello and Pick, 1993;Montello, 1998;Montello, 2005a).

The first level of spatial knowledge consists of landmarks. In the model, landmarks are described as discrete objects or scenes that are recognisable to the individual. Landmark knowledge is acquired first. Route knowledge is described as chains or sequences of recognisable environmental features. These sequences are ordered and relevant information for navigation at decision points is included in the route level information. At this stage no metric information regarding distance is encoded. Survey knowledge, the most flexible and detailed spatial knowledge is at the top of the hierarchy. Survey knowledge is map like knowledge about an area within a common frame of reference. At this level of spatial knowledge distances and spatial relationships are encoded and individuals can derive novel shortcuts or communicate detailed information to a third party through speech or map-drawing by accessing this detailed information.

Some of the most striking evidence of these distinctions in the levels of spatial knowledge derives from studies of sex differences in the ways in which spatial knowledge is reported. Saucier et al. (2002) report that females are more likely to report directions at the landmark and route levels of spatial knowledge. Males are more likely to report at the survey level when asked to give directions. More recently, Bell and Saucier (2004) showed that women performed best on navigation tasks driven by route and landmark knowledge as opposed to survey knowledge. Rahman et al.(2005) report similar navigational strategies for both females and homosexual males. Whether these differences are concerned more with the experimental method than real differences between sexes and sexuality remains an issue, but the studies do indicate different levels of reported spatial knowledge may be grouped into the three LRS categories.

Landmarks represent a particular controversy when considering the LRS model. Many researchers understand landmarks to be the foundations of navigation, the other stages simply being expressions of organised groups or sequences of landmarks (for example Cornell et al., 1992;Cornell et al., 1994;Foo et al., 2005;Stankiewicz and Kalia, 2007). Other research indicates that individuals are very good at memorising landmark to landmark associations and nothing more, since these simple associations are sufficient with which to orient and navigate

(Shelton and McNamara, 2001;Mou and McNamara, 2002). Landmarks remain difficult to classify and this difficulty of an environmental feature or object being considered a landmark by one individual and not by another is a continuing problem when designing automatically generated route instructions (Hansen et al., 2006). Stankiewicz and Kalia (2007) define landmarks on three different dimensions:

- Persistent

  The landmark should remain after a period of time has elapsed and the individual returns to the location of the landmark

- Perceptually salient

  The landmark must be detectable and able to be identified quickly

- Informative

  The landmark should give unique information about the location that it marks

Stankiewicz and Kalia suggest that individuals evaluate landmarks based on these three dimensions when navigating through an environment. An immediate difficulty of this classification scheme is the automatic derivation of landmarks for route guidance systems and LBS. What may be informative to one navigator may be trivial to another, depending on the task or cultural background of the individual. Stankiewicz and Kalia performed a detailed experiment that manipulated how informative landmarks were. They differentiate structural and object based landmarks. Structural landmarks are embedded within the structure of an environment for example, corridors, staircases, buildings, whereas object landmarks are contained within an environment, pictures or statues. Through a controlled experiment they found that structural landmarks tended to be encoded and used by a larger proportion of the sample when compared to object landmarks. This effect was particularly pronounced in buildings where structural features gave significant route guidance acting as structural landmarks. This theoretical explanation supports the previous work of Aginsky et al. (1997) who suggest that decision points tend to act as landmarks in themselves and are memorised more than landmarks placed in arbitrary locations. Mallot and Gillner (2000) found strong memory for landmarks and turning direction at intersections. If decision points and significant turns are counted as landmarks, the argument that route knowledge is nothing more than a series of interconnected landmarks is more convincing than ever. Individuals may use routes to connect landmarks together, the routes being explicit representations of directions and heading rather than being encoded as a separate level of spatial knowledge. Landmarks have also been shown to be important in guiding navigation through portable navigation aids. In real contexts, both Goodman et al. (2005) and May et al. (2003b) show that landmarks are often the preferred cues from which to navigate.

The LRS approach is endearing to both geographers and psychologists alike. However, the model may be too closely connected with cartographic conceptions of layered structures in space proceeding from the simple to the highly detailed. Montello (1998) suggests that the LRS approach is little more than a ‘useful heuristic’ when thinking about spatial cognition in adults. Typically, the LRS model is presented as a hierarchical model, a judgment is made regarding the quality of spatial information available to the individual at any given time. In the same way that Piaget describes the stage-like development of spatial-knowledge acquisition in the infant (cited in Golledge and Stimson, 1997), this stage approach is carried through to the adult. This appears wholly unfair since sufficiency should be the thrust of any discussion of geographical knowledge in relation to human factors. If an individual has sufficient knowledge in order to perform a task with a spatial component such as navigation, then that spatial knowledge is fit for purpose and should not be discounted as inferior or incomplete. Only when the level of spatial knowledge drops below the required level or standard for the task should we go back and examine the different ways of representing or communicating that knowledge. Montello takes this into account and suggests new tenets upon which to understand the development of spatial knowledge. Firstly, he disputes the LRS model's hierarchy suggesting that spatial knowledge is never wholly contained within a single stage of the model. Montello suggests that there is no single stage where the pure form of knowledge at that stage is wholly contained; an individual would never navigate just using one form of knowledge. For example, no individual would have pure landmark knowledge of an area following limited exposure. Montello and Pick (1993) showed that individuals with limited exposure to a two storey structure developed survey knowledge allowing them to integrate knowledge of the two storeys together. Thorndyke and Hayes-Roth (1982) showed in their seminal paper that individuals who studied maps of an area developed improved survey knowledge over individuals who had long exposure times to the environment. The LRS model does not allow for this prediction since landmark and route knowledge are nested within survey knowledge, yet the map learning group did not possess good knowledge of landmarks. The group learning from the real environment reported distorted versions of the path navigated but at a local level would still be able to correctly repeat the route.

Moeser (1988) tested the level of spatial knowledge acquired by new and experienced nurses at a large hospital. Her results again contradict the hierarchical conception of the classic LRS approach and support the more fluid structure suggested by Montello. Moeser found that experienced nurses had predominantly route-level knowledge that enabled them to perform everyday navigation between relevant locations. This route level knowledge was highly distorted and significant areas of the hospital were not reported. Newer nurses displayed better survey knowledge of areas on paper but found it harder to navigate effectively. Moeser suggests that newer nurses actively used survey knowledge in the form of maps and floor plans at the hospital, supporting the empirical work of Thorndyke and Hayes-Roth. This explanation implies that survey knowledge is not simply a developmental 'step up' as exposure to the environment is increased. These experiments suggest the following:

- Reduced experience and exposure to an environment does not automatically lead to reduced levels of survey knowledge (Montello and Pick, 1993, Thorndyke and Hayes-Roth, 1982).
- Survey knowledge of an area does not necessarily lead to effective navigation (Moeser, 1988).
- Effective navigation can still take place with limited or distorted knowledge of an environment (Moeser, 1988,Thorndyke and Hayes-Roth, 1982)

2.4.3 Survey knowledge: the cognitive map?

Yet another metaphor in the spatial cognition community which generates controversy is the idea of the 'cognitive map', a phrase first used in 1948 by Edward Tolman. Tolman found that rats were able to take novel shortcuts to return to origin and proposed the term 'cognitive map' to reflect a form of mental cartographic knowledge that could be accessed and used to inform navigation. O'Keefe and Nadel (1978) in their seminal work proposed that the neural substrate of the cognitive map lay within the hippocampus in the brain. More recently, structural changes have been found in the hippocampi of London taxi drivers who display excellent survey level knowledge of the London area (Maguire et al., 2000). The continuing research developments in the neuropsychological literature are not matched in the cognitive science literature. Regardless of the neuroanatomy of spatial knowledge, the structure, content and even existence of the 'cognitive map' is debated. Mackintosh (2002) makes the distinction between knowledge that is explicitly spatial and knowledge organised into ‘temporal sequences’. For example, a route consisting of paths interspersed with landmarks is not inherently spatial in nature, more an organised sequence of memories. For Mackintosh, the cognitive map metaphor holds only if there are explicit spatial relationships between different locations, of the sort which tend to be reported more by males than females (Bell and Saucier, 2004). The cognitive map is a representation of the external environment in memory, closest to the survey knowledge level described in the LRS model. The levels of knowledge that are described in the LRS model are contained and structured within the cognitive map providing access to different levels of knowledge required for different tasks. Bennett(1996) reviews and critiques three original conceptions of the cognitive map found in the literature. The conception of the cognitive map by Tolman (1948) and later O'Keefe and Nadel (1978) embody the concept of distorted and incomplete information being stored in memory that enables novel shortcuts to be taken in the environment. This conception of distorted but usable information both pre-dates and supports the fluid LRS model proposed by Montello (1998). The cognitive map within this conception can support navigation under uncertainty, when certain parts of a route are missing or incomplete; other information contained within the map supports decision making.

Thinus-Blanc (1987) suggests a very different view of the cognitive map. Her conception is far more ‘map-like’ in nature; the individual has an allocentric representation of the environment in their heads from which to navigate with. Thinus-Blanc suggests that the use of this map is fundamentally at the procedural knowledge level so may not be highly accessible to reason and as such, not reported accurately. Gallistel (1993) takes this explanation one step further and suggests that a cognitive map is a representation of any space with the central nervous system of the animal and is concerned directly with the geometry of the environment. Bennett (1996) suggests that there is limited evidence for cognitive maps arguing that novel shortcuts could be taken while adjusting the individual's position with respect to seen landmarks or other knowledge of the area, rather than a definite representation of the environment itself. Essentially, Bennett suggests that simpler explanations may exist for navigation not requiring a complex, allocentric representation in memory with which to work from. These simpler strategies described in section 2.3.2 would incur less cognitive demand and therefore would be preferable to complex access and retrieval processes involving a cognitive map. Since navigation may take place with incomplete, simplified knowledge about an area, there is little reason to suspect that complex, survey like representations are formed for everyday tasks. The cognitive map may well be a case of analogical reasoning rather than having any explanatory power. Recent research indicates that again, individuals are likely to engage strategies that minimise cognitive demand. Foo et al. (2005) show that individuals tended to use route knowledge, correcting errors by using landmark knowledge rather than an allocentric cognitive map of the area.

More recently, Newman et al. (2007) provide further evidence to support this position finding that individuals tend to move down the LRS hierarchy rather up it when correcting for error, even if they have a degree of survey knowledge about an environment. In their study, individuals drove a taxi around a VE. Survey information and landmark information was disrupted and the study showed more disruption in navigation when landmarks were disrupted rather than the overall layout. Although this may represent the way the environment is learned, it does not support the case for a detailed, veridical, cognitive map.

2.4.4 Section summary

Spatial knowledge may be divided into declarative knowledge, which is accessible to reason, and procedural knowledge. Procedural knowledge is likely to play a role in automatic navigation of familiar routes and may be developed through experience of navigation or sensory experiences while navigating. Declarative knowledge about space can be gained from direct experience or through geocentric, external representations of space. Either source of spatial knowledge can inform navigation.

The LRS model is the dominant framework for understanding how spatial knowledge is organised. The model proposes three levels of knowledge in a nested hierarchy: landmark, route and survey knowledge. Recent research indicates that landmark knowledge plays an especially important part in navigation and route knowledge may even be a connected series of landmarks. Some features in space are more likely to be encoded and used in navigation than others and these features may constitute landmarks. Examples include route intersections or structural features in buildings such as staircases. When using external representations of space, recognition is more likely to take place if features in space that are more likely to be encoded by individuals are represented on the plan or map. The existence of survey knowledge or ‘the cognitive map’ is controversial however, it has been shown that humans are able to report map-like knowledge of space and this knowledge may well inform navigation. However, the implied level of detail from a cognitive map is not required for successful navigation. The knowledge may be significantly distorted, generalised or otherwise incomplete but still support navigation effectively.

2.5 Displaying spatial information

2.5.1 Displaying spatial information on a mobile device

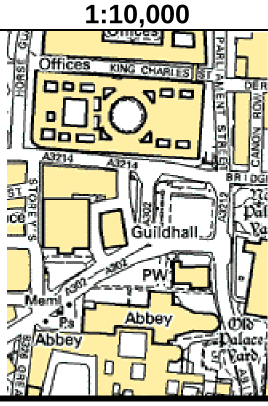
Spatial information can be complicated, and may include many details of the environment. Table 2.4 shows examples of the Westminster area in London. Even at the largest scale (1:10,000) an extraordinary amount of detail is available to the user. To maintain clarity at these levels of detail, a variety of techniques have been applied to the maps. For example, different colours are used to differentiate types of road in the smaller scale maps (1:50,000 and 1:25,000). It is easy to imagine maps, especially OS maps, as providing a veridical representation of the environment. In fact, the spatial information contained within the map has undergone significant distortion and generalisation in order to clarify features of the environment (see Wood, 1992). One example of this distortion is the width of the roads displayed in the small scale maps. In the 1:50,000 scale map, many roads would not visible if printed to scale; road width is increased on the map in order to deliver useful spatial information at that scale. Another example in the smaller scale map is the generalisation of groups of buildings. In the Gestalt tradition, groups of similar buildings have been merged. The sense, shape and location of the buildings may be retained but the actual complexity of the different configurations has been reduced. The degree of distortion permissible is often determined by the task. The distortion of the buildings in the 1:10,000 scale map would not be acceptable for a surveyor but may be entirely appropriate for the driver or tourist. This point is made explicitly in Mark Monmonier's book 'How to Lie With Maps' (Monmonier, 1996). The art of cartography involves representing spatial information in a way appropriate to the task; direct correspondence between the environment to representation is not always appropriate. OS maps are not specific to a given task, hence the inclusion of much detail at all scales.

Table 2.4 Examples of OS maps at different scales all showing a similar region of London

1:50,000

1:25,000

1:10,000



(Source: Ordnance Survey)

The art of cartography has developed as a creative discipline. While there are certain agreed conventions for the production of maps, many cartographers work with specific user groups such as the military. Presenting spatial information on a mobile device provides an entirely new set of challenges in understanding how to display spatial information (Richter and Klippel, 2002). New research is needed to understand the best way of presenting spatial information on these novel devices. It is worth noting that the sizes of the images in Table 2.4 are not far from the screen sizes often found on a mobile phone.

In order to contextualise these challenges a comparison between mobile devices and desktop devices is shown in Table 2.5. The differences are divided into three categories: context, hardware and software. The contextual considerations are unlikely to fade with technological breakthroughs and time. Differences in hardware are more flexible, particularly with the speed of advances in technology. Although the display size certainly constitutes hardware, contextual considerations may preclude the use of large displays. If an item is designed to be highly portable, a user may not desire larger screens or displays for reasons of convenience, weight or indeed fashion. Since vision is the dominant sense by which spatial information is presented, the selection of information to display is a critical consideration. This may not be the case when large displays are used, the user may zoom in or remove different elements of a map, quickly and at will. Greater variation in interaction or interface design in the mobile environment is apparent in the software category. While advantageous in many respects, a service that may be appropriate for one device may not be successful in supporting users on another device if the interface or interaction type is too specific.

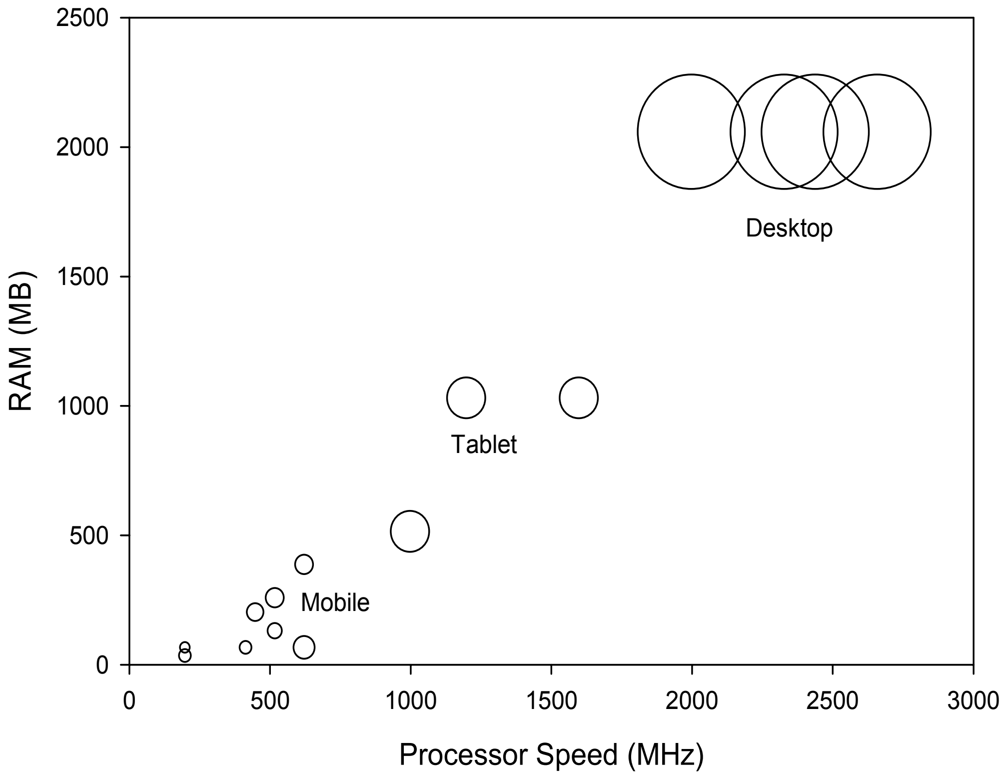
Table 2.5 Comparison of desktop and mobile computing environments

Category	Desktop Environments	Mobile Environments
Context	Fixed environment	Mobile Environment
Context	Use of the device is the primary task	Use of the device is a supporting task
Context	More control over working environment	Less control over working environment
Context	Most often used in conventional, indoor environments	Often used in unusual environments
Hardware	No real limit on display size	Smaller display size
Hardware	Higher processing power	Lower processing power
Hardware	Unlimited power generally available	Variable power available from batteries
Hardware	Higher bandwidths	Lower bandwidths
Hardware	Reliable availability of bandwidth	Variable availability of bandwidth
Software	Small number of dominant operating systems	Wide variety of operating systems
Software	Dominance of visual information	Multimodal interfaces often used
Software	Metadata often available for examination	Metadata rarely available for examination
Software	Wide choice of data providers	Often no access to data providers or data providers are chosen with mobile service
Software	Predominantly WIMP interface	Other forms of interaction frequently used, for example touch screen or speech

Figure 2.12 shows a comparison of a range of devices. A range of the highest specification, consumer devices in three categories: mobile, tablet and desktop, were selected for inclusion. Mobile phones have not been included due to the difficulty of sourcing reliable specifications in the dimensions considered. Mobile computers were selected from Hewlett Packard (Hewlett Packard, 2007), desktops from Dell (Dell Computers, 2007) and tablets from Samsung (Samsung, 2008). A strong trend towards higher processing power, memory and screen size is evident as the platforms become less mobile. Tablets represent an interesting intermediate stage in development but are still far larger than the average pocket. These levels of technical resources may be appropriate for the tasks for which a mobile device is intended. The differences serve to illustrate how it would be inappropriate to apply

the same human factors approaches and models used in desktop computing to mobile computing.

Figure 2.12 Comparison of screen-size, memory, and processing power in a range of mobile and desktop devices (Width of bubble indicates relative screen size)



2.5.2 Humans factors and LBS

Delivering complex information to a user through mobile LBS may offer a solution to many of the problems associated with the limitations of a mobile device described in Section 2.5.1, such as reduced screen size or processing power.

Human factors issues for users of mobile technologies are summarised by Pascoe et al. (2000). These issues are highly relevant to framing the human factors challenges involved in designing mobile LBS. Table 2.6 shows the four key characteristics that define users of mobile devices identified by Pascoe et al.:

Table 2.6 Characteristics that define the user of mobile devices

Characteristic	Description
Dynamic user configuration	Using information in many different locations while often engaged in other activities.
Limited attention capacity	Information must be comprehended using the minimum of cognitive resources. Other activities that the user is engaged in may route cognitive resources away from attending to the mobile LBS itself.
High speed interaction	In dynamic situations information requirements may change rapidly and the mobile LBS must quickly respond to these changing requirements and locations.
Context dependency	Activities performed by mobile LBS users are intrinsically connected with their context. This context may be spatial such as where they are in relation to a destination or connected to environmental factors such as the level of noise or ambient light.

These characteristics may be present at different levels depending on the task being performed. Certainly, all characteristics would be significant when designing a mobile LBS to support navigation.

One advantage of mobile LBS is that it can be used to deliver information specific to the user's location and task. This information would only make sense to the user in a certain location, at a certain time and in this way the amount of information can be reduced or otherwise simplified. This capability would take into account the dynamic nature of the user and provide only contextually relevant information, hopefully reducing the attentional requirements of the task. This aspect of mobile LBS is positively aligned with the user characteristics outlined by Pascoe et al. (2000).

Paay and Kjeldskov (2005) suggest that when an individual uses a location based device, the user's environment and objects within that environment, become part of the interface. Knowledge of the user's position and information about the surrounding environment at that position can prescribe the information displayed on the mobile device. Paay and Kjeldskov suggest that the information shown by a mobile device can be indexed to a user's environment and context. This indexing would eliminate redundant information that a user could gain from the environment itself, or guide a user's attention to a specific feature of that environment. In this way use of the limited display size and processing power of a mobile device can be optimised for a given task. Good knowledge of a user's position is critical for the accurate delivery of information. This positional information must be interoperable with other information sources for a mobile LBS to operate and fully take into account user context.

Kaasinen (2003) focuses on the idea of context arguing that user context should dictate the type and characteristics of the information displayed on a mobile device. For example the physical context may change; the level of ambient noise or light in an environment. The context of the environment may change, for example navigating in a built up environment or inside a factory. Context is a dynamic and difficult concept to define computationally for automatic service delivery (for example see Barnard et al., 2007).

Kaasinen (2005) gives other examples of information delivered in connection with location, for example nearby shops and services. The indexing metaphor described by Paay and Kjeldskov (2005) becomes especially clear in this case. Normally shops and services are indexed by type or in alphabetical order, as in a directory. Searching through information indexed and organised like this would swamp the display of most mobile devices. However, indexing by location would allow a user to search through shops in the immediate area. Specification of specific context, for example buying a takeaway meal, would allow for shops not selling takeaway to be removed from a display. Further indexing could take into account the time of day or the method of transport used to travel to the shop, increasing the display of task relevant information and reducing unnecessary information. Kaasinen (2003) argues strongly for the adaption of the information displayed and the user interface to the context of the task.

This kind of information filtration could allow complex spatial information to support navigation to be simplified and refined so that only those elements in the environment relevant to the task of navigation are shown to the user (Chae and Kim, 2004). Only the immediate surroundings of the user could be displayed rather than the overall area being displayed as would be the case with a large paper map. Displaying important and highly relevant information, tied to the interaction between the user and the environment would support efficient navigation at a minimum cognitive cost. The question then becomes what information in the environment should be displayed to best take into account the complex user characteristics described by Pascoe et al. (2000).

Human Factors Research

In this section a number of different LBS which support navigation are reviewed. The ways in which designers have dealt with the user challenges discussed previously are presented. Table 2.8 shows a review of a number of papers which describe an LBS. In order to be selected articles had to include an LBS which supports pedestrian navigation. In addition, a human factors component had to be present. This component could refer to evaluation of the device or application of human factors in the design of the service. In addition to the authors, other details presented in Table 2.8 are shown in Table 2.7.

Table 2.7 Key to table of human factors research into LBS

Heading	Explanation
Name	The name of the device developed.
Platform	The device on which the mobile LBS operates
Positioning	How user position is determined
Interface	The type of spatial information delivered by the device
Evaluation	What is measured in the evaluation
Field /Lab	Whether the evaluation was field or lab based
Interaction	The methods whereby users can interact with the device
Modality	The sensory modality or modalities used to deliver information to the user

Table 2.8 Review of human factors research into LBS

Paper	Year	Name	Platform	Positioning Technology	Interface	Evaluation	Field /Lab	Interaction	Modality
Ishikawa et al.	2008	-	Mobile Phone	GPS	Small maps	Time, error during navigation and memory for the route	Field	Mobile Phone keypad	Visual
Arikawa et al.	2007	Navitime	Mobile Phone	GPS	Small maps and photorealistic imagery	Interview about navigation experience	Field	Mobile Phone keypad	Visual
Paay and Kjeldskov	2005	MIRANDA1	PDA	Mobile phone network	Photorealistic imagery augmented by text	-	-	Stylus	Visual
Kjeldskov et al.	2005	TramMate	PDA	GPS and Wizard of Oz	Small maps and text	Usability	Both	WIMP based with stylus	Visual
Goodman et al.	2005	-	PDA	None - user input required	Small maps and photorealistic imagery, text & speech	Time and workload using different presentation types	Field	WIMP based with stylus	Visual and Auditory
Bosman et al.	2003	GentleGuide	Bespoke wearable	Wizard of Oz	Haptic ‘nudges’ indicating direction	Time and error during navigation	Field	No interaction available	Haptic
Kaasinen	2003	Benefon Esc!	Mobile Phone	GPS	Small Maps	Usability	Field	Mobile Phone keypad	Visual
Kray et al.	2003	-	Notebook Computer	None - user input required	Small maps and photorealistic	Time to navigate	Field	WIMP based	Visual

[1] **M**ultilayer **I**nformation **R**elated to **A**rchitecture a**N**alysis **D**ata **A**bstraction

Paper	Year	Name	Platform	Positioning Technology	Interface	Evaluation	Field /Lab	Interaction	Modality
					imagery				
Chincholle et al.	2002	PNT2	Mobile Phone	Mobile phone network	Choice of small maps or text	Usability	Lab	Miniature QWERTY,	Visual
Hermann and Heidmann	2002	SAiMotion	PDA	None - user input required	Small maps	-	-	Stylus	Visual
Vainio et al.	2002	3D City Info	PDA	GPS	Small maps and photorealistic imagery	Interview about navigation experience	Field	Touch screen	Visual
Pospischil et al.	2002	LoL@3	Notebook Computer	GPS, Mobile phone network	Choice of small map or text	-	-	WIMP based	Visual and Auditory
Bohnenberger et al.	2002	-	PDA	Fixed Beacons	Directional Arrows and Distances in metres	Time to navigate and subjective experience	Field	WIMP based with stylus	Visual

2 **P**ersonal **N**avigation **T**ool
3 **Lo**cal **L**ocation **A**ssistan**t**

Table 2.8 shows a wide variety of navigation tasks supported by LBS. Tasks range from navigation around a supermarket to navigating from a tram station to a destination. Immediately apparent is the diversity of platforms on which the service is delivered, positioning systems used to simulate or fix user position, type of interaction and the different interfaces which are engaged to inform and support navigation. This diversity makes for interesting research but does not allow easy comparison or evaluation between different types of interface.

Despite these differences there are strong similarities between the LBS. Ten out of the thirteen studies use small maps as the primary source of spatial information to inform navigation. The amount of detail that is provided on these maps or the type of information presented is not discussed in any paper. The dominance of small maps also means that information presented in the visual modality is over-represented in the table. Only one paper (Bosman et al., 2003) presents an LBS which relies solely on haptic information. Goodman et al. (2005) compare different visual presentations augmented by speech. Another LBS uses auditory cues, but again the primary source of spatial information is visual (Pospischil et al., 2002). Research by Vainio et al. (2002) suggests that users prefer a mixture of interfaces rather than being bound to one specific modality or information type. Another theme is the predominance of field studies as opposed to laboratory studies. Since the task of navigation is embedded in an environment, field studies which use the real environment are represented well in this area. The proportion of field studies may also reflect the type of evaluation performed on the devices. Usability is a key theme of the evaluations performed on the LBS and the output of the research is mainly usability guidelines for the design of LBS. Some examples of the research-led guidelines are shown in Table 2.9.

Table 2.9 Examples of research-led design guidelines for LBS

Example of Research	Guideline
Chincholle et al., 2002,Kray and Baus, 2003;Pospischil et al., 2002;Vainio et al., 2002	Use a mixture of interfaces that target different modalities
Howell et al., 2005;Pospischil et al., 2002; Vainio et al., 2002	Use an interface metaphor, for example small book or filing cabinet for search
Kaasinen, 2003,2005; TruePosition, 2003	Provide good positioning accuracy and make metadata available where possible
Kaasinen, 2003,Kjeldskov et al., 2005,Kray and Baus, 2003,Holland et al., 2002;Kjeldskov, 2002	Ensure minimum attention is required to use information
Chincholle et al., 2002;Kaasinen, 2003,2005	Support momentary use sessions ‘on the move’
Kaasinen, 2005	Use a mixture of complementary interaction styles

Although worthy in themselves, the guidelines identified are not specific enough to inform the entire design process. It would be difficult for a designer to use the guidelines to inform the selection of features and elements to display on a device. There is a gap in the human factors literature relating to LBS. Research is needed which specifies the type of information that should be presented and how this information should be delivered to the user of the service. Both Klippel et al. (2005a) and Urquhart et al. (2004) also allude to this gap, suggesting that research is required to inform designers of the best representations to use for a specific context. Kjeldskov et al., 2005 stresses that research into desktop-based services does not transfer seamlessly to mobile applications, particularly those applications that support mobile tasks such as navigation where the environment should not be disengaged from the information displayed. New research is required to inform the selection of information to portray.

2.5.3 What to display?

Delivering location-based information can help reduce the quantity of visual information presented on a mobile device since only information specific to a location can be presented. The designer is still left to decide what information to include in this display to support the task of navigation, and how best to display it. Many personal navigation aids to be used in cars (Burnett, 2000;Burnett and Lee, 2005) use ‘moving-map’ displays where the display shows a relevant section of the road ahead at all times and this section is slowly advanced in the appropriate direction of the driver. This method of presentation is well supported by the consistent glances made by the driver of a vehicle who is in a fixed position within the controlled environment of a car. This type of presentation may not be appropriate or indeed necessary in order to support the momentary glances sessions required by pedestrians who may be engaged in a wider variety of contexts and environments (Chincholle et al., 2002;Kaasinen, 2003;Kaasinen, 2005). The research presented in this thesis will make use of the display type proposed by Zimmer (2004). Zimmer proposes that users can follow information on maps when they are split into a number of fragments. Users are able to infer continuation from one map display to the next without noticeable loss of route knowledge or incurring undue cognitive load. This kind of presentation would suit a navigation aid for pedestrians who cannot attend consistently to the continuous feedback of a moving map display. This may be the case when engaged in a concurrent task, especially safety critical or occupational tasks. Selection of the type of information displayed on these segments is critical so that individuals can match what they see in the environment to the segment presented on the display. Kray et al. (2003) describe a field study using different types of information that has been segmented and displayed to participants at the appropriate locations. The different types of information are text, 2D route sketches, 2D maps and 3D photorealistic scenes. They propose that the map should always be presented egocentrically to 'reduce cognitive resources' and that the maps should contain 'eye-catching buildings'. Their paper is important since it compares the computational resources required for each type of maps presentation. For example, 3D visualisation is rated as a high consumer of resources whereas text is rated 'low'. The technical requirements are crossed with the level of 'cognitive resources' required when navigating using these different methods of presentation. While interesting at an anecdotal level, particularly in regard to the technical resources consumed, it is of less use when informing human factors research. Although cognitive demand is discussed, the nature of this demand and its source are not considered. Critically, no experimental evidence is either cited or produced to support the different variation in demand with the different types of presentation.

Aretz and Wickens (1992) investigated how different map orientation affected workload. They found that when maps were presented which matched the user's forward view of the world (egocentric) workload was lower. Maps presented in an alternative frame of reference (allocentric), for example north-up elicited higher workload and lower navigation performance. More recently, Seager and Stanton-Fraser (2007) have suggested that this distinction is too general, especially when considering small screen devices. Their research indicates that the automatic map rotation and physical map rotation elicit differential levels of performance and workload. Results of the study suggest that when the extent of the map is large providing a wide overview manual, user driven rotation is the most effective. When the extent of the map is smaller, as is often the case on mobile devices, automatic rotation elicits the lowest levels of workload.

Meilinger et al. (2006) present the results of a controlled experiment to inform the selection of information to present during a navigation task. Meilinger et al.

presented participants with spatial information with which to navigate. In one condition the spatial information was a full floor plan of the area. In other conditions the spatial information was simplified. The simplified information used was characterised as schematised. Definitions of schematisation are varied (see Klippel et al., 2005b).However, general agreement is that relational information is preserved, while other features in a map are emphasised, diminished or indeed removed completely depending on the task, so called ‘task-specific maps’ (Freska, 1999). In Meilinger et al. the task is navigation and a variety of different information types are presented. The information concentrates on routes. As discussed in Section 2.4, landmark and route knowledge are particularly critical when considering navigation, survey knowledge less so. The simplified information does not support survey knowledge of the area but does support turn-by-turn wayfinding. The findings show that simplified information is related to faster navigation times. The findings are presented in terms of Passini’s model of navigation (Section 2.3.3). Framed in this model, comparison of the environmental features with the map takes less time to encode and execute when using the simplified information. It is noteworthy that staircases were always represented in the simplified condition, possibly acting as structural landmarks (Stankiewicz and Kalia, 2007, section 2.4.2). The experiment provides strong support for investigating how different types of information change navigation performance and identifies the need for further research in this area.

2.5.4 Section summary

The complexity of many forms of spatial information, particularly maps, means that selection of the type of information to display and how to display it on a mobile device is of critical importance. Transfer of human factors research findings from desktop based systems to mobile systems is not recommended given the range of differences in hardware, software and context of use between the different systems. Current human factors research into LBS tends to focus on usability or measurement of time and error for a specific device or system. The main output of the research reviewed is guidelines for the design of systems rather than guidance of the selection of information to display and how to display it. Small maps are most often engaged to display spatial information but the content of the maps is not the focus of the literature reviewed. Three studies in particular (Kray et al., 2003;Zimmer, 2004;Meilinger et al., 2006) suggest that veridical, map -like presentation of spatial information is not necessary and may even elicit poorer performance in some when navigating. This finding is important when designing an LBS since presentation of a full map display may not be possible given the smaller screen sizes or cognitive resources available. New research to determine what should and should not be presented is needed for the effective design of mobile LBS.

2.6 Thesis rationale

In order to support the task of navigation using mobile LBS, relevant and sufficient information must be delivered to the user to inform spatial decisions. LBS can be employed to deliver spatial information to a user from which to navigate. LBS can deliver information relevant only at a specific location, often reducing the total amount of information that needs to be displayed. This property of LBS can be exploited on a mobile device.

The models and empirical data discussed in this chapter suggest that detailed and complete information is not always required for successful navigation. Changing the information displayed, or systematically excluding some information delivered to the individual can still support navigation effectively. Navigation can still take place effectively using transient, incomplete spatial information. Changing the way in which this information is presented or the type of information displayed could reduce the level of cognitive demand incurred, while maximising the ability to navigate successfully.

Understanding what information to display is also important when considering small screen devices since the amount of information delivered can be optimised to support navigation while operating within the constraints of a mobile device with smaller displays and lower processing power.

Displaying significant and informative parts of an environment that are quickly attended to and encoded may well lead to successful and efficiently supported navigation. Significant features such as landmarks or route intersections that have been shown experimentally to be important in navigation should be emphasised to best support navigation in a range of environments.

Human factors research into LBS tends to concentrate on usability and the generation of guidelines for system design. New research and research-led guidelines which could specify what types of spatial information should be presented on an LBS and how this information should be presented are needed to specify the design of mobile LBS for navigation.

These findings from the literature are central to the question of how best to present information to firefighters. Understanding what information is required in order to navigate efficiently may allow information displayed on a mobile device to be reduced or otherwise simplified. Reducing the information to the minimum level required to navigate may also reduce the cognitive demand placed on firefighters when navigating.

The main research challenge addressed in this thesis is how different types and different methods of presentation of spatial information on a mobile LBS affect navigation. Research targeted at this question will also provide specific guidelines for what spatial information should be displayed in different environments.

Chapter 3 Real-World Context

3.1 Introduction

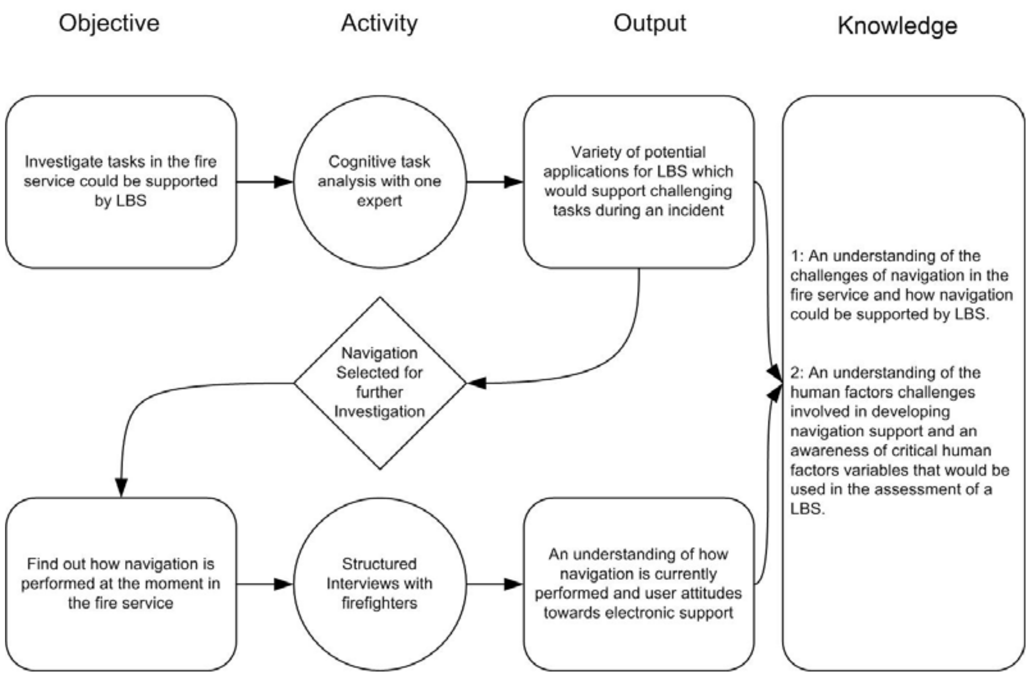
This chapter describes research was which was conducted to ground the thesis in a real-world application. In this instance Nottinghamshire Fire & Rescue Services was selected as the application domain. Examples of research into delivering geographical information to firefighters includes applications in training (Bliss et al., 1997;Waller et al., 1998) and overall incident command (Jiang et al., 2004). Until recently, the technical limitations of delivering positioning inside a building or transmitting large amounts of data to a mobile device proved overwhelming. These complex challenges are now slowly being met (for example Graham-Rowe, 2007).

The first sections (Sections 3.2 to 3.5) examine the potential for a wide range of LBS in the fire and rescue services. These services could deliver geographic or geographically referenced information directly to the user. In this way, context specific data can be delivered in real time in response to rapidly changing situations.

One outcome of the first part of the research was that navigation is a critical task in the fire service. The second part of the research examines personal navigation in detail (Sections 3.6 to 3.10) focusing on this specific and valid task for mobile LBS. This task was selected since it represents a particular problem in large incidents where navigating to locations, hazards or casualties is essential for effective operational response. Finally, a selection of human factors challenges when delivering spatial information for navigation are presented in section 3.11.

The structure of the research presented in this chapter is shown in Figure 3.1. The dual objectives of the research result in connected but distinct knowledge in the discussion. However, the output of the first part of the research informs the second part.

Figure 3.1 The structure of the research presented in chapter 3



3.2 The potential for LBS in the fire service

The first part of this research uses a specific form of task analysis, the Critical Decision Method technique (CDM) (Klein et al., 1989), which allows the researcher to gain insight into a particular domain, with a view to developing useful services or products, in this case, the potential for LBS in the fire service. Hierarchical task analysis (HTA) (see Shephard and Stammers, 2005 for review) enables the researcher to understand user tasks by observing the user at work in varying degrees of detail. When the task is documented and understood, new approaches or technology that could assist the user can be specified and prototyped.

Cognitive Task Analysis (CTA) is employed as a methodology in such cases where analysis of non-observable actions is particularly important. Among the themes that CTA is concerned with are the capturing of knowledge and how knowledge is represented and used. Planning, decision making and strategy formation are frequently themes that a CTA will probe (Hoffman et al., 1998;Shephard and Stammers, 2005). When developing computer interfaces for decision making or control, understanding how people use and react to information presented is of vital importance to understanding and improving their performance or decision making on a task.

No single method of conducting and reporting a CTA exists, increasing the difficulty of producing reliable results in this field. (Vicente, 1999). Often different methods of knowledge elicitation are used leading to criticism of the reliability of any results. Shephard and Stammers (2005) suggest that CTA and HTA should not be treated as separate methodologies but as two sides of a tool used to understand how people interact with the things and people around them in order to do a job.

One of the issues with mobile LBS is that users who need geographical information systems (GIS) the most are often the users from which gaining clear descriptions of their activities and requirements is the most challenging. Examples include the military or the emergency services. Building a picture of the activities involved in these jobs by direct observation would expose the researcher and the worker to unacceptable risk due to the safety critical and unpredictable nature of the work. Asking an individual what decisions they are making whilst engaged in an emergency is obviously inappropriate and impractical. Simulation is one option that is often used in the nuclear and aviation sectors to address this issue (see Stanton, 1996 for review). However, users in these domains are often static, in a control room or aircraft cabin, which although highly complex can at least be simulated to a high degree of fidelity given sufficient will and money.

Many military or emergency services occupations involve large, multi-skilled teams of people, operating over geographically distributed spaces. Activities require fast response to dynamic, real time information. These are precisely the circumstances where LBS using interoperable data sources could assist yet are precisely the circumstances that are difficult to replicate in a simulator.

To identify candidate LBS, a form of CTA, Critical Decision Method (CDM) was used in order to develop a clear picture of the tasks and decisions made by firefighters. (Klein et al., 1989;Klein et al., 1997;Hoffman et al., 1998). CDM was adapted as a framework to elicit the ways in which geographical knowledge could influence decisions and actions during an incident. The procedure involves developing a detailed incident timeline and probing decision making and actions taken using this timeline as a framework.

Klein et al (1997) used the CDM technique to elicit knowledge about decision making to inform the design of interfaces which improve the decision making of military personnel. In the same way, the interview presented in this paper was used to explore the ways in which location based, geographical information could be used to improve firefighters decision making when engaged in an incident. The technique has previously been shown to be effective in eliciting operational knowledge of these hard-to-observe groups.

An in-depth interview was conducted with a senior member of Nottinghamshire Fire & Rescue. The overall aim of the interview was to gain a high level overview of a real scenario and identify if, and when, geographical information was used in order to assist decision making and operational performance.

Two groups of aims were developed: descriptive and analytical. The descriptive aims concern the actual nature of the incident itself whereas the analytical aims pinpoint where LBS could inform actions during an incident.

Descriptive Aims

- Understand the nature of the information required to inform actions and decisions during an incident.
- Establish how that information is currently derived
- Develop scenarios in sufficient depth so that use cases can be developed for candidate LBS

Analytical Aims

- To establish the scope for the incorporation of LBS when attending an incident
- To identify when decisions are based on or affected by geographic information

3.3 Method

3.3.1 Participants

The expert selected for the study is a practising firefighter who has over 25 years of experience in the fire service. The expert is an incident commander called to serious incidents in order to assess risk and develop strategies in response to the nature of the incident.

In addition to this role, the expert has a senior-level role in procuring and evaluating the use of mobile data-terminals (MDTs) in fire-engine cabs. The expert has an overview of how current technology is used in the fire service, together with the ability to 'think-forward' to future applications. The expert is experienced in articulating complex ideas and decision making processes as a result of significant teaching and training experience at all levels in the fire service.

A single expert was used in this research. The breadth of experience and length of service of the expert mitigates the sometimes uncertain validity of a single-case study. The data gained from the extended interview with the expert formed the basis for further interviews with five practising firefighters establishing specific needs.

3.3.2 Procedure

The full CDM procedure comprises of seven stages (Klein et al., 1989). An abridged description of the stages is shown in Table 3.1 taken from Hoffman et al. (1998). These stages were applied in the CDM conducted with the expert.

Table 3.1 Abridged description of generic CDM procedure

Stage	Definition
Preparation	Develop knowledge of the domain and define the goals for knowledge elicitation
Incident Selection	An example incident where the expert functioned in a key decision making role.
Incident Recall	Expert ‘walks’ interviewer through the incident according to their own structure.
Incident retelling	The interviewer goes back through the incident whilst the expert offers clarifications and corrections
Timeline Verification and decision- point Identification	The expert reviews the incident and constructs a timeline based on meaningful events during the incident.
Progressive Deepening	Interviewer reviews the timeline with the expert and focuses attention on specific points within the timeline.
What-if Queries	The interviewer introduces different factors and scenarios into the event, asking the expert how they would respond given the new conditions

Preparation

Preparation for the CDM procedure consisted of spending two days at Nottingham Fire & Rescue Headquarters developing knowledge of the domain and the terminology employed by the fire service.

Following this period, the aims of the CDM were developed and focused on the geographic aspects of the incident. A number of ways of referring to and questioning geographic aspects were brainstormed in preparation for the interview

Incident Selection

Twenty-four hours before the interview, the expert was asked to think of a scenario which had been challenging to manage and where he was the primary decision maker.

Interview

The expert gave written consent to participate in the interview and for the interview to be recorded. No payment or other incentive was offered to the expert in return for participation in the interview. The CDM process was conducted at Nottinghamshire Fire & Rescue and took approximately two hours and 45 minutes to complete. Large sheets of paper and coloured markers were available to both the expert and interviewer to draw the timeline and clarify ideas if necessary.

3.4 Analysis

3.4.1 Approach to analysis

The approach taken to the analysis is broadly based on Klein et al. (1997). Their approach examined ways in which decisions could be aided by different interfaces. The decision that must be taken is identified and the reason why that decision is difficult is described. If a decision is trivial or straightforward to make, then there is little point in supporting it using complex technology. Next the information required to make that decision is described and finally the technological assistance required is suggested.

In the current analysis, the potential for LBS is examined. A rich picture of the example incident was built up and framed by the timeline developed by the interviewer and the expert. Knowledge which could be required to perform operational duties is organised around the timeline. The critical decisions which emerge from this timeline will be entered into the analysis, exploring the information requirements of the decision and the potential for location-based support.

General description of the incident

The incident described was a large fire at a warehouse under development in Beeston, Nottinghamshire. The fire took place at night, near to midnight, and took over seven hours to bring under control. The premises were in the process of being redeveloped into flats having previously been industrial premises built in the 19th Century. Original features had been retained and the building was five storeys high.

The fire had started on the fourth floor and was rapidly spreading to the fifth floor and the roof. The local area was surrounded by shops and homes.

Immediate geographic consequences of these circumstances are:

- Layout of the building is unpredictable and unfamiliar since redevelopment is taking place
- Given that the building was once used for industrial purposes, many lift-shafts and voids were still in the building
- The building contained a large amount of oil soaked wood from machinery previously in the building
- The building had many points of entry and access due to its location near the centre of the town and its previous use as a factory.

Assessment (prior to Arrival)

Prior to arrival at the scene the expert relied on prior knowledge of the area gained through direct experience and current weather conditions. A strategic plan was formulated at this stage. Critical knowledge at this stage was the location of water mains and knowledge that the building was unoccupied and undergoing redevelopment. Additionally, a high level of local knowledge informed procedures to reduce risk to the surrounding community.

> *"I am actually coming down a hill and I can start to see the building, I can see the fire developing, at 4th, 5th and roof levels so by the time I'm here [at incident] I am putting my kit on and have already started to get some information"*

> *"My assessment was aided in those first 10 to 15 minutes because of how much knowledge I'd got. Had that not been available then the crews would have had a ops 1 form[4], there is an ops1 form which is a risk assessment form for the premises in our system from when it was occupied. However you have gotta adjust that against it is now actually unoccupied"*

> *"But again, because I know the area, it's also within our information systems. I know that there is a 18 inch main situated about ¾ of a mile away through the town square"*

Assessment (on arrival)

At this stage, the expert gathered critical knowledge about the current deployment of resources and any potential hazards. Data about the building is called on the mobile data terminals if available. Data normally includes 3D CAD plans of the building and

[4] An 'ops 1' form stands for operations form 1. The form contains plan and risk data for the building or area where the incident takes place.

data about the surrounding services, again if available. This assessment forms the basis of the strategy used to fight the fire.

During this incident, the following knowledge was used to formulate the strategic plan:

- Location of hazards in and around the building
- Knowledge of voids and shafts in the building
- Wind Direction
- Location of Fire in the building
- Spread of fire between floors
- Where the fire is developing
- Location of access points around the building

> *"They have committed some breathing apparatus[5] into what I know is an unsafe structure because the only access point they've had off the main street is through an archway into a building, through a door and then there's a rickety wooden staircase so they're actually committed into what I consider an unsafe area"*

Fight Fire (Model Selection)

Following appraisal of the incident, an overall strategy for fighting the fire is selected. Two major methods of fire-fighting are used: defensive and offensive.

The degree of risk to expose the crew to is a major factor in model selection. If any casualties are present in the building, the degree of risk to which the incident commander is prepared to expose the crew increases. Broadly, an offensive

[5] 'Breathing Apparatus or BA is a commonly used term to refer to a crew member wearing the breathing apparatus.

strategy involves entering the premises to rescue casualties or reduce hazards. A defensive strategy minimises risk to the crew.

In this case, the risks to the fire crew outweighed any benefit of entering the building so a defensive plan was adopted in the first instance. The information requirements for this phase of the incident consisted of locating aerial appliances to control the spread of fire. The expert used knowledge of fire spread, wind direction and location of the fire.

When the spread of the fire was under control and the risk to the crews had reduced, the offensive model takes over:

> *"We've done an initial assessment, initially. We've then gone through a defensive strategy. We've then got to a point where the defensive strategy has been successful. We have controlled the fire. We have brought it under control to the point where the aerial appliances can't actually get there anymore cos they're either under a bit of debris or it's just in a pocket so therefore that's when you've gotta start to go to an offensive model."*

During this phase, knowledge of the layout of the building is critical to the fire crews. Thermal imaging is used to assist wayfinding inside the building. Guidelines can be laid by the fire crews in order to navigate back to points outside the building. In addition, normal routes into and out of the building may not be available:

> *"The danger with this [current scenario] is that the normal emergency exits are likely to be locked. Also there's no regulation under law that says, at night, when there's nobody in the building you have to leave the emergency exits accessible. We saw this again at an incident the other week where an emergency exit was open but the inside was grilled. Your crews would expect to be able to use an emergency exit but part of your training is not to expect the expected."*

Fire crew must report their location back to the incident command. Additionally, they will inform other crew members of safe routes into the building.

3.4.2 Potential for location-based services

The approach taken to assessing the potential for LBS is adapted from Klein et al. (1997). Actions taken during the incident that include location as a critical factor are listed, together with why those actions are difficult and how decisions are currently made. Possible information that could be delivered by LBS is then listed in Table 3.2 and Table 3.3.

Applications are divided into two tables for clarity. Table 3.2 shows applications that are geographically referenced. Table 3.3 shows applications that are more likely to require, geographical data sources.

Table 3.2 Abstraction of key actions during an Incident and potential LBS (Geographically referenced data)

Action	Why Difficult?	How decisions are made	LBS
Find safe routes into building	High risk operational environment. Dynamic environment. Limited time due to physical demands and oxygen requirements of crews	Overall impression of fire. Type of structure. Location of hazards or casualties. Sometimes, static 3D CAD models available.	Interactive model of building layout with data representing distance and time.
Find safe routes out of building	High risk operational environment. Dynamic Environment. Limited time due to physical demands and oxygen requirements of crews.	Guidelines laid on way into building	Representation of location within the building. Service directing the firefighter to specific points in the building. Indication of time and distance travelled. Display of alternative routes if hazards occur.
Search & Rescue (Uncertain location)	High risk operational environment. Sometimes risk to crew outweighs the benefit of rescue. Limited time due to oxygen requirements	Dependent on state of fire. Size of building is critical. Potential knowledge from MDT data	Planning aid to direct search attempts or segment building into areas. Fastest search route planning. Fastest exit if necessary. Device to direct individual crew members to a location.
Search & Rescue (Known/ suspected location)	High risk operational environment. Sometimes risk to crew outweighs the benefit of rescue. Limited time due to oxygen requirements.	Dependent on state of fire. Size of building is critical. Potential knowledge from MDT data	Aid to guide firefighters to specific location within building Fastest exit if necessary

(Adapted from Klein et al 1997)

Table 3.3 Abstraction of key actions during an Incident and potential LBS (Geographical data)

Action	Why Difficult?	How decisions are made	LBS
Fight Fire – Model selection	Dynamic situation that requires continuous updating. Requires dynamic assessment of risk with many variables. Choice dictates whether to commit crews into building	Key decision node concerns risk to crew. Relies on prior experience of situation and location. Relies on spatially distributed data sources: reports, data gathering crews, MDT information, thermal imaging, knowledge of building structure and type.	Display all information in one place. Predicted movement of fire through building, access points and location of any known hazards or casualties within structure.
Fight Fire – Positioning of jets	The need to co-ordinate many resources in the correct locations. Access to and knowledge about fire ground and appropriate water supplies is key.	Prior knowledge about local water mains and fire ground. Walking around fire ground. Taking into account future movement of fire within structure	Represent fire ground and jets. Ability to create what-if scenarios. Visualizing spread of water jets or cooling effects on spread of fire. Show location and size of water mains. Infer resource requirements.
Protect Public	Balancing risk with the need to keep roads, shops etc open. Knowledge of peripheral hazards required which may not be obvious	Prior knowledge of environment. Macro view of area showing key access routes or hazards, e.g. petrol stations. Places where many people congregate – pubs, halls, shops. Appraisal of fire behaviour leads decisions.	Macro level view of area indicating specific public risks given particular movement of fire. Conflation of weather and thermal data to predict movement of fires. Especially to include modelling the dispersion of smoke or fumes.
Protect surrounding structures	Requires prediction of fire spread and knowledge of the structure and contents of nearby buildings.	Visual search and local knowledge. Walk – around. MDT data if available. Some integration of thermal data if available.	Representation of surrounding structures and distance to seat of fire. Data about fire loadings of surrounding buildings

3.5 Discussion

The first part of this chapter provides an overview of the management of a large incident from an experienced incident commander. The knowledge developed by using the CDM process has highlighted many potential applications for LBS. Many of these applications would be required to deliver geographic information or other information referenced by geospatial data.

The data suggest that many activities are driven by tacit or local knowledge about the area. When attending very large incidents with crews from multiple locations this knowledge is likely to be diluted or even absent. Mobile LBS may go some way to bootstrapping responder's 'local' knowledge of the fire ground leading to good decisions being made

Much of the time information is not present when required. A mobile LBS has the potential to deliver rapidly changing information immediately. Additionally, other sources of information; casualty location, hot-spots, wind direction can be fused with current location to provide highly context-specific, relevant advice to the individual.

In order to provide these services, it is important to consider not only the technological requirements of any such system e.g. positioning technologies, data interoperability, but the ability of the operator to interpret and interact with any data which is displayed by such a device.

The analytical aims described at the start of chapter three are revisited:

- To establish the scope for the incorporation of LBS into the fire ground.
- To identify when decisions are based on or affected by geographic information

Both analytical aims are reviewed and the critical human factors challenges of providing such information are discussed.

To establish the scope for the incorporation of LBS into the fire ground.

Reliable LBS could provide essential real time data to most personnel attending an incident. The data suggest that geographic information at both the command level and the response level would have a positive effect on service response. At the command level, delivering information about wind and fire direction, resources and local information would inform strategy. At the response level, delivering maps, plans and information about causality or hazard location would reduce risk to the crews.

Human factors must be a central component of delivering LBS onto the fire ground. Fire crews must respond quickly to changing information and communicate geographic information to each other during the course of an incident. Understanding how geographic information; for example, maps or plans are interpreted and acted on is central to delivering location-based information.

To identify when decisions are based on or affected by geographic information

Most decisions made during the incident described have some geographic component to them. Resource requirements, allocation and position are determined by the immediate geography of the incident. Strategies which reduce risk to the local population are decided by examining hazards in the local area or predicting the spread of fire using wind direction or thermal imaging techniques. Finally, the approach to fire fighting and the behaviour of the firefighters themselves is dictated by the layout of the building or area. Firefighters are required to communicate their position and actions, and be aware of the environment they are in. Essentially, decisions are made by conflating different sources of information. Underlying these sources of information are location and position in relation to other features in the environment, or their colleagues.

The CDM is not without methodological limitations. One significant area of controversy is the quality of verbal data reports when describing events which happen in the past. Additionally, ‘think-aloud’ research can change the way that individuals report, reason about or remember incidents (Wilson and Schooler, 1991 and especially Ericsson and Simon, 1993). A more pragmatic approach is taken to this problem by Hoffman et al. (1998) who acknowledge the problems with verbal, retrospective reports, as used in the CDM, but suggest that the technique itself does much to reduce this problem. Developing a detailed scenario, structured by the experts themselves, increases the accuracy of recall over and above simply asking a series of questions. Additionally, CDM has been shown to be beneficial in a range of mission-critical applications including the military (Klein et al., 1997;Bolstad et al., 2002), transport (O'Hare et al., 1998) and medicine (Crandall and Getchell-Reiter, 1993). The successful, real world application of the results of the CDM to these applications speaks for itself when examining the validity of the technique.

Many opportunities for mobile location-based support during an incident are evident from this interview. The problems involved in navigating during large incidents are especially emphasised. The ability to be safely guided in or out of an incident, to locate hazards or navigate to trapped individuals is especially important. The second part of this research will focus specifically on navigation in the fire service and how LBS could be used to support successfully.

3.6 Navigation in the fire service

The CDM indicated that reduced spatial knowledge leading to problems when navigating during incidents was a barrier to effective operational response. Five first-responders at Beeston fire-station were asked about navigation problems and how they are currently overcome in an operational context.

The focus of the interviews was to gain insight into the experience of navigation in an operational context and to develop a broad sense of the human factors challenges in developing interfaces to deliver spatial information in order to support navigation.

The subordinate aims are as follows:

1. Develop rich picture of navigation
2. Develop understanding of how navigation is supported currently
3. Assess firefighters attitudes towards personal navigation aids which could assist navigation

Themes arising from interviews will be used to generate a broad human factors framework for future research to operate in.

3.7 Design

A series of five semi-structured interviews with first-responders in the fire service were conducted to meet the aims of the study.

Aim 1

Develop rich picture of navigation.

Firefighters described a situation where they had experienced problems navigating during in incident. Five to ten minutes were allocated for this part of the interview.

Description of thoughts and feelings were encouraged rather than general description of the incident.

Aim 2

Develop understanding of how navigation is supported currently.

In this phase of the interview, firefighters were asked open-ended questions about how navigation is supported.

Central themes were the extent to which disorientation is overcome and what methods of wayfinding and navigation support are currently used during an incident. Firefighters were also asked any problems with the current method of navigating in buildings.

Aim 3

Assess firefighters' attitudes towards personal navigation aids which could support navigation.

During the final phase of the interview, the firefighters were asked to imagine that they had a personal navigation-aid which would assist them in wayfinding and navigating during an incident. Open-ended questions, probing attitudes, perceived problems and advantages of navigation aids were asked.

Firefighters were asked about the kinds of information that would be of use to them during an incident. This question was related back to the incidents described in the first phase of the interview whenever possible.

3.8 Method

3.8.1 Participants

Participants comprised of five duty firefighters on the morning shift. All participants were male and had varying experience in the service (Table 3.4). No selection of personnel took place; the interviews were conducted with firefighters who were on duty at the time. Participants gave written consent to participate in the interview and to be recorded. No payment or other incentive was offered to participants

Table 3.4 Occupational experience of participants interviewed

Participant	Experience
1	10 months, Full-time
2	3 Years, Full-time
3	25 years, Full-time
4	23 years, Full-time
5	10 years, Part-time 3 years, Full time

3.8.2 Procedure

All participants were interviewed individually at Beeston fire station. Interviews lasted for approximately 30 minutes. The short interview time was necessary due to the possibility of interruptions and the amount of access allowed by the senior officer. The interview was divided into three phases, corresponding with the three aims developed. Each phase normally lasted for ten minutes.

3.9 Results

Aim 1

Develop rich picture of navigation

All firefighters described a scenario in which they had been disoriented and felt unable to navigate. All the firefighters interviewed described feelings and thoughts related to their experiences. The least experienced firefighter recalled examples during his training.

Major themes emerging from these descriptions were:

- Being unable to orient and navigate is an expected consequence of going to an unfamiliar building or site

  “Everyone is guaranteed to get lost sometime in this world. If you do get back, it may be a lucky guess rather than some homing pigeon instinct.”

- The scale or complexity of the building or site does not predict the probability of being unable to navigate

  “Small area. Didn’t expect it and also the furniture layout threw me as well... I could not figure it out; I just really could not figure it out. It didn’t seem logical that we were in the corridor.”

  “So, when we eventually did find it and put it out and looked back I thought how could I have been so stupid, how could I have got lost in here.”

- In an incident, the psychological and physical demands placed on the firefighter can lead to a distorted appraisal of the distance or direction travelled:

  “…it was so completely disorientating because there was a lot of noise. ...You get lost; you panic and try to find your way out. And there’s a time factor on this all the time because you know that people are waiting to put the fire out so you can open it up. So that’s my worst possible time when I was actually getting lost”

  “…your minds playing tricks on you. You may have walked three metres and you think you’ve walked ten metres.”

> *"Because you get lost, you panic and try to find your way out. And there's a time factor on this all the time"*

- Firefighters have problems in delivering reports of where they have been or routes they have taken in a building.

> *"When there's a team of BA's*[6] *they're supposed to give a debrief to the entry control officer. The general layout…what they've discovered. Some people have a better instant memory than other people. My instant memory isn't that good."*

Aim 2

Develop understanding of how navigation is currently supported

Firefighters described a number of methods used to navigate during an incident.

During smaller incidents, house fires or flat fires, the furniture frequently gives clues as to where the firefighter is in the property. Frequently, these cues can be misleading especially within multiple occupancy buildings or mixed-use buildings, for example, a public house with an upstairs flat.

In the majority of cases, firefighters will maneuver in pairs, following a hose reel by touch or ensuring one side of a wall is followed at all times.

An experienced officer interviewed encouraged new recruits to memorise where they had been, how many turns made or steps taken:

> *"The easiest and most best way [sic] of doing it is early on to say here's where I am, here's the door and to count how many steps. So two steps to a corner, then you turn right, three steps then try to think in your own mind how this room's looking…"*

[6] 'BA' stands for 'Breathing Apparatus'. Crew members who enter a building using breathing apparatus are referred to as 'BA's'.

In larger fires guidelines are used by the firefighters in conjunction with an entry-control officer (ECO). Guidelines are long ropes which are laid into buildings from a safe access point. Firefighters carry a bag which deploys the lines in the correct direction (Figure 3.2). The ECO records who enters the building and for how long. A maximum of two lines are controlled by the ECO denoted A and B (Figure 3.3). Firefighters navigate by touch. The knots on the line provide tactile stimuli indicating whether a firefighter is coming into or leaving the building (Figure 3.4). Each line can have a maximum of four branches, identified by one to four finger holes (Figure 3.5).

Figure 3.2 Line deployment Bag

Figure 3.3 Entry control identifiers

Figure 3.4 Directional knots

Figure 3.5 Branch identifiers

Maps and plans are also used during an incident. Plans of larger buildings and sites are available on the mobile data terminals (MDT) contained within the cab. Maps of sites such as reservoirs or industrial estates are presented as two-dimensional plan-views. Plans of buildings are presented as three-dimensional CAD drawings. No interaction is available to users examining buildings on the MDT.

When conditions allow, firefighters also take plans of buildings into a property to locate a specific site or hazard. Frequently, firefighters draw a map of the routes they have taken in buildings to inform other team members which rooms or areas have been searched. In very large incidents a so-called 'rapid laying' team is sent in to lay guidelines throughout an area, to guide other teams of firefighters through the building.

It must be remembered that due to the physical stresses placed on firefighters during incidents, they must be given rest frequently. Spatial knowledge must then be acquired or passed on between teams.

All the methods to navigate discussed by the firefighters are tried and tested methods. However, firefighters do experience problems using these methods. When using attributes of a building or furniture as cues to navigate and orient, firefighters are frequently faced with cues that do not match their expectations:

> *"I was completely lost and I could not figure out a way of getting back onto it because the furniture completely blew me."*

All firefighters recalled the physical difficulties of carrying and holding onto a hose reel. Additionally, two experienced firefighters gave an alternative scenario where following a wall would not lead to successful egress from a building. In modern buildings, partition walls are often erected in central locations, for example, partitioning an open-plan office. Under these circumstances, following a wall would fail to provide the anticipated cues from which to navigate:

> *"Some big premises have complex internal walls which won't lead to anywhere and if you go across onto them, you could actually go round in circles so that's the drawback with that."*

> *"Every building's hard. You take these open-plan offices. If you go in on the left hand wall all the way round, or someone's house when they've had a party-wall taken down and it's all open plan so you're expecting a door."*

A recurring theme with the use of maps and plans was information overloading and an inability to quickly digest spatial information to put to use:

> *"The problem with having a plan before you go in is that you have got a lot of information there that you've got to memorise and sometimes that can be more of a hindrance than a help…"*

> *"…some people probably couldn't read a map to save their lives. You've got to transpose what you see on the paper and put it into your mind. It's like if I go to a new town and look around I go back there again and drive round, and know where I am but other people might need a map and get lost ten times."*

References are also made to the difficulty in reproducing routes following egress from a building:

> *"What we try and do…when someone has been in an incident they try and draw a plan of where they've been. Sometimes when you go back into it you think. My god, that's miles out ."*

Guidelines were universally unpopular with all the firefighters interviewed. Reasons included the difficulty in correct deployment and the problems caused by laying lines over a building that can easily cause confusion among different teams.

> *"Guidelines are a nightmare, I have already said that I am glad not to have used them in anger. They really are unpleasant. They get into knots, the training I have done with them…that is…I'd rather have a map than those."*

> *"If you became a little bit panicked, or distracted, because there are coils that …you know…get muddled up. Hose reels cross…there might be two different hoses from two different teams so you could get mixed up accidentally with which hose reel you're supposed to be following ."*

Firefighters were concerned at the length of time required to lay guidelines. A senior firefighter also suggested that potentially lethal lapses in procedure when using guidelines tend to be a result of speeding up the laying process to save time:

> *"If we had a job that required guidelines, we'd be very careful. It would slow me down perhaps. I would tie it off properly because I would be thinking I've got to get this right. It's very dangerous, if you're going to rely on this, it's gotta be right. Therefore it can slow us down getting from A to B."*

However, grudging ascent to the benefits of guidelines tended to be made, albeit reluctantly, particularly the confidence that having a tactile 'object' to follow engendered:

> *"I might even prefer guidelines to this [personal navigation device] if I have 40 minutes of air and I want to come back in 20 minutes exactly the same way. And that's possibly something, just telling you which way is back"*

Aim 3

Assess firefighters attitudes towards personal navigation aids

During the final phase of the interview, firefighters were asked their opinions about the use of personal navigation aids to assist in navigation and wayfinding during an incident. Firefighters were shown a PDA and pictures of head-up displays and asked to assume that devices were reliable and could fix position accurately within the building.

A major concern firefighters had was the limited usefulness of a device in very low visibility, for example thick smoke. However, all firefighters interviewed suggested that modern thermal imaging cameras could give a sense of where walls, corridors or doors are located. Additionally, the interviewer suggested that such devices could be used on a larger scale, possibly within an industrial complex.

The response to the suggestion of electronic navigation aids was one of cautious optimism and often positive when compared to current methods:

> *"I'd be happier using that [personal navigation device] rather than the guidelines, cos I don't trust them to be honest. I use them cos I have to, but the guidelines…people go round in circles, get stuck in knots, that's what happens."*

One concern voiced was that the devices may produce an elevated sense of confidence in navigation which may not be warranted given the dynamic nature of any incident. One firefighter used the introduction of thermal imaging camera's as an example, suggesting:

> *"…they thought they could see through smoke."*

It was pointed out to the interviewer that a thermal-imaging camera would show hidden hotspots but would not assist in the more trivial, but no less dangerous, hole in the floor.

Firefighters suggested that the location of hazards, casualties or exits could be shown on a mobile device. One firefighter described the 'free-search' method used by another fire brigade in the UK. During a free search, firefighters quickly search all rooms in a given area without the support of guidelines. The idea of a mobile device giving location information in this kind of activity is appealing

Another concern expressed was that the amount of information that would have to be processed. One firefighter suggested that in order to be of use it would have to remove another task, the interviewer interprets this as a cognitive task, such as wayfinding or remembering distance:

> *"… only if it [personal navigation device] helps by getting rid of something else. If I feel more comfortable, it helps. But there is always a risk that it could add to it, if it's inaccurate, out of date, too difficult to understand , it's not making sense, it's going to get discarded and we're going to go back to old methods I think."*
>
> *"Also you don't want to be overloading the senses. You'd probably want it to be simple."*

3.10 Discussion

In conclusion, firefighters experience navigation problems during their everyday duties. This becomes more operationally problematic, the larger the incident becomes. During large incidents, many areas may have to be searched or people accounted for.

Current methods of navigation in difficult circumstances rely on highly structured techniques involving guidelines in larger incidents or by the use of maps and plans. Additionally, firefighters may draw plans from memory on egress from a building or site. Current techniques although methodical take time and may involve wasted time for firefighters or increased risk where reduced knowledge of current location with respect to hazards or danger is present.

The potential for location-based support to assist in navigation was greeted with cautious optimism by the firefighters interviewed. All expressed the need for such services to have high quality, accurate data and very good ability to fix position, and above all, be easy to use and understand. Location-based support delivering the appropriate information has the potential to increase the efficiency of navigation in a variety of contexts.

3.11 Human factors challenges

Exploiting these opportunities will only be possible with significant human factors input. Even taking into account predicted rises in the speed and overall capability of mobile devices, the perceptual and decision making abilities of the individual do not follow this exponential trend. Below, are requirements that should be applied to the design of LBS for navigation in the fire service:

Information Requirements

- Spatial information should be sufficient to enable navigation.
- Spatial information must be straightforward to map onto the environment.

Data Complexity

- Spatial information provided by a location-based device must be easy to understand and follow.
- The appropriate amount of spatial information should be provided to support the activity being performed.

User needs and Capabilities

- Minimal increase or ideally, a reduction, in mental workload should be achieved by using spatial information location-based context.

Specific human factors challenges within this area include the complexity and quantity of information communicated to the individual. The complexity and quantity of information delivered must be congruent with the working environment of the user. Firefighters are in high stress, high workload environments. Fast, accurate and complete comprehension of the information is prerequisite for a valuable and informative LBS. Understanding the issues that individuals currently have when understanding and interpreting spatially specified instructions will lead to useful and usable interfaces.

To conclude, the human factors challenges outlined should be supported by an effective research base. So far, field and laboratory based research into navigation cannot inform the design of location-based support that would meet the requirements outlined. Research presented in this thesis will examine how spatial information is perceived, used and acted on by users in order to inform the future design of location-based services for use by firefighters.

Information to assist firefighters to navigate must take into account the high workload, safety critical tasks that must be performed concurrently. This study suggests that there is a place for navigation support using location-based visual information. Understanding how and what information should be presented is of central importance to meet the user requirements identified in this chapter. Spatial information which maximises performance and experience while reducing mental workload would be a requirement of any service required to support navigation.

Chapter 4 Experimental Methods

4.1 Introduction

This chapter explains in detail the key variables recorded in experiments one, two and three. Variables were selected to reflect the human factors requirements relevant to the application domain: performance, workload and experience. Firefighters need to navigate effectively, with minimum workload and maximum confidence in their navigation choices. The variables selected reflect these requirements. The design of each is presented in detail in each chapter. Finally, a critical review of the methodology is conducted. The outcome of the methodological review is used to inform the design of each subsequent experiment and the selection of dependent variables used.

The experiments investigate navigation using various presentation methods and information types. Table 4.1 shows a summary of the experiments presented in this thesis.

Table 4.1 Summary of major experiments presented in thesis

	Experiment One	**Experiment Two**	**Experiment Three**
Chapter	5	6	7
Title	Navigating using spatial information presented in different ways	Navigating **inside** using different types of spatial information	Navigating **outside** using different types of spatial information
Independent Variable (IV)	Method of presentation	Type of spatial information	Type of spatial information
Number of IVs	4	3	3

Choice of independent variable is discussed in detail in the method sections for each experiment. IVs for experiments two and three are identical to allow overall comparison in the meta analysis presented in Chapter 8.

4.2 Participant details and dependent variables

A core group of dependent variables are used in experiments 1, 2 and 3. Continuing use of these variables throughout the experimental work allowed a comprehensive meta analysis of all data to be completed (Chapter 8). Certain variables were removed following experiments one and two. Reasons for their removal are discussed in the methodological review sections for each experiment. The core dependent variables are shown in Table 4.2. Detailed explanations of core variables are given in the sections below.

Table 4.2 Summary of core dependent variables

Dependent Variable	Measurement	Section Number
Performance	Route completion time (seconds)	4.2.2
Individual Differences*	i. Sense-of-Direction Scale ii.Object Perspective taking Test	4.2.3
Workload	NASA-TLX	4.2.4
Experience	Integrated Navigation Questionnaire (INQ)	4.2.5
Usability**	System Usability Scale	4.2.6
Behaviour	Behaviour checklist	4.2.7

* The object-perspective taking test was not used as a measure of individual difference after experiment one. For detailed reasons for its removal, see the methodological review in Chapter 5 (Section 5.13.1, p162).

** Usability was measured in experiments two and three only. For detailed reasons for its inclusion see the methodological review in Chapter 5 (Section 5.13.2, p162).

4.2.1 Participant details

For each participant a variety of personal details are recorded at the start of each experiment. Participant sex, age and familiarity with the area are recorded at this stage. Familiarity is assessed on a seven-point scale (very familiar – not at all familiar) and mean participant familiarity is reported at the start of each experimental chapter. Any participant scoring above the median familiarity level (3.5) will be excluded.

Other details recorded included participants familiarity and confidence with maps. Although this data is not reported systematically in the thesis, it is used to explain any anomalous behaviour during trials from participants who are especially familiar with maps and map data, or who have had specialised training in the use of maps.

4.2.2 Performance

Route completion time is treated as the main indicator of participant performance in all experiments. The majority of experiments that examine navigation use some form of time based data, frequently route completion time (for recent examples see Pfendler and Schlick, 2007;Ishikawa et al., 2008). Increased time spent viewing a display, or stopping to compare map information with the environment, all contribute to longer times taken to complete a prescribed route. Times in the experiments are measured to the nearest second generating interval data. In experiment three, time is used to calculate average speed since participants complete routes of different lengths within the experiment itself that must then be compared. In this case, time would reflect the length of the route rather than the efficiency of navigation. This same approach is used in the meta analysis when comparing all experiments where all time data is converted into average speeds.

A recurring problem using time taken to navigate is differences in participant's normal walking pace. Two approaches can be used:

1. Reduce natural variation by measuring walking speed before the experiment and then controlling for this variable
2. Accept natural variation by using an appropriate sample size or a within-subjects experimental design

The value of the first approach is questionable. Controlling for variation in walking speed in this way assumes that individuals walk at a constant speed which is rarely the case. Using the first approach may increase the amount of error in the design rather than reduce it.

The second method was selected and participants were instructed to walk at their normal speed around the route to avoid very high or very low times, unrelated to the independent variables.

4.2.3 Individual Differences

The individual difference measures selected for the experiment are the Santa Barbara Sense-of-Direction Scale (Hegarty et al., 2002) and the Revised Santa Barbara Object Perspective Taking test (OPT) (Kozhevnikov and Hegarty, 2001;Hegarty and Waller, 2004). Psychometric data from both tests has been published and reliability studies have been conducted as part of the test development. The Sense-of-Direction Scale (SDS) was selected owing to the identification by Hegarty et al. (2002) of significant relationships between actual navigation performance and perceived ability. The OPT task specifically tests a participant's ability to imagine different perspectives, for example, using a map but not rotating the map in the direction of travel. Like the SDS, the OPT has been shown to correlate with actual navigation performance (Hegarty and Waller, 2004)

SDS

The Sense of direction scale consists of fifteen items. Participants rate their agreement with the item on a seven-point Likert scale from 7 (strongly agree) to 1 (strongly disagree). Scores from questions worded in a negative direction were subtracted from eight (maximum scale +1). All scores were then summed to generate a single number representing sense of direction. The scale generates scores between 15 and 105. A higher score indicates a more positive perception of the responder's sense of direction. The data generated is treated as interval data (Oppenheim, 1992). All SDS questions and their scoring directions are shown in Table 4.3.

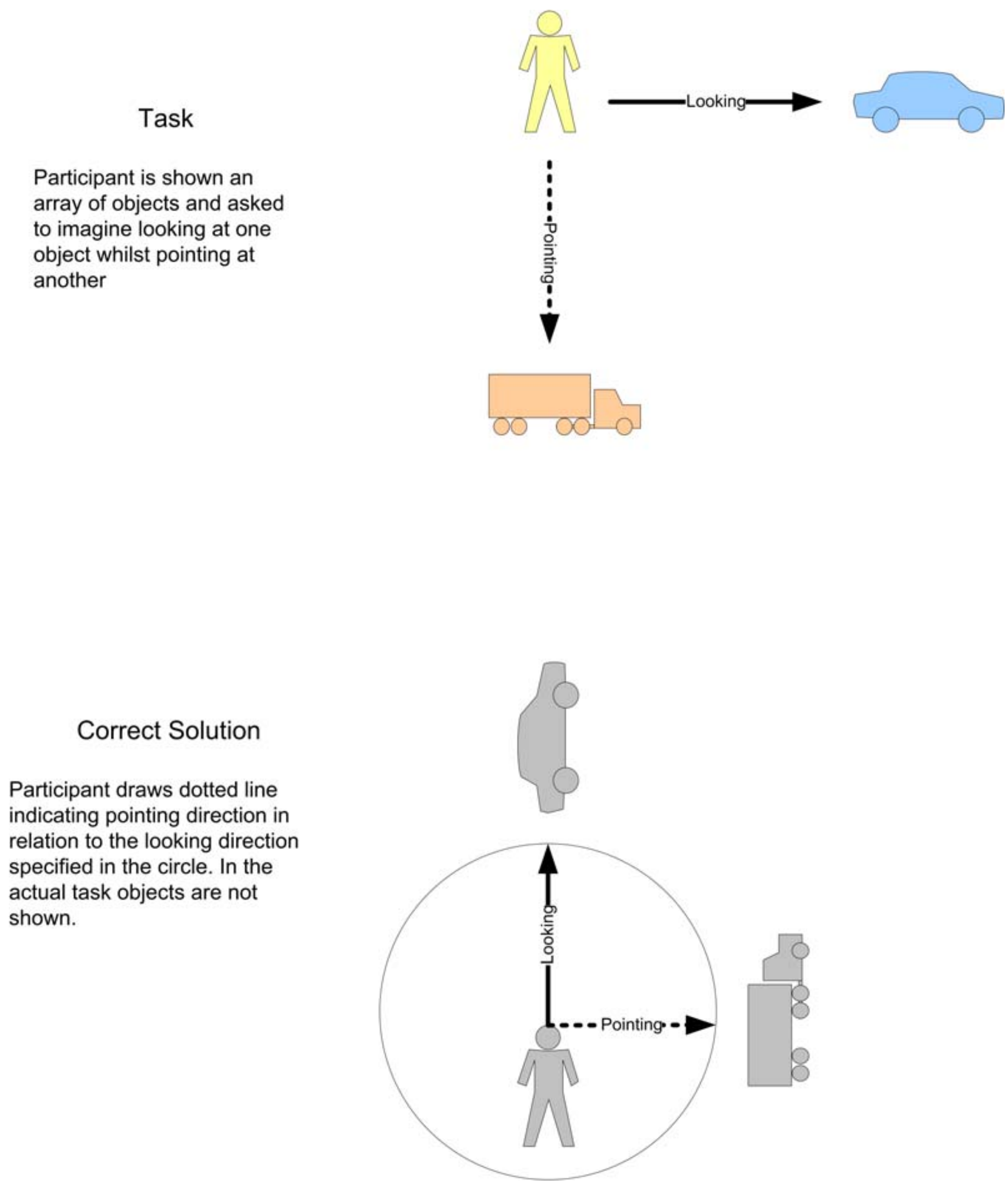
Table 4.3 Questions and scoring directions for the SDS

Number	Question	Direction
1	I am very good at giving directions	+
2	I have a poor memory for where I left things	-
3	I am very good at judging distances	+
4	My "sense of direction" is very good	+
5	I tend to think of my environment in terms of cardinal directions	+
6	I very easily get lost in a new city	-
7	I enjoy reading maps	+
8	I have trouble understanding directions	-
9	I am very good at reading maps	+
10	I don't remember routes very well while riding as a passenger in a car	-
11	I don't enjoy giving directions	-
12	It's not important to me to know where I am	+
13	I usually let someone else do the navigational planning for long trips	-
14	I can usually remember a new route after I have travelled it only once	+
15	I don't have a very good mental map of my environment	-

OPT

The Object Perspective taking test consists of twelve spatial problems. The problems present an array of seven objects and participants are required to imagine they are standing in the position of one object, looking at another. Participants must then imagine they are pointing at a third object and draw the angle at which they would be pointing. Participants complete as many of the problems as they can within five minutes. Participants are asked not to rotate the booklet or draw lines on the array of objects while completing the task. This ensures that all spatial transformations are performed in the mind. A simplified version of a problem is shown in Figure 4.1 to illustrate the concept.

Figure 4.1 Simplified version of the object perspective-taking test

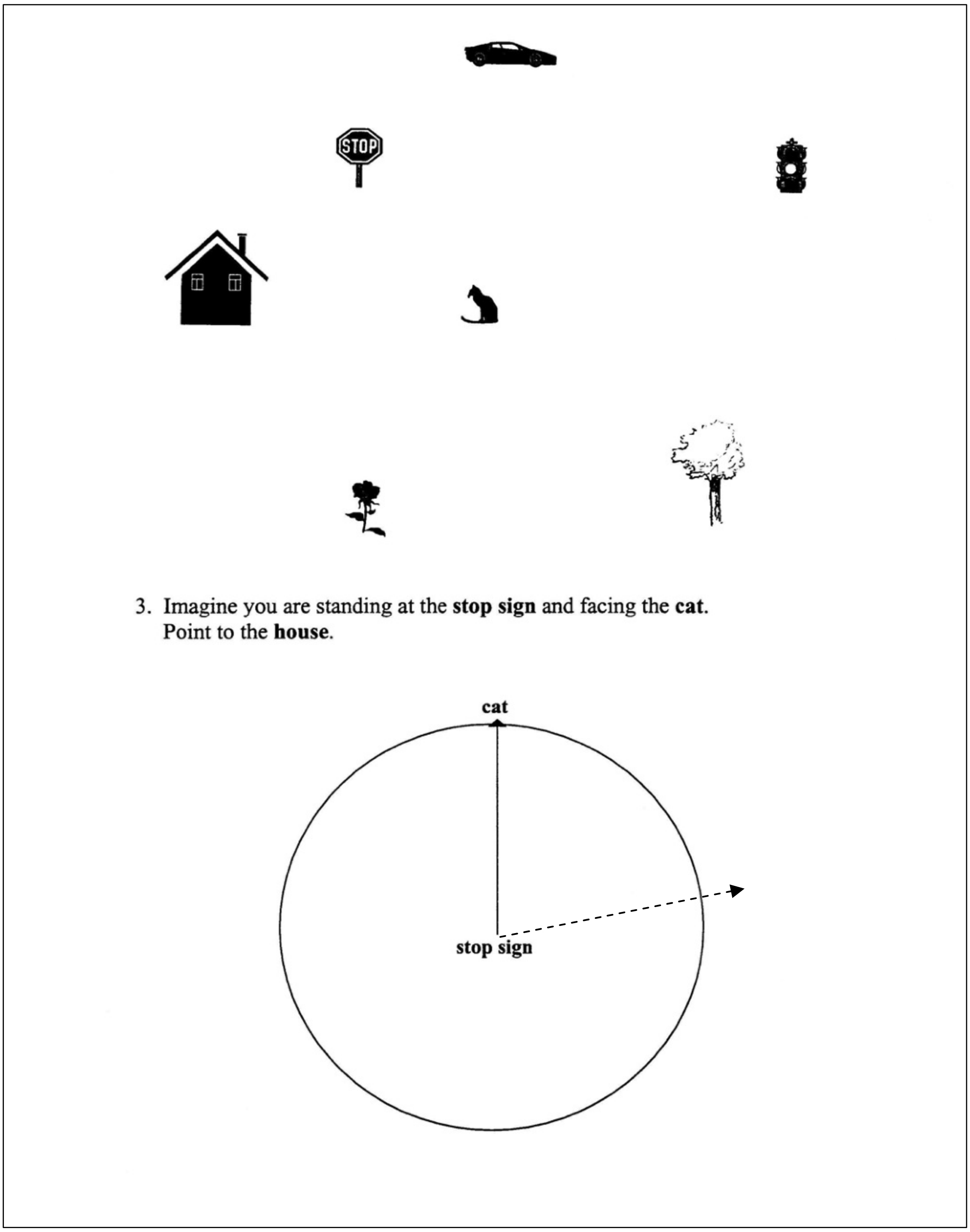


In this example, participants, shown as a yellow stick figure, are required to imagine themselves looking at the blue car. They are then asked to imagine pointing at the red lorry. Participants are then presented with a circle and a solid line running from the centre to the top marked with the object they are asked to imagine looking at, in this case the car. Participants imagined the objects in a different perspective and must draw a line (shown as a dotted line) from their imagined position to the object in the specified orientation. In other words, participants are required to take on a different perspective and imagine pointing to that object in the new perspective.

An example question and the array of objects used in the test are shown in Figure 4.2. The imagined orientation corresponds to an angle of approximately 83^{O} between the stop sign and the house. The dotted line shown corresponds to a line drawn by a participant who has correctly imagined the orientation.

Each problem uses the same vertical line but positions different objects in the object array at each point in the line. Pointing angles vary from 26^{O} to 333^{O}. The measurement used is the mean, absolute deviation in degrees from the correct angle. A large deviation indicates greater error in perspective taking. The test yielded two measurements. The average, absolute deviation from the correct orientation across all questions attempted, and the time taken to complete the test were recorded. The average absolute deviation ranged from 0^{o} (perfect accuracy) to 360^{o} (perfect inaccuracy). Angles were measured to the nearest degree since the measurements were performed manually with a 360^{o} protractor. The time taken was recorded in seconds and used to test for speed-accuracy trade-offs in the test.

Figure 4.2 Example of a spatial problem from the object perspective-taking test



4.2.4 Workload

The NASA TLX (Task Load Index) (Hart and Staveland, 1988) was selected to measure workload experienced during the task. All experiments require participants to complete a task: navigating a route. Therefore the task-based nature of the TLX is an appropriate tool to measure subjective workload. The TLX has been shown to be both a reliable and sensitive measure of workload (see Tsang and Wilson, 1997, for review). The TLX was selected due to the diagnosticity made possible by treating the subscales as separate, sensitive measures of the different components of workload. This technique is supported and discussed by Vidulich and Bortolussi (1988).

All subscales of the NASA TLX were used including the overall maximum and average workload ratings. Scales comprised 60 mm continuous scales marked with endpoints taken directly from Hart & Staveland. Hart & Staveland's definitions of the scales are shown in Table 4.4. Distance from the left end point in millimetres is used as the measurement. The scale questions, overall rating scale formats, question wording and instructions were taken directly from the NASA TLX handbook (Hart, 1986). In experiment two, a computer program was developed to automatically score the scale measurements and weightings. Although a proprietary programme was considered, poor interface design precluded its use in experiment two. To use the programme participants were given instructions verbally and a laminated card containing written scale definitions. Participants could refer to the definitions as often as they wished. Figure 4.3 and Figure 4.4 show screenshots of both the rating and weighting elements of the programme.

Figure 4.3 Screenshot of the workload rating programme

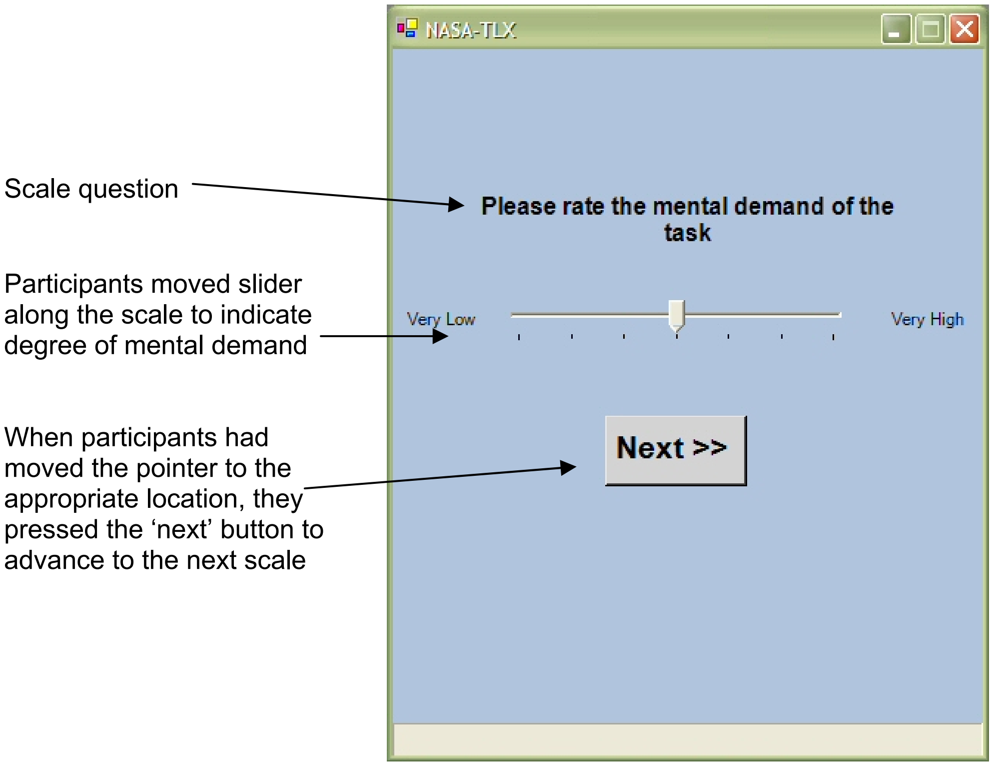


Figure 4.4 Screenshot of the workload weighting programme

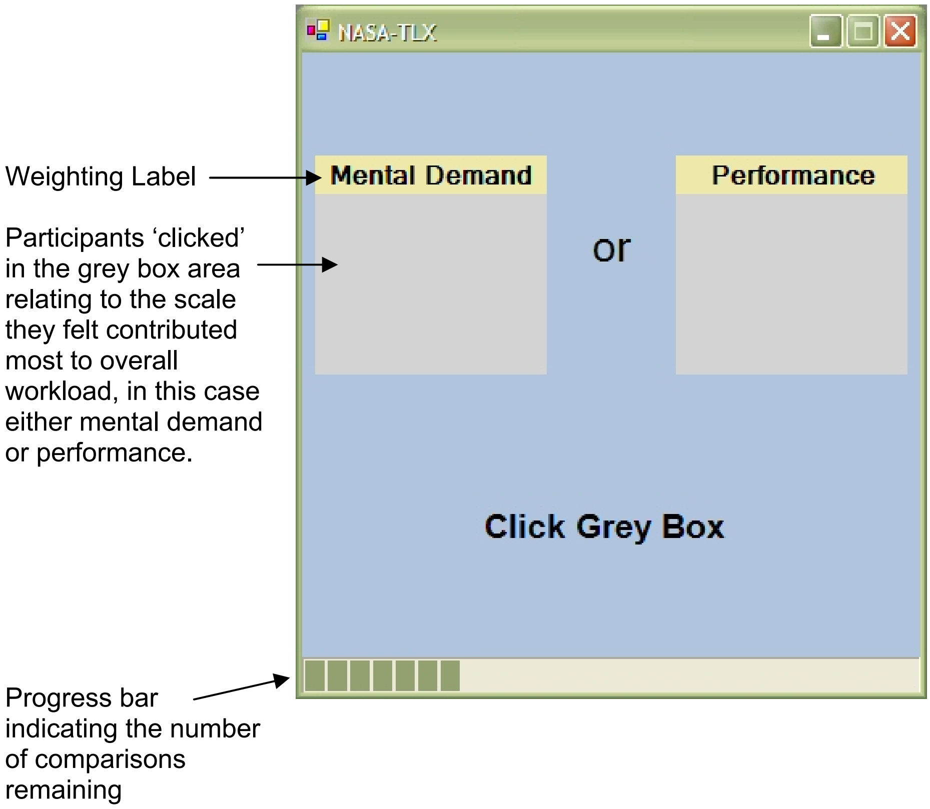


Table 4.4 Definitions of the NASA TLX Scales (Hart & Staveland, 1988)

Title	End-points	Descriptions
Mental Demand	Very Low/ Very High	How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Very Low/ Very High	How much physical activity was required? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Very Low/ Very High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Perfect/ Failure	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Very Low/ Very High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Very Low/ Very High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

4.2.5 Integrated navigation questionnaire (INQ)

A questionnaire was developed to assess participant's subjective experience of navigating the route in dimensions not considered by the other dependent variables. Twenty-five items were developed during a brainstorming session with other members of the research centre around two themes:

1. Confusion and anxiety when navigating with the mobile device
2. Confidence of route knowledge following navigation with a mobile device

These themes were selected to explain differences and relationships unrelated to the other dependent variables used in the studies. Examples of some of the concepts around which questions were developed are shown in Table 4.5.

Table 4.5 Concepts from which INQ questions were developed

Confusion and Anxiety	Knowledge and recall of Route
Lost	Returning to the start of the route
Confused	Complexity of route
Uncomfortable	Number of turns
Unsure of location	Giving directions to someone else
Disoriented	Recall of the distance travelled
Unsure of heading	Drawing the route

All questions developed for the first iteration of the INQ and their scoring directions are shown in Table 4.6.

Table 4.6 First set of questions used in the INQ

	Question	Direction
1	I could write down directions that I have taken on this route for a friend	+
2	I would be able to draw the route that I took	+
3	I felt confused as to where I was	-
4	I felt disoriented when walking on this route	-
5	This route was very complicated to navigate	-
6	I am uncertain of how far I travelled	-
7	I felt lost when navigating this route	-
8	I could use the picture of this route in my mind to navigate	+
9	I would be unable to find my way again if I had made a wrong turn on this route	-
10	I could identify the route I have just taken on a plan of the area	+
11	I can remember the direction from where I started	+
12	I felt under pressure when walking this route	-
13	There were too many turns to remember	-
14	I was not sure I was heading in the correct direction	-
15	I would be able to get back to where I started from quite easily	+
16	I would be able to tell somebody else how to navigate this route	+
17	I can remember the number of left or right turns I made to get to the end of this route	+
18	I am sure of how much time I took to walk along the route	+
19	I would not feel confident giving directions of this route to someone	-
20	I have a clear picture of this route in my mind	+
21	I am sure of the distance I have travelled	+
22	I felt uncomfortable when walking around this route	-
23	I was not sure where I was heading to on this route	-
24	Details on the map helped me to find my way through the route	+
25	I disliked finding my way using the plans	-

Response to items was assessed using a five-point Likert scale from 5 (strongly agree) to 1 (strongly disagree). Scores from questions worded in a negative direction were subtracted from six (maximum scale + 1) and then all scores were summed to give a single number representing subjective experience of navigation ranging from 25 to 125. As with the SDS, data from the questionnaire is treated as interval.

Further development of the questionnaire proceeded in two stages. Firstly a preliminary reliability analysis is performed at the end of Chapter 5 (Section 5.13.4, p163). This preliminary analysis will remove poor questions and shorten the questionnaire for use in experiments two and three. Following all experimental work, meta analysis of questionnaire results for all experiments will be performed. Another reliability analysis is conducted and a principal components analysis (PCA) clarifies the different constructs measured by groups of questions, helping to develop a more diagnostic questionnaire for future experiments.

4.2.6 System usability scale

The System Usability Scale (SUS) is a published scale which has been validated against many other scales of usability (Brooke, 1996). The scale was selected since it is short, only ten questions are presented, does not refer explicitly to desktop based systems and generates data that can be treated as interval and entered into statistical analysis.

The questionnaire wording and scoring procedure is taken directly from Brooke (1996). Each question is associated with a five point Likert scale from 1 (strongly agree) to 5 (strongly disagree). Table 4.7 shows the questions and scoring instructions. The sum of the scores is multiplied by 2.5 to give a single number between 1 and 100, reflecting usability. A usability score of 50 is considered satisfactory (Brooke, 1996) and this value is always shown as a reference line on any graph of SUS scores.

Table 4.7 Questions in the Systems Usability Scale (τ indicates response on the Likert scale)

	Question	Scoring
1	I think that I would like to use this system frequently	τ - 1
2	I found the system unnecessarily complex	5 - τ
3	I thought the system was easy to use	τ - 1
4	I think that I would need the support of a technical person to be able to use this system	5 - τ
5	I found the various functions in this system were well integrated	τ - 1
6	I thought there was too much inconsistency in this system	5 - τ
7	I would imagine that most people would learn to use this system very quickly	τ - 1
8	I found the system very cumbersome to use	5 - τ
9	I felt very confident using the system	τ - 1
10	I needed to learn a lot of things before I could get going with this system	5 - τ

4.2.7 Behavioural variables

Behaviours recorded during navigation task:

1. Pausing
2. Looking
3. Confusion
4. Plan / Device Rotation

Pausing is defined as a participant stopping to think about the current location and planning the next action or decision. Looking was recorded when participants visibly and purposefully searched for cues in the environment to assist in navigation of the route. Although participants are more-or-less continuously engaged in this behaviour, instances were recorded where this behaviour was visible and purposeful. Confusion was recorded whenever participants deviated from the route or failed to understand where they were in relation to the plan shown on the navigation device. Plan rotation was recorded whenever participants rotated the device or plan to correspond with the direction of travel or to make sense of cues in the environment.

One rater (the author) recorded instances of behaviour at a coarse-grained level since a more fine grained approach would require another observer. Estimating the reliability of observations made is not possible under these circumstances. As such, no statistical inference will be drawn from the results, rather comparison of location and amount of each behaviour observed throughout the route will be performed between conditions. Instances of these behaviours were coded and recorded on a paper plan of the experimental route.

4.3 Simulation of location-based services

In experiments one, two and three the location-based element of the information presented is simulated. Simulation is used in preference to positioning technologies for a number of reasons.

The routes and environment used in experiments one and two are inside buildings. Although a variety of positioning technologies do exist which allow location fixes inside, these technologies are very expensive, require modification of building infrastructure and present variable accuracy given the different environments used.

Experiment three is based outside and would be a candidate for GNSS technology such as GPS. This approach was rejected since the environment selected contains many urban canyons and blind spots which would adversely affect the reliability of GNSS and thus the level of experimental control achievable. The accuracy of GNSS positioning at any given point fluctuates with the time of day. This is due to satellites occupying different positions within orbits at different times. As such, a controlled study using GNSS technology would be inconvenient to implement since to ensure similar levels of accuracy, trials would have to be completed at similar times of day. In large experiments the increase in time required would be prohibitive.

Given these reasons, the location-based element of the experiments is simulated. The essence of an LBS for the purposes of the experiments is that it reflects the current environment that the participant finds him or herself in. The participant is then able to use this contextual information. Since all experiments involve navigating along a fixed route, the experimenter cued participants to tap a button at specific points in the route by clearly saying ‘next’ in the appropriate location. The software then presents the correct interface at the appropriate time and location.

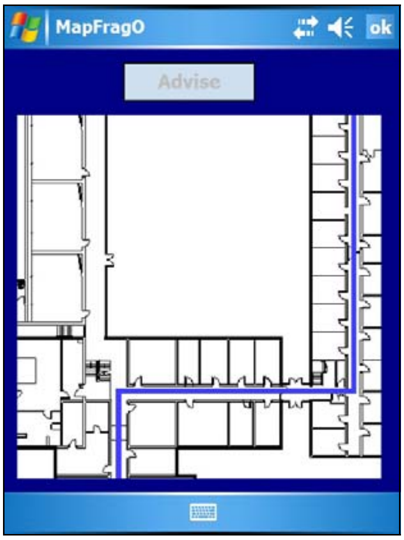
4.3.1 Development of spatial information

Different types of spatial information were developed and displayed to support navigation in order to test the experimental hypotheses in experiments one, two and three.

Experiment one

In experiment one, floor-plan information of the Sir Clive Granger building is used in all conditions. Overlaid onto the floor-plan, is a blue line that participants are required to follow to achieve successful navigation (Figure 4.5).

Figure 4.5 Example of the spatial information used in experiment one



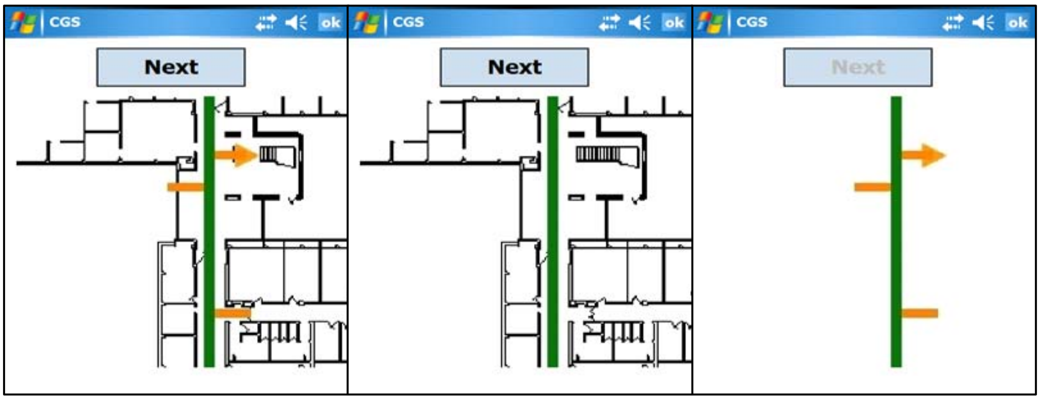
Floor plan information is often available to firefighters in large incidents. Testing participants understanding of information presented in this way provides useful parallel with the real world context presented in the thesis.

Experiments two and three

Spatial information used in Experiments two and three is developed in way that allows for the systematic removal and inclusion of different features of the environment. Furthermore, very similar information is used for the experimental conditions in both experiments to allow for overall comparison between environments in the meta analysis presented in Chapter 8.

Three stimuli for each experiment were developed: enhanced, route and simplified (Figure 4.6). The diagram shows the information overlaid onto a floor-plan, as in experiment two. The same information was used in experiment three overlaid onto OS MasterMap data. Figure 4.10 (B) shows an example of the enhanced information used in experiment three.

Figure 4.6 Examples of the spatial information used in experiments two and three



Enhanced	Route	Simplified

The route information is analogous to the information used in experiment one. A route overlaid onto either a floor-plan for the inside environment or basic OS MasterMap data for the outside environment. In the outside environment, outline MasterMap data was used without any colour or shading so that comparison with the inside environment would be possible. The enhanced information contained specific reference to changes in route direction and available paths in the environment. Stankiewicz and Kalia (2007) suggest that these features of the environment act as landmarks to anchor and orient an individual while navigating. Finally the simplified information has only the available paths and the main route participants are required to follow without the floor-plan or MasterMap information displayed. The systematic variation of the stimuli allow for conclusions to be reached on which type of information differentially affects navigation. The information used in the studies eliminates other factors which could be used such as the colour of the backgrounds or shading to reflect the type of land cover or features.

4.3.2 Software development

A process of continuous development was adopted for the software. The interface elements and data recording capability of the software underwent significant design changes as the experimental studies progressed. This development was partly due to the author's improvement in programming skills and partly to the availability of Microsoft Compact Framework 2.0 during the course of the research. The versions of software used are documented in Table 4.8. Detailed screenshots of the software are shown in Figure 4.7 to Figure 4.10.

Table 4.8 Summary of software development as the experimental programme progressed

	Experiment 1 (Version 1)	Experiment 2 (Version 2)	Experiment 3 (Version 3)
Language	Visual Basic .net (Compact Framework 1.1)	Visual Basic .net (Compact Framework 1.1)	Visual Basic .net (Compact Framework 2.0)
Data Recorded	No	Yes. Stamps start and end time and participant number on output file	Yes. All data that can be recorded is recorded on comprehensive output file
Timing Support	None. All timing is manual	Limited: Start and end times recorded by Windows system timer for enhanced accuracy	Comprehensive: Start and end times recorded. All intermediate times recorded in addition to length of time that map is viewed. All timings use the Windows system timer for enhanced accuracy
Embedded Experimental Control	No. Different conditions require separate programs	No. Different conditions require separate programs	Yes. Conditions are automatically counterbalanced and controlled from an experimenter control screen
Practice Program	Separate Program to train technique	Separate Program to train technique	Embedded Program to train technique
Interaction Features	Next button disabled for 5 seconds following tap to prevent double clicking	Next button disabled for 5 seconds following tap to prevent double clicking. Audio feedback when button is pressed	Next button disabled for 5 seconds following tap to prevent double clicking. Unique audio feedback for each button when pressed.
Image Management	Images called from memory card	Images embedded into program and made visible/invisible depending on sequence	Images embedded into program using image containers and managed by the program.

Figure 4.7 shows screenshots of the Version 1 software. Version 1 is the most basic version of the software offering a single interaction type. Participants tap the ‘Advise’ button (screenshot A) in response to instruction from the experimenter, advancing the plan which displays the next location.

In pilot studies, participants frequently double-tapped the advise button. This action caused the map segments to be shown out of sequence and the experimental trial had to be stopped. To prevent the plan segment advancing on a double tap, the button was disabled for five seconds following input. Screenshot B illustrates the disabled ‘Advise’ button. During this delay any further taps would not be registered by the software, preventing any unwanted progression of the plan segment.

Figure 4.7 Screenshots of version 1 software

A B

Figure 4.8 shows screenshots of version 2 software. Screenshot A shows the experimenter start-screen. Participants select a three digit number and this number is entered into the program. The start and finish times of the route are recorded in a text file, identified by the participant number entered. Screenshot B shows an example of experiment 2 stimuli. The design and interaction are very similar to the

first experiment except the ‘advise’ button has been renamed the ‘Next’ button to reflect experimenter instruction.

Figure 4.8 Screenshots of version 2 software

A B

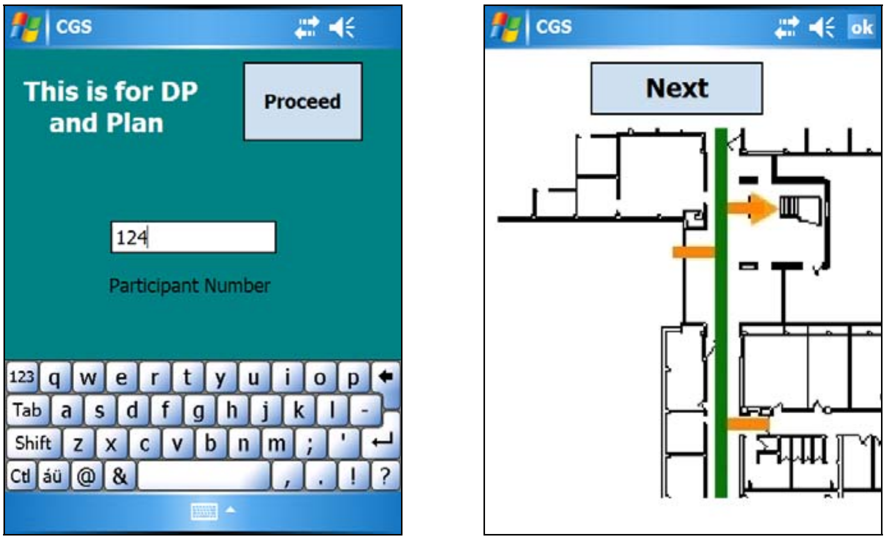
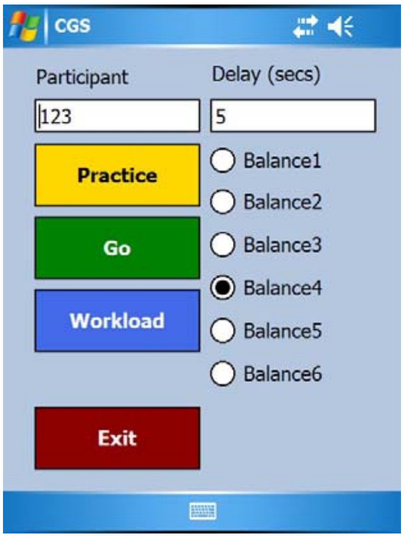


Figure 4.9 shows screenshots of Version 3 software. Screenshot A shows the fully featured experimenter interface. Participant number and button delays are entered by the experimenter. As with version 2 software, all data were associated with the participant number and recorded in a single text file. The ‘balance’ radio-buttons automatically counterbalance the presentation of the different stimuli. Different counterbalancing was selected depending on which experimental block participants were allocated to. The different phases of the experiment: practice, trial and workload were controlled from this screen. The experimenter selected the phase by tapping the coloured practice, go or workload buttons.

All instructions were delivered on the PDA (Screenshot B). Participants tapped the next button to advance through the instruction screens, familiarising themselves with the method of interaction used in the actual experiment.

Figure 4.9 Screenshots of version 3 software: experimenter and Instruction screens

A



B

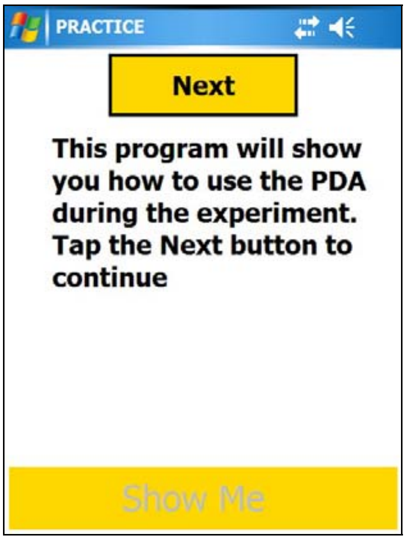
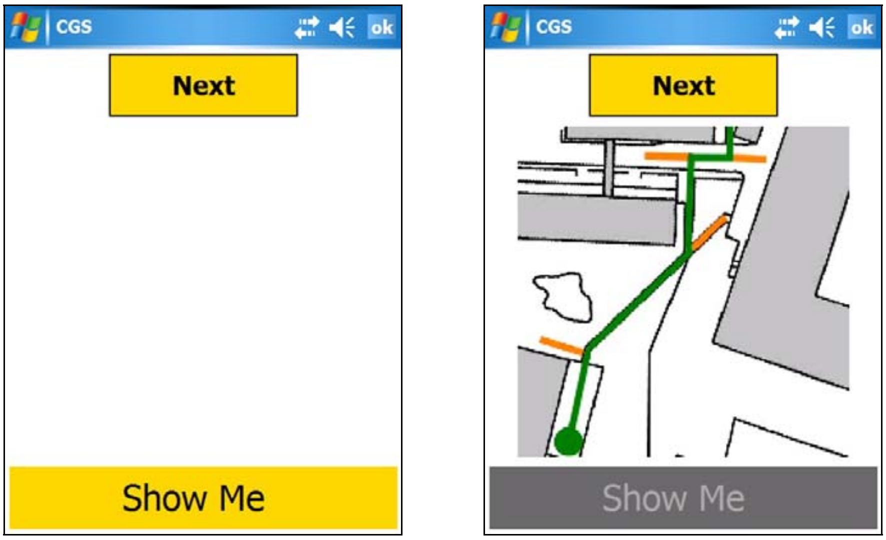


Figure 4.10 shows the screen participants are shown during an experimental trial using version 3 software. Screenshot A is the default screen. Without input from the participant, no information is displayed. As in version 1 and 2 software, the participant taps the next button when instructed by the experimenter. When tapped, the 'Next' button was disabled as in previous experiments (Not shown). In order to view the spatial information, participants tapped and held the 'Show Me' button, illustrated in screenshot B. When participants tapped and held the 'Show Me' button, the appropriate map was displayed for as long as the button was held down. This time was recorded on the participant's data file in order to infer the length of time spent viewing the map. While being held down, the 'Show Me' button was disabled and greyed (screenshot B). When participants released the button, the spatial information was cleared and the screen returned to the default view (Screenshot A).

Figure 4.10 Screenshots of version 3 software: experimental trial screens

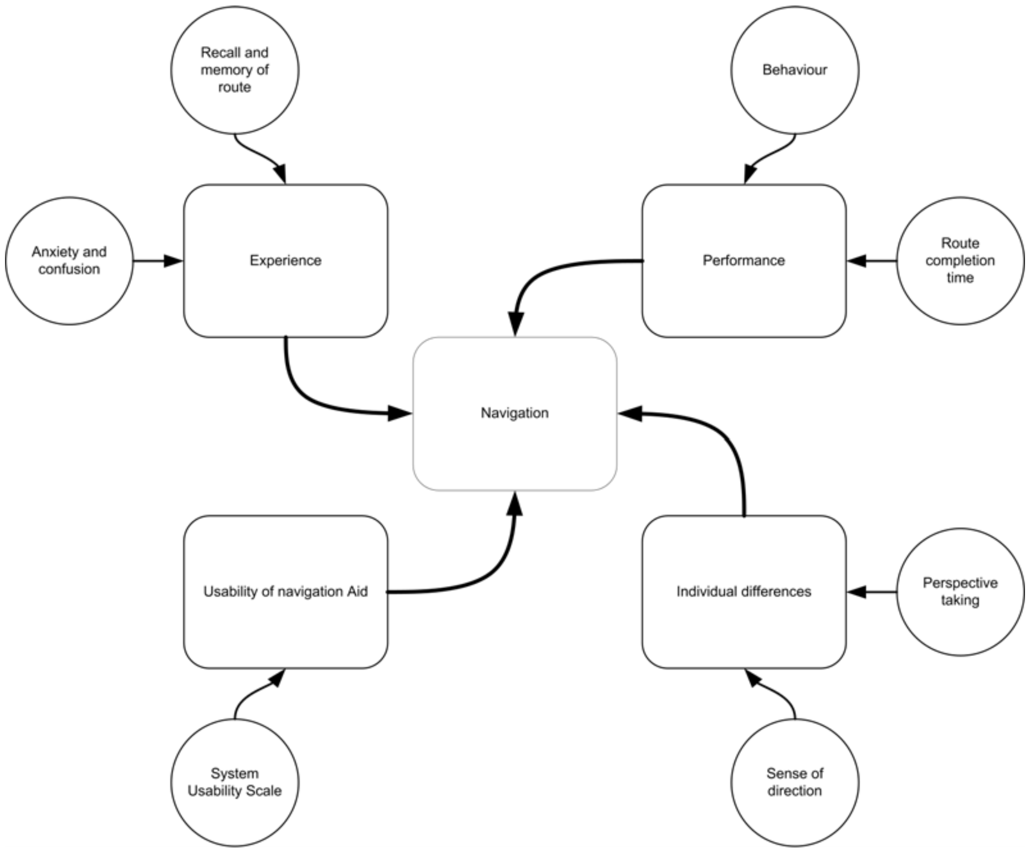
A B



4.4 Summary of dependent variables

The variety of dependent variables used in the experimental work reflects different aspects of navigation. The human factors approach taken to navigation goes beyond simply arriving at the correct destination and expands to include individual differences, workload while navigating and the usability of the mobile navigation aid itself. A summary of these variables is shown in Figure 4.11.

Figure 4.11 Summary of dependent variables used in experimental work



4.5 Presentation of results

Unless otherwise stated:

- All error bars represent one standard deviation
- All statistical tests are two-tailed

Chapter 5 Experiment One

5.1 Introduction

Currently, firefighters use paper floor-plans to gain an understanding of the layout of buildings during incidents. This floor-plan information is available for larger premises. Interviews conducted in Chapter 3 suggest that often this information is not referred to. Information is often is too complicated to rapidly inform navigation sometimes required at the start of an incident. This experiment compares paper floor-plan information with three other methods of presenting the same floor-plan information on a mobile device. The methods of presentation are general enough to be employed on a variety of novel devices but for the purposes of the experiment, a PDA is used to display the floor-plan data. The spatial information was presented in four different ways, summarised in Table 5.1.

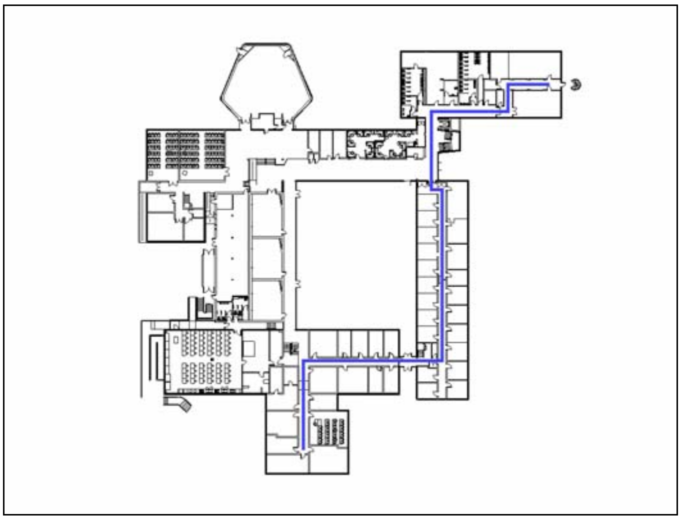
Table 5.1 Summary of the different methods of presentation

Condition	Paper Plan	Plan Overview	Allocentric Segment	Egocentric Segment
Overview of area or segment:	Overview	Overview	Segment	Segment

In the paper plan condition, participants are presented with an entire plan of the area. In the remaining three of the methods: plan overview, allocentric segment and egocentric segment, involved presenting the spatial information electronically on a PDA. Egocentric information is presented to participants track-up on the first presentation of the map. Initial presentation of allocentric information was in a fixed, north-up orientation, participants then rotated the device to their preferred orientation. The limited screen size (77mm × 58mm) of the PDA means that it is not possible to display the full extent of the plan on the PDA screen. Two methods were used in order to communicate the information to participants. In one method, the entire map was available to participants to move around within the screen (plan overview condition). The second type of presentation divided the map into route segments; participants could not choose which parts of the map to use to navigate in these conditions since the information displayed was under the control of the device. In the overview conditions, participants could view any part of the plan as they wished Zimmer (2004) suggests that humans are able to navigate from, and recall good overall spatial information from segments of maps. In their study, spatial knowledge gained from consecutive presentation of map segments was as effective when informing navigation as overall information being presented. This finding is relevant to the present study since presenting less information by using small segments is an effective way of overcoming limited screen sizes, especially if the formation of spatial knowledge is not impaired when using this method of presentation Burnett and Lee (2005) found that the formation of a cognitive map from fragmented information found in in-car navigation systems is impaired. However, since the focus of this experiment is navigation rather than memory of the route this is an effective way of presenting the information. Unlike the previous method, participants will not have access to the full plan, rather a static plan that refers to the immediate environment. Aretz and Wickens (1992) found that track-up, or egocentric presentation of map information reduced workload when navigating. Seager and Stanton-Fraser (2007) also replicated this finding when a map showing a small segment of the environment, as in this experiment, is automatically rotated. in order to test these findings in the current context both initial egocentric and allocentric presentation of the segments will be used in the experiment.

Participants were required to navigate a route of 120.7m around the Sir Clive Granger building at the University of Nottingham building using one of the four types of navigation support. The floor plan and route are shown in Figure 5.1. The route was restricted to a single storey. Three representations were displayed on the PDA.

Figure 5.1 Plan of Sir Clive Granger building with route shown as a continuous line (Not to scale)



5.2 Experimental Hypotheses

- Different representations will result in differences in route completion time
- Different representations will result in differences in workload experienced
- Different representations will generate different experiences of navigation
- There will be relationships between route completion time and workload experienced
- There will be relationships between route completion time and subjective measures
- There will be relationships between workload and subjective measures

5.3 Design

Four experimental conditions were developed to test the experimental hypotheses. The study is a full, between groups design. The conditions are summarised in Figure 5.2. The first method of presentation was the paper plan. The second, electronic, method of presentation was to present the entire plan in an image viewer (Figure 5.3). Participants were required to use the PDA stylus to move parts of the floor plan into view on the screen depending on where they were in the route. In the third and fourth methods, the floor plan was split into parts and these segments were presented to participants, in sequence, on the screen at the appropriate location (Figure 5.4). The segment method of presentation was split into two further groups. In the allocentric segment condition, the plan maintained the same initial orientation throughout the route. In the egocentric segment condition, the segment was rotated relative to the position of the user, equivalent to rotating a map automatically.

Figure 5.2 Experimental conditions

Condition	**Paper Plan**	**Plan Overview**	**Allocentric Segment**	**Egocentric Segment**
Overview of area or segment:	Overview	Overview	Segment	Segment
Orientation Assistance:	×	×	×	✓
Interaction:	Any available to participant. Rotating of plan allowed	Moving image around the screen using a finger. Rotation of device allowed	None available: Rotating of device allowed	None available: Rotating of device allowed

Figure 5.3 Participant using the PDA in the plan overview condition

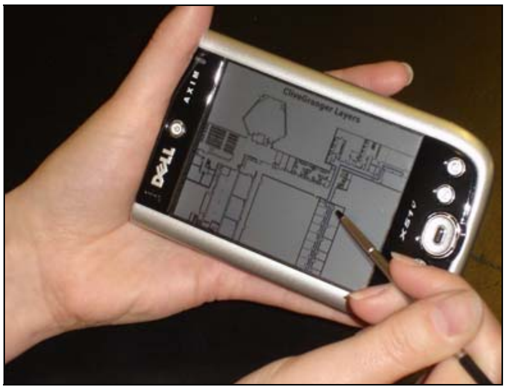


Figure 5.4 Participant using the PDA in a segment condition

Figure 5.5 Participants using the navigation support in each of the four conditions

Paper Plan | Plan Overview | Plan Segments

5.3.1 Dependent variables

Core dependent variables used in this experiment are shown in Table 5.2. Full details of these dependent variables can be found in the experimental methodology (Chapter 4, p100).

Table 5.2 Core dependent variables used in experiment one

Dependent Variable	Measurement
Performance	Route completion time (seconds)
Individual Differences	i. Sense-of-Direction Scale & ii. Object Perspective taking Test
Workload	NASA-TLX (Scales only)
Experience	Integrated Navigation Questionnaire (INQ)
Behaviour	Behaviour checklist

5.3.2 Power analysis

Forty-eight participants were used in the study. This corresponds to twelve participants per experimental condition. No literature that could contribute to a realistic calculation of power or inform selection of one of Cohen's standard effect sizes is available. Indeed, this experiment will produce data that will inform power calculations in future experiments.

5.4 Method

5.4.1 Participants

Forty-eight participants completed the study. Participants were drawn from staff and students at the University of Nottingham. Data from four participants was excluded from the analysis since these participants did not appear to understand the requirements of the task despite clarifications to the instructions being given. Forty eight participants completed the study. Male and female participants were counterbalanced across conditions. All participants had English as a first language and reported normal or corrected to normal vision. Table 5.3 and Table 5.4 show full details of participant's age and familiarity with the experimental environment.

Table 5.3 Age, in years, of participants

	Age (SD)			
Condition	Paper Plan	Plan Overview	Allocentric Segment	Egocentric Segment
Male	22.4 (2.4)	26.3 (8.7)	29.1 (12.2)	25.2 (6.4)
Female	25.6 (8.8)	21.8 (6.7)	28.6 (8.6)	24.6 (5.7)
Total	24.3 (6.8)	24.1 (7.8)	28.9 (10.4)	24.9 (5.8)

Table 5.4 Familiarity with experimental environment

	Familiarity (SD)			
Condition	Paper Plan	Plan Overview	Allocentric Segment	Egocentric Segment
Male	1.8 (0.4)	2 (0.0)	1.4 (0.8)	1.5 (0.5)
Female	1.1 (0.4)	1.5 (0.8)	1.4 (0.5)	1.5 (0.8)
Total	1.4 (0.5)	1.8 (0.6)	1.4 (0.7)	1.5 (0.7)

5.4.2 Materials

For each condition, navigation support was developed in line with the experimental treatments.

Presentation of plan data

Paper Plan

A laminated plan was given to participants at the start of the route.

Plan Overview

A digital image of the plan was displayed, full screen on a Dell Axim™ X51v PDA. Resco® image-viewer software was used to display the image. The full image is too large to be displayed on the screen so participants interacted with the device by moving the image using their finger on the touch-sensitive screen.

Plan Segments

Version 1 of the software is used to present the plan segments. Full details of the software are discussed in Chapter 4. A screenshot of the type of display experienced by participants is shown in. Figure 5.6 The division of the area into plan segments is shown in Figure 5.8.

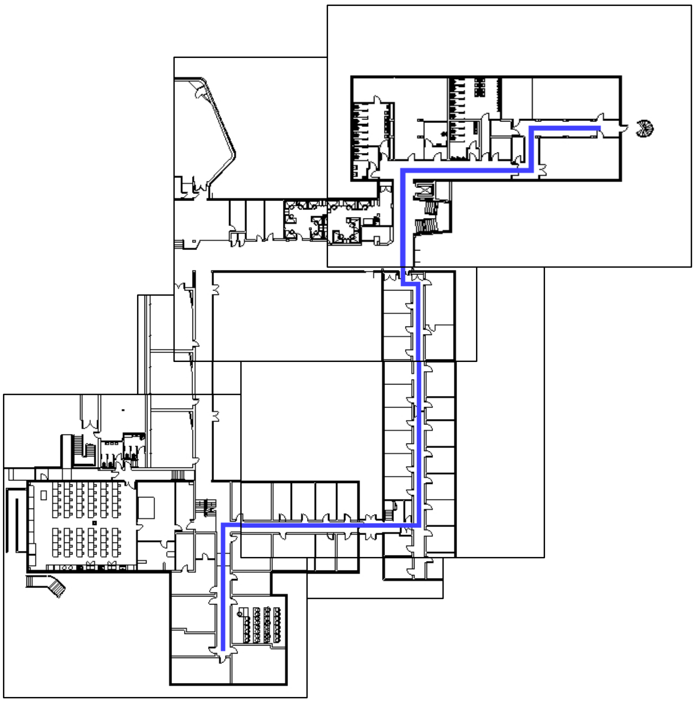
Figure 5.6 Screenshot of the type of display used

Route Selection

A route in the Sir Clive Granger Building, University of Nottingham was selected for the experiment. The route was selected since it contains several 90^{O} turns and as such is not straightforward to navigate or recall. Also, the route mainly consists of corridors which contain few distinguishing features or distractions. On a practical level, the route also avoids areas which become crowded by students such as the cafeteria or the lecture theatres. Figure 5.8 shows how these segments ‘mesh’ together if they were viewed as a whole. Figure 5.7 shows examples of the route used in the study.

Figure 5.7 Examples of the route navigated

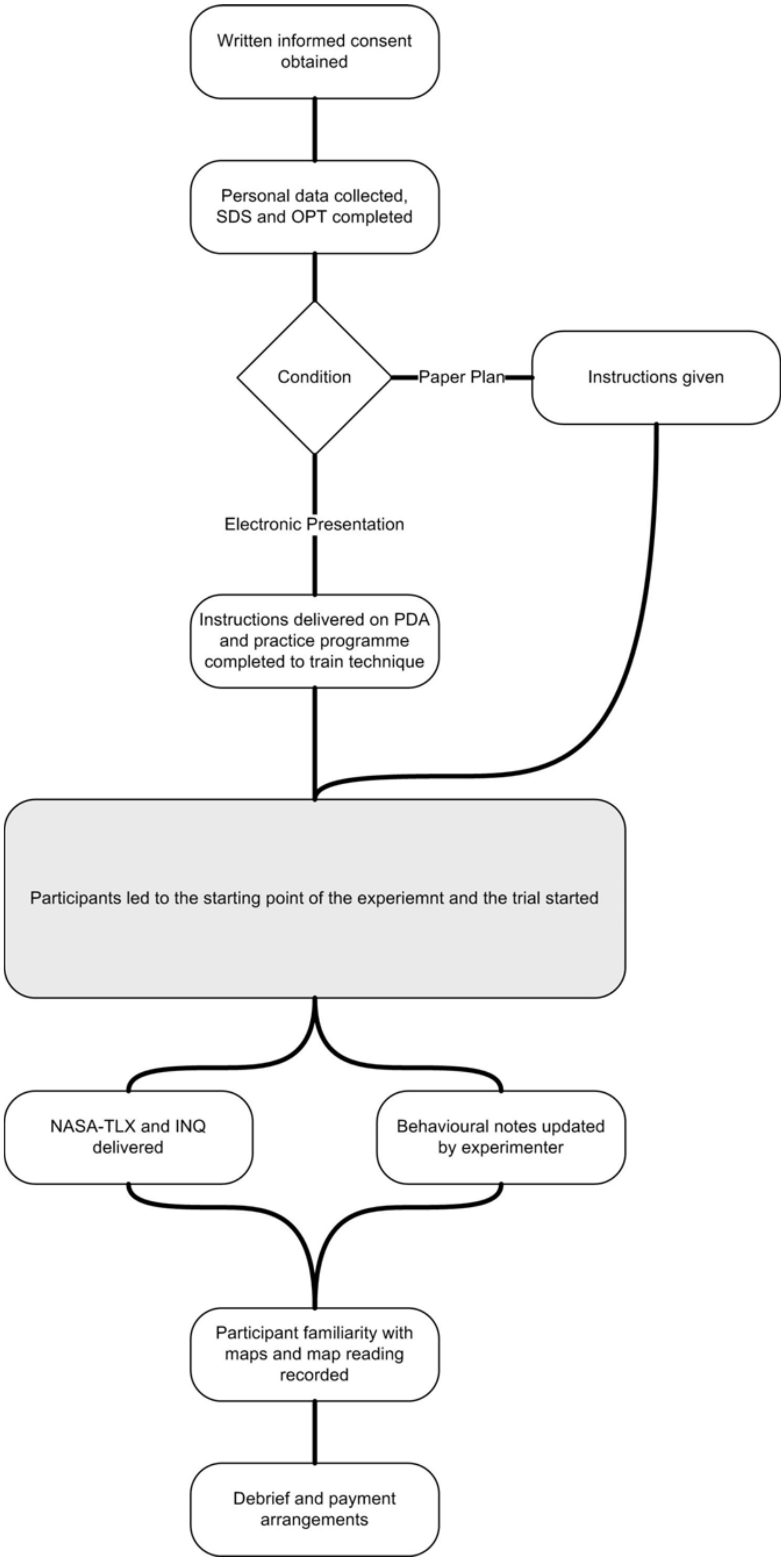
Figure 5.8 Composite of plan segments arranged in order



5.4.3 Procedure

Figure 5.9 shows a flow diagram of the procedure used in experiment one. The description of specific parts of the procedure are discussed below.

Figure 5.9 Diagram of the procedure used in experiment one



Participants gave written, informed consent in a room away from the route taken in the experiment. Participants then were required to submit personal data and complete the complete the Santa-Barbara Sense of direction questionnaire and the Object Perspective-Taking Test.

Participants completing trials in the PDA conditions then had the opportunity to use the PDA and practice with the interface they would be using with stimuli comparable to, but not actually used in the experiment.

When participants indicated that they were comfortable interacting with the PDA, they were led to the starting point of the experiment. The route taken to the starting point was deliberately selected so that no part of the experimental route would be either traversed or visible to the participant.

The participant was then handed the PDA or paper plan and instructed to start when ready. Timing was started by the experimenter. At specific points on the route, the experimenter would instruct the participant to advance the map by tapping the 'Next' button. This instruction was also given in the paper plan condition to maintain experimental control, but in this condition no action was taken by the participant. The experimenter counted instances of observed behaviour (see Section 4.2.7, p114) on a form during the experiment.

When participants completed the route the timing was stopped by the experimenter and participants were led into another room, adjacent to the completion point. Participants then completed the NASA-TLX workload questionnaire and the Navigation questionnaire. Whilst participants were engaged in these tasks the experimenter updated behavioural notes and noted anything unusual about the trial. Participants then indicated their level of familiarity with maps and map reading and their employment. Participants were then debriefed and arrangements for payment were put in place.

5.5 Results: individual differences

5.5.1 Object perspective-taking test (OPT)

The OPT score is the absolute deviation (in degrees) from the true angle participants are required to draw. The psychometric properties of the test are discussed in Hegarty and Waller (2004) and comparison with their results is drawn. Descriptive statistics are shown in Table 5.5. Results are broadly comparable to Hegarty and Waller (2004).

Exploratory Analysis

The sample used in the present study showed more variation which could be attributed to differences in the sample tested. Scores exhibit severe skew and kurtosis and the Shapiro-Wilks (W_s) test reveals significant departure from normality ($W_{s(48)}$= 0.72, p< 0.001). The data were adjusted in line with the approach taken by Hegarty and Waller (2004). Participant scores greater than three standard-deviations from the mean were adjusted to exactly three standard deviations in order to control skew and reduce variance. Three scores were treated in this way. All subsequent analyses will use the adjusted scores.

The re-expression does reduce skew, kurtosis and variance but not sufficiently to conclude that scores are distributed normally ($W_{s(48)}$ = 0.77, p<0.001). A reciprocal transformation was applied to the adjusted data to reduce the impact of extreme values in the positive tail. Following this transformation the data still did not meet the assumptions for parametric analysis, as such, only non-parametric statistics will be applied to the OPT scores.

Analysis

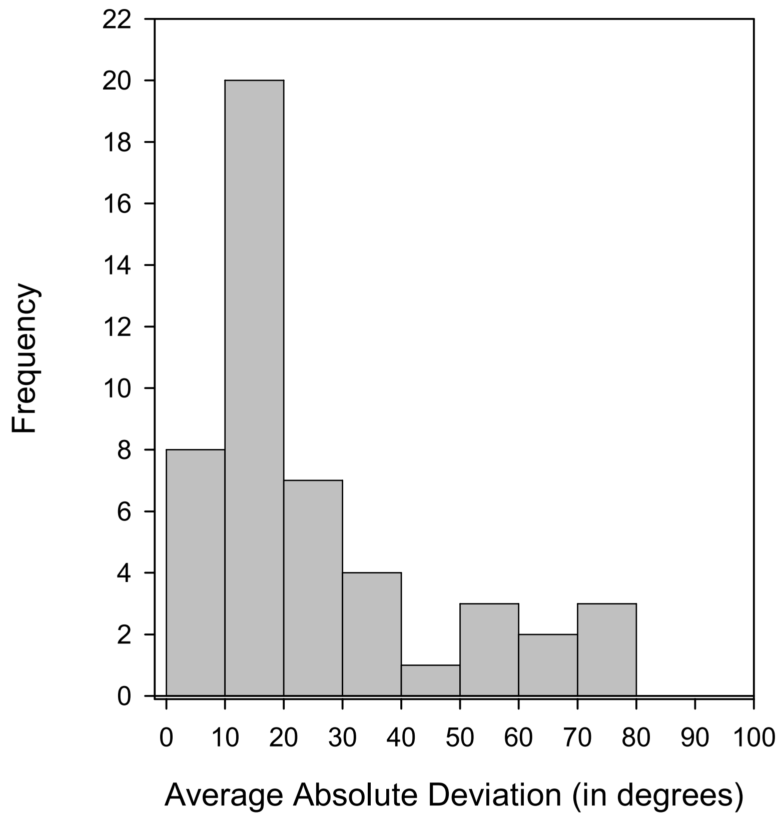
The adjusted scores are shown in Table 5.5. and compare well with Hegarty and Waller (2004). The distribution of the scores is very skewed and approximates a Poisson distribution rather than a normal distribution (

Figure 5.10).

Table 5.5 Descriptive statistics for the OPT and comparison with results obtained from Hegarty & Waller (2004)

	Mean Score (Degrees)	SD	Skew (SE)	Kurtosis (SE)
Current Study (Unadjusted)	27.2	26.5	2.2 (0.3)	4.9 (0.7)
Hegarty & Waller (2004)	24.53	14.29	1.51	2.32
Current Study (Adjusted)	25.5	21.1	1.4 (0.3)	1.0 (0.7)

Figure 5.10 Histogram showing the distribution of angle deviation scores (adjusted)



In addition to the test scores, the time taken to complete the test (in seconds) and the number of problems attempted was recorded. These measurements were taken to test for speed accuracy trade-off in the results. The correlation matrix is shown in Table 5.6.

Table 5.6 Correlation matrix showing OPT score, time taken to complete test and the number of problems attempted

N = 48	Time (Seconds)	Problems Attempted
Score (Degrees)	$r_s = 0.36$ $p<0.05$	$r_s = -0.39$ $p<0.01$
Time (Seconds)		$r_s = -0.58$ $p<0.01$

Significant correlations exist between all variables. No speed-accuracy trade-off emerges from the data. Poorly performing participants took longer to complete the test and attempted fewer problems than higher performing participants.

5.5.2 Santa Barbara sense of direction scale (SDS)

Exploratory Analysis

Exploratory analysis of participant scores from the SDS reveal no significant departure from normality ($W_{s(48)} = 0.98$, $p>0.05$). Skew and kurtosis are within two standard errors so the data is suitable for parametric analysis. Descriptive statistics are shown in Table 5.7.

Table 5.7 Descriptive statistics for the SDS scale

Mean Score	SD	Skew (SE)	Kurtosis (SE)
49.6	15.4	0.4 (0.3)	0.7 (0.7)

5.5.3 Relationship between OPT and SDS

Another correlation was performed between the SDS and OPT scores to test the hypothesis that there is a directional relationship between perception of spatial ability and spatial ability inferred from the OPT, better accuracy displayed on the

OPT will suggest better perception of spatial ability. A weak negative correlation revealed that greater inaccuracy on the OPT is significantly related to a more negative perception of spatial ability on the SDS (r_s = -0.26, N = 48 p <0.05, one-tailed test).

5.6 Results: analysis of differences

5.6.1 Participants

A 2 × 4 ANOVA ([male vs. female] × [paper plan vs. plan overview vs. allocentric segment vs. egocentric segment]) revealed no significant difference in age between condition ($F_{(3,40)}$ = 0.9, p> 0.05) or between sex ($F_{(1,40)}$ = 0.06, p > 0.05). A non-parametric ANOVA (Kruskal-Wallis) indicated no significant differences in familiarity between conditions ($\chi^2_{(3)}$ = 2.6, p >0.05). No significant difference in familiarity was found for participant sex (W = 503.5, p > 0.05).

5.6.2 Route completion time

Hypothesis

Different representations will result in differences in route completion time

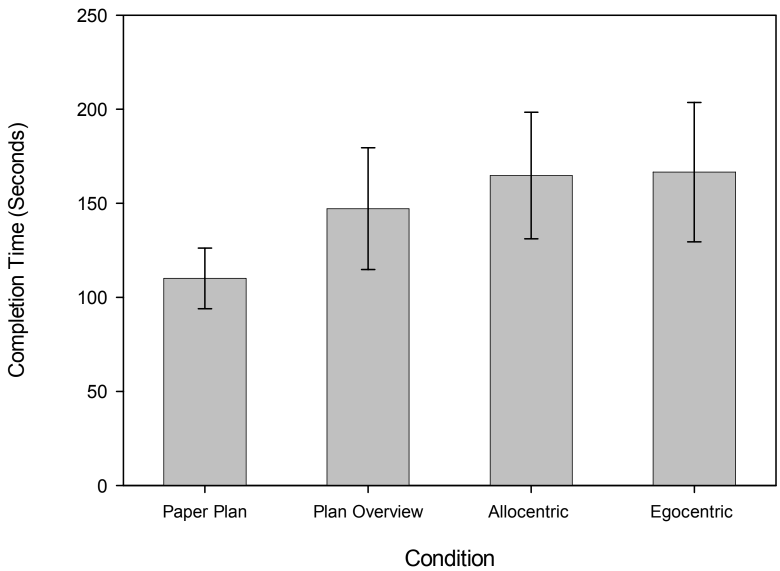
Exploratory Analysis

Exploratory analysis revealed acceptable skew and kurtosis in each condition. Skew and kurtosis were verified as acceptable when equal to less than twice their standard-errors. The Shapiro-Wilks test indicated no significant departure from normality in all conditions. A logarithmic transformation was applied to the data which stabilised the per-condition variance. All subsequent analyses use the transformed data.

Analysis

Figure 5.11 clearly shows lower completion times and less variation in completion time for participants using the paper map. Higher variation and completion time is apparent in the other conditions. A one-way ANCOVA (paper plan vs. plan overview vs. allocentric segment vs. egocentric segment) was conducted to test the hypothesis that significant differences in completion time result from different ways of presenting spatial information. Participant SDS scores were entered into the model as a covariate since a significant linear relationship between SDS scores and log completion time was found ($r = -0.33$, $N = 48$, $p<0.05$). Scores on the OPT are not included in the model since they do not meet the assumptions for parametric analysis. The ANCOVA revealed a significant effect of condition on route completion times ($F_{(3,43)} = 10.4$, $p<0.01$). The analysis also revealed the SDS as a significant covariate in participant completion times ($F_{(1,43)} = 4.5$, $p<0.05$).

Figure 5.11 Mean completion time (in seconds) for each condition



Simple contrasts were performed between each of the four conditions, controlling for the covariate. Significance values for the differences in means are shown in Table 5.8.

Table 5.8 Simple contrasts between mean completion times

	Plan Overview	Allocentric Segment	Egocentric Segment
Paper Plan	p<0.01	p<0.001	p<0.001
Plan Overview		p>0.05	p<0.1
Allocentric Segment			p>0.05

Table 5.8 supports the relationship seen in Figure 5.11. Significant differences were found between completion time in the paper plan condition and all other conditions. The difference in completion time between the egocentric segment condition and the plan overview approached significance but did not reach it ($p = 0.59$).

These results support the hypothesis that different types of presentation result in differences in performance.

5.6.3 Workload

Hypothesis

Different representations will result in differences in workload experienced

Scores from the six NASA-TLX sub-scales were entered into an exploratory analysis. Distances in millimetres along the visual-analogue scales are used values. Workload does not have dimensions.

The performance scale of the TLX is scored in reverse direction; a lower score indicates a better performance. The score on this scale was reversed by subtracting the participant score from 60 (the maximum extent of the scale) to produce a more intuitive direction.

Exploratory analysis

Exploratory analysis revealed no significant skew or kurtosis in any variable with the exception of physical demand which is skewed in the negative direction and has a high kurtosis co-efficient indicating many scores at the lower end of the physical exertion scale. This is expected since minimal physical exertion was necessary in the task. Reduction in skew and kurtosis could not be achieved by transforming the data so only non-parametric statistics will be used when analysing this subscale.

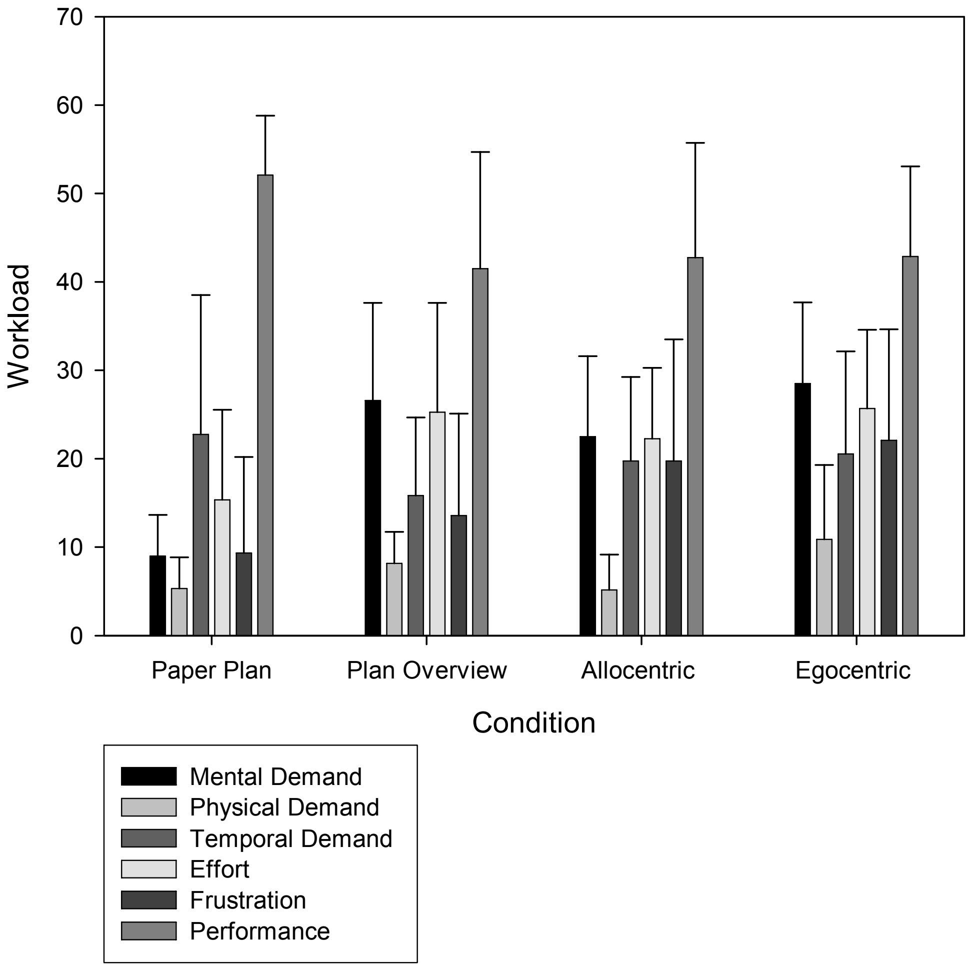
Levene's test for homogeneity of variance indicated significant differences in variance between conditions in the mental demand scale. Differences in variance between the temporal and effort scales approached significance. In order to stabilise variance between conditions within each scale, the data were re-expressed using a logarithmic transformation. Re-examination of the data revealed improved homogeneity of variance, particularly in the mental demand and temporal demand scales. All parametric statistics are derived from the transformed data. One-way ANOVAs (paper plan vs. plan overview vs. allocentric segment vs. egocentric segment) and Tukey HSD *post hoc* tests are used in all cases to test pairwise differences. No significant linear relationships were found between the transformed data and the SDS scale. As such, SDS scores are not entered into the analysis as a covariate.

Analysis

Figure 5.12 shows mean workload on each subscale of the NASA-TLX against condition.

Figure 5.12 Mean scores on each subscales of the NASA-TLX for each condition

(Error bars (±SD) are symmetric)



Mental Demand and Effort

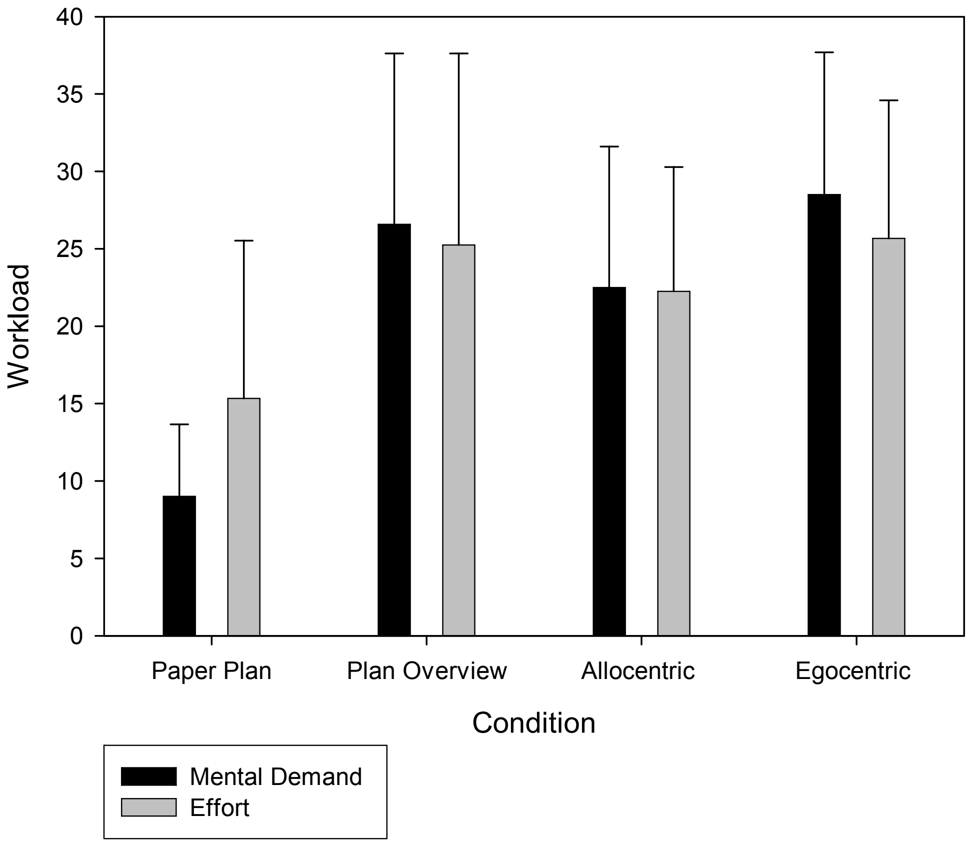
A similar relationship emerges from both sub-scales. The paper plan produces the lowest levels of mental demand. The plan overview and the egocentric segment conditions elicit the highest levels of mental demand whilst the allocentric segment elicits in intermediate level of mental demand between the paper plan and the other conditions. This pattern is clarified in Figure 5.13. Results for mental demand indicate less variation in the paper plan condition than other conditions. A similar pattern of variation is seen in other scales.

The main effect of presentation method had a significant effect on the level of mental demand experienced ($F_{(3,44)} = 19.1$, $p<0.001$). *Post hoc* tests revealed that differences between the paper plan and all other conditions were significant. No other significant pairwise differences between conditions were found.

Table 5.9 Tukey HSD tests between paper plan and all other conditions for Mental Demand

		Electronic Plan	Allocentric Segment	Egocentric Segment
Paper Plan	Difference	-0.49	-0.42	-0.53
	Significance	<0.05	<0.05	<0.05

Figure 5.13 Mental demand and effort subscales of the NASA-TLX



The main effect of presentation method had a significant effect on the level of effort reported ($F_{(3,44)} = 4.2$, $p<0.02$). *Post hoc* tests support the emergent relationship shown in Figure 5.13. Effort is highest in the egocentric segment and plan overview conditions. There are significant differences between these two conditions and the paper plan. No significant difference in effort was found between the allocentric segment and the paper plan. *Post hoc* tests are shown in Table 5.10.

Table 5.10 Tukey HSD tests between paper plan and all other conditions for effort

		Electronic Plan	**Allocentric Segment**	**Egocentric Segment**
Paper Plan	Difference	-0.27	-0.24	-0.31
	Significance	<0.05	>0.05	<0.02

Performance and frustration

With reference to Figure 5.12, participants rated their performance as better in the paper plan condition than any of the other conditions. A 'negative' of the mental demand and effort scales emerges in the performance data. Perception of performance improves as effort and mental demand fall, however, this relationship is very weak. The overall ANOVA indicates no significant differences in rated performance between the experimental conditions ($F_{(3,44)}$ = 1.8, p>0.05).

Frustration rises through the different conditions from paper, overview to the segment conditions. A significant main effect of presentation method emerged from the frustration scale ($F_{(3,44)}$ = 4, p<0.02). *Post hoc* testing indicated the only the segment conditions differed significantly from the paper plan condition (Table 5.11).

Table 5.11 Tukey HSD tests between paper plan and all other conditions for (log) Frustration

	Electronic Plan	**Segment**	**Rotating Segment**
Difference	-0.25	-0.44	-0.52
Significance	>0.05	<0.05	<0.02

Temporal and Physical

The temporal and physical demand scales show the least between-groups variation. With reference to Figure 5.12, variation between groups is subsumed by variation within groups, particularly within the paper plan condition. The overall ANOVA for this scale supports this interpretation. No significant differences were found between any of the conditions for this scale ($F_{(3,44)}$ =0.23, p>0.05).

A non-parametric ANOVA (Kruskal-Wallis) revealed significant differences in physical demand experienced between conditions ($\chi^2_{(3)}$ = 9.2, p<0.05).

With reference to Figure 5.12, the lowest physical demand is found in the paper plan and allocentric segment condition. Higher levels are found in the plan overview and egocentric segment conditions. Increased variation is also evident in the egocentric segment condition. *Post hoc* testing indicates significant differences between each level sequentially: paper plan vs. plan overview (U = 30, p<0.02), plan overview vs. allocentric segment (U = 30, p<0.02), allocentric segment vs. egocentric segment (U = 37.5, p<0.05).

5.6.4 Workload summary

In summary, significant differences were found between effort and mental demand. This difference was especially apparent between the paper plan condition and any other condition. A weak pattern emerged suggesting the highest levels of effort and mental demand are in the plan overview and egocentric segment conditions. Subjective rating of performance was highest in the paper plan condition but no significant differences in performance were found overall. Frustration was lowest in the paper plan condition and increased throughout the conditions. Frustration was highest in the segment conditions and significant differences between these conditions and the paper plan were observed.

No significant differences between conditions were found for the temporal scale. Significant differences between each pair of conditions were found in the physical demand rating.

These results support the hypothesis that differences in methods of presentation will elicit difference levels of demand.

5.7 Navigation experience

Hypothesis

Different representations will generate different experiences of navigation

In order to test the hypothesis, the questionnaire scores were entered into a one-way, non-parametric ANOVA (Kruskal-Wallis). Exploratory analysis of the data indicated large negative skew in all conditions. A variety of transformations were applied to the data but negative skew persisted so only non-parametric analysis is used.

A significant main effect of presentation method was found ($\chi^2 = 8.1$, df =3, $p < 0.05$). Pairwise comparisons (Mann-Whitney) revealed significant differences between the paper plan condition and both segment conditions. The difference between the paper plan and the plan overview approached significance but did not reach it (see Table 5.12). No other significant differences between conditions were found. Figure 5.14 supports this conclusion. Means and standard deviations are very similar for all conditions except the paper plan. Variation across all conditions is similar.

Figure 5.14 Mean INQ score for each condition

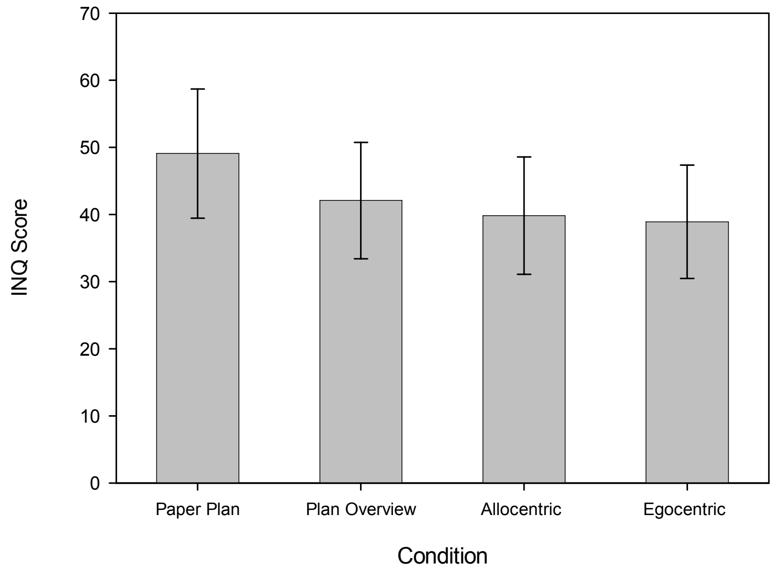


Table 5.12 Pairwise comparisons (Mann-Whitney) between paper plan and all other conditions

	Electronic Plan	Plan Segment	Rotating Plan Segment
Paper Plan	U = 40.5 p< 0.1	U = 34.0 p< 0.05	U = 29.0 p< 0.02

The hypothesis that there will be differences in experience depending on the presentation method used is supported.

5.8 Results: analysis of relationships

In this section, a full analysis of the relationships between route completion time, workload and all other subjective measures (SDS, INQ, OPT) is presented. Results from the exploratory analyses in the analysis of differences section (Section 5.5) are used to inform the selection of parametric or non-parametric tests. If any one variable in a correlation is not appropriate for parametric analysis, the equivalent non-parametric test is used.

Table 5.13 to Table 5.15 use the following coding to indicating level of significance:

*	$p < 0.05$
**	$p < 0.01$
***	$p < 0.001$

No asterisk indicates that the test failed to reach significance. Pearson's r is reported unless otherwise indicated. Spearman's correlation is denoted r_s. All tests are two-tailed unless otherwise indicated.

5.8.1 Route completion time and workload

Hypothesis

There will be relationships between route completion time and workload experienced

Significant differences between demand on the mental and effort sub-scales of the NASA-TLX were found between conditions. Table 5.13 shows correlations between workload scales and route completion. Significant positive correlations between mental demand, effort, frustration and completion time were found indicating higher demand is related to longer completion time overall. A significant correlation in the negative direction between completion time and performance suggests that lower rating of performance is associated with longer route completion times. These results support the hypothesis that there will be relationships between route completion time and workload.

Table 5.13 Correlations between route completion time and workload sub-scales

N = 48	Mental Demand	Physical Demand	Temporal Demand	Effort	Frustration	Performance
Completion Time	0.47**	<0. 1	- 0.17	0.41*	0.36*	- 0.59***

5.8.2 Route completion time and subjective measures

Hypothesis

There will be relationships between route completion time and subjective measures

With reference to Table 5.14, a weak but significant, negative correlation was found between sense of direction scale and completion time, suggesting that the lower individuals rate their spatial ability, the longer they take to complete the route. Similarly, a significant positive relationship was found between performance on the OPT and route completion time: increased error on the OPT is related to increased route completion time. A significant negative correlation indicates that higher INQ scores, indicating a more positive experience, are significantly associated with lower route completion times. These results support the hypothesis that there will be relationships between route completion time and subjective measures

Table 5.14 Correlations between route completion time and subjective measures

	INQ (r_s)	SDS	OPT
Completion Time	-0.57*	- 0.28*	0.65**

5.8.3 Workload and subjective measures

Hypothesis

There will be relationships between workload and subjective measures

With reference to Table 5.15. All subjective measures show significant association with the performance scale of the NASA-TLX. Other significant correlations are found only within the SDS and INQ measures. Significant relationships between mental demand and these scales were found indicating a lower quality of experience and lower rating of navigation ability is related to longer route completion times. Lower INQ scores are also correlated with higher effort and higher levels of frustration experienced by participants.

Table 5.15 Correlations between workload sub-scales and subjective measures

N = 48	Mental Demand	Physical Demand	Temporal Demand	Effort	Frustration	Perform
INQ (r_s)	-0.39**	-0.01	0.11	-0.50**	-0.49**	0.40**
SDS (r_s)	-0.40**	-0.1	0.07	-0.57**	-0.27	0.42**
OPT (r_s)	0.19	0.12	0.04	0.26	0.28	-0.43**

5.9 Results: analysis of behaviour

Frequencies of participant confusion and plan rotation are shown in Figure 5.16 and Figure 5.17. The analysis was performed by creating an arbitrary, ordinal scale along the route in one centimetre graduations on the paper plan. This distance provided a realistic granularity of the behavioural assessment by the experimenter. Instances of participant behaviours observed (confusion and map rotation) were then grouped and tallied according to this scale.

The tallied frequencies are then mapped onto the overall plan of the route according to a colour code shown in Figure 5.15. The scale runs from no instance of the behaviour to behaviour recorded in over 50% of the sample.

Figure 5.15 Colour code used to represent frequency of observed behaviour

Participants exhibiting behaviour	0	1-2	3-4	5-6	>6
Colour					

Figure 5.8 should be referred to in order to see the information that participants were presented with at each point in the behavioural map.

Figure 5.16 Plan of experimental route showing frequency of participant confusion

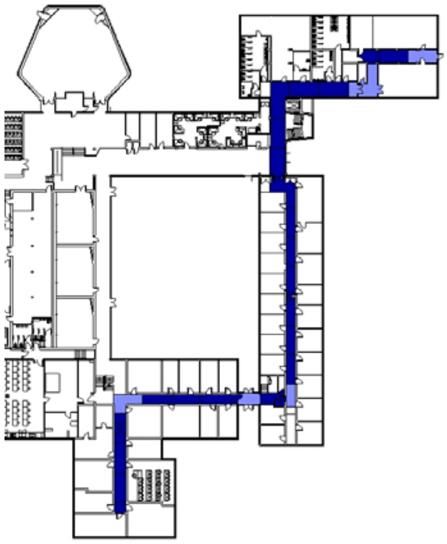
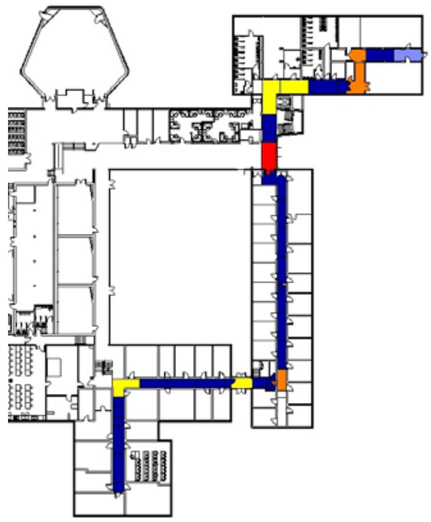
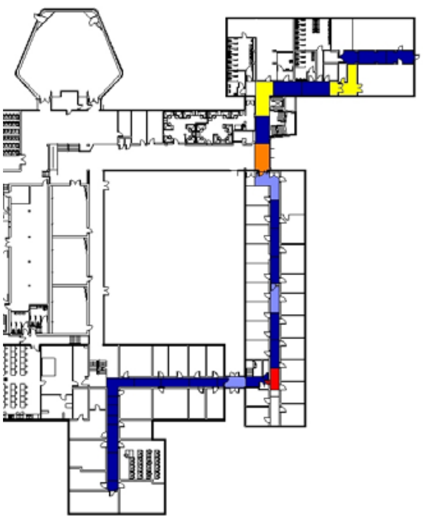
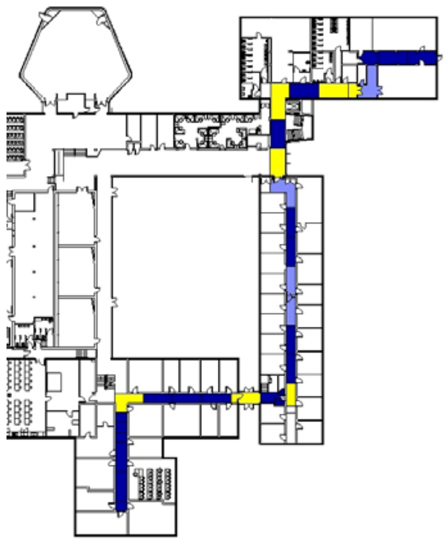
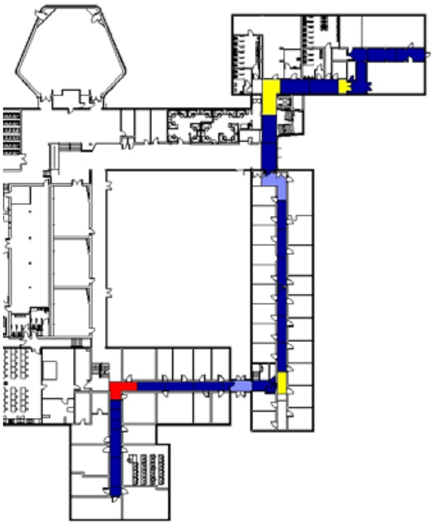
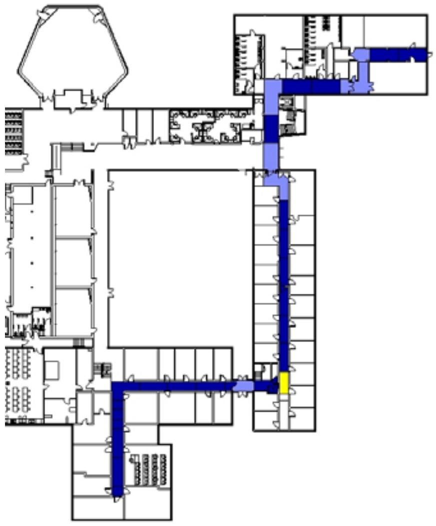
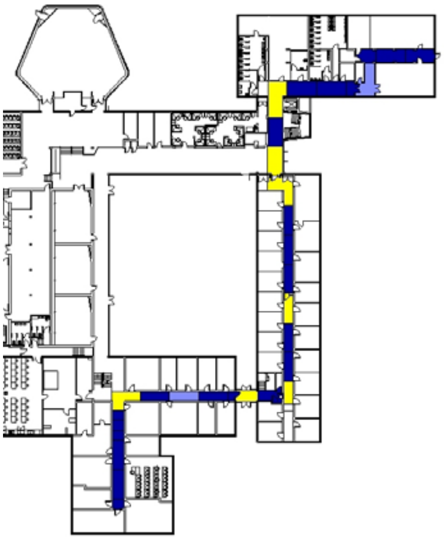
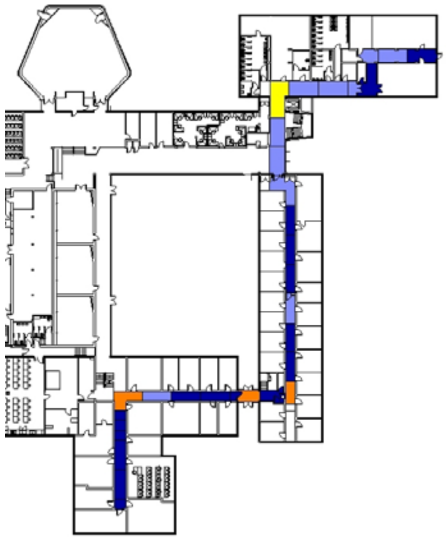
Paper Plan	**Plan Overview**
	
Allocentric Segment	Egocentric Segment
	

Figure 5.17 Plan of experimental route showing frequency of participant plan rotation

Paper Plan	**Plan Overview**
	
Allocentric Segment	Egocentric Segment
	

5.10 Summary

Participant performance on the Object Perspective Taking test is comparable with Hegarty and Waller (2004). Participants tended to perform well and as a result the distribution of scores is highly skewed to the left. No speed-accuracy trade was evident in the results. Scores on the Santa-Barbara Sense of Direction Scale (SDS) are normally distributed and a weak negative correlation was found between the two scales.

Significant differences were found in participant route completion time between the paper-plan condition and all other conditions. No significant differences were found between the three conditions that used the PDA based support. This supports the hypothesis that different representations will result in differences in route completion time. SDS scores emerged as a significant covariate, explaining variation in route completion time and reducing error in the model.

Significant differences were also found between conditions for the mental demand and effort sub-scales of the NASA-TLX. The paper plan condition generated less workload on these scales than any of the three PDA based conditions for both scales; pairwise tests confirmed that these differences were significant. A weak trend emerged indicating that the allocentric segment condition elicited less mental demand than either the egocentric segment or plan overview condition. Pairwise comparisons to test this difference did not reach significance.

Participant's rated their performance as best in the paper plan condition however no significant main effect of presentation method was found. Frustration was rated lowest in the paper plan condition and higher ratings were given in the three PDA based conditions. Significant differences in frustration were found between the paper plan condition and the other conditions.

No significant main effect of presentation method was found for temporal demand. Significant differences were found between the levels of physical demand experienced by participants. Differences in physical demand were found between all conditions.

These results support the hypothesis that different representations will result in differences in participant workload experienced.

Significant correlations between both psychometric tests (OPT and SDS) were found with route completion time. Generally poor performance on the OPT and poor self-perception of navigational ability predicted higher route completion times. These results support the directional hypothesis that lower perceived and measured spatial ability will result in higher route completion times.

Significant correlations between route completion time and two subscales of the NASA-TLX were found. The mental demand and effort sub-scales are positively correlated with completion time suggesting higher completion time is related to higher mental demand. This result supports the hypothesis that there will be relationships between route completion time and workload.

Using the refined version of the experience questionnaire developed, significant differences in experience were found between the paper plan condition and all other conditions. Exploratory analysis revealed significant relationships between the questionnaire and mental demand scales and route completion time.

Results of the behavioural analysis are generally consistent with the empirical data. Results indicate less confusion in the paper plan condition than in other conditions.

5.11 Discussion

Results indicate that participant’s performance was better and their workload lower when using the whole paper map when compared to any of the electronic methods of presentation used.

One explanation for these results is that the spatial information displayed using a paper plan is more closely aligned with participant's expected image on presentation of a new environment. With the paper map participants can develop expectations in advance of the immediate environment given the overview presented. Using the paper plan, participants may have been able to use their own preferred strategy to encode information on the plan bringing the expected and perceived images close together, enabling efficient navigation.

The three electronic conditions are bound by the fact that display and presentation is more under the control of computer rather than driven by the participants' themselves. This is a necessary trade-off since the entire plan cannot be displayed on the small screen of the mobile device. Participants must encode small segments of the plan presented, matching them to the local environment. Frequently, perception of the environment extended beyond the spatial information displayed which may increase the time and cognitive resources required to match the expected image due to the requirement to perceive increased information in the environment. Participants in the plan overview condition frequently performed better than participants in either of the plan segment conditions. Again this finding may be connected with greater control over interacting with the plan overview condition than the plan segment conditions. Despite strong empirical evidence suggesting that egocentric presentation of spatial information is the preferred orientation (for example Aretz and Wickens, 1992), no significant differences were found between these conditions. One explanation for this difference between the results found and the literature that the extent to which participants were able to match the perceived and expected images may depend more on the type of information presented rather than method of presentation itself. The type of information used to test the different methods, floor-plan information, is designed to be used as an entire overview of an area whereas the segments break up the overall spatial pattern of the journey across the building. When presented in this way, the paper plan information may be used in a familiar way by participants unlike the segment views. The plan information presented in the electronic conditions may be too cluttered or fragmented to allow encoding and efficient generation of an appropriate expected image which can be matched to the environment as in the model proposed by Passini (1980). When presented in short bursts, under the control of the computer, only the most relevant information should be presented.

Familiarity with paper based maps may also explain the significant difference in navigation experience reported by participants in the paper-plan condition. Shorter completion times, lower workload and positive experience may reflect an improved ability to orient using the paper map. Orientation may be more challenging when presented with parts of a map at specific locations. This observation is supported by the behavioural data where very low levels of confusion are recorded in the paper plan condition. Rotation in this condition is far more strategic; rotation only occurs when required by the route to maintain a track-up plan alignment. This observation is consistent with Aretz and Wickens (1992) who report that egocentric plan alignments are preferred in navigation. In the other conditions rotation is more diffuse and at times inappropriate. One explanation for this behaviour is that participants are comparing the environment with different orientations of the plan information to find a match rather than rotate the plan or PDA according to the direction travelled and the number of turns made. Only one participant did not rotate the plan at all during the route. In post-experiment interviews this participant reported expert levels of map use in the military. The highest levels of confusion are seen in the electronic plan and in the allocentric segment conditions. One unexpected finding is the failure to find significant differences between the allocentric and egocentric segment conditions. The experiment may not have been sensitive enough to find differences in these conditions, the unfamiliarity of both the method of presentation and the mobile device may have masked any advantage in the egocentric condition. Increased levels of confusion were found in the allocentric condition compared to the egocentric condition, supporting the egocentric alignment as the preferred plan orientation. Confusion is evident in the egocentric condition but appears to reduce towards the end of the route suggesting that participants become accustomed to this form of presentation.

Interaction problems were observed by the experimenter in the plan overview condition which may account for increased confusion recorded in this condition. Despite giving participants the opportunity to practice the technique, a wide variation in ability was observed which was not evident in the pilot studies. Many participants found the stylus difficult to use in this way. Others found that attending to the method of interaction interfered with the task of navigation. The lack of clear difference between this condition and the other electronic methods of presentation may be explained in terms of the large between-subject variation observed. Measuring usability in future studies could control for this effect.

In this study, information displayed on the PDA was simply a replication of information originally on the paper plan of the building. Much of the information may not have been necessary and may even have detracted from supporting users' navigation requirements. This experiment suggests that in order to compete with a traditional approach of using paper based plans or maps, significant input from human factors is needed when designing location-based services viewed on handheld devices. As only limited information can be shown on the screen at any one time, new representations of space are required that draw users' attention to the relevant parts of the environment. Effective presentation and use of spatial information would ensure that information can be quickly and accurately transformed into appropriate navigation decisions. In the following experiments the type of information that is displayed on a plan will be manipulated in order to improve performance when navigating.

5.12 Conclusion

The contribution of this experiment to the overall thesis is that the type of spatial information presented should be tailored to the method of display. Floor-plan information which supported navigation well when presented on a paper map was not as effective when the spatial information was presented on a small screen device in different ways. Displaying different types of spatial information or simplified information may allow for highly context specific information to be displayed on a small screen device in the ways described in this chapter, supporting navigation at least as well as a paper plan.

5.13 Methodological review

5.13.1 Use of the OPT

The OPT will not be used in subsequent experiments. Testing of individual differences was performed with the specific intention of reducing within-groups variation through covariates. The OPT scores are not suited to parametric analysis and since no non-parametric analysis of covariance is available it will not be delivered in future experiments.

5.13.2 Measurement of usability

It became obvious that during the course of the experiment that participants' experienced problems interacting with the PDA in the electronic plan condition. This problem did not emerge in the pilot studies. As such, this may have affected their responses to other measures, especially the workload scales. In future experiments the System Usability Scale (SUS) (Brooke, 1996) will be given to participants and entered into the analysis in order to mitigate any effect of system usability on the results. Details of the SUS are given in the experimental methodology (Section 4.2.4, p108).

5.13.3 Measurement of workload

In experiment one, an assumption that the cognitive elements of workload are directly related to the task has been made. This is a result of strong correlations and differences being found in the mental demand and effort scales. Other results, such as the significant differences found in the physical demand scale are not as easy to explain given the nature of the task. In experiment two, the full weighting procedure will be used and a detailed analysis performed to assess which scales are loading onto the task empirically. A computer programme to deliver the test and weight the scales has been developed.

5.13.4 Development of the INQ

Questions contained in the INQ (integrated navigation Questionnaire) were derived in an exploratory way. In order to improve the reliability of the questionnaire, a full reliability analysis was carried out at this stage to improve the results in future experiments.

All questions included in the first version of the questionnaire are shown in Table 5.16. Prior to reliability analysis, the scoring direction of each item was checked. Items scored in the negative direction are greyed. Correlations between raw response and the scale total indicate that the original scoring directions adopted are justified. A more positive experience is reflected by a higher score on the questionnaire using this method.

Table 5.16 Original set of questions included in the questionnaire

	Question	Correlation with total (r)
1	I could write down directions that I have taken on this route for a friend	0.68**
2	I would be able to draw the route that I took	0.67**
3	I felt confused as to where I was	-0.70**
4	I felt disoriented when walking on this route	-0.72**
5	This route was very complicated to navigate	-0.65**
6	I am uncertain of how far I travelled	-0.52**
7	I felt lost when navigating this route	-0.78**
8	I could use the picture of this route in my mind to navigate	0.56**
9	I would be unable to find my way again if I had made a wrong turn on this route	-0.48**
10	I could identify the route I have just taken on a plan of the area	0.60**
11	I can remember the direction from where I started	0.29
12	I felt under pressure when walking this route	-0.56**
13	There were too many turns to remember	-0.47**
14	I was not sure I was heading in the correct direction	-0.76**
15	I would be able to get back to where I started from quite easily	0.69**
16	I would be able to tell somebody else how to navigate this route	0.62**
17	I can remember the number of left or right turns I made to get to the end of this route	0.49**
18	I am sure of how much time I took to walk along the route	0.15
19	I would not feel confident giving directions of this route to someone	-0.30*
20	I have a clear picture of this route in my mind	0.73**
21	I am sure of the distance I have travelled	0.51**
22	I felt uncomfortable when walking around this route	-0.60**
23	I was not sure where I was heading to on this route	-0.36*
24	Details on the map helped me to find my way through the route	0.39**
25	I disliked finding my way using the plans	-0.22

(* Correlation is significant at the 0.05 level, ** Correlation is significant at the 0.01level)

Participant responses were then transposed by variable creating twenty five new variables corresponding to the twenty five questions in the scale. A reliability analysis was then performed using Cronbach's alpha. Cronbach's alpha is a statistic that reflects the internal consistency of the scale (Kline, 2005). In this case, the scale is designed to measure individual experience following navigation of the route. Scale statistics are shown in Table 5.17. Kline suggests an alpha co-efficient of at least 0.80 for a scale to be considered reliable. The value of 0.89 for the current scale is well within this recommendation. Lowenthal (1996) argues that higher co-efficients reflect repetitious questionnaires, however with only twenty-five items this criticism is rejected and the conclusion that the questionnaire in its current form has high reliability is supported by the high alpha co-efficient.

Table 5.17 INQ scale statistics

Mean	SD	$\alpha_{Cronbach}$	Items	N
78.8	14.3	0.89	25	48

The item total statistics (Table 5.18) were then critically evaluated to remove items that do not load onto the overall scale. With reference to Table 5.18, removal of any item does not increase Cronbach's alpha by any significant margin. Alpha co-efficients on removal of single items remain between 0.88 and 0.90. The decision to remove items was made on the basis of the corrected item-total correlation. This is a correlation between the item score and the overall test score, excluding the item in question from the total score. This correction is performed to avoid inflation of the item-total correlation (Kline, 2005). Removal of test items is based on the mean item-total correlation of 0.49. Correlations which fell below the mean were excluded from the questionnaire. This figure is high. Lowenthal (1996) suggests a more generous removal threshold of between 0.15 and 0.30. Due to the exploratory nature of the questionnaire, a more robust approach was taken using the mean item-total correlation as an indicator. Application of this rule resulted in the removal of twelve items. Removed items are greyed in Table 5.18.

Table 5.18 INQ item-total statistics

Question	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
1	76.6	183.3	0.64	0.89
2	76.1	185.3	0.62	0.89
3	75.6	183.1	0.66	0.89
4	75.3	182.6	0.69	0.89
5	74.8	188.6	0.61	0.89
6	75.5	189.5	0.46	0.89
7	75.2	179.4	0.74	0.88
8	76.0	186.0	0.47	0.89
9	75.5	188.0	0.41	0.89
10	75.2	187.9	0.56	0.89
11	75.6	195.6	0.21	0.90
12	74.9	189.2	0.51	0.89
13	75.7	189.8	0.40	0.89
14	75.6	176.6	0.72	0.88
15	75.1	185.7	0.65	0.89
16	76.4	186.0	0.57	0.89
17	76.8	192.2	0.44	0.89
18	75.6	200.1	0.08	0.90
19	76.4	195.3	0.23	0.90
20	76.2	181.6	0.70	0.89
21	76.1	191.2	0.46	0.89
22	74.7	189.5	0.56	0.89
23	76.4	192.1	0.27	0.90
24	74.5	195.2	0.34	0.89
25	75.0	197.4	0.13	0.90

Table 5.19 shows the new scale statistics following removal of items. The new scale consists of thirteen items and Cronbach's alpha remains high, indicating high reliability.

Table 5.19 INQ scale statistics following removal of items and second reliability analysis

Mean	SD	$\alpha_{Cronbach}$	Items	N
42.5	9.5	0.91	13	48

The remaining thirteen items will be used in future studies and are scored according to the directions indicated by correlations in Table 5.16.

Chapter 6 Experiment Two

6.1 Introduction

This experiment examined three different types of spatial information and presented them in a location-based context on a mobile device. Experiment one has shown that route segments are not as effective as paper maps for navigation. This experiment examines whether there are differences in navigation depending on the type of information presented in the route segments, as opposed to the way in which this information is presented. Selection of the different types of information presented to participants in this experiment is grounded in current theoretical perspectives on spatial cognition. Lynch (1960) was the first to suggest that space could be parsed into a variety of different elements and that these elements are used differentially to support activities involving spatial knowledge. Tverksy (2000) suggests that different kinds of spatial knowledge can support different activities: wayfinding, route planning or shortcuts. Tverksy goes further still arguing that not all components of the environment are represented and frequently mental representations of space are schematised, idealised or otherwise distorted. Despite these distortions, this spatial knowledge can be translated into appropriate spatial behaviour and action. Meilinger et al. (2006) provide empirical evidence for this position. Stankiewicz and Kalia (2007) lend further support to the idea of hierarchical organisation of spatial knowledge, suggesting that certain environmental features are more salient than others when used for navigating or comparing the environment with an external representation. Their research indicates that not all environments are created equal.

Given correct appraisal of the environment and the physical representation such as a map, spatial decisions can be taken and the correct choices for successful navigation can be made. Garling and Golledge (2000) propose a model of navigation which centres on the interaction between spatial knowledge and spatial decision making. They propose that any form of spatial information, representation in memory or a physical representation mediates spatial decision making. Selection of route at decision points is high in the hierarchy and is the precursor to action. Misinterpretation of cues in the environment (see also Cornell and Heth, 2000) as a result of inattention to, or complexity of the spatial information can lead to navigation errors. Selection of the type and amount of spatial information presented on a small-screen device is critical for successful and efficient navigation.

The present experiment focuses on supporting the task of pedestrian navigation in an indoor environment using a mobile device. Three different types of information which could all support navigation inside a building are presented to participants. The first type of spatial information is simply a green line that participants should follow. The line is overlaid onto a floor plan of the area. The second type of information is identical to the first but more information is given at decision points; routes that participants should not follow are marked as orange bars. Finally, the third type of information contains route information but no floor plan information. Only the green route line and the decision point information are shown.

6.2 Experimental Hypotheses

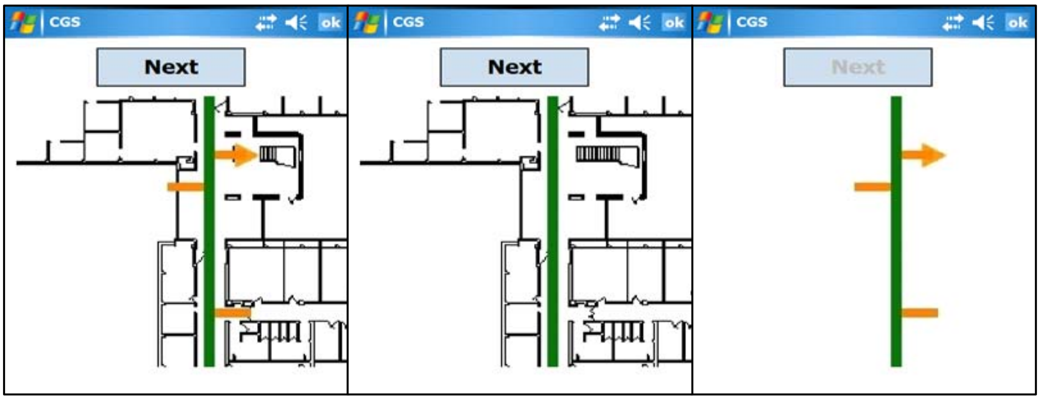
- Different types of spatial information will result in differences in route completion time.
- Different types of spatial information will result in differences in workload experienced by participants
- There will be differences in navigation experience depending on the type of spatial information used
- There will be differences in the perception of system usability depending on the type of spatial information used

- There will be relationships between route completion time and workload experienced
- There will be relationships between route completion time and subjective measures
- There will be relationships between workload and subjective measures

6.3 Design and stimuli

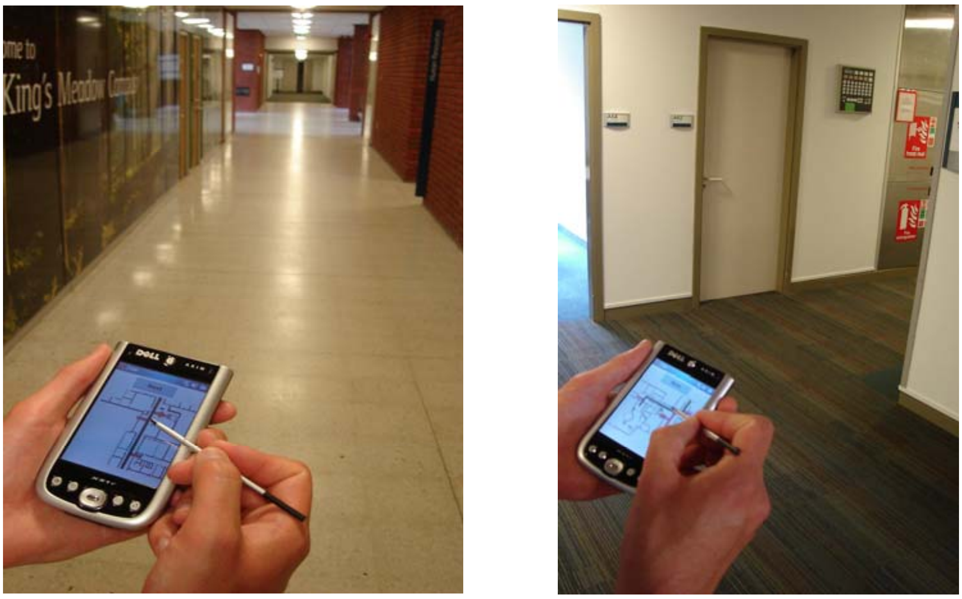
Three experimental conditions were developed to test the experimental hypotheses. The study is a full, between groups design. Conditions are shown in Figure 6.1. A participant completing the experiment is shown in Figure 6.2.

Figure 6.1 Examples of stimuli used in each condition



Enhanced	Route	Simplified

Figure 6.2 Example of a participant taking part in the experiment



With reference to Figure 6.1, a solid green line indicates the route that participants should take. Staircases were marked by arrows in the information since they are static and salient features of the environment which can be used to orientate. Arrows were used since they were highly visible on the small screen of the PDA. Other information used to indicate stairs were difficult to resolve at the small scale used. The three conditions are enhanced, route and simplified. In the enhanced condition the decision points augmented by orange bars indicated to participants that they should not take the particular route. Since correct spatial choice at decision points is critical for correct navigation, information was enhanced at these points. The route condition showed a green line that participants should follow. In both of these conditions, plan information is overlaid onto the route information. The simplified condition contained the route information in green and the decision-points again marked in orange. The decision points in this condition are critical in order to anchor and update participant's spatial knowledge. No overall plan information was shown in the simplified condition and participants were expected to navigate using the simplified route information only. In all cases, presentation of the spatial information was location-based in that only the segment on the route relevant at that specific time was shown. Presentation was egocentric in all conditions in order to assist participants to orientate. Egocentric presentation of spatial information has been shown to be more effective in assisting navigation than other forms of presentation (Aretz and Wickens, 1992, Seager and Stanton-Fraser, 2007).

6.3.1 Dependent variables

Core dependent variables used in this experiment are shown in Table 6.1. Full details of these dependent variables can be found in Chapter 4 (p100).

Table 6.1 Core dependent variables used in experiment two

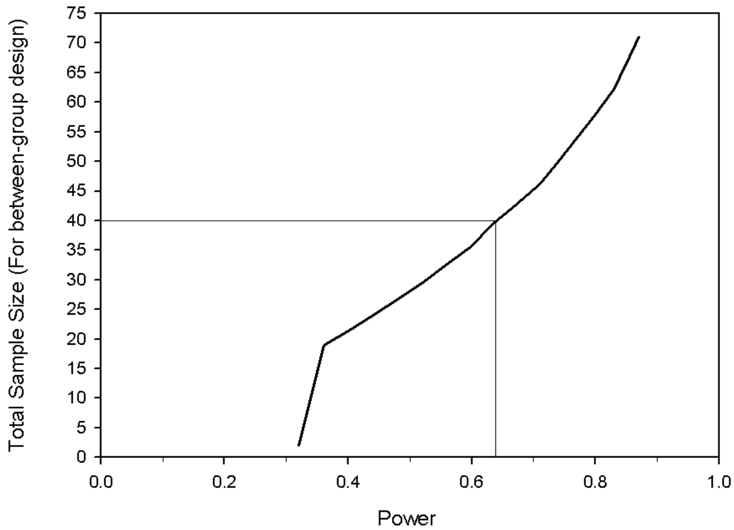
Dependent Variable	Measurement
Performance	Route completion time
Individual Differences	Sense-of-Direction Scale
Workload	NASA-TLX (Scales and weighting procedure)
Experience	Integrated Navigation Questionnaire (INQ)
Usability	System Usability Scale
Behaviour	Behaviour checklist

6.3.2 Power analysis

An assessment of power was used to derive an appropriate sample size. The variable selected for the assessment is time of completion of the route since this is of high importance in the fire service.

The sample means from two conditions in the first experiment will be used to estimate the effect size required for the power calculation. Using these estimates, an effect size (d) of 0.52 is developed. The relationship between sample size and power is shown in Figure 6.3. Funding for sixty participants across three groups is available. From the two-group case, a power of 0.63 is achieved for a single, between-group effect, each group consisting of twenty participants. This is a satisfactory level of power for this experiment and justifies the use of twenty participants in each group.

Figure 6.3 Power as a function of sample size for a two-group case (d = 0.52, α = 0.05)



6.4 Method

6.4.1 Participants

Sixty two participants completed the study. Participants were drawn from staff and students at the University of Nottingham. Data from two participants were excluded. One participant became upset during the trial for reasons unconnected with the experiment, and the trial was stopped. Another participant found the trial very challenging. The reasons for this are reviewed in the discussion, but the data were excluded from the overall analysis. Participants were assigned to one of the three experimental conditions randomly generating three groups of twenty participants. Sex was counterbalanced across all groups. Full details of participant age and familiarity with the route used in the experiment are shown in Table 6.2.

All participants reported normal or corrected to normal vision and all had English as a first language

Table 6.2 Age (years) of participants and familiarity with the experimental environment

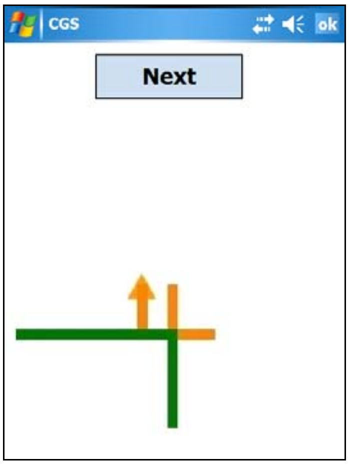
Variable	Age (SD)			Familiarity (SD)		
Condition	Enhanced	Route	Simplified	Enhanced	Route	Simplified
Male	24.4 (8.7)	27.3(9.1)	23.0(8.2)	1.4 (0.5)	1.2(0.4)	1.5 (0.7)
Female	26.8(11.8)	25.1(5.2)	22.9(6.4)	1.4 (0.5)	1.0(0.0)	1.2 (0.4)
Total	25.6(10.2)	26.2(7.3)	23.0(5.2)	1.4(0.7)	1.1(0.3)	1.4 (0.6)

6.4.2 Materials

Plan Segments

Version 2 of the software is used to present the plan segments. Three separate programs were developed to present each kind of stimuli (Figure 6.1). Full details of the software are discussed in Section 4.3 p115. A screenshot of the type of display experienced by participants is shown in Figure 6.4.

Figure 6.4 Screenshot of the display used by participants in experiment 2 (simplified condition)



Route Selection

A different route in the Kings Meadow Campus at the University of Nottingham was selected for this experiment. The route was selected since it contains several 90^{O} turns and as such is not straightforward to navigate or recall. Most participants will be unfamiliar with this location since this building is used specifically for university administration. The route is longer and more complex than the route used in

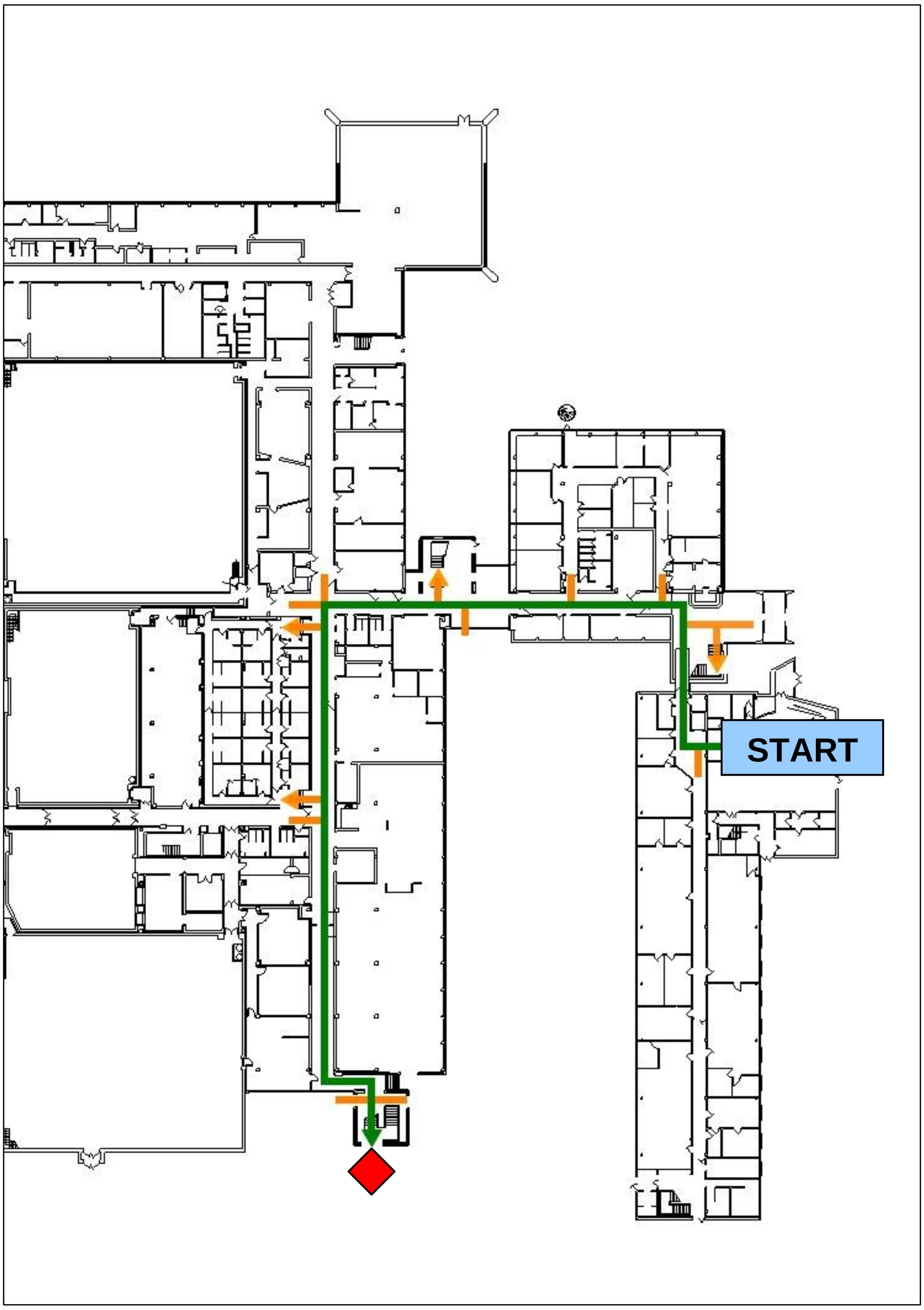
Experiment 1. Participants are required to navigate between different floors. Full floor plans of the route are shown in Figure 6.6. The plan is split into three diagrams. The second diagram is the first floor route, the first and third diagrams show the ground floor route. Start and end points are indicated and coloured diamonds show how the routes connect together. These extra markers were not available to participants in the actual experiment. The total length of the route is 301m.

The route mainly consists of wide corridors which contain very few distinguishing features or distractions (Figure 6.5). On a practical level, the Kings Meadow Campus is not used by students so very few people were present when the experiment was being conducted.

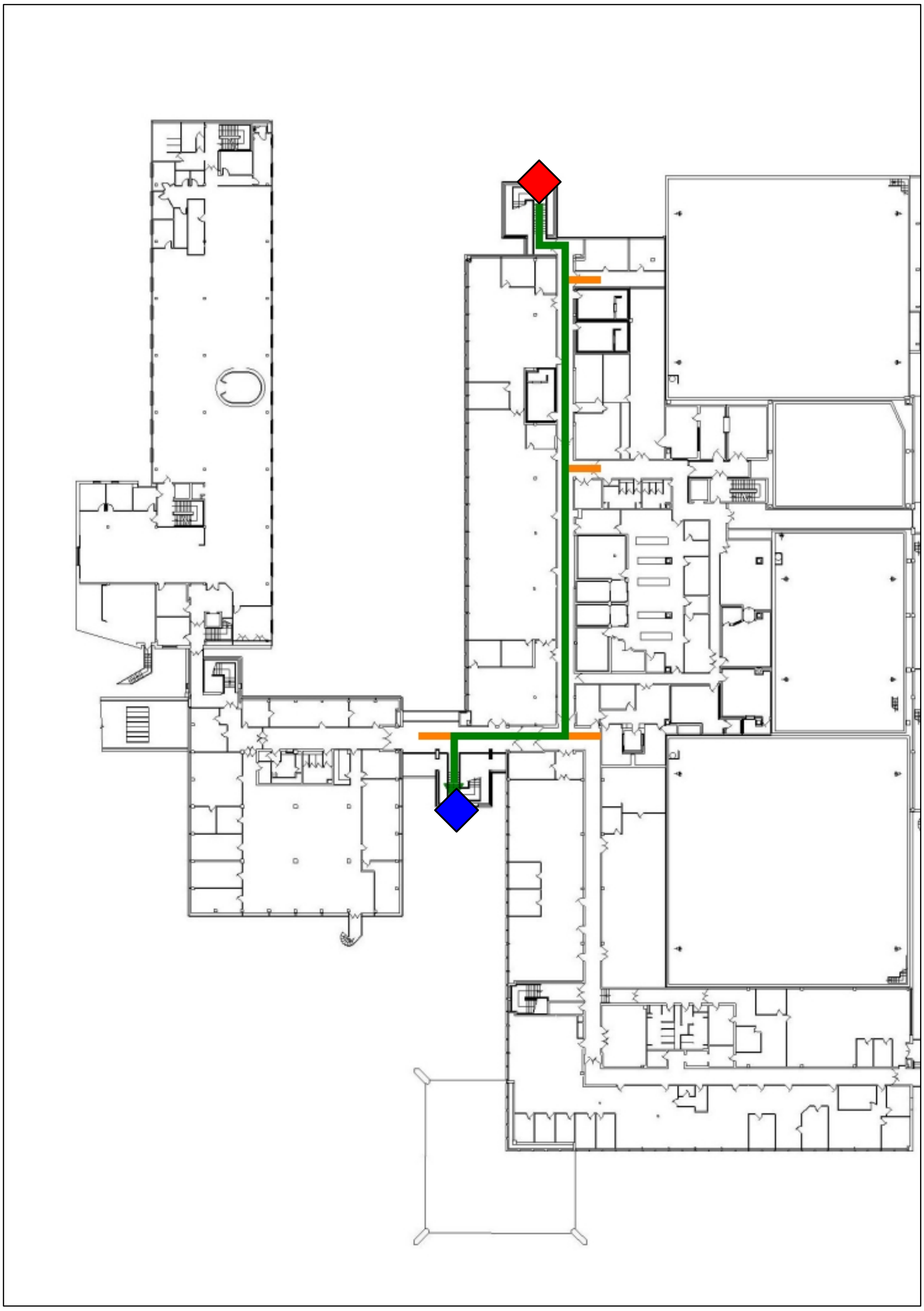
Figure 6.5 Example of the environment at the Kings Meadow Campus

Figure 6.6 Full floor plan of route

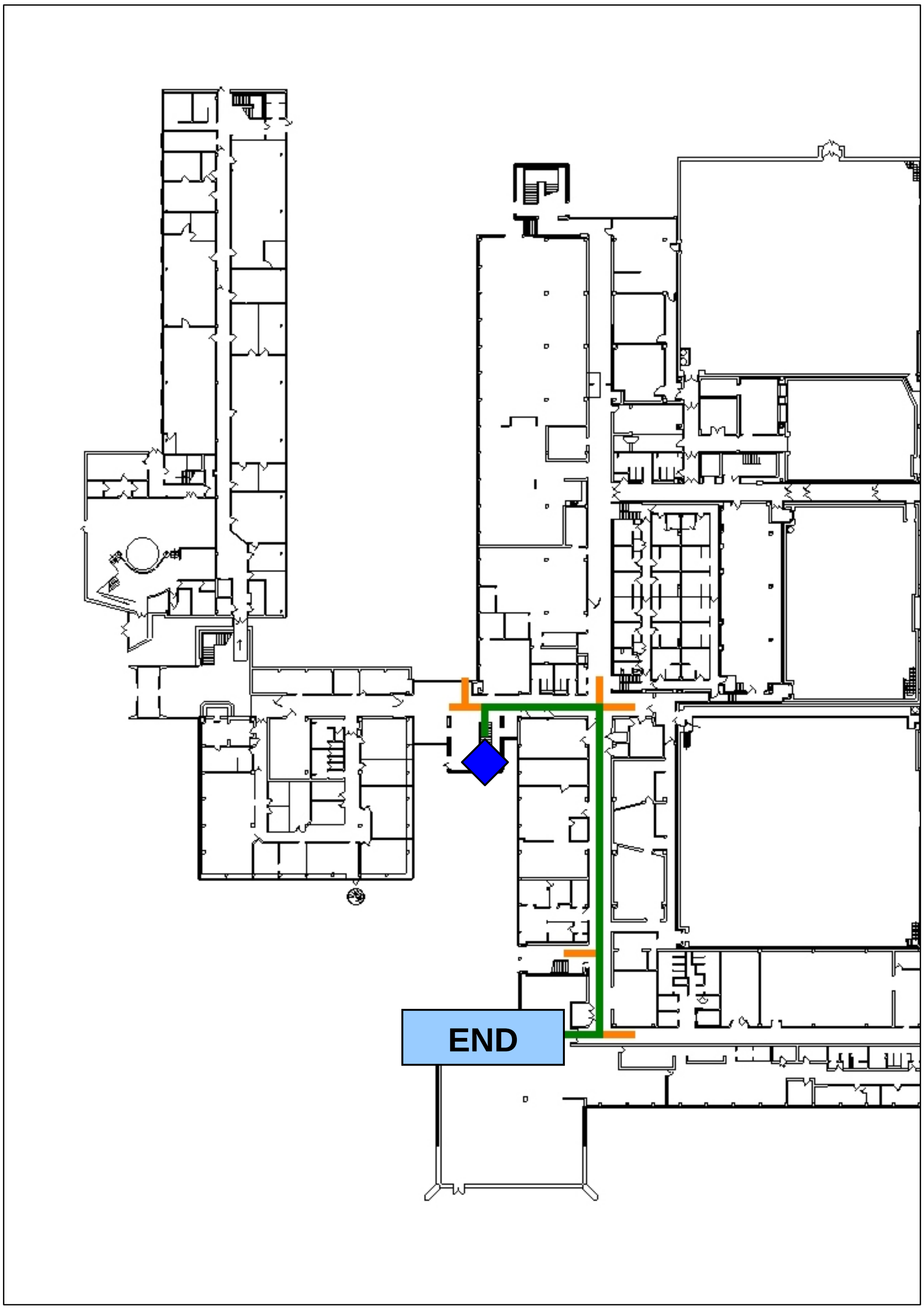
(Ground floor, 1)



(First floor)



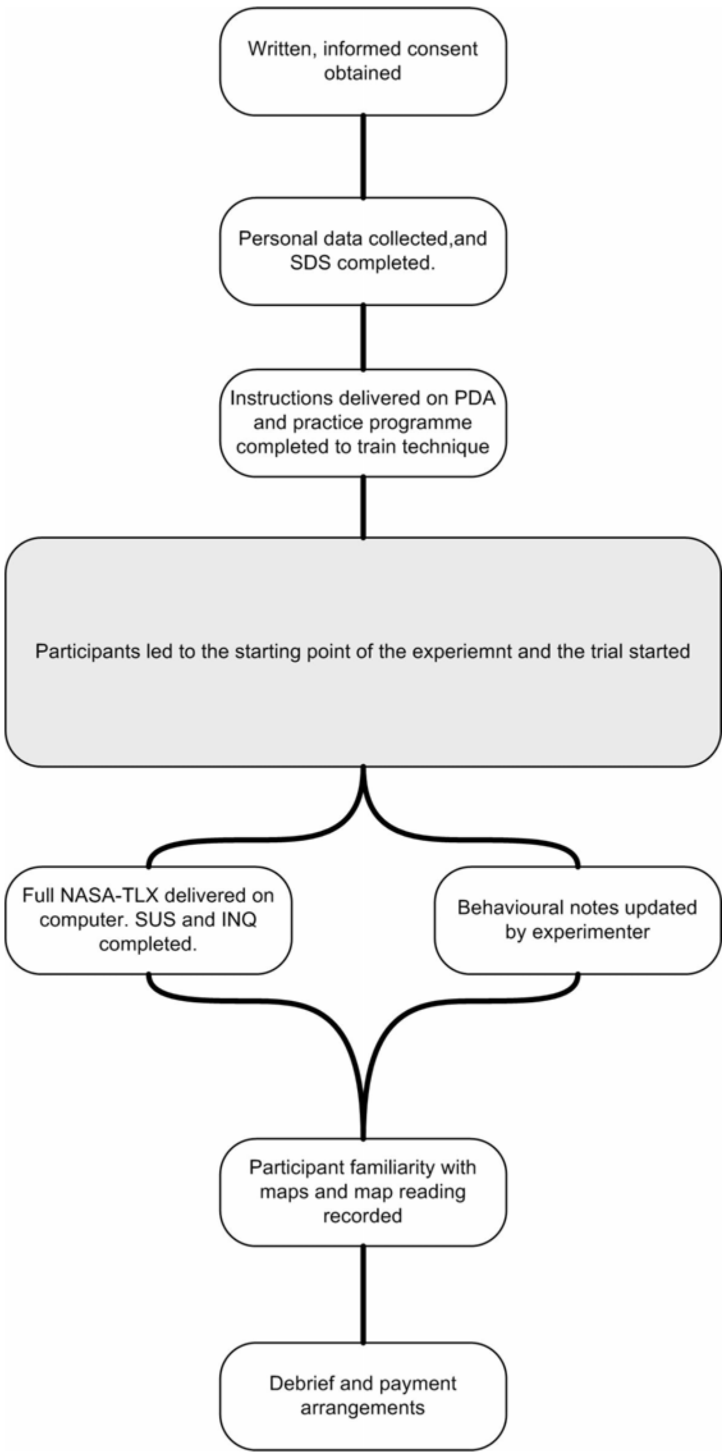
(Ground floor, 2)



6.4.3 Procedure

Figure 6.7 shows a flow diagram of the procedure used in experiment one. The description of specific parts of the procedure are discussed below.

Figure 6.7 Diagram of the procedure used in experiment two



Participants gave written, informed consent in a room away from the route taken in the experiment. Participants submitted personal data and completed the Santa-Barbara Sense of direction questionnaire. Participants were then randomly assigned to an experimental condition and the instructions for the appropriate condition were delivered on a laptop computer using Microsoft PowerPoint.

Following completion of the instruction set, participants had the opportunity to use the PDA and practice with the interface they would be using with stimuli comparable to, but not actually used in the actual experiment.

When participants indicated that they were comfortable interacting with the PDA, they were led to the starting point of the experiment. The route taken to the starting point was deliberately selected so that no part of the experimental route would be either traversed or visible to the participant.

The participant was then handed the PDA instructed to start when ready. Timing was started by the participant tapping the start button. As in experiment 1, the experimenter would instruct the participant to advance the map by tapping the ‘Next’ button at predefined points on the route. The experimenter counted instances of observed behaviour on a form during the experiment. If participants made deviations from the prescribed route, they were led back to the last correct location and asked to re-localise themselves on the plan.

When participants completed the route the timing was automatically stopped and recorded on the PDA and participants were led into another room, adjacent to the completion point. Participants then completed the NASA-TLX workload scales. These scales were delivered on a laptop. Following completion of the NASA-TLX, participants completed the INQ questionnaire. Whilst participants were engaged in these tasks the experimenter updated behavioural notes and noted anything unusual about the trial. Participants then indicated their level of familiarity with maps and map reading, and their employment was recorded. Participants were then debriefed and arrangements for payment were put in place.

6.5 Results: analysis of differences

6.5.1 Participants

A 2 × 3 ANOVA ([male vs. female] × [enhanced vs. route vs. simplified]) revealed no significant differences in age between male and female participants ($F_{(1,54)} < 0.001$, $p>0.05$) or across conditions ($F_{(1,54)} = 0.9$, $p>0.05$) . Non-parametric ANOVAs (Kruskal-Wallis) revealed no significant differences in familiarity between experimental conditions ($\chi^2_{(2)} = 3.1$, $p > 0.05$) or between participant sex ($\chi^2_{(1)} = 0.5$, $p > 0.05$).

6.5.2 Santa-Barbara sense of direction scale (SDS)

Exploratory Analysis

Exploratory analysis of overall participant scores from the SDS revealed no significant departure from normality ($W_{s(60)} > 0.9$, $p > 0.05$). Skew and kurtosis are within two standard errors so the data is suitable for parametric analysis. Descriptive statistics are shown in Table 6.3. For comparison, the overall results of this test for experiment one (Section 5.5.2, p139), are also shown. Although the distribution of scores displays slight negative skew, overall the results are very similar suggesting that the SDS is a reliable test of perception of sense-of-direction.

Table 6.3 Descriptive statistics for the SDS scale

	Mean Score	**SD**	**Skew (SE)**	**Kurtosis (SE)**
Current experiment	50.1	10.8	-0.2 (0.3)	-0.07 (0.6)
Experiment 1	49.6	15.4	0.4 (0.3)	0.7 (0.7)

No significant between-condition differences were found between SDS scores

Correlations with other dependent variables

No significant linear relationships were found between SDS scores and route completion time or any workload scale. As such, SDS scores cannot be entered into the between-condition analysis of these variables as a covariate. A weak but significant linear relationship was found between INQ scores and SDS scores ($r = 0.41$, $N = 60$, $p < 0.01$, two-tailed) indicating that these two measures may be testing similar aspects of participant perception of navigation.

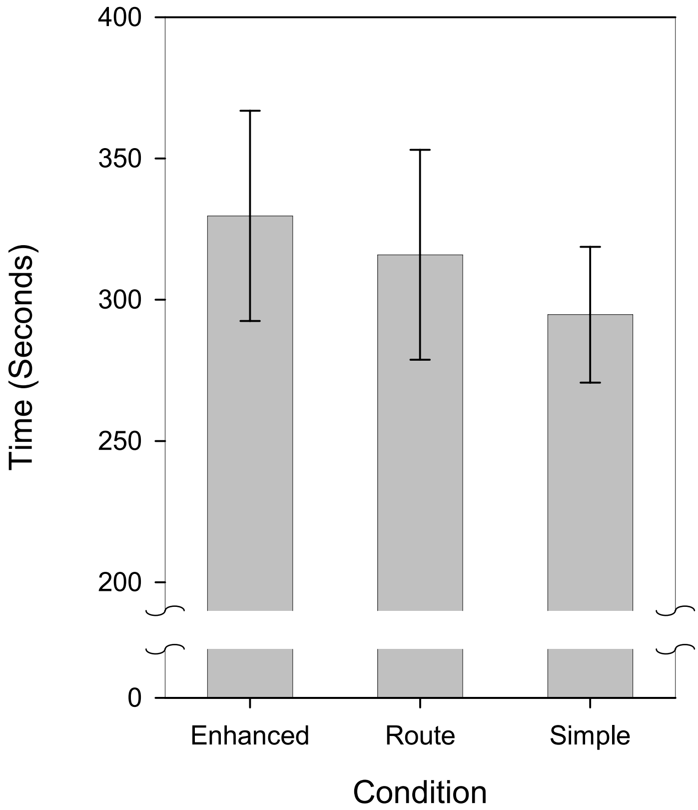
6.5.3 Route completion time

Hypothesis

Different types of spatial information will result in differences in route completion time.

As in experiment one, route completion time is treated as the main measure of participant performance and is measured in seconds. Figure 6.8 shows lower route completion times in the simple condition compared to the other two conditions.

Figure 6.8 Route completion times across all conditions



Exploratory Analysis

Exploratory analysis of the route completion-time data for each condition gave mixed results. The data were distributed normally in the all condition ($W_{s(20)}$ = 0.9, p > 0.05) and in the simple condition ($W_{s(20)}$ = 0.9, p >0.05). The route condition failed the statistical test of normality ($W_{s(20)}$ = 0.8, p = 0.01).

In order to improve the distribution of the time data a number of transformations were applied. A reciprocal transformation improved the distribution shape and no significant departure from normality was found in the route condition following the transformation ($W_{s(20)}$ = 0.9, p <0.05) distributions for all conditions. The transformed data is used in subsequent parametric analysis.

Analysis

A one-way ANOVA (Enhanced vs. Route vs. Simplified) revealed significant variation between conditions ($F_{(2,57)} = 5.5$, $p<0.01$). *Post hoc* testing confirmed one significant difference in route completion time between the enhanced condition and the simple condition (Tukey HSD = -0.00034, $p<0.01$). Participants took longer to navigate the route when using the enhanced route information. No other significant between-condition differences were found. The hypothesis that different information will lead to differences in route-completion time is supported by the data.

6.5.4 Workload

Hypothesis

Different types of spatial information will result in differences in workload experienced by participants

Results of all six scales are presented in addition to the overall load-index derived from the weighted average of all scales. An analysis of the way in which the scales were weighted by participants is also presented.

Exploratory Analysis

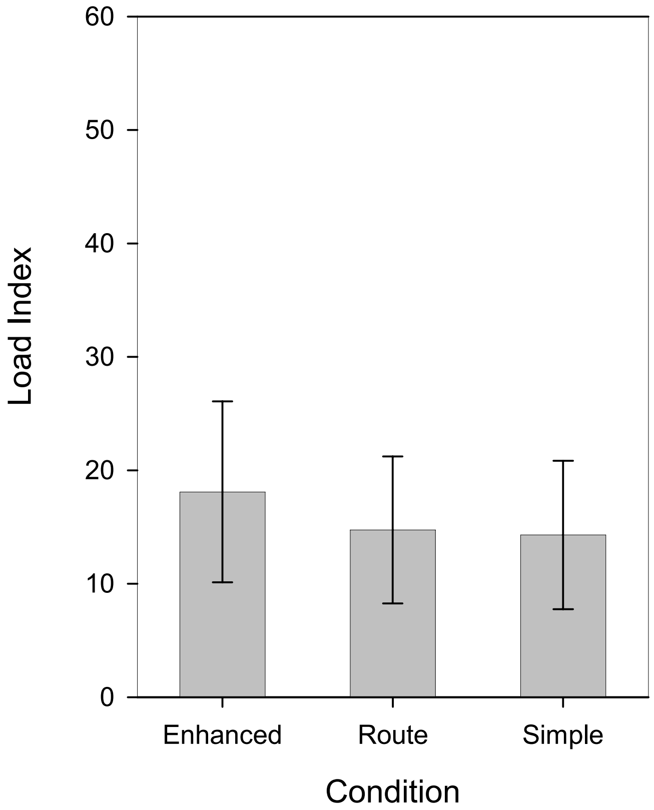
Exploratory analysis revealed significant departure from normality in most sub-scales and all scale weightings. The overall load-index is also significantly different from normal. Only non-parametric analysis will be used in the analysis.

Analysis

Load Index

Figure 6.9 shows load-indices for all conditions. The enhanced condition shows a higher overall load index than either the route or simple condition. However, a non-parametric ANOVA (Kruskal-Wallis) indicated no significant differences in overall load-index between conditions ($\chi^2_{(2)}$ = 2.8, p>0.05).

Figure 6.9 Comparison of load-index for each conditions



Sub-scales

Figure 6.10 shows a comparison of all TLX subscales for each condition. Examination of the graph shows similar patterns of physical and temporal demand, and effort for each condition. Frustration is slightly higher in the all and simple conditions but any effect is subsumed by the large, between subjects variation. Subjective rating of performance is very similar for all three conditions. Statistical analysis of these five scales shows no significant between-condition differences. Larger, between-condition differences are evident in the mental demand scale. Higher mental demand is experienced in the all condition and the lowest demand in the simple condition. Analysis confirmed a significant difference between conditions for ratings of mental demand ($\chi^2_{(2)}$ = 6.8, p<0.05). *Post hoc*, pairwise testing confirmed a significant difference between the enhanced and simple conditions ($U_{(20,20)}$ = 107.0, p<0.02). No other significant between-condition differences were found. A comparison of the mental demand scale only is shown in Figure 6.11.

Figure 6.10 Comparison of sub-scales for each condition

(Only positive error-bars are shown for clarity. Error bars are symmetrical)

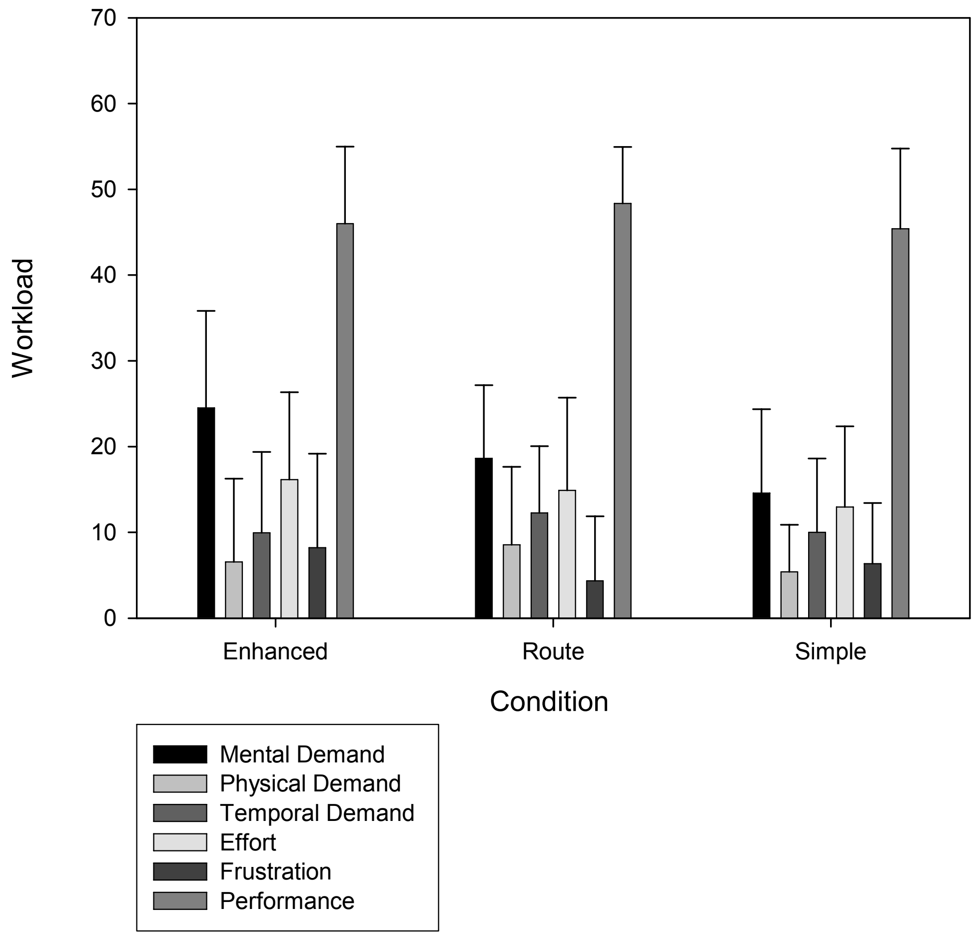
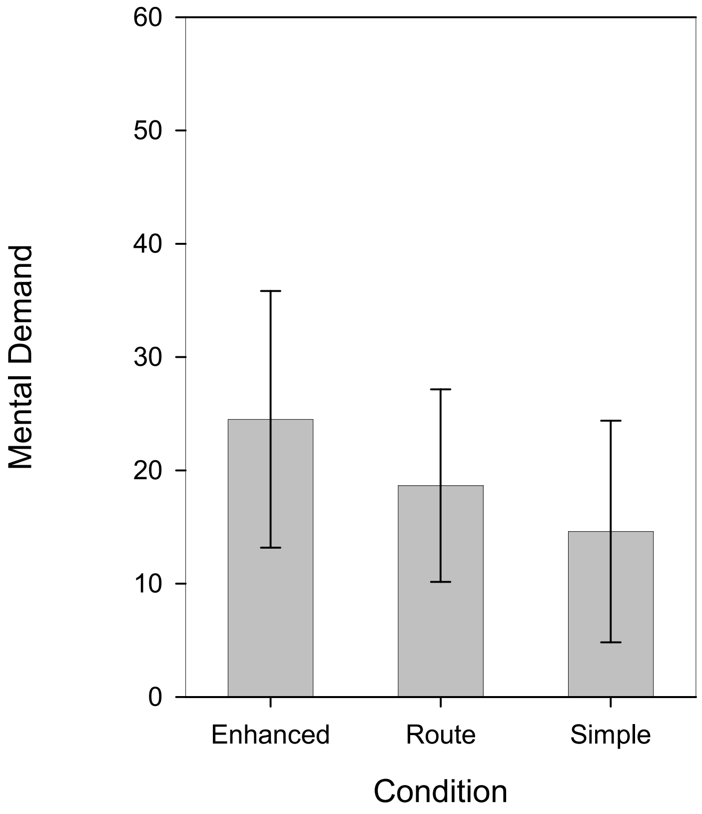


Figure 6.11 Comparison of the mental demand subscale for each condition

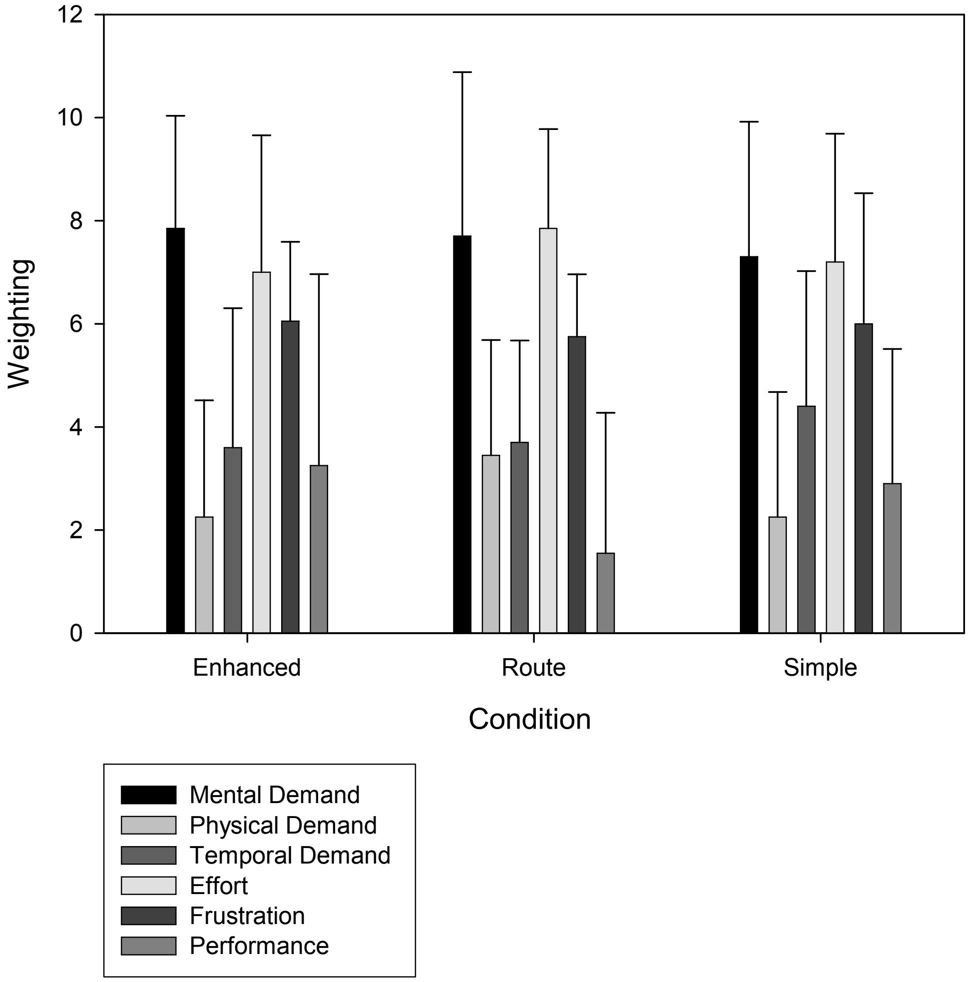


Weights

A full analysis of the weightings assigned to each scales is presented. Figure 6.12 shows mean weightings assigned to each subscale in each experimental condition. Similar patterns of variation are observed between subscales and between conditions and overall, variation within each scale is high. Participants rated their performance as lower in the route condition but overall, no significant differences in weightings were found between conditions.

Figure 6.12 Comparison of weightings for each condition

(Only positive error-bars are shown for clarity. Error bars are symmetrical)



Since no significant between-condition differences were found in weightings, the data was restructured and the weightings were collapsed across the conditions. Figure 6.13 shows the mean weighting for each scale, regardless of the condition participants were assigned to. The mental demand, effort and frustration scales are weighted more frequently than other scales. Higher variation is evident in weightings assigned to performance. A non-parametric ANOVA (Friedman) shows significant variation in the weightings assigned to scales by participants ($\chi^2_{(5)}$ = 118.2, p<0.001). Fifteen comparisons are required to test the pairwise differences between rating scales. A Bonferroni correction was used to reduce the probability of a type-1 error given the high number of pairwise comparisons. The adjusted significance level is 0.003 (0.05/15). Using this stricter level of significance, the Wilcoxon Signed-Ranks test revealed differences between the effort and mental demand weightings and all other scale weightings. No significant difference between participant weightings of mental demand and effort were found and a significant negative correlation was found between the weightings of these two subscales (r_s= -0.37, p<0.01). This result indicates that participants weighted the mental demand and effort component of workload significantly more frequently than other components. The correlation suggests that the mental demand scale and the effort scale are viewed as using a similar cognitive resource.

Figure 6.13 Comparison of weightings collapsed across all conditions

(Only positive error-bars are shown for clarity. Error bars are symmetrical)

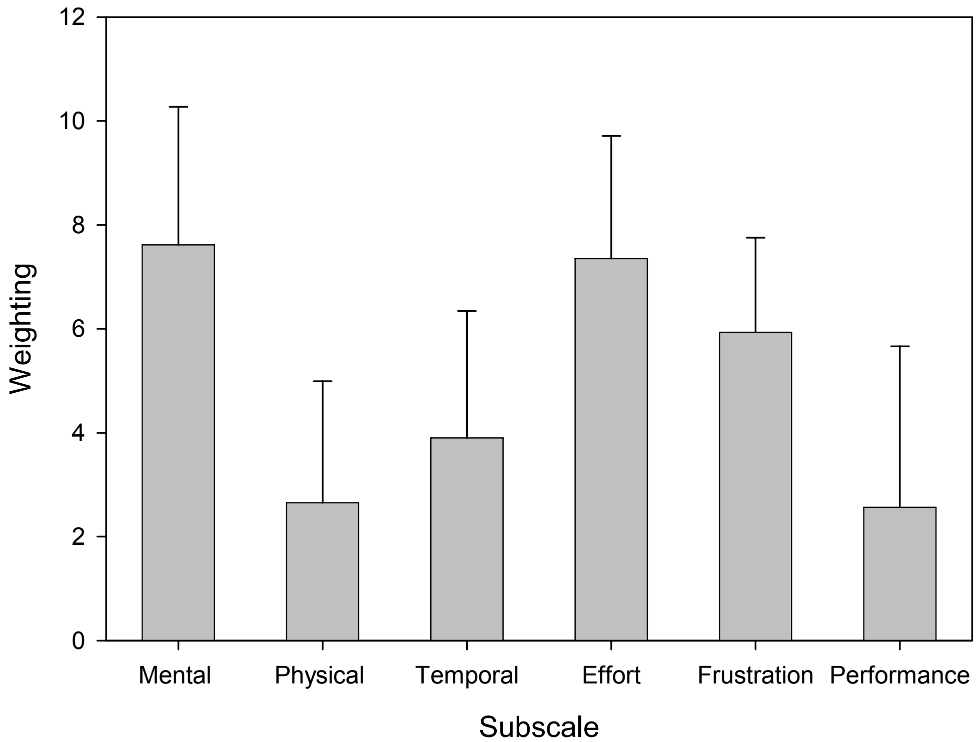


Table 6.4 Pairwise comparisons between the weightings assigned to the mental demand and effort scales compared to all other scale weightings

N = 60	Mental Demand	Physical Demand	Temporal Demand	Frustration	Performance
Mental Demand		W = 110.5*	W = 254.5*	W = 350.0*	W = 115.5*
Effort	W = 773.5	W = 98.0*	W = 108.0*	W = 380.0*	W = 120.5*

(* = significant at p < 0.003 level)

6.5.5 Navigation experience

Hypothesis

There will be differences in navigation experience depending on the type of spatial information used

Navigation experience was measured using the INQ questionnaire.

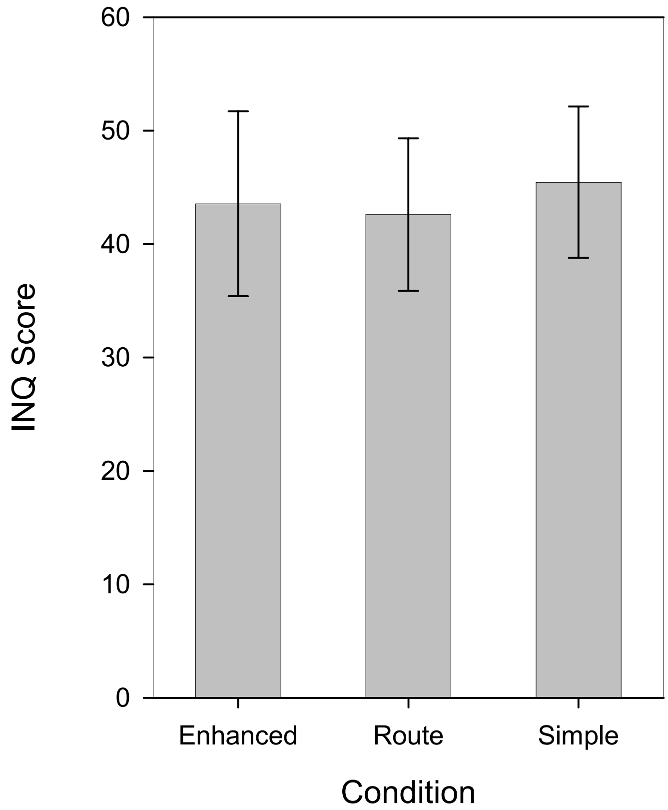
Exploratory Analysis

Exploratory analysis revealed no significant departure form normality and the raw scores were entered into a parametric analysis.

Analysis

Figure 6.14 shows the INQ score for each condition. No differences in either mean or standard deviation are apparent from the graph. A one-way ANOVA (Enhanced vs. Route vs. Simplified) confirmed no significant between-condition variation supporting this observation ($F_{(2,57)}$= 0.8, p>0.05).

Figure 6.14 INQ Scores for each experimental condition



6.5.6 System usability

Hypothesis

There will be differences in the perception of system usability depending on the type of spatial information used

Navigation experience was measured using the System Usability Scale (SUS).

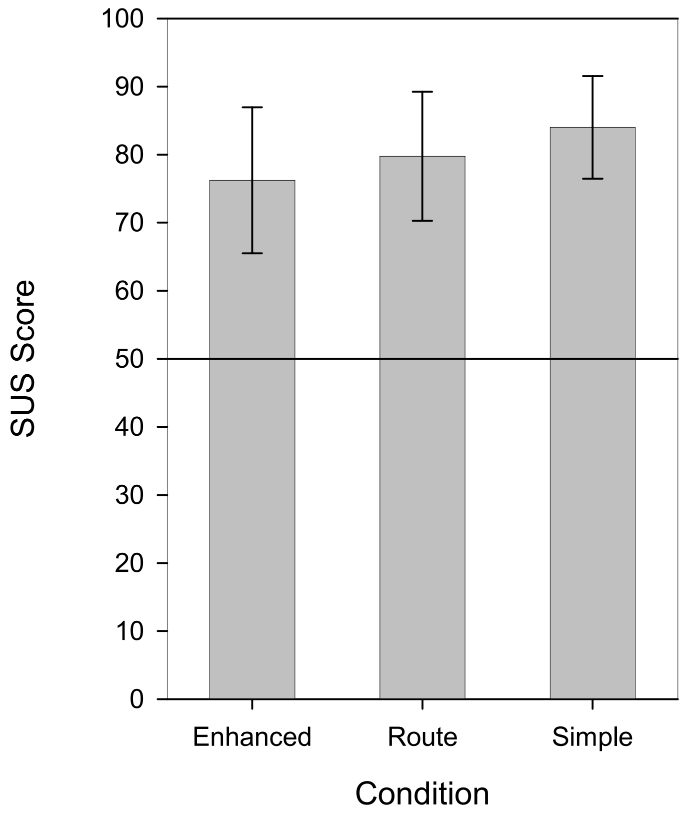
Exploratory Analysis

Exploratory analysis revealed no significant departure form normality and the raw scores were entered into a parametric analysis.

Analysis

Figure 6.15 shows the SUS score for each condition. No differences in either mean or standard deviation are apparent from the graph. A one-way ANOVA (Enhanced vs. Route vs. Simplified) confirmed significant between-condition variation ($F_{(2,57)}$= 3.5, p<0.05). *Post hoc* testing confirmed one significant difference between the enhanced and simplified condition (Tukey HSD = 7.8, p < 0.05).

Figure 6.15 SUS Scores for each experimental condition



6.6 Results: analysis of relationships

In this section, a full analysis of the relationships between route completion time, workload and all other subjective measures is presented. Results from the exploratory analyses in the analysis of differences section (Section 6.5) are used to inform the selection of parametric or non-parametric tests. If any one variable in a correlation is not appropriate for parametric analysis, the equivalent non-parametric test is used. Table 5.13 to Table 5.15 use the following coding to indicating level of significance:

*	p <0.05
**	p <0.01
***	p <0.001

No asterisk indicates that the test failed to reach significance

6.6.1 Route completion time and workload

Hypothesis

There will be relationships between route completion time and workload experienced

A very significant relationship was found between mental demand and route completion time, longer times being correlated with higher mental demand. A weaker significant correlation was found between completion time and frustration. A significant negative correlation between performance and route completion time was found indicating as route completion time increases, participants relate this to a reduction in performance. These results support the hypothesis that there will be relationships between route completion time and workload.

Table 6.5 Correlations between route completion time and workload sub-scales

r_s, N = 60	Mental Demand	Physical Demand	Temporal Demand	Effort	Frustration	Performance
Completion Time	0.51***	0.06	-0.17	0.18	0.27*	-0.33*

6.6.2 Route completion time and subjective measures

Hypothesis

There will be relationships between route completion time and subjective measures

Unlike experiment one, no significant relationships were found between the INQ and SDS scores and route completion time. A weak negative correlation was found between the SUS, usability scores indicating that as route completion time increases, perceived usability of the software reduces. This finding partially supports the hypothesis that there will be relationships between subjective measures and route completion time.

Table 6.6 Correlations between route completion time and subjective measures

N = 60	INQ	SDS	SUS
Completion Time	0.14	0.1	-0.47*

6.6.3 Workload and subjective measures

Hypothesis

There will be relationships between workload and subjective measures

Table 6.7 Correlations between workload sub-scales and subjective measures

r_s, N = 60	Mental Demand	Physical Demand	Temporal Demand	Effort	Frustration	Performance
INQ	-0.12	-0.19	0.10	-0.37*	-0.06	0.27*
SDS	0.04	0.13	0.16	-0.12	0.06	0.01
SUS	-0.28*	-0.13	0.05	-0.16	-0.17	0.07

6.7 Results: analysis of behaviour

Differences in behaviour were far less variable than in experiment one. Only behaviours that were represented more than once in a specific location are described and two locations fulfil these criteria. Unlike experiment one, most participants rotated the map in a predictable way, maintaining an egocentric orientation throughout the route. Different methods of presentation may elicit a greater variety of visible behaviour than the type of information displayed. This consistency of behaviour, particularly rotation, may also be due to the more detailed instructions on using the spatial information given to the participants. Two participants did not rotate the plan at all and reference to these participant's details showed that they were experienced at orienteering and therefore used to reading map information.

Figure 6.16 shows the first location where participants experienced confusion when navigating. The associated spatial information in each condition is shown in Figure 6.17. The location itself is not complex. Participants could see that the arrow was directing them to use the staircase. The problem may be connected with matching the environment to the spatial information displayed. The staircase is split across a landing. The lower part of the staircase is shown on the ground floor plan. The upper part and together with the landing is shown on the first floor plan. Since participants were instructed to and expected to climb stairs completely, the precise configuration of the landing and staircase was not shown. Participants may have been searching for a detailed staircase configuration and become confused when only the lower portion of the stairs was visible on the display but all sections, including the landing, are clearly visible at this point. Further support for this explanation comes from the reduced counts of confusion in the simplified condition (Figure 6.18). Where no staircase detail is shown, participants simply climbed the stairs, unconcerned with their precise architectural configuration.

Figure 6.16 Location one

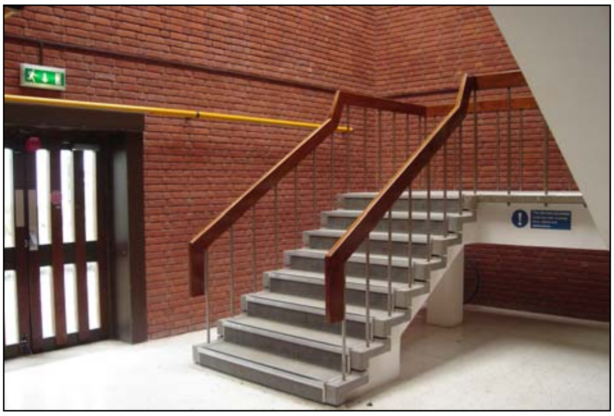


Figure 6.17 Spatial Information displayed for location one

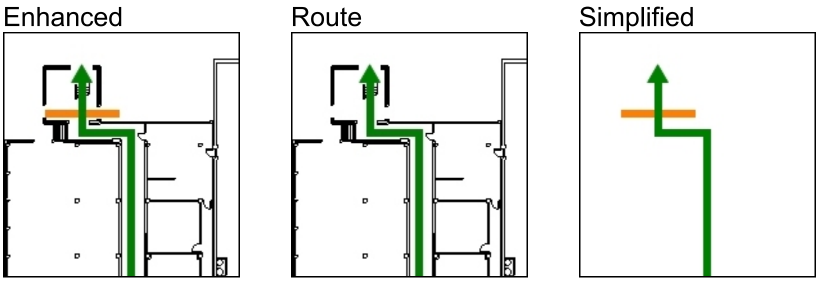


Figure 6.18 Observed confusion for location one

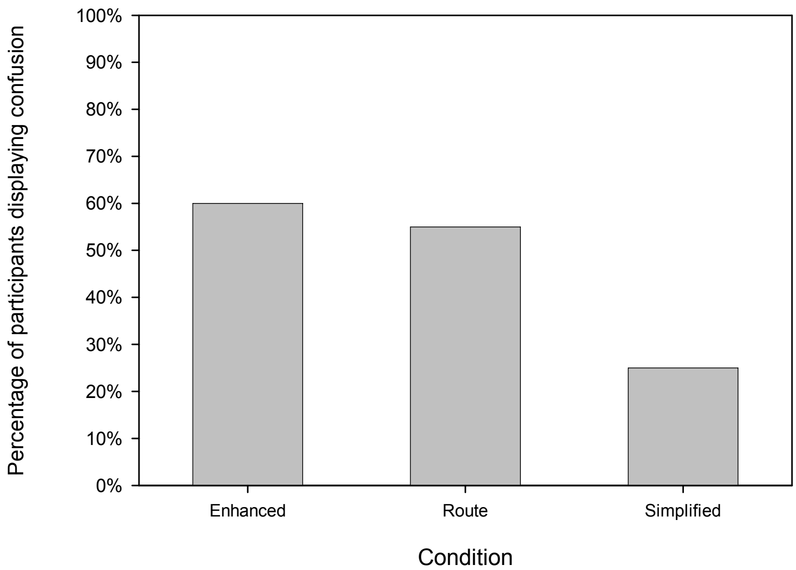


Figure 6.20 shows the second location where almost all participants displayed visible confusion in all conditions (Figure 6.22). The location itself is uncomplicated; participants are required to simply turn right at the bottom of the staircase. Reference to the spatial information (Figure 6.21) shows a unique configuration, not found in any other experiment. Egocentric information is presented bottom to top. This track-up alignment is expected by participants and reinforced since all other presentations follow this rule. This segment does not follow this rule. Figure 6.19 shows the location that participants begin the route in. Since the destination location is displayed as lower than the origin, many participants positioned themselves at this location and tried to turn left instead of right. This track-up expectation is so strong that it appears to override all other information. Even though the staircase is clearly marked and the alternative route is clearly in a long corridor, many participants still took an incorrect route based on the track-up expectation. Perhaps the slightly lower incidence of confusion on the route condition is due to participants being forced to examine the plan information rather than the various route choices found in the enhanced condition.

Figure 6.19 Detail of plan segment in location two

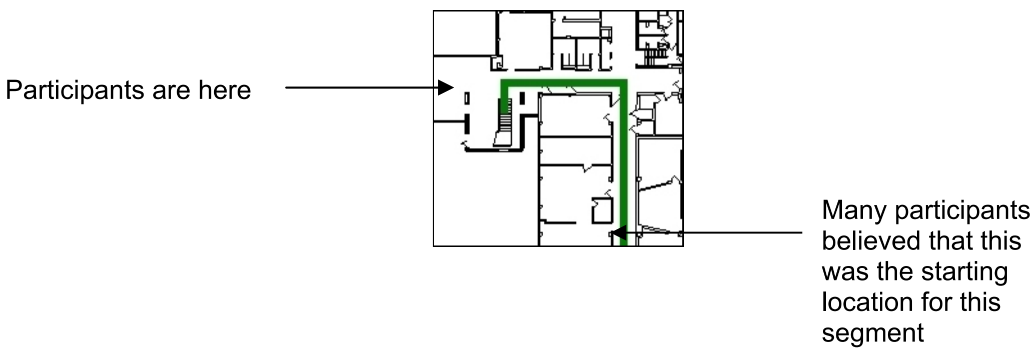


Figure 6.20 Location two

Figure 6.21 Spatial information displayed for location two

Enhanced Route Simplified

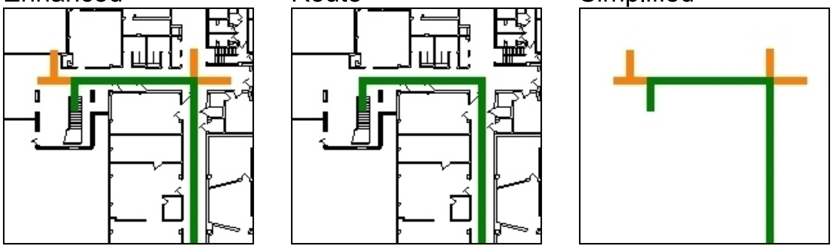
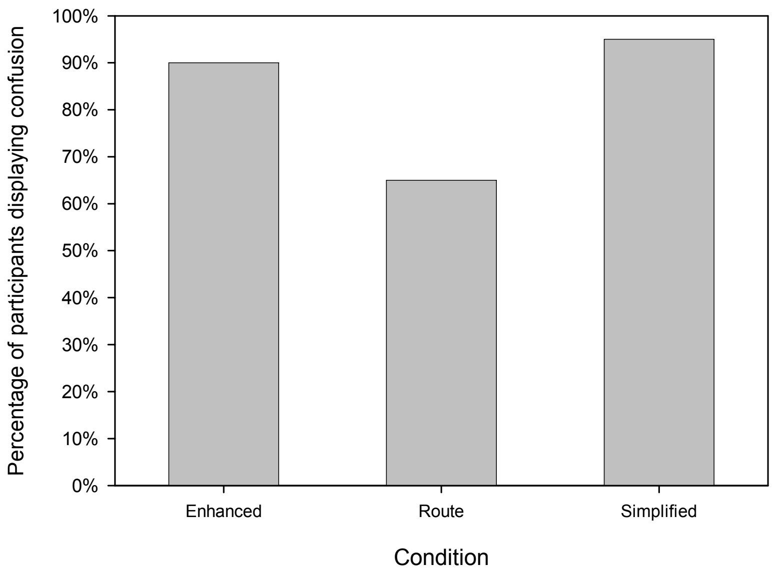


Figure 6.22 Observed confusion for location two



6.8 Summary

In contrast to Experiment one, no significant correlation was found between SDS scores and route completion time. This variable could not be used as a covariate. Route completion time was significantly shorter in the simplified information condition and longer in the enhanced condition. This pattern of differences is further supported by the significantly higher mental demand reported by participants in the enhanced condition when compared to the simplified condition. No other between condition differences were found in any other workload scale. The overall workload index was not sensitive to between condition differences. Analysis of the weightings applied to scales by participants shows that significantly higher weighting was given to the mental demand and effort scales in comparison to the other scales used. No significant differences were found between INQ scores indicating similar subjective experience of navigation, regardless of the type of information displayed. Significant differences in SUS scores were found between the enhanced and simplified condition, however, all usability scores were significantly higher than the target usability score of fifty. This indicates systematic variation in SUS scores rather than an issue with usability per se. Significant correlations between completion time, mental demand, frustration and performance were found overall. No significant correlation was found between effort and route completion time which is unexpected considering the weighting that participants gave to this scale. Only one significant correlation was found between the subjective measures and completion time; usability and completion time was negatively correlated. A scatter of significant correlations were found between the workload scales and the subjective measures including mental demand and usability, and INQ, effort and frustration. Surprisingly, no workload subscale correlated with the SDS scores.

6.9 Discussion

Results indicate that the shortest route completion times and lowest mental demand is associated with the simplified information type. In all cases, participants were able to navigate effectively using the representations, supporting the view that idealised or simplified spatial information can support spatial decision making. This is evident in the simplified information condition where no overall plan information is given. Participants tended to regard the task as cognitive and this is reflected in the higher weightings that participants gave to workload scales that tap cognitive resources, such as the mental demand scale. A number of explanations may account for the reduced mental demand and shorter completion time observed in the simplified condition. The reduced complexity of the spatial information could have directed participant's attention more efficiently towards the relevant cues in the environment from which to navigate. The types of information presented in the simplified condition may have been more appropriate for the specific environment and as such, this information may be more readily accessible and therefore acted on more quickly (Stankiewicz and Kalia, 2007).

Another explanation concerns the complexity of the information displayed. Garling and Golledge (2000) suggest that since navigation has a cognitive component, it is open to human information processing limitations. In the enhanced condition, the increased amount and complexity of information at decision points would take longer to process and act on when overlaid with the plan information than in the simplified condition. Divided attention or capacity limitation in working memory may conspire to increase mental demand elicited while comparing the environment with the spatial information on the screen and acting accordingly. The simplified condition provides sufficient spatial information from which to navigate while avoiding the inclusion of superfluous information. The empirical evidence shows that mental demand and completion time in the route condition fall between the other two conditions suggesting that decision point markers are necessary on the simplified information but not on the enhanced information. No significant differences were found between the route condition and either the simplified or enhanced conditions. During the experimental procedure, participants tended to use whatever information they were given whether it was necessary for successful navigation or not. In both the route and enhanced condition participants tended to be far more cautious than in the simplified condition, checking the information on the screen against the surrounding environment. In the simplified condition, this strategy was not available to participants who appeared to navigate far more confidently and quickly. These observations are supported by the empirical evidence presented in this paper of reduced route completion times and lower mental demand.

One participant found the simplified information condition very challenging to use. In the post trial interview, the participant indicated a very high level of experience with maps. This may represent an ability to use a lot of information and become disorientated when less information is made available. Unlike other participants in this condition, the experienced map reader was less confident and asked the experimenter questions throughout out the trial.

The subjective measures used in the study, the SDS and INQ were not successful predictors of performance or workload. This is in contrast to the first study. One explanation for this difference is that in the first study plan presentation was the variable of interest rather than the specific information contained within the plan, as is the case in the present experiment. The SDS and INQ may not be sensitive enough measures to discern differences in information type, but can differentiate different types of plan presentation. A surprising number of significant results were found in relation to the usability scale, the SUS. Significant differences were found in usability between conditions, the simplified was reported to have better system usability than the enhanced condition. Significant relationships were found between route completion time and mental demand. The SUS is a validated test and a target score of fifty was exceeded in all conditions. This difference was very significant. Nevertheless, the measure is tapping some aspect of use which is correlated with navigation performance and mental demand.

One problem with the simplified information set is that error recovery would be seriously impaired since less information is available to the participant to match the environmental stimuli with external spatial information if lost. Any commercial product would have to give the option of increased information on demand or automatic indication of position. Further research being conducted will examine whether this pattern of results is similar for outdoor, built-up environments.

6.10 Conclusion

The major contribution of this experiment to the thesis are the results indicating that simplified spatial information is more effective than the other types of spatial information used when supporting navigation in the inside environment. This finding is important as simplified information can reduce cognitive demand in addition to maintaining performance when navigating. These are two major requirements of the fire service when proposing LBS to support navigation (see Chapter 3). Whether this pattern of results is the same for the outside environment is the focus of experiment three.

6.11 Methodological review

6.11.1 Workload

The results of this experiment indicate that the overall task-load index is not a sufficiently sensitive measure when examining differences in information type. The main workload scale that continues to diagnose significant differences and correlations is the mental demand scale. This scale was also weighted as significantly more important than other scales in this task. In experiment three, only the mental demand scale will be used. The main reason for exclusion of the other scales is one of reliability. Due to the within-subjects design, each participant must recall workload for three different conditions using a within-subjects design. Under these circumstances recalling workload on six scales would mean forming eighteen judgements. Taking this as a reliable measure of workload is not realistic. The strong performance and importance assigned by participants to the mental demand scale means that this is the scale of choice in experiment three.

6.11.2 SUS

The success of the SUS in this experiment is worthy of further comment. Unlike experiment one, no visible signs of participants having difficulty interacting with the software were observed. This observation is further supported by the high (>50) scores collected from participants. The significant correlations and differences may reflect cross-over in certain dimensions of the SUS, the mental demand scale and route completion time. For example, A strong disagreement with question 3…

> *"I thought that the system was easy to use"*

…may reflect higher mental demand being elicited in order to navigate if a user found the system challenging or difficult to use.

> *"I felt very confident using the system"*

…may be caused by a participant needing to pause less or refer to the environment fewer times during the trial. These behaviours would result in shorter route completion times. These tentative explanations aside, results from the SUS will be monitored closely in experiment three.

Chapter 7 Experiment Three

7.1 Introduction

This experiment examined pedestrian navigation using different types of spatial information in a built up, outside area of the campus. The area selected for the experiment comprises a variety of buildings around the Faculty of Engineering at the University of Nottingham. The area is composed of a complex arrangement of buildings, storage areas and manufacturing laboratories (Figure 7.6 shows photographs of the area). This type of environment was selected since it could well be the site of a large, geographically distributed incident that the fire service would attend.

As in previous experiments, location-based spatial Information was presented. Underlying OS MasterMap data showing buildings and major features was used to design the maps. If such a service were to be developed it is likely that OS MasterMap data would be used to support it. OS MasterMap data is not optimised for this type of application. The comprehensive nature of this dataset means that often more information than is desirable may be displayed. No attempt has been made in this study to systematically alter OS MasterMap data. This constraint is important when interpreting guidelines which may refer explicitly to the way in which OS MasterMap data is used or displayed.

The range of structural features in the inside environment may be more predictable than the outside environment. Often large buildings will contain recognisable configurations of corridors, staircases and offices. Conversely, the development of outside environments may be more organic and location specific. While the supporting navigation at decision points is still critical, positive matching of the environment to the spatial information may be more challenging given the range of features perceived or displayed on the map.

This experiment used the same types of spatial information employed in experiment two. Using the same types of information allowed for comparison of results between the inside and outside environments. The route to be taken was shown as a green line. Instead of floor plan information, OS MasterMap data was displayed.

7.2 Experimental Hypotheses

- Different types of spatial information will result in differences in route completion time.
- Different types of spatial information will result in differences in mental demand experienced by participants
- There will be differences in map viewing behaviour depending on the type of spatial information used.
- There will be a relationship between map viewing and route completion time
- There will be a relationship between mental demand and route completion time
- There will be a relationship between mental demand and map viewing
- There will be relationships between map viewing and subjective scales
- There will be a relationship between mental demand and subjective scales
- There will be a relationship between route completion time and subjective scales

7.3 Design

Figure 7.1 shows examples of the spatial information used in the experiment.

Figure 7.1 Examples of the information types used in experiment three

Enhanced   Route   Simple

With reference to Figure 7.1, a solid green line indicates the route that participants should take. As in experiment two, the three conditions are enhanced, route and simplified. In the enhanced condition the decision points augmented by orange bars indicated to participants that they should not take the particular route. Since correct spatial choice at decision points is critical for correct navigation, information was enhanced at these points. The route condition showed a green line that participants should follow. In both of these conditions, OS MasterMap information is overlaid onto the route information. Buildings and other static features in the environment were marked in light grey. The simplified condition contained the route information in green and the decision-points again marked in orange. The decision points in this condition are critical in order to anchor and update participant's spatial knowledge. No overall map information was shown in the simplified condition and participants were expected to navigate using the simplified route information only. In all cases, presentation of the spatial information was location-based in that only the segment of the map relevant at that specific location was displayed. Presentation was egocentric in all conditions in order to assist participants to orientate. Egocentric presentation of spatial information has been shown to be more effective in assisting navigation than other forms of presentation (Aretz and Wickens, 1992).

The design of experiment three is different to experiments one and two. In previous experiments high between-subject variation may have masked experimental effects. A full, within-subjects design was developed for the present study. Each participant used all three types of spatial information to navigate at different parts of the route. Presentation of the different types of spatial information was counterbalanced according to both the order of presentation and the location of presentation. The route was segmented into three parts of similar length for the counterbalancing. Map segments of the same type were presented in these three locations. In this way, participants were grouped into blocks of six where information type-environment combinations were represented. A visual representation of this counterbalancing process is shown in Figure 7.2.

Figure 7.2 Visual representation of counterbalanced information type and location

	Location1	Location 2	Location 3
1	Simplified	Route	Enhanced
2	Enhanced	Simplified	Route
3	Route	Enhanced	Simplified
4	Enhanced	Route	Simplified
5	Route	Simplified	Enhanced
6	Simplified	Enhanced	Route

7.3.1 Dependent variables

Core dependent variables used in this experiment are shown in Table 7.1. Full details of these dependent variables can be found in Chapter 4 (p100).

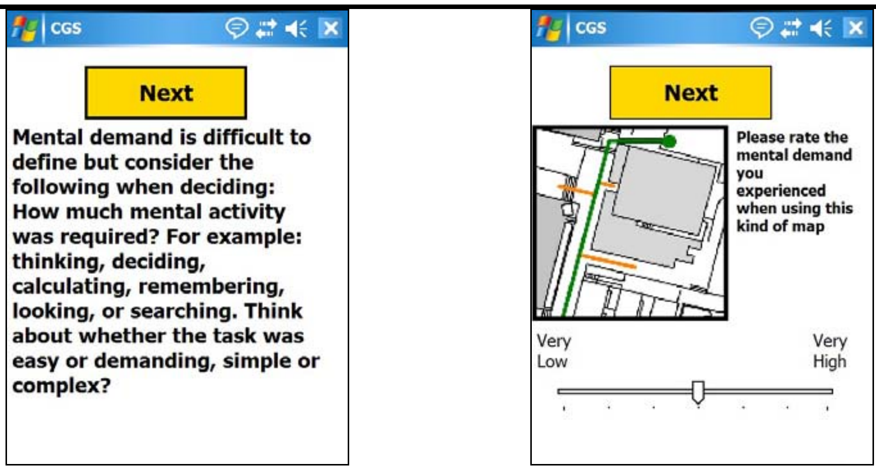
Table 7.1 Core dependent variables used in experiment three

Dependent Variable	Measurement
Performance	Average speed (metres per second)

Individual Differences	Sense-of-Direction Scale
Workload	NASA-TLX (Mental demand scale only. No weightings recorded)
Experience	Integrated Navigation Questionnaire (INQ)
Usability	System Usability Scale

Mental demand was recorded following the experiment on the PDA (Figure 7.3). Participants supplied three mental demand ratings for each type of map following extensive instructions, delivered automatically on the PDA. Participants were reminded of each type of map using an example map taken from another location, unconnected with the experiment. Participants then moved a slider along a scale to indicate the mental demand experienced.

Figure 7.3 Examples of the PDA presentation of the practice screen and workload scale



Example of Instruction Screen	Rating screen for the enhanced condition

No record of behaviour was kept for this experiment since attention was focused primarily on the safety of the participant. As this experiment took place outside, several roads had to be crossed and the experimenter took on primary responsibility for checking that routes were clear since the participant was often completely engaged in the navigation task.

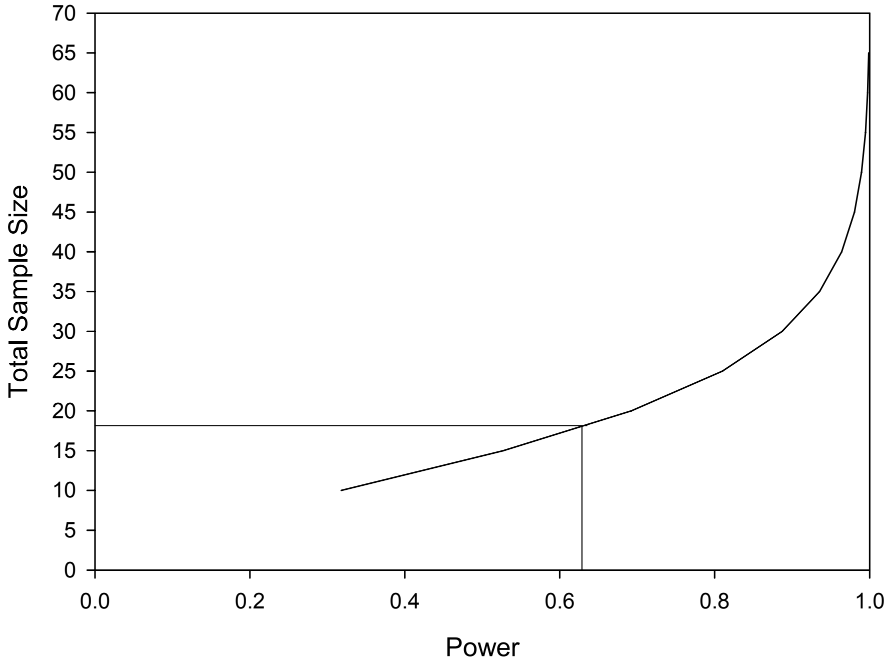
Other dependent variables, specific to this experiment include the total time (in seconds) that the participant looked at each type of spatial information and the number of times that the participant looked at the information for each route section. Dividing these variables into each other gives the average length of time that the participant glances at each type of map. Collectively, these variables are described as ‘Map Viewing’ in the results section.

7.3.2 Power analysis

An assessment of power was used to derive an appropriate sample size. The variable selected for the assessment is time of completion of the route since this is of high importance in the fire service.

The sample means from three conditions in the second experiment will be used to estimate the effect size required for the power calculation. Using these estimates, an average effect size (d) of 0.53 is estimated. The relationship between sample size and power for this experimental design is shown in Table 7.2 Due to the counterbalanced design, the number of participants must be a multiple of six. A sample size of eighteen develops a satisfactory level of power of 0.62 and this is the sample size that will be used in the study.

Table 7.2 Power as a function of sample size (d = 0.53, α = 0.05)



7.4 Method

7.4.1 Participants

Twenty participants completed the study. Participants were drawn from staff and students at the University of Nottingham. All participants completed all conditions. Sex was counterbalanced. Full details of participant age and familiarity with the route used in the experiment are shown in Table 6.2.

All participants reported normal or corrected to normal vision and all had English as a first language.

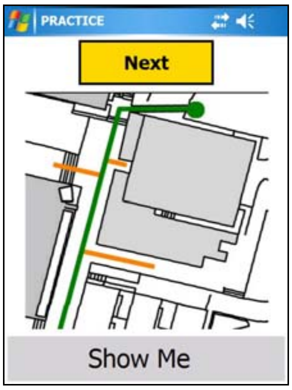
Table 7.3 Age (years) of participants and familiarity with the experimental environment

Variable	Age (SD)	Familiarity (SD)
Male	20.6 (2.1)	4.2 (2.6)
Female	22.5 (7.3)	2.5 (1.6)
Total	21.9 (6.2)	3 (2.0)

7.4.2 Materials

Version 3 of the software was used to present the map segments. Full details of the software development are discussed in Chapter 4. A screenshot of the type of display experienced by participants is shown in Figure 6.4.

Figure 7.4 Screenshot of the display used by participants in experiment 3



Route Selection

A route at the Faculty of Engineering, University of Nottingham was selected for the experiment. The route was selected since it contains several 90^{O} turns and as such is not straight-forward to navigate or recall. The route is approximately 637m long. Participants were required to navigate between buildings. Figure 7.5 shows the route taken by participants. Circles are used to indicate the start and end points of the route and the start point is identified by a red arrow. Figure 7.6 shows different views of the route at various locations.

Figure 7.5 Map of the route taken by participants

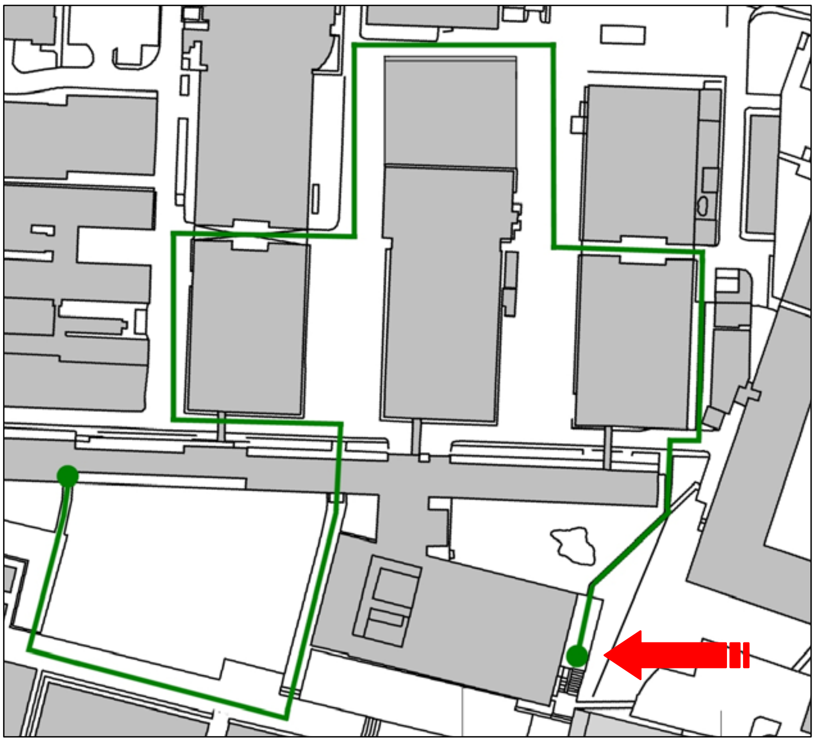
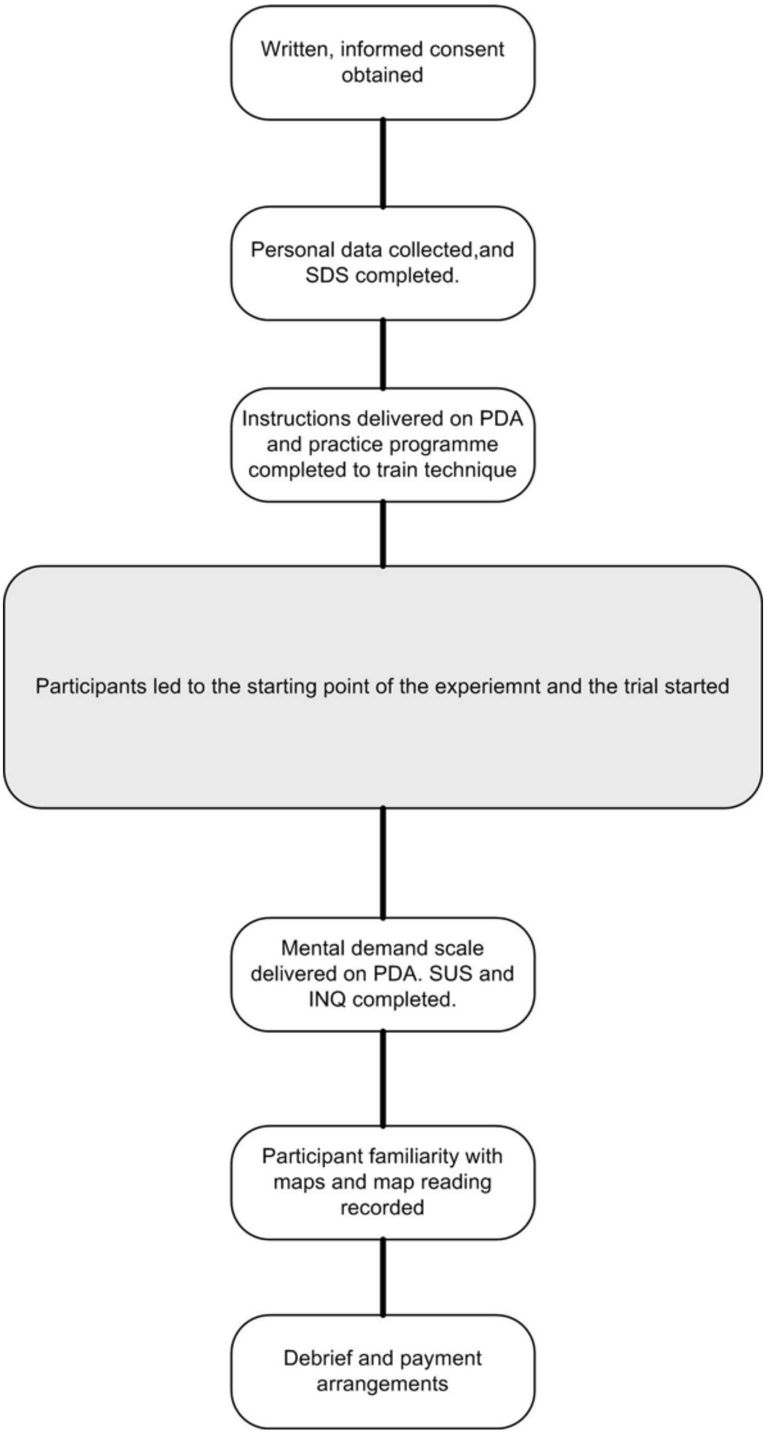


Figure 7.6 Different views of the route navigated by participants

7.4.3 Procedure

Figure 7.7 shows a flow diagram of the procedure used in experiment one. The descriptions of specific parts of the procedure are discussed below.

Figure 7.7 Diagram of the procedure used in experiment three



Participants gave written, informed consent in a room away from the route taken in the experiment. Participants then submitted personal data and completed the SDS questionnaire. Instructions for using the different types of information were delivered on the PDA itself. This gave participants the opportunity to use the PDA and practice with the interface they would be using.

Participants were then led to the starting point of the experiment. The route taken to the starting point was deliberately selected so that no part of the experimental route would be either traversed or visible to the participant.

The participant was then handed the PDA instructed to start when ready. Timing was started by the participant tapping the start button. As in experiments 1 and 2, the experimenter would instruct the participant to advance the map by tapping the 'Next' button at predefined points on the route. If participants made deviations from the prescribed route, they were led back to the last correct location and asked to re-localise themselves on the map.

When participants completed the route the timing was automatically stopped and recorded by the PDA. Participants were then led into another room, adjacent to the completion point and completed the NASA-TLX mental demand scale. This scale was delivered on the PDA. Following completion of the NASA-TLX, participants completed the INQ and SUS questionnaires. Participants then indicated their level of familiarity with maps and map reading and their occupation was recorded. Participants were then debriefed and arrangements for payment were put in place.

7.5 Results: analysis of differences

7.5.1 Participants

Non-parametric ANOVAs (Kruskal-Wallis) revealed no significant in between-sex differences in familiarity ($\chi^2_{(1)} = 1.7$, $p > 0.05$) or age ($\chi^2_{(1)} = 0.2$, $p > 0.05$).

7.5.2 Santa-Barbara sense of direction scale (SDS)

Exploratory Analysis

Exploratory analysis of overall participant scores from the SDS revealed no significant departure from normality ($W_{(18)} = 0.9$, $p > 0.05$). Skew and kurtosis are within two standard errors so the data is suitable for parametric analysis. Descriptive statistics are shown in Table 6.3. For comparison, the overall results of this test for experiment one and experiment two (Section 5.5.2, p139 and Section 6.5.2,p181), are shown. Although the distribution of scores displays slight negative skew, overall the results are very similar suggesting that the SDS is a reliable test of perception of sense-of-direction.

Table 7.4 Descriptive statistics for the SDS scale

	Mean Score	SD	Skew (SE)	Kurtosis (SE)
Current Experiment	50.2	14.8	-0.5 (0.5)	-0.9 (1.0)
Experiment 2	50.1	10.8	-0.2 (0.3)	-0.07 (0.6)
Experiment 1	49.6	15.4	0.4 (0.3)	0.7 (0.7)

7.5.3 Correlations with other dependent variables

No significant linear relationships were found between SDS scores and route completion time or any workload scale. As such, SDS scores cannot be entered into the between-condition analysis of these variables as a covariate. A weak but significant linear relationship was found between INQ scores and SDS scores ($r = 0.41$, $N = 60$, $p < 0.01$, two-tailed) indicating that these two measures may be testing similar aspects of participant perception of navigation.

7.5.4 Estimated route completion time

Hypothesis

Different types of spatial information will result in differences in route completion time.

As in experiment one and two, route completion time is treated as the main measure of participant performance. Since participants completed route sections of different lengths using the different types of spatial information, a measure of average speed (ms^{-1}) was used to compare performance between the different conditions. To create a more meaningful variable, the average speed was then multiplied by the total route length in metres giving an estimate of the time taken to complete the entire route using that specific type of spatial information.

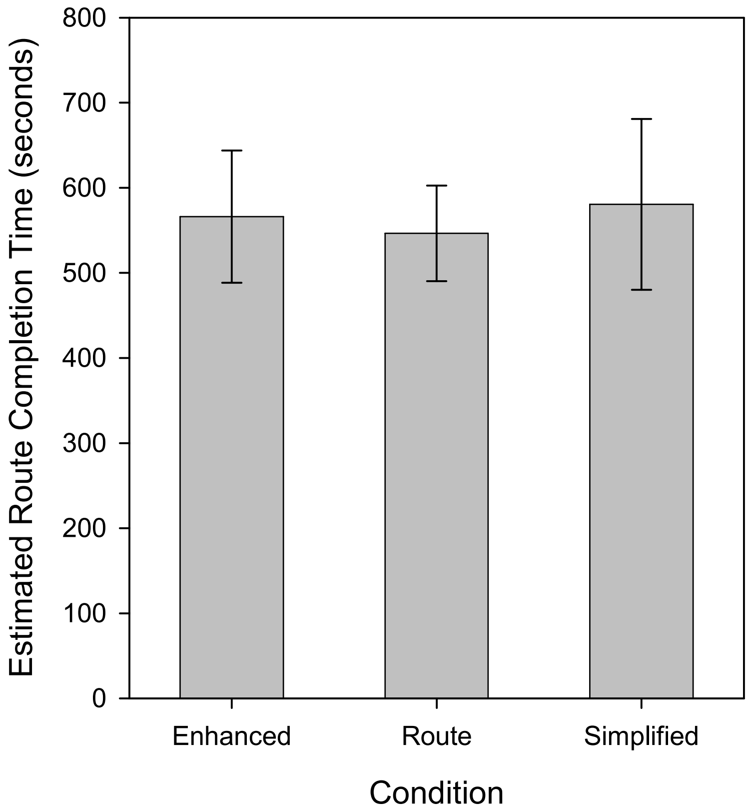
Exploratory Analysis

Analysis showed significant departure form normality in the enhanced ($W_{(18)} = 0.89$, $p < 0.05$) and simplified ($W_{(18)} = 0.84$, $p< 0.05$) conditions. A $\log_{10}$ transform corrected the distribution of the data and the Shapiro-Wilks test indicated no significant departure from normality in any of the transformed conditions. Parametric analysis will be used for this data.

Analysis

Figure 6.8 shows slightly higher route completion time in the simplified condition with larger variation lower route completion times in the simple condition compared to the other two conditions. Overall, very little difference between conditions is apparent. A one-way, within subjects ANOVA (enhanced vs. route vs. simple) confirms this observation, showing no significant variation in estimated route completion time between the conditions ($F_{(2,34)} = 0.9$, $p>0.05$). This finding does not support the hypothesis that different types of spatial information will affect route completion time.

Figure 7.8 Average, estimated route completion time for each type of spatial information



7.5.5 Mental demand

Hypothesis

Different types of spatial information will result in differences in mental demand experienced by participants

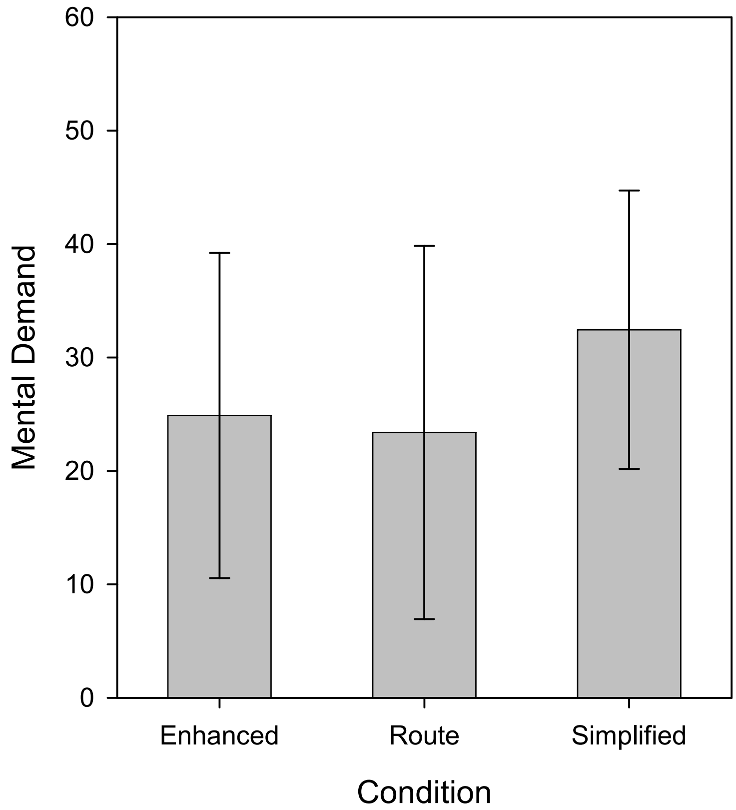
Exploratory Analysis

Exploratory analysis revealed significant departure from normality in the route condition ($W_{(18)} = 0.90$, $p < 0.05$). A square-root transformation corrected the distribution and parametric analysis will be used.

Analysis

Figure 6.9 shows higher mental demand in the simplified condition when compared to both the enhanced and route conditions. High variation is apparent in all conditions. A one-way, repeated measures ANOVA was conducted. Mauchly's statistic is shows significant departure from sphericity (Mauchly's $W_{(2)} = 0.7$, $p < 0.05$). The Greenhouse-Geisser F-ratio is reported to account for this property of the data. The analysis shows significant variation in mental demand between conditions ($F_{(1.5,34)} = 4.7$, $p < 0.02$). Planned contrasts showed one significant difference between the route condition and the simplified condition ($F_{(1,17)} = 6.7$, $p < 0.02$). These findings support the hypothesis that different types of spatial information will affect mental demand.

Figure 7.9 Comparison of mental demand for each condition



7.5.6 Map viewing behaviour

Hypothesis

There will be differences in map viewing behaviour depending on the type of spatial information used.

Exploratory Analysis

The Shapiro-Wilks test confirmed normality in the enhanced condition for average viewing time but significant departure from normality in the route and simplified conditions was identified. A Log_{10} transformation was applied to the data and repeat analysis confirmed suitability for parametric analysis. Significant departure form normality was observed for total viewing time and total number of views for all conditions. Non-parametric analysis will be used for the analysis of these variables.

Analysis

Lower average viewing time is clear in the route condition and the simplified condition shows higher variation in average viewing time than the other conditions (Figure 7.10). Overall, no significant difference was found in map viewing time between the conditions ($F_{(2,34)} = 1.4$, $p > 0.05$). The total number of views and the total map viewing time is also very similar for each condition (Figure 7.11). Variation is consistently high across all conditions, especially for total viewing time. Non parametric ANOVAs (Friedman) confirm this pattern indicating no significant difference in total viewing time ($\chi^2_{(2)} = 1.8$, $p > 0.05$) or total number of views ($\chi^2_{(2)} = 1.2$, $p > 0.05$). The hypothesis that different types of spatial information will affect average viewing time is not supported.

Figure 7.10 Comparison of average map viewing time for each condition

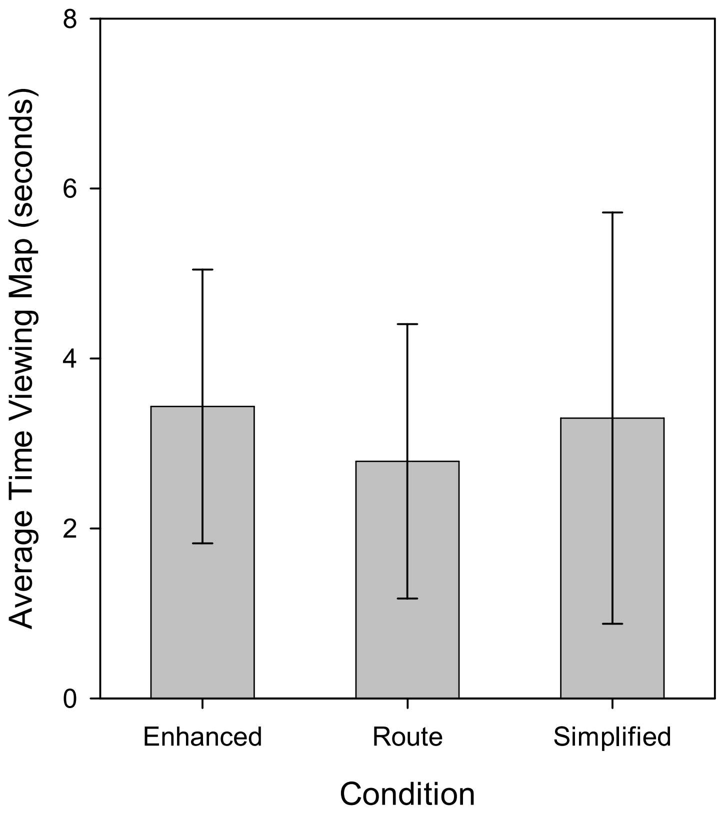
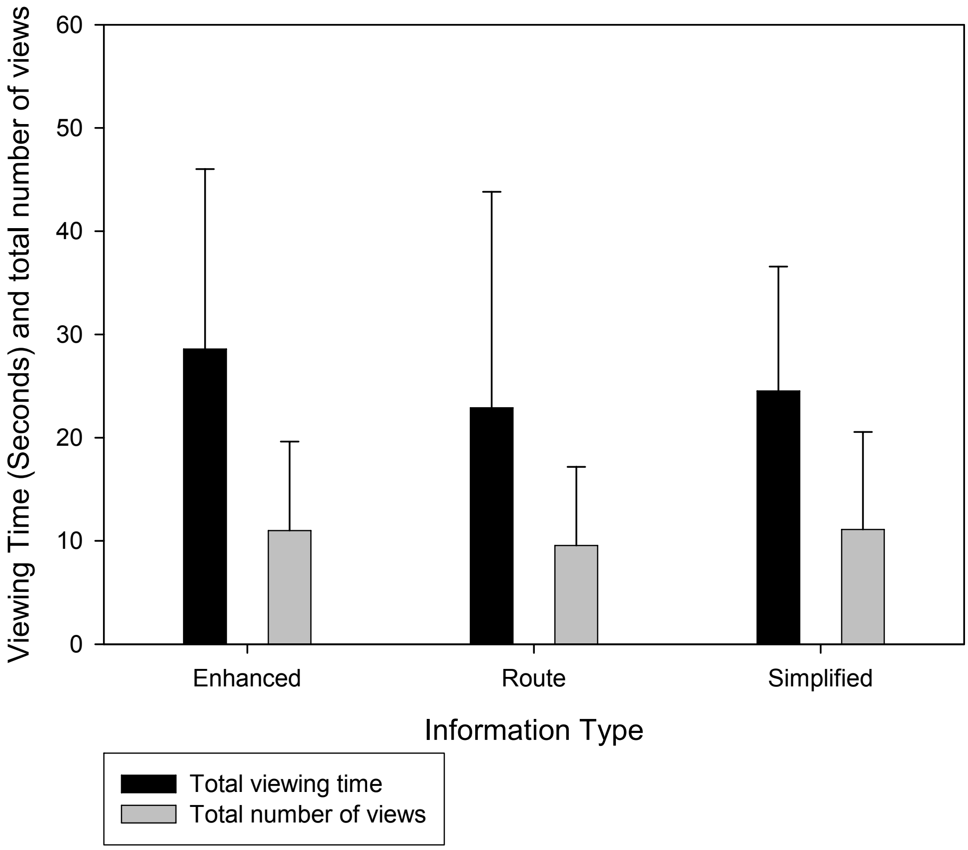


Figure 7.11 Comparison of total viewing time and number of views for each condition



7.6 Results: analysis of relationships

In this section, a full analysis of the relationships between route completion time, workload and all other subjective measures (SDS, INQ and SUS) are presented. Results from the exploratory analyses in the analysis of differences section (section 7.5) are used to inform test selection. Transformed data is used where appropriate. The following coding indicates level of significance:

*	p <0.05
**	p <0.01
***	p <0.001

No asterisk indicates that the test failed to reach significance.

7.6.1 Restructuring of the data

In order to perform the correlations in sections 7.6.1 to 7.6.5, the dataset required restructuring. The original design comprises of eighteen participants each of whom provide scores in three conditions. The new data merged each group creating a new dataset comprising of fifty-four unique cases for each dependent variable (route completion time, mental demand, average viewing time, cumulative viewing time and number of views). Participants gave a single score on the subjective measures (SDS, INQ and SUS). As such, each score is replicated three times in the dataset. This pseudo-replication can give rise to type-1 errors due to artificial inflation of the sample size. In order to correct for this problem, r generated by the full dataset on these variables will be used, but evaluated against a significance level appropriate for a sample size of eighteen. Since r is a function of sample size, this method will correct for type-1 errors.

7.6.2 Route completion time and map viewing

Hypothesis:

There will be a relationship between map viewing and route completion time

A significant but weak, positive correlation between route completion time and cumulative viewing time was found. No other significant correlations were found. These results support the hypothesis that there will be a relationship between map viewing and route completion time.

Table 7.5 Correlations between route completion time and map viewing

	Average viewing time	Total viewing time	Number of views
Route Completion Time (r_s)	0.10	0.33*	0.10

7.6.3 Route completion time, map viewing and mental demand

Hypotheses:

1. *There will be a relationship between mental demand and route completion time*
2. *There will be a relationship between mental demand and map viewing*

Table 7.6 shows significant, weak positive correlations between the number of views, the total time spent viewing the map and mental demand. This supports the hypothesis that there will be a relationship between mental demand and map viewing. No significant relationship between route completion time and mental demand was found and the hypothesis that there will be relationships between mental demand and route completion time is not supported

Table 7.6 Correlations between mental demand, route completion time and map viewing

	Route Completion Time	Average viewing time	Total viewing time	Number of views
Mental Demand (r)	0.17	-0.17	0.28*	0.37**

7.6.4 Map viewing and subjective scales

Hypothesis:

There will be relationships between map viewing and subjective scales

Table 7.7 shows significant negative correlations between the number of views and scores on the SDS and INQ. A more negative perception of navigation ability and a more negative navigation experience are associated with more frequent viewing of the map. The time spent viewing the map is not associated with any subjective measures. No significant correlations between the SUS scores were found. These results partially support the hypothesis that there will be relationships between map viewing and the subjective scales.

Table 7.7 Correlations between route completion times, map viewing and subjective scales

$r_{(adj, N=18)}$	Average viewing time	Total viewing time	Number of views
INQ	0.32	-0.24	-0.49*
SDS	0.22	-0.35	-0.51*
SUS	-0.10	0.10	0.10

7.6.5 Mental demand, route completion time and subjective scales

Hypotheses:

1. *There will be a relationship between mental demand and subjective scales*
2. *There will be a relationship between route completion time and subjective scales*

Table 7.8 shows only one significant correlation between mental demand and the INQ score. A more negative experience overall is related to higher workload while navigating. The hypothesis that there will be a relationship between workload is partially supported. Low, non-significant correlations are apparent between all subjective scales and route completion time. The hypothesis that there will be significant relationships between subjective scales and route completion time is not supported.

Table 7.8 Correlations between mental demand and subjective scales

$r_{(adj, N=18))}$	INQ	SDS	SUS
Mental Demand	-0.40*	-0.17	0.10
Route Completion Time	0.10	-0.20	0.3

7.7 Summary

Participant scores on the SDS are normally distributed and produce means and standard deviations very similar to the previous experiments indicating a degree of reliability in the measure. A weak significant correlation between the SDS and the INQ was found. No other significant correlations with the SDS were found and as such SDS scores were not entered into any analysis as a covariate. No significant differences in route completion time or average map viewing time between conditions were found. In both cases between-subject variances were high, particularly in the simplified information condition. Significant variation in mental demand was found between conditions. Further analysis revealed only one difference in mental demand between the route and simplified information conditions. Mental demand was higher in the simplified condition. The large variance in mental demand for the enhanced condition accounts for the lack of significant difference between this condition and the simplified information conditions.

A significant, positive correlation was found between the cumulative map-viewing time and route completion time indicating that more time spent viewing the map is related to longer completion time. No other map viewing variables (average viewing time and number of views) were significantly correlated with completion time. Mental demand is significantly correlated with both the cumulative viewing time and the number of views. Correlations between mental demand and route completion time were not significant.

Significant, negative correlations between the INQ, SDS and the number of views were found. Lower perception of sense of direction and a more negative experience of navigating predicts a higher number of views of the maps. Measures relating to the length of viewing time did not correlate with any subjective scales. Mental demand correlated significantly with the INQ scores. A more positive experience of navigation leads is associated with lower mental demand experienced. No significant correlations between route completion times and the subjective scales were found. The SUS did not correlate with any dependent variables.

7.8 Discussion

Overall, the results from experiment three remain diffuse and any interpretation is speculative. The lack of significant between-condition differences in map viewing and route completion time indicate that other factors are influencing participant navigation rather than the specific type of spatial information presented in the study. The significantly higher mental workload in the simplified information condition is of interest. In the inside environment, workload was lowest in this condition indicating that more information may be required when navigating in the outside environment. However, this result remains difficult to interpret since no significant pairwise difference in workload was found between the simplified condition and the enhanced condition. Since the enhanced condition also showed lower workload, no convincing argument that simplified information elicits higher workload in the outside environment can be proposed.

Analyses of relationships in the data indicate that longer route completion times are associated with greater time spent viewing the map. This behaviour may present as either stopping to view the map while matching the environment or slowing down to view the map for a longer time while moving in the correct direction. Map viewing, both the number of views and the total viewing time is associated with mental workload. Viewing the map more, for longer is related to higher perceived mental demand. These measures could very well be developed to provide an objective measure of mental workload in this area of study. Increased map viewing is related to a more negative perception of navigation ability and a more negative experience of navigation overall. The mediating factors in this case may be confidence than any specific ability. Increased checking of the map, for longer periods of time may indicate a less confident approach to navigation which would be predicted by a lower SDS score.

A series of non-significant correlations between the subjective scales, mental demand and route completion time were found. This suggests that route completion time is not performing as a diagnostic variable in this experiment and may be due to the selection of the independent variables.

Taken as a whole, the results suggest that in the external environment, many more variables are interacting to affect navigation. These other variables may swamp the effect of the independent variable, information type, leading to the results achieved in this study. Further support for this position is provided by the large, between and within-group variation seen in Section 7.5. While the counterbalancing may have removed any systematic effect of environment, the unique characteristics of each segment of the environment displayed on the map may have produced sufficient random error to annul any effect of the independent variable on navigation as a whole. In essence, the environmental counterbalancing elicits a less than impressive selection of randomised environmental effects.

The theoretical perspective of the modified LRS approach (Montello, 2005a) may explain the results found. In the modified approach different levels of spatial knowledge interact and tend towards simplicity rather than increasing complexity. Structural and object landmarks (Stankiewicz and Kalia, 2007) may explain why the information types discriminated navigation performance and workload in the inside environment but not in the outside environment. Structural features of the inside environment such as stairs and corridors can behave as landmarks. These features were marked on the spatial information delivered to participants. Although simplified information looks like a route, the intersections and staircases marked may be viewed as landmarks. Together with the reduction in extraneous information this may have contributed to improved performance in the simplified condition in the inside environment. In the external environment, structural landmarks are far less consistent from one part of the environment to another. In the outside environment, route intersections and decision points were displayed in all conditions. Perhaps this type of information does not unduly disrupt navigation but at the same time, does not support it either leading to poor discrimination of navigation performance due to inappropriate independent variables. The higher workload elicited in the simplified condition when compared to the route condition may be an effect of a reduction of object landmarks such as buildings or other features which are displayed in the route condition. Object based landmarks may be more useful to include than structural landmarks when representing the outside environment and perhaps it is these features that should be included when developing future experiments rather than the structural landmarks employed in the present study.

7.9 Conclusion

The major contribution of this experiment to the overall thesis is the finding that the information simplification and enhancements do not improve navigation performance in the outside environment. The simplified information actually increases cognitive demand when navigating. This finding is important overall since it indicates that the interaction between the environment and the information displayed must be considered when supporting navigation. For firefighters, the type of information to deliver optimal support for navigation must be considered within the context of the environment.

7.10 Methodological review

7.10.1 Experimental design

The within-subjects design was less successful than anticipated. Although the selection of independent variables may have been a significant contributory factor, there remains a difficulty in asking participants to recall workload for specific parts of the journey or the statistical treatment of replicated questionnaire results. Perhaps a less complex approach using the more successful map-viewing variables may be productive in future experiments.

The inevitable truism of ‘more participants needed’ cannot be avoided in this study. With hindsight, the multiple interacting variables in the feature-rich, outside environment may lead to smaller effect sizes. The effect size used in this study ($d = 0.53$) was based on studies carried out in inside environments. Perhaps this figure needs reducing in the light of these results.

7.10.2 Independent variables

The independent variables used in his study were selected specifically for the purposes of comparing navigation performance outside and inside using the three types of information. While these three types of information may differentially affect navigation in the inside environment, this does not appear to be the case in the outside environment. This study does not show significant differences in major dependent variables in navigation between the conditions. This may reflect the properties of the different environments experienced in the outside environment. In order to explore this explanation further the data was restructured. Route completion times for the three route segments used to counterbalance the maps were extracted from the data. These times were further sub-divided into the different types of spatial information. Figure 7.12 shows the three locations in the route.

Figure 7.13 shows mean route-completion time for each location. No inferential statistics are presented to accompany this data since each mean is comprised of only three data points, insufficient for any meaningful statistics to be applied. In each location the shortest completion times are associated with the route condition. The high variation, particularly in the simplified and enhanced conditions probably precluded any significant differences being found. The lower completion times in location three may be a product of the broad overview of the environment in the final leg of section three (Figure 7.14). Clear paths are visible to the participant unlike other sections. This observation supports the explanation that when navigating outside, route and decision point based support may not be the most appropriate form of information to deliver. In the outside environment routes and intersections are not always obvious.

Figure 7.12 The three route segments used to counterbalance map presentation

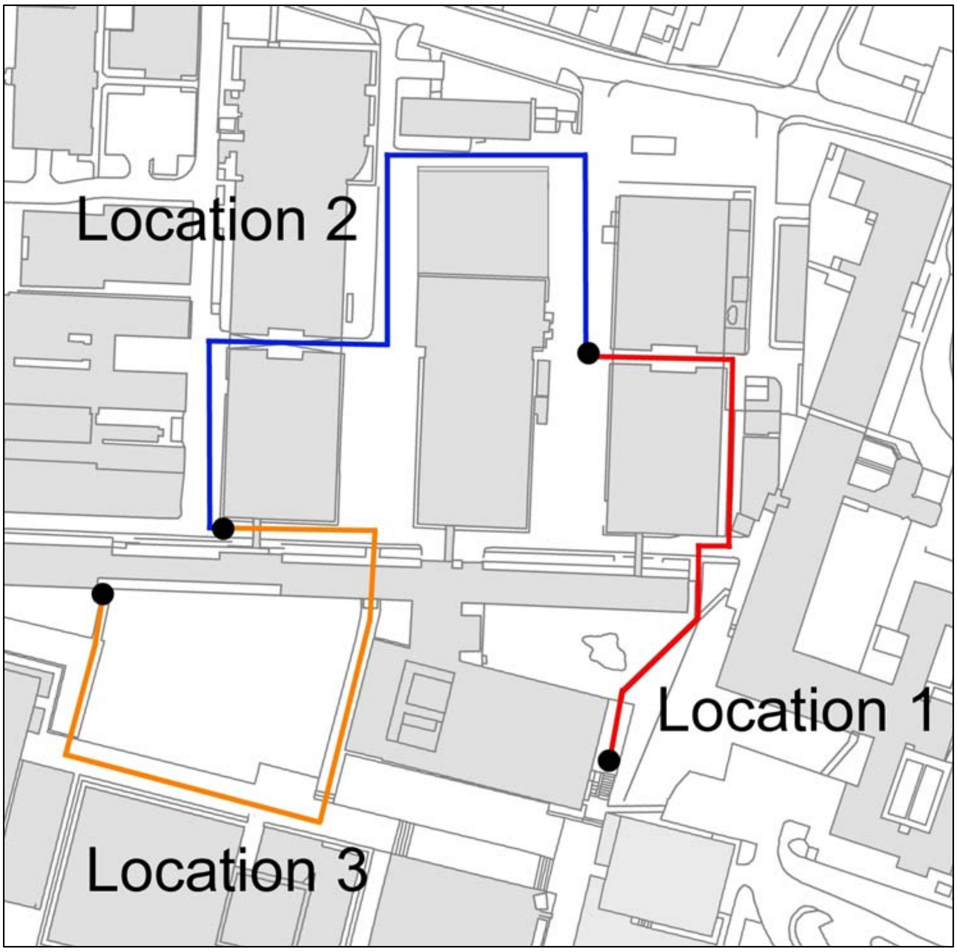


Figure 7.13 Mean route completion time for each location

(Error bars are symmetrical)

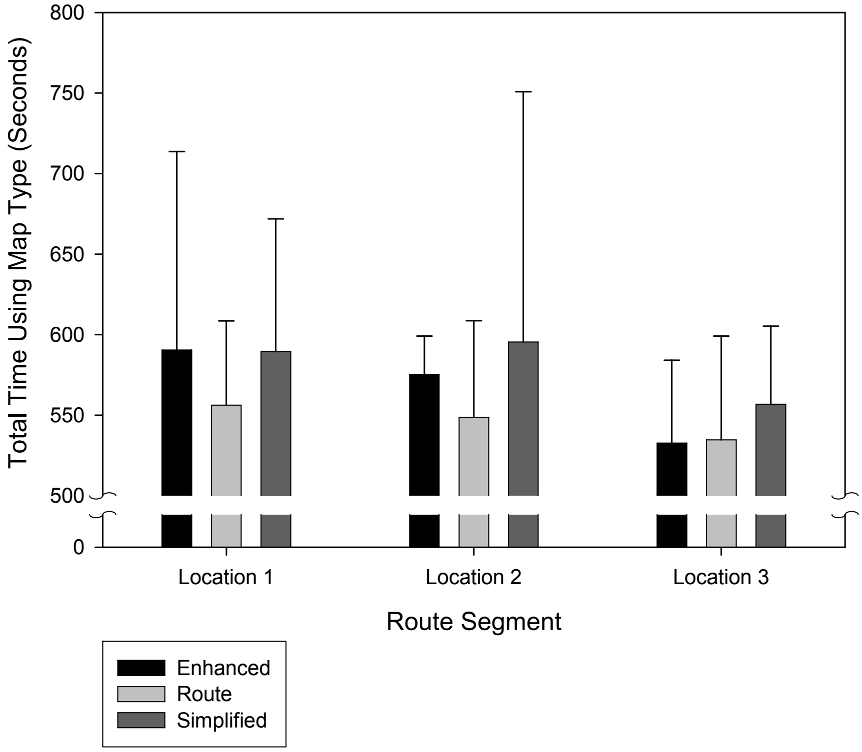


Figure 7.14 Participant view of a section of location three

7.10.3 Map-viewing variables

Improvements to version 3 of the software allowed a variety of map-viewing variables to be measured. These variables may provide a unique way of validating other subjective measures, especially workload. In addition they are also of critical importance when considering the application. Increased cumulative time spent viewing a map may amount to important time being wasted. The independent variables in this study did not give the map viewing results their best chance to shine. However the correlations between the individual components of map viewing indicate that further use of these is entirely warranted.

Chapter 8 Quantitative Meta Analysis

8.1 Introduction

Following completion of the experimental work, a large dataset consisting of 162 cases was available for analysis. Many dependent variables were used throughout all the experimental work and exploratory analysis of these variables as a group exploited the larger sample size available.

This sample size allows a principal component analysis (PCA) to be performed on the Integrated Navigation Questionnaire (INQ) data and analysis of the subscales developed by the PCA to be conducted. The matched independent variables used in experiments two and three allow for comparison between the outside and inside environments for certain variables.

8.1.1 Review of experiments

Three experiments are considered in this meta analysis. An overview of the experiments and their conditions is shown in Table 8.1. Correlations between variables across all experiments are considered. The same independent variables in experiments two and three were used in different environments. As such, differences in dependent variables between environments are examined in this chapter.

Table 8.1 Overview of all experiments including independent variables

Experiment	One	Two	Three
Title	Navigating using different methods of presentation	Navigating inside using different types of information	Navigating outside using different types of information
Independent Variables	Paper Plan	Enhanced Information	Enhanced Information
	Plan Overview	Route Information	Route Information
	Allocentric Segment	Simplified Information	Simplified Information
	Egocentric Segment	-	-

Dependent variables common to all experiments were used in the meta analysis (Table 8.2). Other variables had to be excluded. The mental demand scale of the NASA-TLX is the only scale common to all experiments. Only experiment two used the weighting procedure. The results of this experiment demonstrate that the main workload scale of interest is the mental demand scale which is the only scale used in experiment three. All other TLX scales except the mental demand scale have been excluded from this analysis.

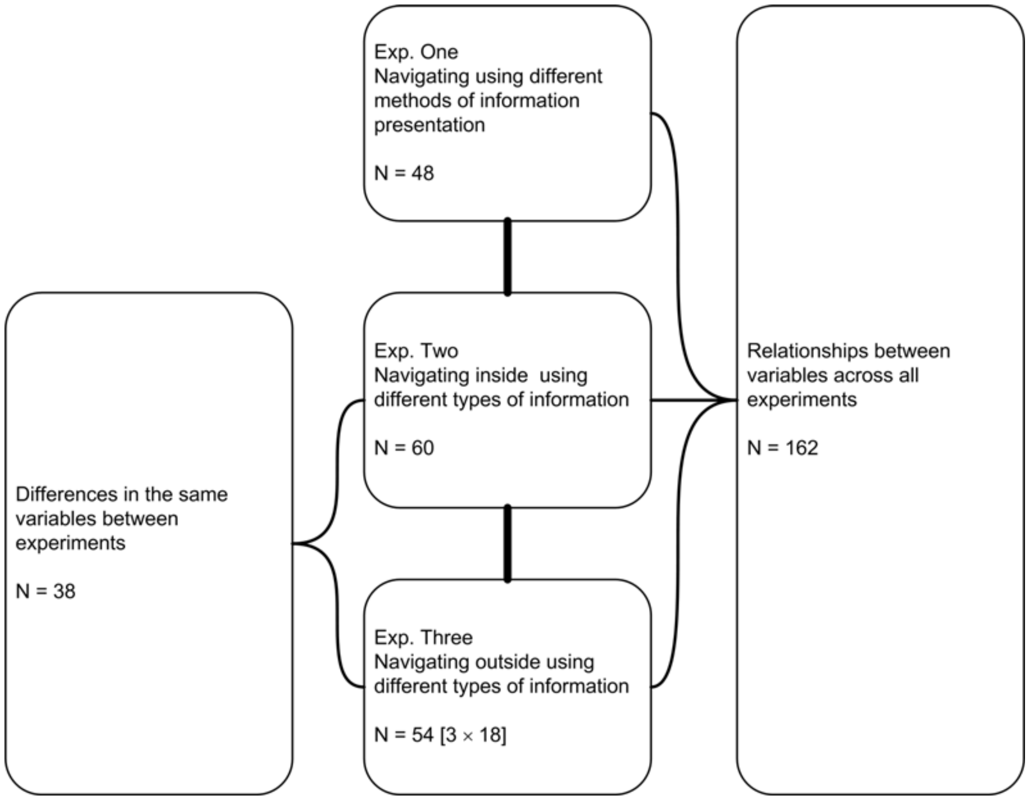
The SUS scores are only available for experiments two and three. Comparison of SUS scores between experiment two and experiment three is not conducted. Participants in experiment three do not provide SUS scores for each condition, rather an overall score reflecting the usability of the mobile device across all conditions. It is not appropriate to compare this single score against the per-condition scores given by participants in experiment two.

Table 8.2 Variables entered into the meta analysis

Variable	Notes
Average Speed	All route times were converted into average speed in order to compare the routes of different lengths used in the experiments
INQ	Following the PCA, factor scores for each component were used rather than the raw INQ score. In this way a more detailed analysis can be performed
Mental Workload	-
SDS Scores	-
Familiarity	-

Figure 8.1 shows a high-level overview of the analyses including the sample sizes achieved for each analysis. Experiment three is a within-subjects design. With the exception of the INQ and the SUS, participants generated unique scores for each condition in experiment three. The data set was structured to reflect this giving a total of 54 (3×18) participants in this sample.

Figure 8.1 High-level overview of the analyses including sample sizes



8.1.2 Summary of the analysis

INQ (Section 8.3)

This section describes a full reliability analysis of the INQ questionnaire followed by a PCA. The component scores will be used to improving the diagnosticity of the questionnaire through separation into component parts which may correlate more or less with other variable interest. The raw INQ scores will not be used in the meta analysis.

Relationships between dependent variables (Section 8.4)

All dependent variables described in Table 8.2 will be correlated to explore how different aspects of the navigation task may be related. The correlations will exploit the full dataset across all experiments (N = 162).

Differences between dependent variables (Section 8.5)

Experiments two and three differ from experiment one in that they share the same independent variables. Comparisons may be made between variables the same conditions between different experiments. This is of particular interest since any differences found may be due to the different environments that participants are exposed to: inside and outside. Inferential statistics presented in this section should be treated with due caution since they are two different experiments but the strong similarity in experimental design and method means that this approach remains credible.

The INQ is excluded from this analysis. Unlike experiment two, participants do not provide unique, per condition INQ scores. Comparing a single score representing overall experience with all information types to per-condition or averaged scores in experiment two is not methodologically appropriate. Either of these approaches would make interpretation of any result highly speculative.

8.2 Data structure

Descriptive statistics for the entire data set are shown in Table 8.3. Participants were all from a wide range of backgrounds and were recruited from the staff and student body at the University of Nottingham. The ratio of male to female participants is 1:1.3; females were generally more willing to participate in the experiment overall. Ages are very similar between males and females and show similar variation. The level of familiarity with the environment used was measured on a seven-point scale and is reassuringly low for both groups suggesting that it is unlikely that prior exposure to the environment affected any of the experiments.

Table 8.3 Descriptive statistics for the whole dataset

Sex	N	Age in years (sd)	Familiarity (sd)
Male	69	24.4 (7.3)	2.1 (1.7)
Female	93	24.0 (7.6)	1.8 (1.2)
All	162	24.1 (7.5)	1.9 (1.4)

Due to the larger sample size, the Kolmogorov-Smirnov test was used to assess normality. The Shapiro-Wilks test used elsewhere in this thesis overestimates non-normality when used on samples of this size. Tests revealed no significant difference from normality for any of the variables used in the meta-analysis. Parametric testing will be used throughout.

8.3 Integrated navigation questionnaire

Merging all participant responses to this questionnaire into one data set gives a sample size of 126. In this section a reliability analysis and a PCA are presented. The component scores generated by the PCA are then entered into the overall meta analysis.

8.3.1 Reliability analysis

The same approach to reliability analysis taken in Section 5.13.4 (p163) is applied to the INQ using the expanded dataset. The new scale statistics are shown in Table 8.4. The results are similar to the scale properties reported in Section 5.13.4 which suggests good reliability. The high α-coefficient confirms high reliability and is in excess of the cut-off of 0.80 suggested by Kline (2005).

Table 8.4 INQ scale statistics

Mean	SD	$\alpha_{Cronbach}$	Items	N
44.0	8.5	0.87	13	126

Item total statistics indicate no appreciable reduction in α on removal of any item. Corrected item correlations are generally high. Questions 5, 8 and 13 show low (< 0.50) correlations. Since weaker questions have been removed in the first reliability analysis the more generous correlation cut-off of between 0.15 and 0.30 suggested by Lowenthal (1996) will be used. All correlations are above these values and no further questions will be removed.

Table 8.5 INQ item-total statistics

Question	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q1	0.61	0.86
Q2	0.59	0.87
Q3	0.62	0.86
Q4	0.64	0.86
Q5	0.45	0.87
Q6	0.61	0.87
Q7	0.62	0.86
Q8	0.36	0.88
Q9	0.51	0.87
Q10	0.52	0.87
Q11	0.61	0.87
Q12	0.68	0.86
Q13	0.38	0.88

8.3.2 Principal component analysis

Sample Characteristics

As with any statistical procedure, the reliability of the results is inextricably linked to the properties of the data. PCA is no exception. A number of recommendations are made concerning sample size, component loadings and commonality statistics. Several methods of determining whether a sample will generate a stable and reliable component structure are described. The three methods presented in this section all confirm that the properties of the data are good enough to produce a strong solution.

Historically, faith in the results of a PCA is based on the absolute sample size and its ratio to the number of components extracted and variables entered into the analysis. Different recommendations are available depending on the specific domain or literature reviewed. Ferguson and Cox (1993) collate and review the different recommendations which are shown in Table 8.5. Also shown are the ratios achieved in the present study. It is clear that using these rules, the sample is an appropriate size with which to generate a stable and reliable solution.

Table 8.6 Subject, variable and component ratio recommendations

Ratio	Recommended Minimum Ratio	Ratio Achieved
Subject: Variables	2:1 - 10:1	10:1
Minimum Subjects	100 - 200	126
Variables: Components	2:1 - 6:1	6.5:1
Subjects: Components	2:1 - 6:1	63:1

MacCallum et al. (1999) reject the notion that the ratios are the key determinants of sample size. They suggest that the diversity of recommendations make any of these ‘rules of thumb’ meaningless. They show through simulation that the ratios summarized by Ferguson and Cox (1993) are neither ‘valid or useful’. Their findings indicate that sample size requirements are closely linked to the variable commonalities. Commonalities reflect the degree of correlation between the variable and the overall model generated by the PCA. If all commonalities were zero, then each variable would be unique and no further reduction into components would be appropriate. Conversely, if all commonalities were one, each variable would represent all variation in the data and selection of any single variable would explain all the variation in the dataset. MacCallum et al. (1999) suggest that sample sizes, traditionally considered as too low for PCA (<100), are appropriate if commonalities are consistently greater than 0.6. When commonalties are in the 0.5 region a sample size of 100 - 200 is very acceptable. The simulation showed unreliable component structures when commonalities fell below 0.5 and there were a small number of variables (< 4) for each component. Table 8.7 shows that commonalities for obtained for the INQ. The mean commonality is 0.60 and all commonalities are above 0.5. This range indicates that a sample size of 126 is within the 100-200 boundary recommended at this level.

Table 8.7 Commonalities for each variable

Variable	Initial	Extraction
Q1	1	0.68
Q2	1	0.68
Q3	1	0.51
Q4	1	0.56
Q5	1	0.57
Q6	1	0.68
Q7	1	0.55
Q8	1	0.53
Q9	1	0.57
Q10	1	0.53
Q11	1	0.67
Q12	1	0.71
Q13	1	0.56

Guadagnoli and Velicier (1988) propose a similar rule, again based on simulation of large datasets. Their rule concerns the loadings of variables onto each component and follows a very similar pattern found by MacCallum et al. (1999). This pattern is summarised in Table 8.8. Again, lower sample sizes of <150 are considered satisfactory. Only when low loadings are coupled with a low number of variables per component do the sample sizes reach the levels recommended historically.

Table 8.8 Sample size guidelines based on component loadings

Sample recommendation	< 150	150	>300
Loadings	High (> 0.6)	Low (0.4 - 0.6)	Low (0.4 - 0.6)
Variables per component	Medium (4 - 10)	High (> 10)	Low (< 4)

Consideration of the results found in this study (Table 8.9) demonstrates that the sample size, component loadings and variable to component ratios generate a stable and reliable component structure for further analysis.

Table 8.9 Average loadings and variable to component levels for this study

	Variables per component	**Mean component loading**
Component 1	6	0.74
Component 2	7	0.67

Component Extraction

Bartlett's test is significant ($\chi^2_{(78)}$ = 826.3, $p < 0.001$). This result indicates that there is significant correlation within the dataset so components are unlikely to occur by chance alone.

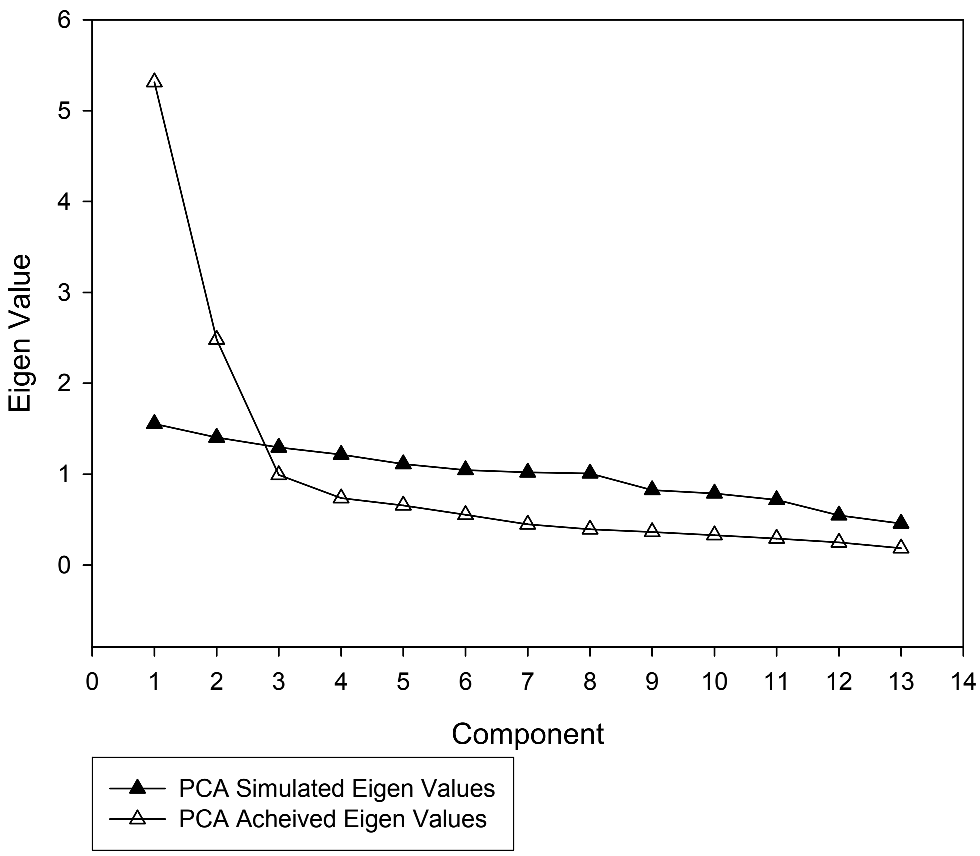
Table 8.10 shows that two components were extracted from the data set explaining 60.0% of the total variation. As the eigen value of the third component is just below one (0.9) a more robust method of selecting the number of components was performed. The approach taken was developed by Horn (1965) and is used and well described by by Witmer et al. (2005). A new PCA was performed on a dataset with the same number of variables (13) and cases (126) as the actual dataset used. Random numbers selected from a normally distributed set of random numbers were entered for each variable and a PCA was conducted on this new dataset. The scree plots from both the real and simulated data are plotted and the number components where the lines cross are extracted.

The scree plot (Figure 8.2) shows an intersection after component two suggesting that other components would have occurred by chance. Two components were retained for further analysis since their eigen values were above the eigen values obtained for the first two components in the simulated PCA.

Table 8.10 Total variance explained

Component	Eigenvalues	% of Variance	Cumulative %	% of Variance	Cumulative %
1	5.3	40.9	40.9	40.9	40.9
2	2.5	19.1	60.0	19.1	60.0
3	0.9	7.6	67.6		
4	0.7	5.7	73.3		
5	0.7	5.1	78.3		
6	0.6	4.3	82.6		
7	0.4	3.5	86.0		
8	0.4	3.0	89.1		
9	0.4	2.8	91.9		
10	0.3	2.5	94.4		
11	0.3	2.3	96.7		
12	0.2	1.9	98.6		
13	0.2	1.4	100.0		

Figure 8.2 Scree plot showing real and simulated data



Component Interpretation and naming

A varimax rotation was applied to the component loadings in order to improve the interpretability of the component matrix. This orthogonal rotation also allows for each component to be treated as a separate subscale and the component scores analysed as such. Oblique rotation would confound the scales developed from the components and make separation of the questionnaire into subscales difficult to interpret in a meaningful way. Table 8.11 shows the component loadings for each variable. Variables were assigned to the component with the highest absolute loading. The variables shaded in grey are associated with the second component. Unshaded variables are associated with the first component.

Table 8.11 Rotated component matrix

	Question	1	2
Q12	I have a clear picture of this route in my mind	0.80	0.17
Q2	I would be able to draw the route that I took	0.79	0.06
Q1	I could write down directions that I have taken on this route for a friend	0.79	0.10
Q11	I would be able to tell somebody else how to navigate this route	0.78	0.10
Q10	I would be able to get back to where I started from quite easily	0.65	0.10
Q7	I could identify the route I have just taken on a plan of the area	0.64	0.24
Q6	I felt lost when navigating this route	0.24	0.77
Q5	This route was very complicated to navigate	0.08	0.69
Q9	I was not sure I was heading in the correct direction	0.18	0.67
Q13	I felt uncomfortable when walking around this route	0.01	0.67
Q8	I felt under pressure when walking this route	0.01	0.64
Q4	I felt disoriented when walking on this route	0.40	0.58
Q3	I felt confused as to where I was	0.43	0.52

Component saturation is good. Ferguson and Cox (1993) suggest that the minimum loading for a variable to be associated with a component is 0.4. The minimum loading in this analysis is 0.52, for question 3, “I felt confused as to where I was”, above the recommended cut-off. Table 8.12 shows that both components are highly saturated with their variables and that unassociated variables show low saturation.

Table 8.12 Mean component loadings for loaded and unloaded variables

	Component 1	Component 2
Mean loaded variables	0.74	0.64
Mean unloaded variables	0.13	0.19

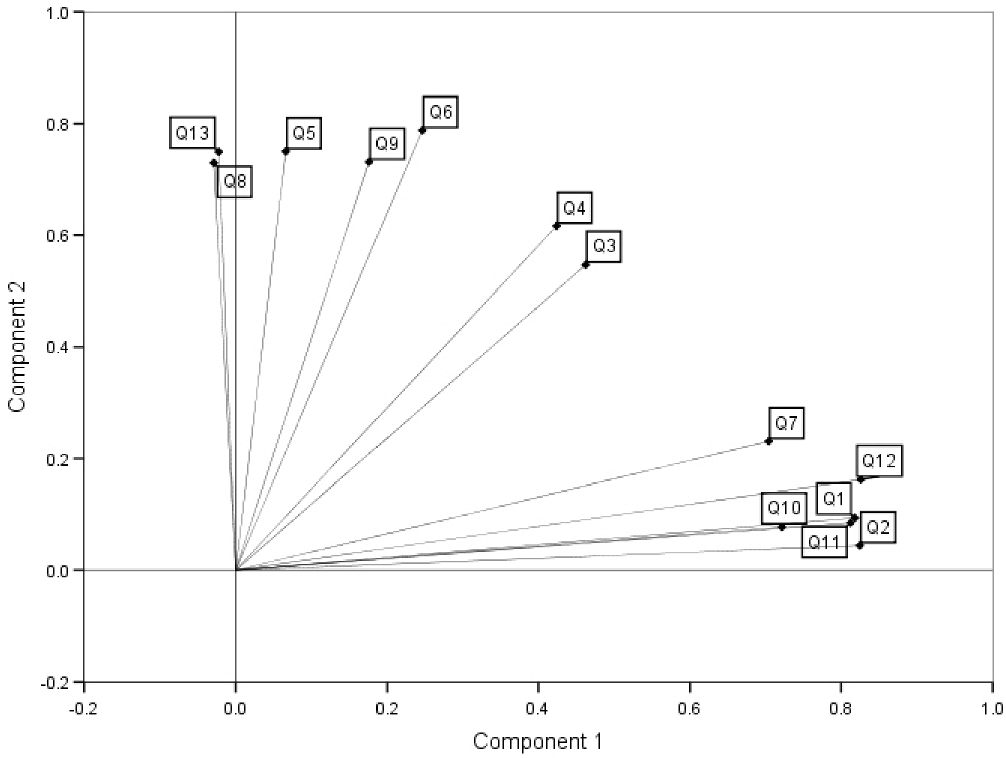
Cross loading, where components have similar loadings for a variable can be problematic for interpretation of a PCA. Ferguson and Cox (1993) suggest that variables which load < 0.2 between components are removed. In this study, the minimum cross loading is 0.18, indicating good separation of the components and no need for further removal of variables.

Eight judges were given the statements relating to each component and were asked to independently generate an overall name for component. Judges were in agreement and following discussion the names shown in Table 8.13 were agreed upon to reflect the variables loading onto each component. The darker the yellow shading, the more strongly the variable loads onto that component. The ordination plot (Figure 8.3) shows the loadings graphically. Component one is more highly saturated than component 2 the variables cluster more closely around the component axis. Component 2 is more diffuse, particularly questions three and four which concern confusion and disorientation. Higher levels of confusion and disorientation may lead to a lower level of confidence and route recall, explaining their proximity to component 1. However, they remain associated with component two owing to their higher loading overall onto this component.

Table 8.13 Component names and variables

Component		Question
1 Navigation confidence and recall	Q12	I have a clear picture of this route in my mind
	Q2	I would be able to draw the route that I took
	Q1	I could write down directions that I have taken on this route for a friend
	Q11	I would be able to tell somebody else how to navigate this route
	Q10	I would be able to get back to where I started from quite easily
	Q7	I could identify the route I have just taken on a plan of the area
2 Navigation confusion and anxiety	Q3	I felt confused as to where I was
	Q4	I felt disoriented when walking on this route
	Q6	I felt lost when navigating this route
	Q9	I was not sure I was heading in the correct direction
	Q5	This route was very complicated to navigate
	Q13	I felt uncomfortable when walking around this route
	Q8	I felt under pressure when walking this route

Figure 8.3 Ordination plot of both components showing all questions

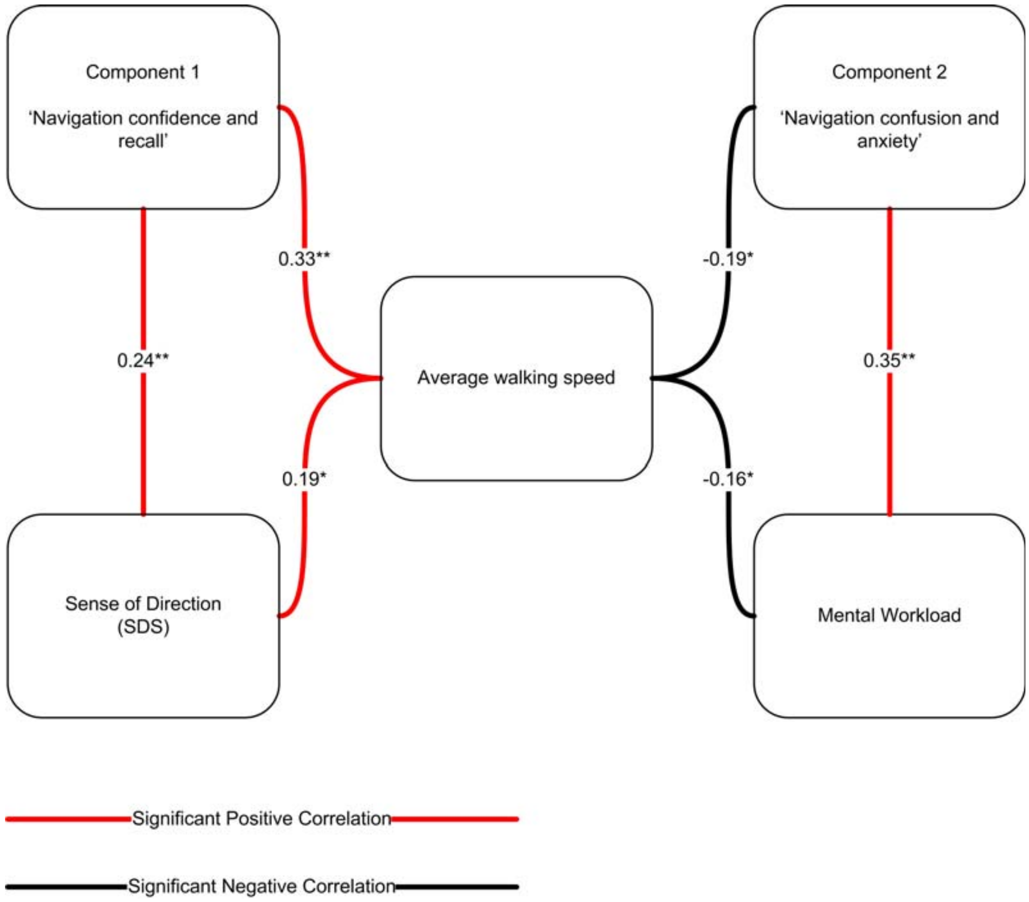


8.4 Relationships between dependent variables

Pearson correlations between the SDS, walking speed, mental workload and component scores were performed. These variables were represented in all experiments giving a total sample size of 162. Figure 8.4 shows the correlations between different variables visually. No causality between variables should be inferred from the diagram.

Figure 8.4 Correlations between dependent variables (N = 162)

* $p < 0.05$
** $p < 0.01$



All variables show significant correlation with average walking speed. This is a useful result since walking speed is an objective measure which could be used to validate the more subjective variables used in the studies. Significant, but weaker, negative correlations between mental workload, navigation confusion and average walking speed indicate that higher mental demand and higher reported levels of confusion may slow down navigation. This result suggests that developing clear displays which show useful features are critical in improving mental workload and increasing navigational efficiency.

Navigation confusion and anxiety is strongly correlated with mental workload. Higher levels of confusion may require increased concentration and matching of environmental features to the display. This in turn may require higher workload. Again this link could be broken by developing excellent displays which guide navigation very efficiently requiring minimum attention.

Higher scores on navigation confidence are strongly related to average walking speed. Higher reported confidence and learning of the route is associated with higher walking speeds. The same pattern is found for sense-of-direction scale which correlates with both average walking speed and the navigation confidence component of the INQ. Again, the relationship between the self report measures and walking speed indicate that individuals may be able to appraise their ability to navigate effectively. Again average walking speed is a useful method of validation of these measures.

Overall, workload is associated with the more negative aspects; slower walking speeds and higher confusion and anxiety while navigating. This may represent responses at the higher end of the workload scale affecting the analysis. A baseline, median level of workload may be required to navigate, regardless of the ability or confidence of the participant explaining the lack of correlation between mental demand and the more positive variables. Nevertheless, a strong group of significant correlations has been found between the self-report variables and the objective measure of average speed.

Finally, it should be noted that the orthogonal rotation minimises any correlation between the two INQ components shown. There may well be a relationship between components 1 and 2 but for the purposes of this model, this correlation has been statistically removed by the varimax rotation used in the PCA. Removal of this correlation allows subscales to be defined in the questionnaire for each group of variables and easier interpretability of the components.

8.5 Differences between the inside and outside environments

The design of experiments two and three allows for cross experiment comparison to be made. Both experiments use the same independent variables so comparison can be made within an independent variable, between experiments. The new independent variable created using this approach is environment. Table 8.14 shows the comparisons made. In the individual experiments comparisons are made down the columns. In this section, comparisons are made along the rows for each information type.

Table 8.14 Comparisons made between environments

Experiment two	**Experiment three**
(Inside Environment)	(Outside Environment)
Simplified Information	Simplified Information
Route Information	Route Information
Enhanced Information	Enhanced Information

The data set was restructured to create new groups. For each information type (enhanced, route and simple) differences in the variables for the inside environment (experiment two) and the outside environment (experiment three) were investigated. The dependent variables appropriate for this type of analysis were the mental workload scales, the SDS and average walking speed.

Ideally, a 2×3 ANOVA (Environment vs. Information Type) would manage all differences but in this case the within-subjects design used in experiment 3 and the between subjects design used in experiment 2 preclude this form of analysis.

Pairwise analysis will be performed instead. The statistical tests are unbalanced. Group sizes in experiment three are 18 compared to 20 in experiment two. Howell (2006) uses a weighted, one-way ANOVA to correct for unbalanced designs. Treatment sums of squares are weighted differentially to reflect the sample size. Since the weighting procedure is only available for ANOVA in SPSS, one-way ANOVAs with two groups (Experiment two vs. experiment three) will be used to establish significance instead of t-tests.

Average walking speed is suitable for parametric analysis and will use the above procedure.

Levene's test for equality of variance indicated a significant difference in between-groups variance for mental demand ($F_{(36)} = 14.2$, $p < 0.01$) and the SDS ($F_{(36)} = 6.6$, $p<0.05$). Non-parametric analysis will be applied to the analysis of these variables. No weighting procedure for non-parametric analysis is available so the results of theses analyses should be treated with caution. The degrees of freedom have been adjusted to reflect the lower sample size (18) in order to guard against a type-1 error.

Table 8.15 shows all relevant pairwise differences. Non-significant results between the inside and outside environments have been shaded grey for clarity.

Table 8.15 Pairwise differences (Inside Environment vs. outside environment) for each variable and each information type

N = 38	Enhanced	Route	Simple
SDS	$U_{(38)} = 344$ $p > 0.05$	$U_{(38)} = 363$ $p > 0.05$	$U_{(38)} = 374$ $p > 0.05$
Average Walking Speed	$F_{(38,36)} = 28.5$ $p < 0.01$	$F_{(38,36)} = 32.9$ $p < 0.01$	$F_{(38,36)} = 5.2$ $p < 0.05$
Mental Demand	$U_{(38)} = 347$ $p > 0.05$	$U_{(38)} = 361$ $p > 0.05$	$U_{(38)} = 482$ $p < 0.05$

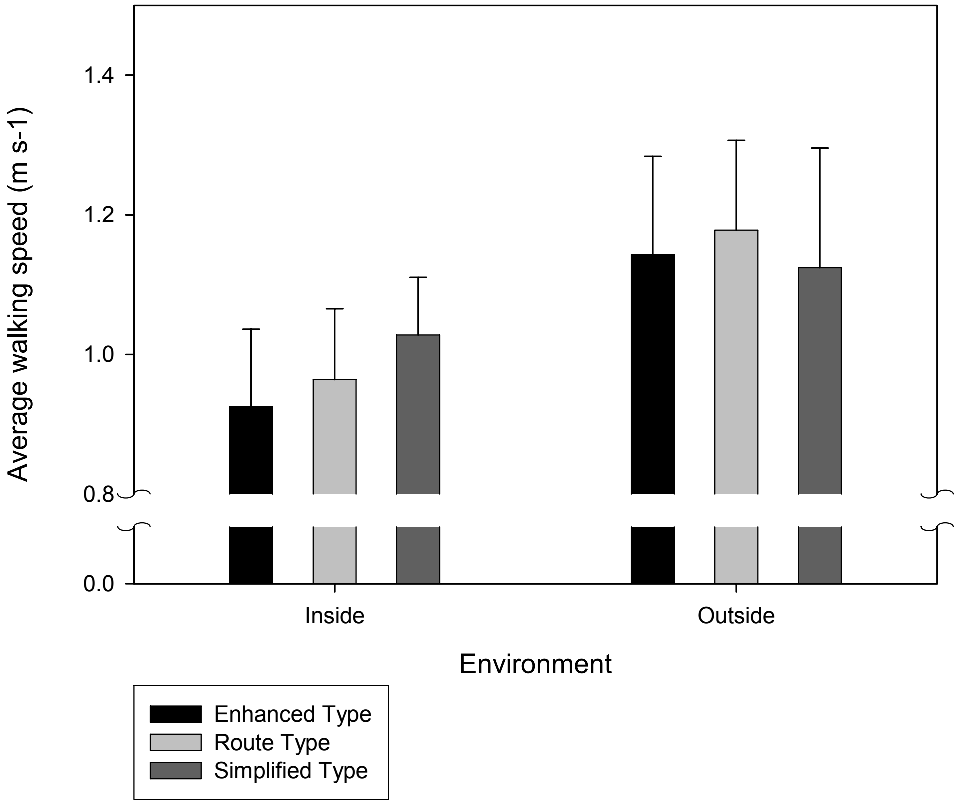
SDS

No significant differences in SDS scores were found indicating that participants reported similar levels of sense-of-direction in each group.

Average Walking Speed

Significant differences between average walking speeds exist across all information types. Average walking speed is significantly higher in the outside environment for all information types. This is particularly obvious in the enhanced and route conditions (Figure 8.5). A smaller difference is evident in the simplified condition. One explanation for this may be that in the outside environment, the increased amount of information available assists the participant to navigate, rather than distracting from the overall route. The smaller difference in the simplified condition supports this explanation since participants may have been able to navigate faster using the simplified information inside due to the lack of distracting elements. In experiment two, this pattern of results was actually found: the simplified information elicited the shortest route completion times.

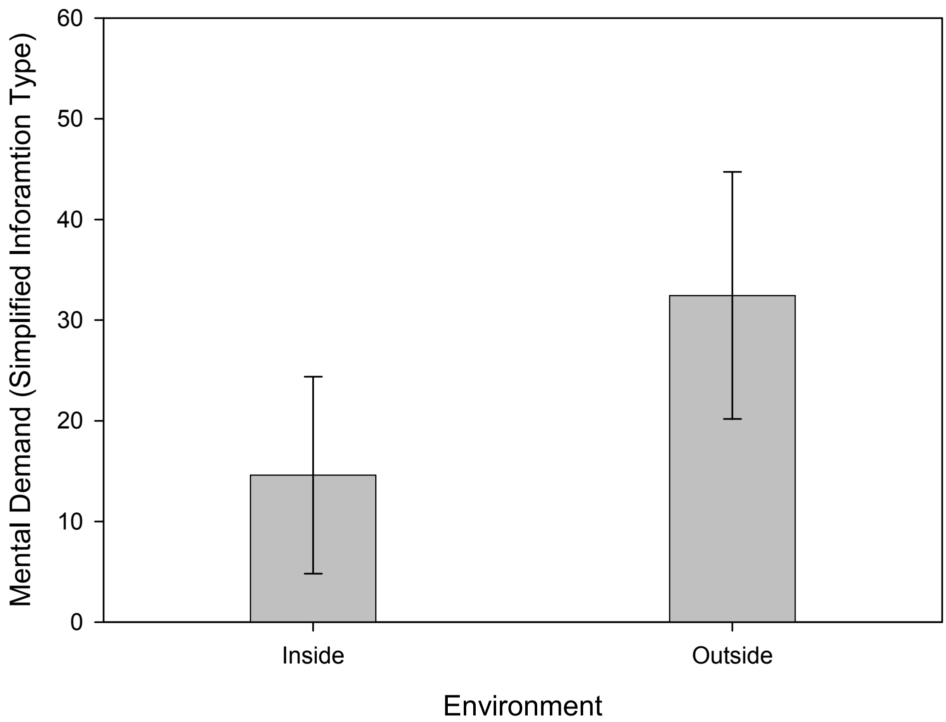
Figure 8.5 Average walking speed between conditions and environments



Mental Demand

A significant difference in mental demand was found between environments in the simplified condition. Participants experienced higher mental demand in the outside environment than the inside environment (Figure 8.6). One explanation for these results is that there is insufficient information when the simplified information type is used outside. Participants may have had to concentrate more when matching the information displayed to the environment. In the inside environment, the simplified information may have reflected the environment more closely, requiring fewer cognitive resources with which to navigate.

Figure 8.6 Mental demand between environments in the simplified information condition



8.6 Discussion

Results from this meta analysis show that many variables are connected with navigation performance and that their use in future studies is warranted. The correlations between all variables considered and average walking speed is a particularly promising avenue to pursue. Objective measurements that explain variation in subjective measurements can be used to validate the more subjective self-report variables used in a study. In experiment three, the number of times that participants view the map and the total length of time spent viewing the map show promise as other objective measures that may relate more generally to workload or navigation ability and could be employed in future experiments.

Results from this analysis show that the SDS should remain as an important variable to reduce the often high variation due to individual differences. No linear correlation was found consistently, in all individual experiments, but overall a correlation between this individual difference measure and actual navigation speed emerges in the meta analysis.

The two components that have emerged from the INQ can now be treated as subscales and their item scores summed separately. This approach increases the sensitivity of the INQ by dividing the questionnaire conceptually.

8.7 Conclusion

The major contributions of the meta analysis are understanding how the dependent variables used to assess navigation interact and the further development of the INQ. The results indicate that average walking speed or route completion time is an effective measure of navigation performance which is related to other, subjective measures of interest including workload. The development of the INQ has outlined the statistical properties of the scale and how each of the two separate dimensions interact with the other dependent variables used in the study.

The meta analysis has highlighted areas for future research. Increased examination of the objective measures such as time spent viewing a map should be included with the self-report measures. Differences are also emerging between the environments when considered as a group. Perhaps a very large scale experiment which would expose participants to a variety of environments may shed further light on the variation in navigation efficiency or ability.

Chapter 9 Adding GPS

9.1 Introduction

Experiments one, two and three simulated a location-based service through user controlled input, cued by the experimenter in specific locations. In this chapter an observational study is presented to explore how automatic display of map information, using GPS, affects navigation. Experiment 3 showed that the enhanced information did not affect navigation and that the simplified information did not successfully support it, incurring greater mental workload. In this study information of the same form as in the intermediate condition, the route condition is used to support navigation. The map was split into segments and these segments were automatically presented when the participant was located in the appropriate position. The route and an example segments are shown in Section 9.3.1.

This study has two overall aims:

1. To investigate how automatic map presentation affects pedestrian navigation behaviour in different locations
2. To identify human factors priorities when designing for the automatic display of maps for pedestrian navigation

To fulfil these aims, different behaviours were noted by the experimenter at locations along the route and these behaviours were then mapped onto the actual locations of the route. In addition, participants were also asked about their experience of navigating the route. These experiences were then summarised and interpreted to inform the human factors priorities.

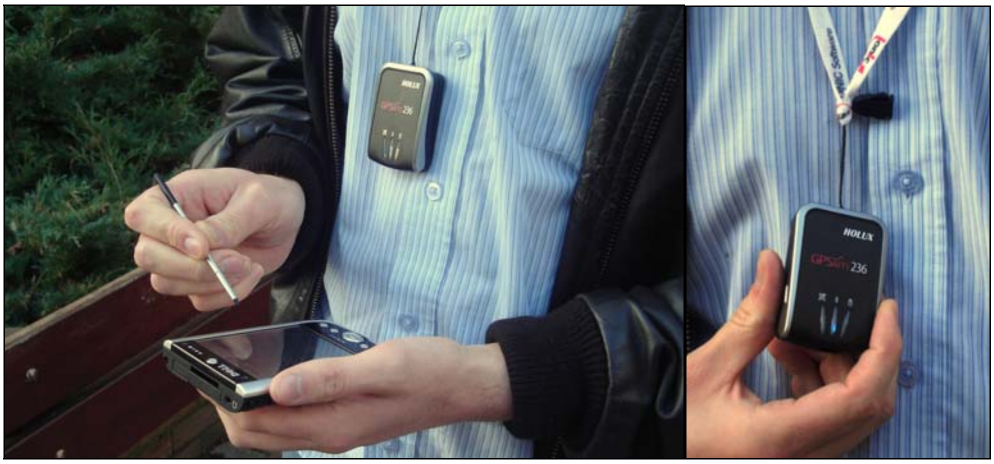
The remainder of this chapter is split into two parts. Sections 9.2 and 9.3 discuss the technical aspects of receiving GPS signals and how the route was selected and tested. Results from the study are presented in Sections 9.4 to 9.6.

9.2 GPS signals

9.2.1 Acquisition of GPS signals

A range of hardware and software was used to create the application that receives GPS signals to determine which map segment to display to the user. The platform used for presenting the maps is the Dell Axim PDA. The PDA was selected to take advantage of the rapid software development that is achievable using the Microsoft Visual Studio development environment. Since the PDA does not have any inbuilt GPS receiving capability a Holux 236, standalone GPS receiver was acquired. The standalone receiver can be worn by the user and the GPS signal is then transmitted to the PDA through a wireless Bluetooth connection. The PDA and receiver are shown in Figure 9.1.

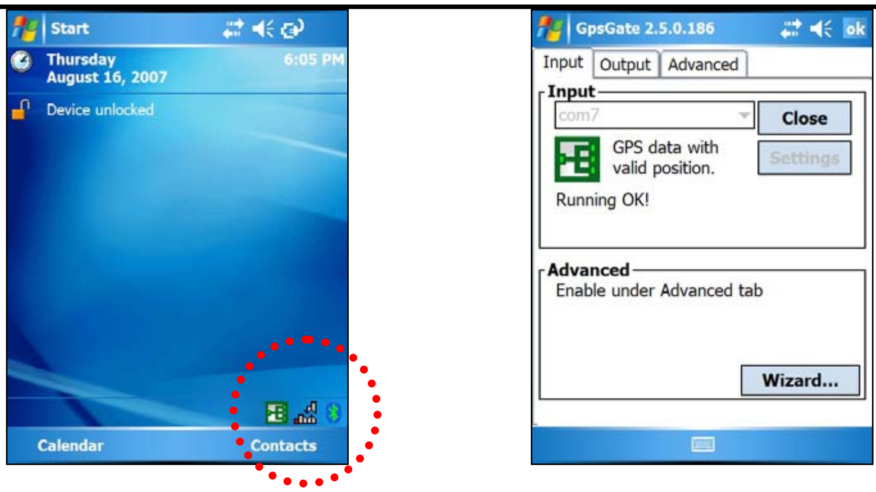
Figure 9.1 Holux GPS receiver used with a Dell Axim PDA



9.2.2 Processing GPS signals

The raw GPS signal from the Holux receiver required two stages of processing. Proprietary software, Franson GPS Tools, was used to acquire the Bluetooth signal from the Holux receiver. Using the Franson application programming interface (API), this signal could then be processed by the application developed to deliver location-specific maps to the user.

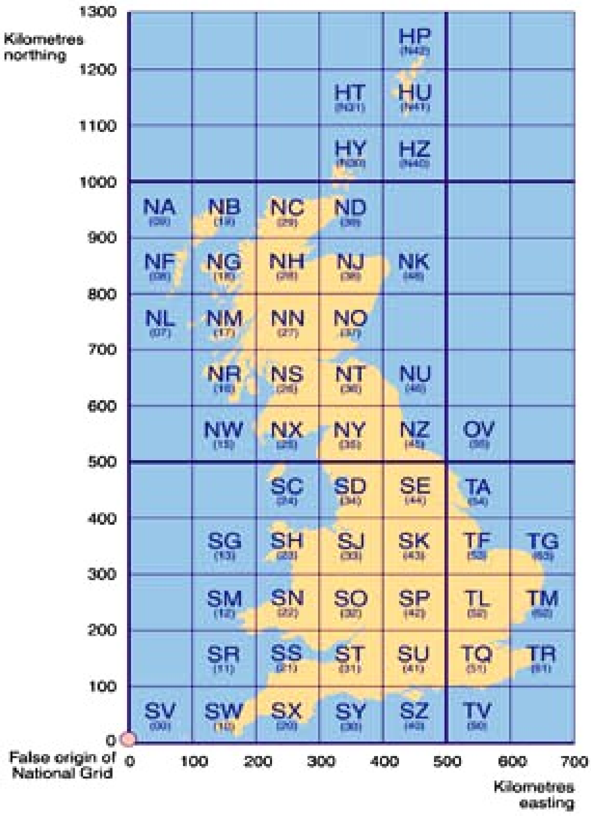
Figure 9.2 Screenshots of Franson GPS Tools running on a PDA



Franson running as a background application, also showing Bluetooth transmission	Franson control screen

GPS data delivered by Franson GPS Tools is in a standardised form. The National Marine Electronics Association (NMEA) is a standards body which ensures interoperability in marine communications and serves as the de facto standard for GPS signals (National Marine Electronics Association, 2008). GPS data is delivered in an ‘NMEA GPS sentence’. Critical components of this sentence are latitude, longitude and time.

Figure 9.3 British National Grid squares in Great Britain



9.3 Route testing and selection

9.3.1 Route selection

A route near to the Sir Clive Granger Building, University of Nottingham, was selected since full OS MasterMap data was available for this area. The route proceeded through open roadways and into a more built up area near buildings. Figure 9.4 shows an aerial photograph of the location overlaid with the route and waypoints A map of the area is shown in Figure 9.5. The map comprises of standard OS MasterMap features. Buildings were coloured dark grey to improve clarity. The start of the route is indicated by a red arrow. An example segment is outlined in red and shown in more detail in Figure 9.6.

Figure 9.4 Aerial photograph of route showing waypoints

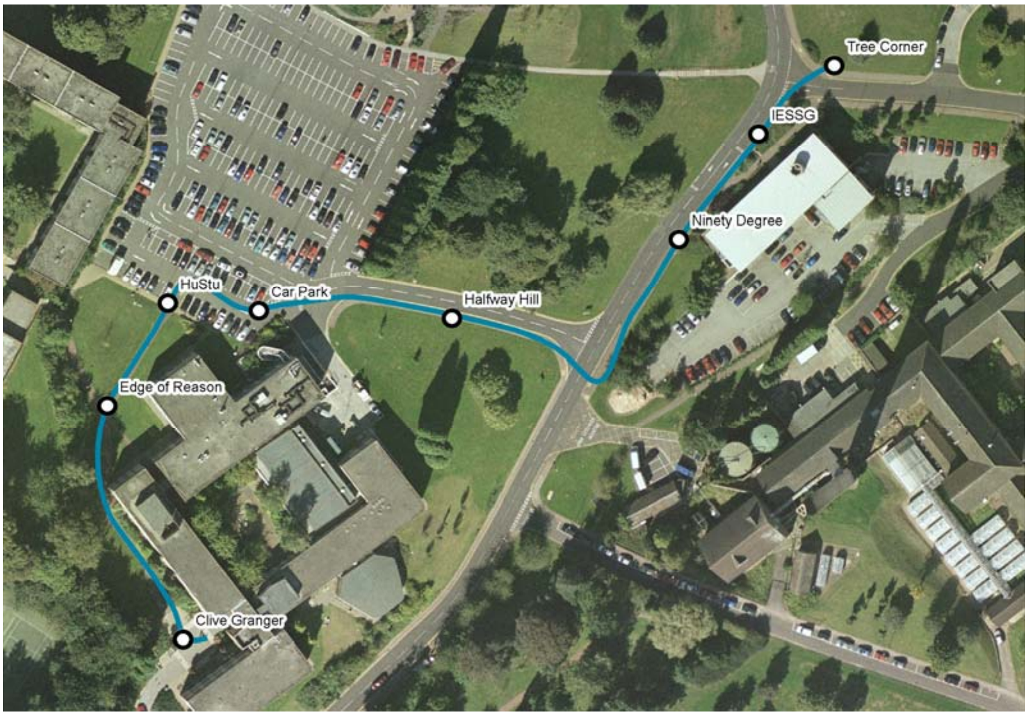
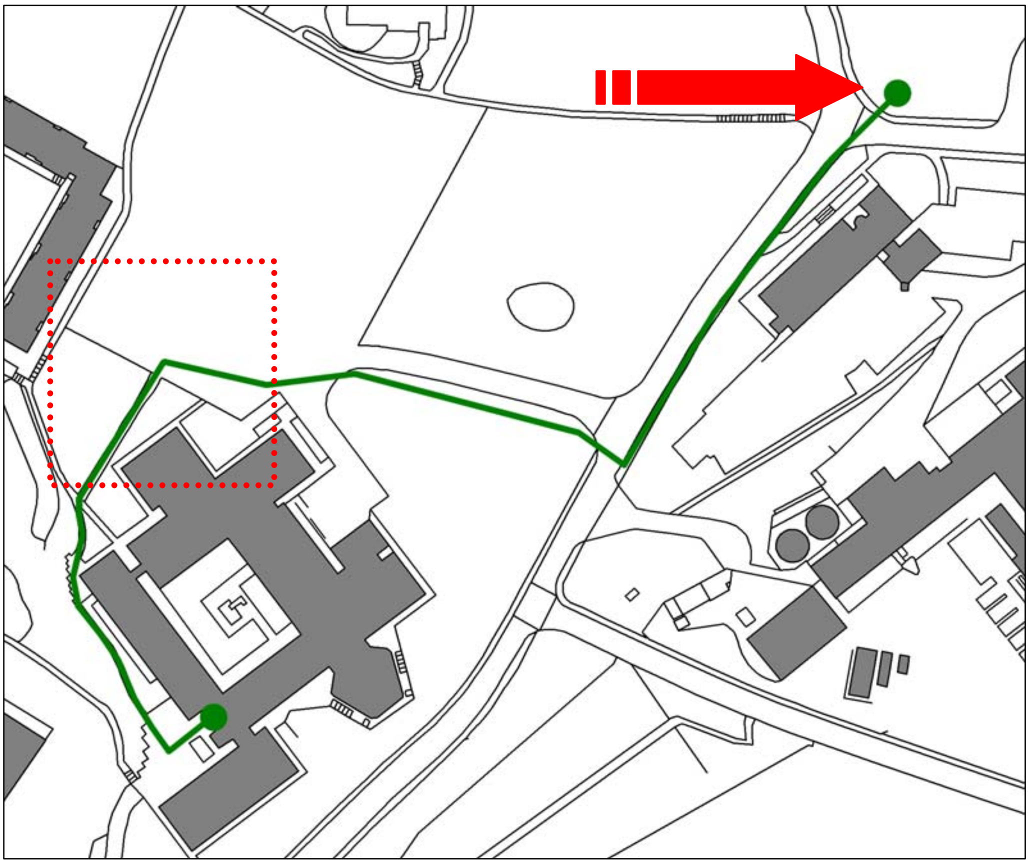
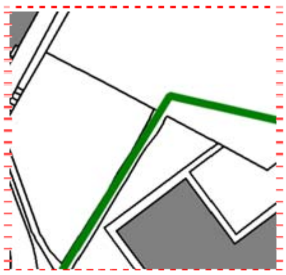


Figure 9.5 Map of the route used, presented in segments to participants



This larger map was then divided into a number of segments (Figure 9.6). Each segment was then assigned a waypoint. When the appropriate waypoint was reached the appropriate map segment was automatically displayed. This process then continued until the end of the route.

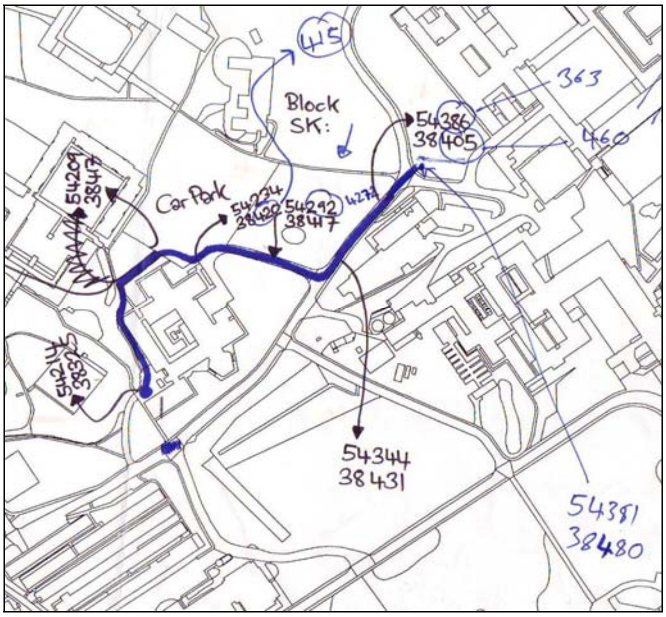
Figure 9.6 Example of a map segment



The GPS co-ordinates of waypoints were recorded using a Garmin GPS receiver and recorded by the author (Figure 9.7). These readings were recorded on three occasions in order to test accuracy and reliability of readings. The original recording sheet used in this process shows the variability in some of the readings over time (Figure 9.8)

Figure 9.7 GPS waypoints being recorded on the route

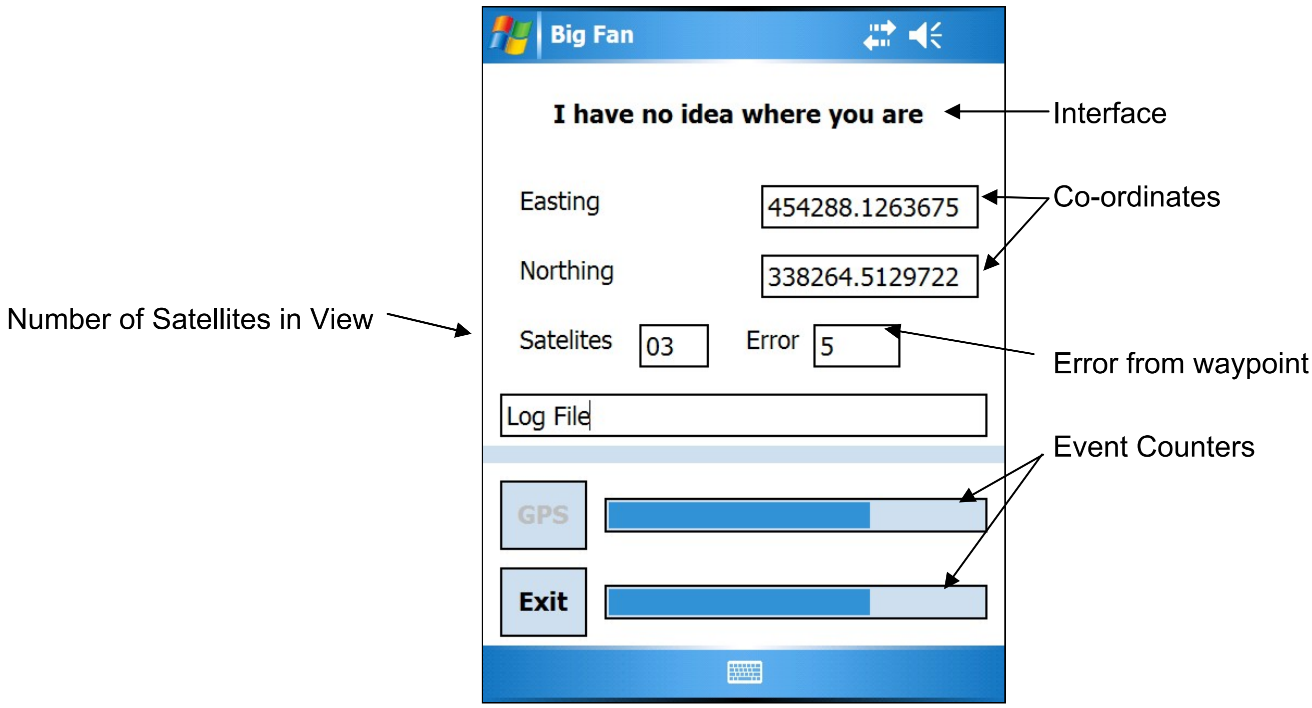
Figure 9.8 Waypoint recording sheet



9.3.2 Route testing

In order to diagnose reception problems and to plan routes new software was developed. GPS signal reception was recorded and different error ranges trialled. The application was used to test areas which could be used in experiments. The log file produced by the program records a number of variables that were entered into a GIS application. The log file variables recorded are time, eastings, northings, number of satellites, error and the text in the interface. The log file recorded each parameter whenever a valid NMEA string was detected and processed. A screenshot of the application is shown in Figure 9.9.

Figure 9.9 Screen-shot of the GPS testing application



Co-ordinates and Interface

- The latitude and longitude delivered by the NMEA string are converted to BNG and shown as eastings and northings in the co-ordinate indicators. When waypoints within the error range were detected, text in the interface changed.

When outside of a waypoint, the 'I have no idea where you are' text was shown so that the true boundaries of reception could be identified

Number of Satellites in view

- The number of satellites used to fix the GPS position were recorded. In this way satellite black-spots could be detected and those areas avoided in future experiments.

Error from Waypoint

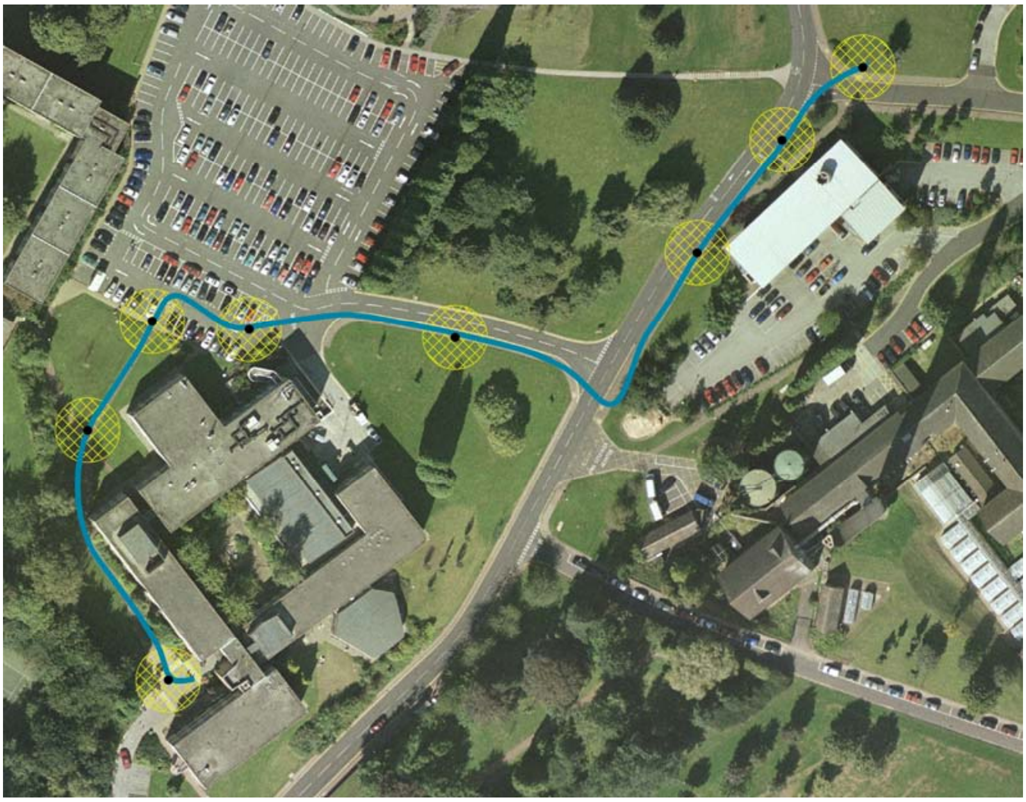
- The amount of error (in metres) tolerated from the centre of each waypoint could be specified. At zero, the GPS co-ordinates would have to match the waypoint co-ordinates exactly to effect a change in the interface. The error allows the user to specify a circular area around a waypoint. In this area the interface will update. The error measurement reflects the radius of the circle in metres.

Event counters

- The two progress bars at the base of the interface represent visually how many GPS events are being read at any one time. The second counter shows how many of these events are valid, GPGGA strings that can be used as co-ordinates. At GPS black-spots, there is a reduction in the speed of valid GPGGA strings being read which could be seen during testing.

The route was evaluated using this software. The waypoints were entered into the program to effect interface changes at the required locations. At all locations a high number of valid $GPGGA strings were received indicating good quality of GPS reception. A variety of different error tolerances were tried and 8m was finally selected as a effective compromise being neither too small so that the GPS would 'miss' the waypoint or so large that waypoints were merged together. An aerial photograph of the area marked with the route, waypoint names and error boundaries is shown in Figure 9.10. In the testing phase, the interface showed the names of the waypoints. In the actual trials, the appropriate map was displayed.

Figure 9.10 An aerial photograph of the area selected showing the route (blue line), the waypoints and error tolerances (yellow hashed areas)



9.4 Method

9.4.1 Participants

Five participants (three male, two female) from the University of Nottingham participated in the study. Participants were aged between 25 and 35 years. Since problems specific to automatic presentation were being explored rather than general navigation ability, participants were familiar with location selected and were confident in the use of maps and spatial data. No payment was offered in return for participation in the study.

9.4.2 Materials

Application

An application was developed to acquire and receive the GPS signals in the way described in Section 9.3.2. No data or timings were recorded by the programme during the trial. Participants started the experiment themselves by tapping an on screen button. This interface is shown in Figure 9.11. When tapped, the application began to process the incoming GPS data. When a GPS fix had been received, the start button was disabled and a green textbox indicated that GPS signals were being received. When a waypoint was reached, the next map segment in the sequence was automatically displayed together with the text for that waypoint.

Figure 9.11 Application start screen

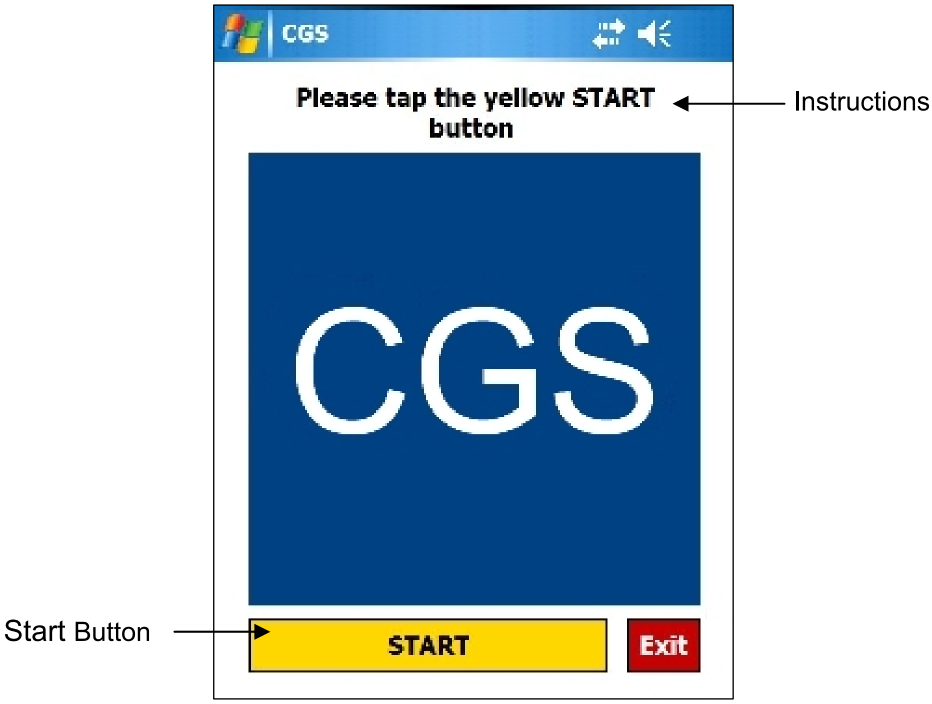
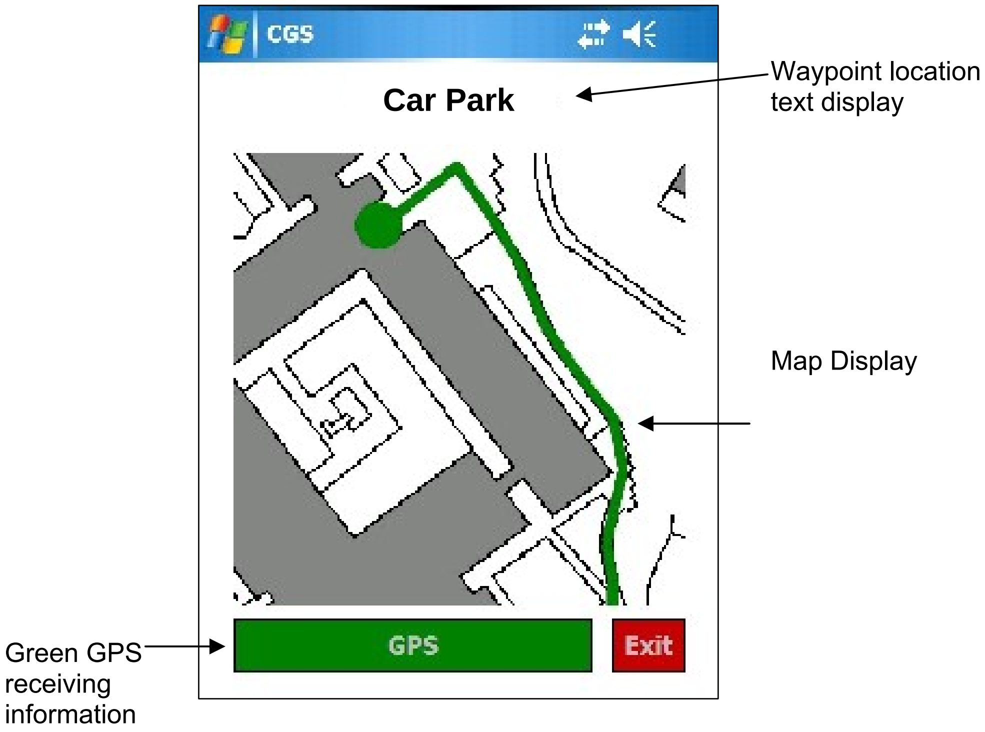


Figure 9.12 Application display



Observation sheet

A behavioural observation sheet was developed in order to record a variety of behaviours at points during the route. An example of this recording sheet is shown in Figure 9.13. The route was divided into segments and behaviour was recorded at each point and at the halfway interval between points. The points are shown in the small map to the right of the behaviour matrix. Participant initials and sex were recorded with the weather and time of day that the trial took place. As the participant navigated the route any behaviour of interest was recorded in the appropriate column which corresponded to the nearest point on the route. The different coloured columns indicate where the map displayed changes. Behaviour not anticipated was recorded in the numbered columns on the matrix. Following the experiment, comments that participants made about the trial were recorded on the sheet. In this way, all participant data could be stored on a single sheet of paper. An example of a completed sheet is shown in Figure 9.14.

Figure 9.13 Behavioural observation sheet

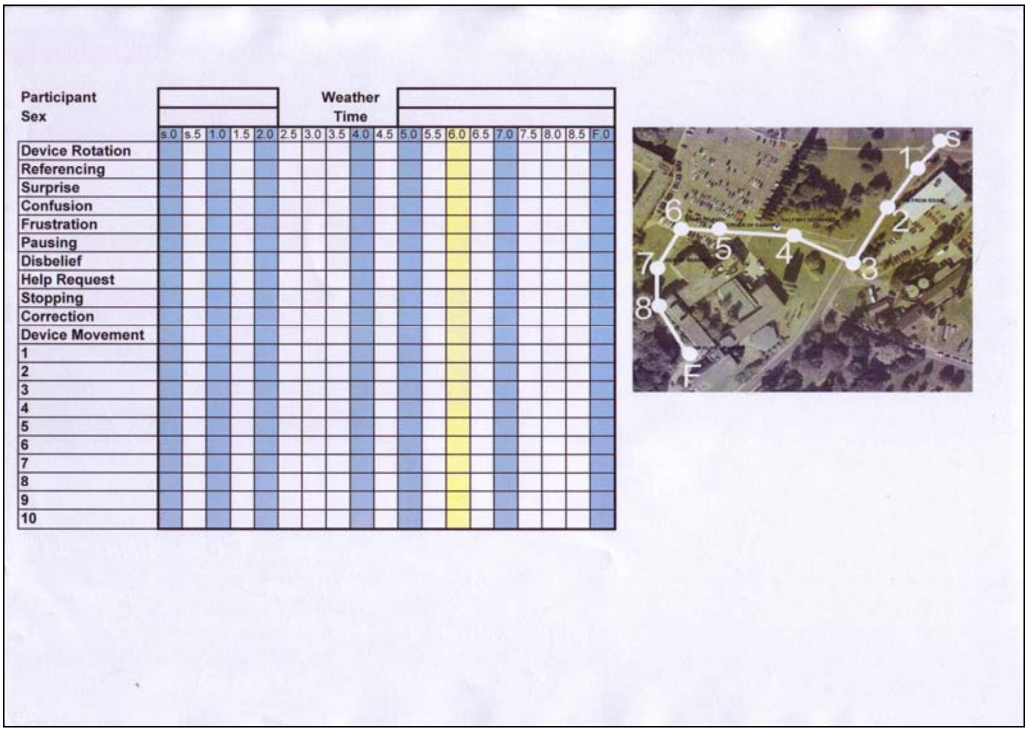
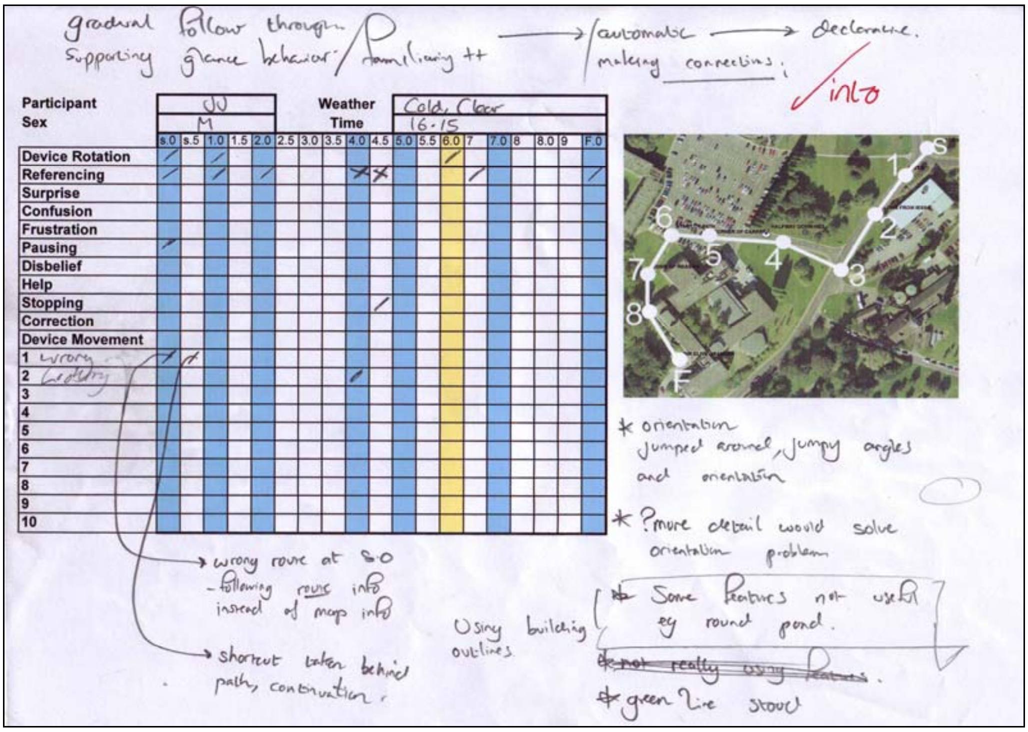


Figure 9.14 Example of a completed behavioural observation sheet



9.4.3 Procedure

All trials took place between 3pm and 5pm on clear days in order to minimise lighting and GPS signal differences between trials. Participants were taken to the starting point of the route and briefed on the nature of the experiment. Participants were informed that they were to navigate by following the green line on the maps displayed. Participants were also informed that the maps displayed would change depending on their location. No further instructions were given. Following completion of the route, participants were debriefed and asked to comment on their experience of navigating.

9.5 Results and discussion

9.5.1 Post-study interviews

All participants were encouraged to discuss their experiences of navigating with the device, for example, whether they found it difficult or straightforward to use the maps and why. Three major themes emerged from these interviews:

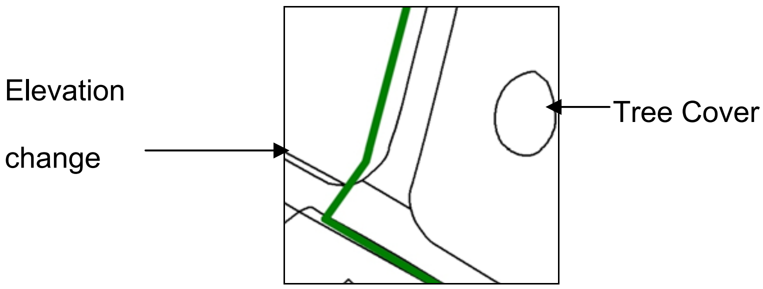
- Map features
    - Landscape features and objects displayed on the map, for example roads or buildings.
- Map transition
    - The change from the current map, to the next map in the sequence
- Self orientation
    - Matching position and heading with the map displayed.

Map Features

Participants reported that many of the features displayed on the map did not assist them in either self-locating in the environment or matching the environment to the map when a new map was presented. Four out of the five participants reported that fewer features of greater importance could be a solution to this problem. Of particular note was the map segment shown in Figure 9.15. Participants frequently mentioned while navigating, and became confused by, the tree cover feature shown in the segment. This circle is a generalized, aerial view of tree cover in the area. Since no details of height were shown, participants reported looking for a pond or area of water. Failure to match this particular feature with the environment created confusion, despite the routes being clearly marked and visible at the start of the map.

Pavements are not shown on this layer of MasterMap. The elevation change labelled in Figure 9.15, created confusion as participants searched for a separate path or pavement, understandably not recognising that the line represents change in elevation rather than a surface feature. Of note is that a seemingly minor feature can cause great confusion if the map-environment matching fails, even when using the other features could clearly overcome the difficulty in navigation.

Figure 9.15 Map segment four



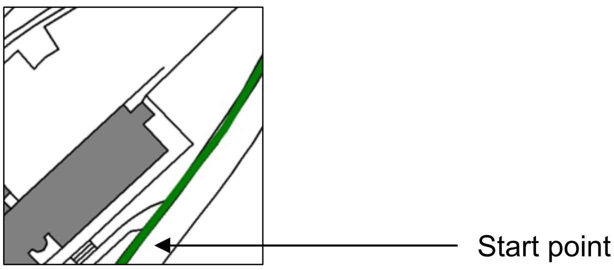
Map Transition

Generally participants were comfortable using the map-by-map changes. All participants mentioned that an audio warning when the map changes or is about to change would have been helpful. On occasion, participants were surprised to find a new map displayed. Whether a warning should be given *when* the map changes, or when it is *about* to change is a very interesting point, made explicitly by two participants. The warning would have to be appropriate to the application. Audio, haptic or visual warnings could be developed depending on the environment in which the device would be used.

Self Orientation

All participants reported that a you-are-here (YAH) marker showing location and orientation would be a helpful addition to the display. Even though participants were instructed that the start of the route would always be at the bottom of the screen, many participants experienced difficulties with map segment five (Figure 9.16). This map was oriented in the direction of travel but not immediately egocentrically due to the path layout. The lack of complete track-up alignment caused many participants problems in this segment, despite other features on the map being highly recognisable. Self-orientation support could be given in conjunction with a warning when a new map is presented.

Figure 9.16 Map segment five



9.5.2 Behavioural observation

Three behaviours were selected for further analysis: device rotation, matching and confusion/surprise. These behaviours were displayed at points by all participants. Surprise and confusion were merged into a single category since surprise at the map's content was always followed by a period of confusion while matching took place. Following an incorrect path leading to a correct destination was recorded for one participant. These results, although interesting, are not included in the analysis since it is difficult to generalise from an individual case. The participant's familiarity with the area may have led to this behaviour. Instances of each behaviour were summed for each observation point.

Figure 9.17 shows the route as a blue line and miniature bar charts, showing the counts for each type of behaviour at the location. Figure 9.18 shows the route with the imagery layer removed for clarity. Specific locations described in the text are marked on this map and referred to by number. Three behaviours are summarised by the miniature charts: device rotation, matching and confusion/surprise. Device rotation was recorded whenever a participant manually rotated the PDA to adjust the orientation of the map displayed. Matching was recorded whenever the participant appeared to compare the environment with the map displayed. Confusion or surprise were recorded when a participant appeared visibly surprised or confused. For example stopping and looking back or retracing steps would be recorded under this category.

Key to Miniature Charts:

Figure 9.17 Map showing the summed counts of three behaviours at specific locations

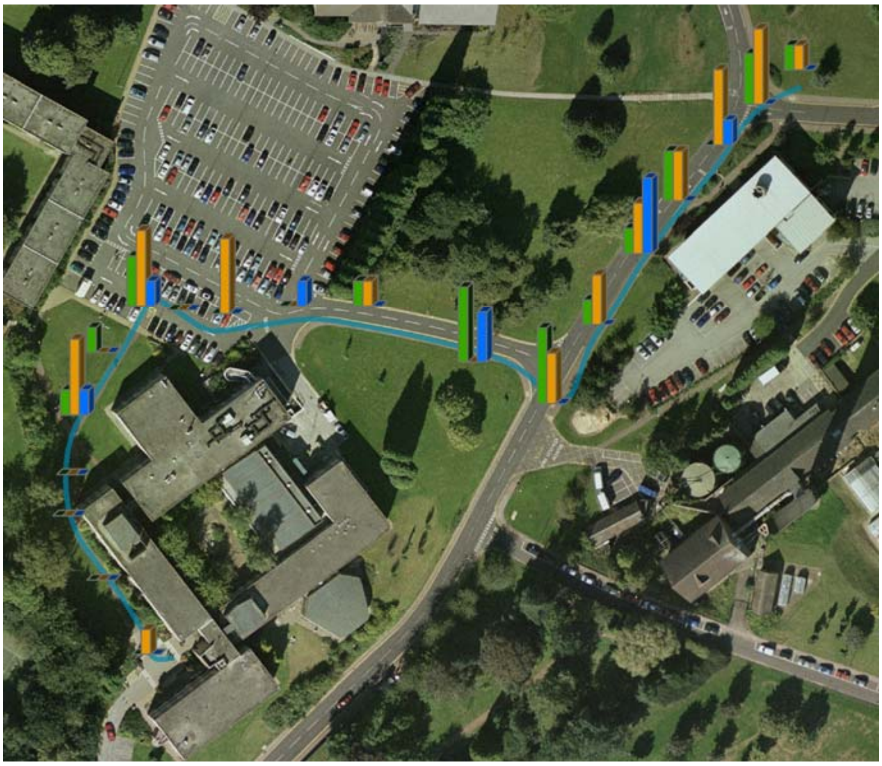
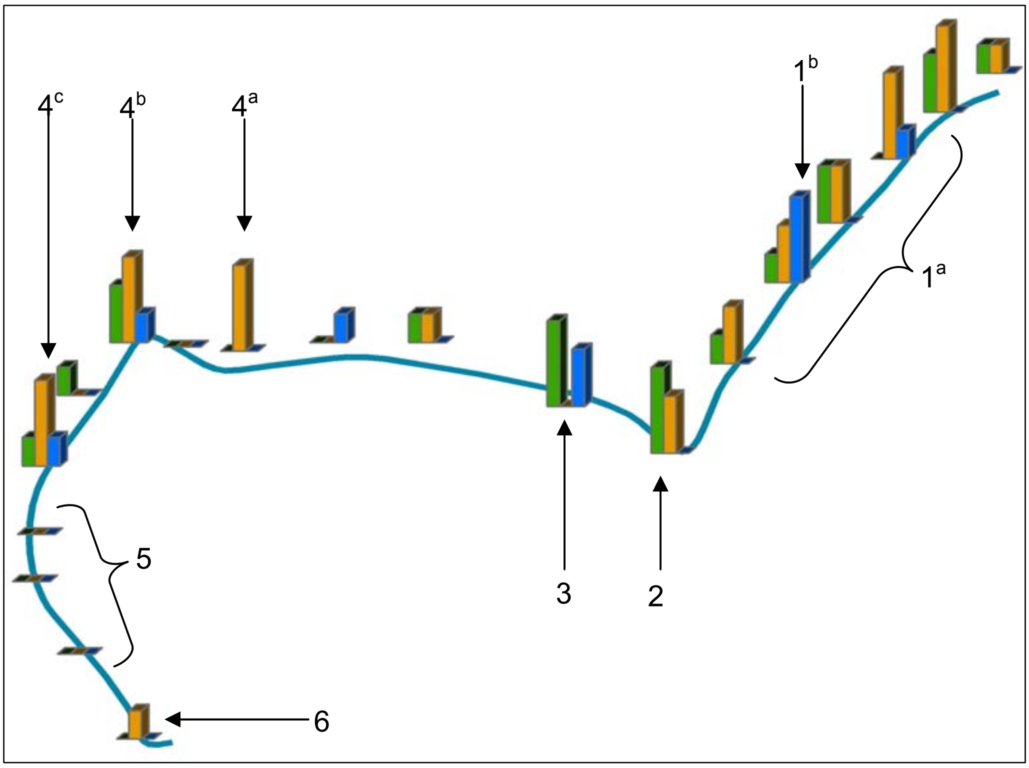


Figure 9.18 Route without imagery layer



Device Rotation

Device rotation tends to increase when the original orientation of the map is ninety-degrees or more from the new route (2, 3). At location 3, a new map is presented in a track-up orientation explaining the increased rotation at this point.

Rotation is also high at the start of the route (1[a]). Rather than complete, purposeful rotation, this may reflect a trial and error strategy when matching the map with the environment. This increased rotation also corresponds with presentation of the map segment reported by participants to generate orientation problems (see Figure 9.16). In future studies it would be beneficial to discriminate trial/error driven rotation from purposeful rotation to align the map with the environment.

Matching

Matching tended to increase where a choice of routes was available to the participants (4[a,b,c], Figure 9.19).

Figure 9.19 Part of section four showing choice of routes

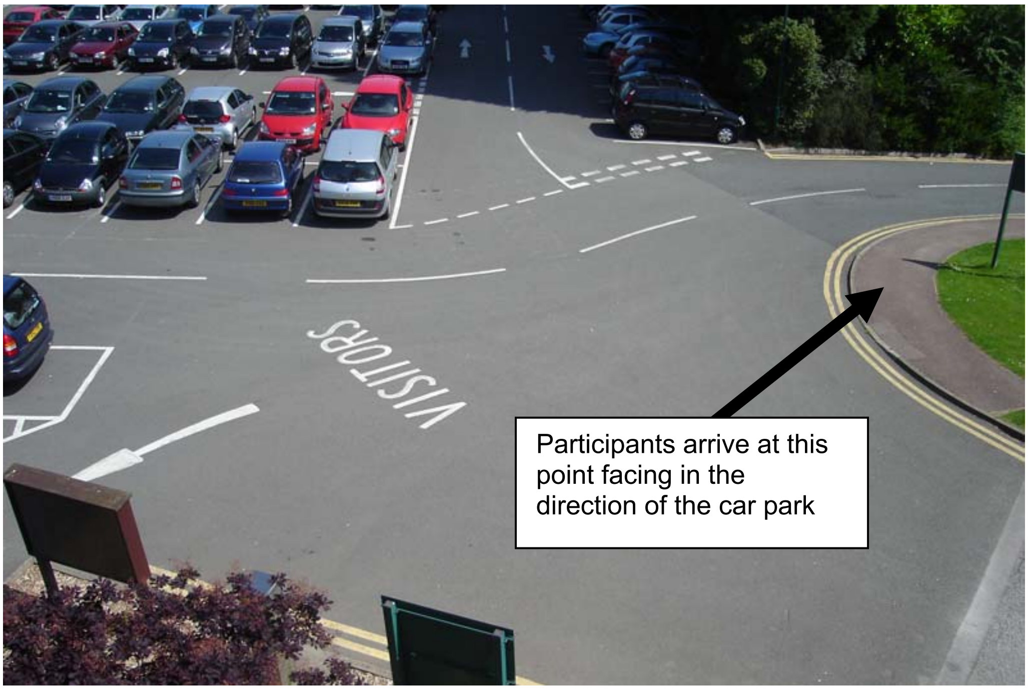
Matching is also high at location 1[b] where orientation problems were experienced by participants. Where little or no choice was available and the path was strongly defined by the environment (5, Figure 9.20), matching reduced to zero until further choices became available (6).

Figure 9.20 A strongly defined path in the environment from a participant's point of view in the route

Confusion/ Surprise

Confusion is high at location 1[a], again due to the ambiguous orientation of the map previously shown in Figure 9.16. The new map is presented at 1[b] may explain the spike in confusion at this location. Confusion increases again at location 3, possibly due to the problems experienced by participants in matching the features displayed on the map (see Figure 9.15). Where the environment is not strongly defined by paths ($4^{b,c}$) confusion also increases since it may not be immediately obvious which direction to head towards in this more open terrain. Figure 9.21 shows an example of weakly defined paths for pedestrian navigation.

Figure 9.21 Weakly defined paths in the environment



9.6 Human factors considerations

The behavioural observation work presented in this chapter strongly supports earlier experimental work. The selection of features to display on the map was reported as a key concern of participants. Presenting useful features and eliminating distracting or ambiguous elements in the display is essential for efficient navigation.

Human factors considerations arising from the study are outlined below:

- Give an option to request orientation information at any point on the route
- Maintain strong track-up map alignment wherever possible

- On 2D, aerial maps do not display features which require elevation information for interpretation
- Display more information when weakly defined paths are present in the environment
- Display less information when strongly defined paths are present in the environment

Chapter 10 Returning To the Context

10.1 Introduction

This study begins to bridge the gap between the experimental work presented in Chapters 6 and 7 and the real world application described in Chapter 3. This study was used as an opportunity to review the different types of spatial information with individuals from the actual application domain.

The different types of spatial information used in the experimental work were presented to a group of practising firefighters at Beeston fire-station, Nottingham. The firefighters then participated in a group discussion about the different types of information and how they could be used in an operational context.

Focus groups are a very efficient way of collecting data (Oppenheim, 1992) and this was a central consideration when selecting this method for the study. Access to the firefighters is granted on an ad-hoc basis. There is no way of knowing how many firefighters will be present at the group or for how long they will be able to participate; during the session it is likely that the majority of firefighters will be on call. The methodology maximises the amount of data that can be collected given these constraints.

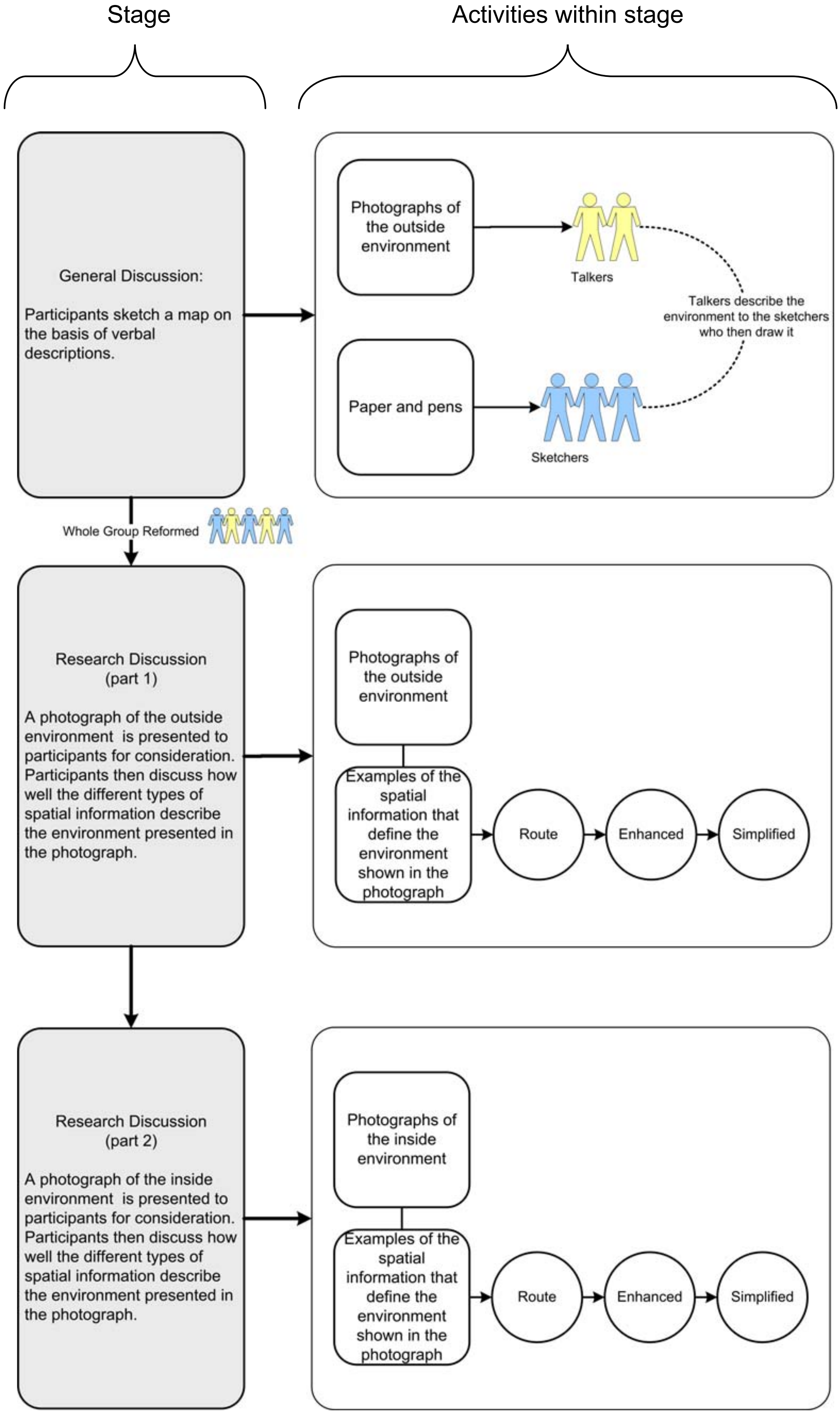
The particular advantage of using the focus group in this context is that a group of firefighters, all with different experiences and skills will lead to interactions and new ideas within the group generating rich, qualitative data. Kuhn (2000) describes the strengths of the focus group method according to three criteria. The relationship to the current study and these criteria is listed in Table 10.1.

Table 10.1 Strengths of focus group studies in relation to the present study

Strength	Relationship to study
Defining	Defining elements of the environment that are important when attending an incident given the stimulus materials
Analysing	Analysing and describing the strengths and weaknesses of the different kinds of spatial information and different methods of presentation used in the experimental work
User Context	Evaluating experimental spatial information in the context of the real world application. Advantages and disadvantages and how the information could be improved for use in different scenarios

The central question addressed by the focus group is: how well would the different types of spatial information support navigation when engaged in an incident. Firefighters were shown photographs of both the inside and outside environments used in experiments two and three. Examples of the different types of spatial information: route, enhanced and simplified, corresponding to the photographs were presented and discussion as to their effectiveness in supporting navigation in an operational context was encouraged. Figure 10.1 shows the procedure, outlining the order of the discussion stages.

Figure 10.1 An outline of the discussion stages presented in this chapter



The organisation of the results section is different to the order shown in the procedure. The results are grouped by information type rather than by environment as was the case in the actual focus group. This more intuitive structure was avoided during the research discussion to avoid undue comparison between environments rather than between different types of information for a specific environment.

10.2 Method

10.2.1 Participants

Participants comprised of all five duty firefighters on the afternoon shift. All participants were male and had varying experience in the service. No selection of personnel took place; the interviews were conducted with firefighters who were on duty at the time. Participants gave written consent to participate in the interview and to be recorded. No payment or other incentive was offered to participants. Details of all participants are shown in Figure 10.2.

Figure 10.2 Age and experience of interview participants

Participant	Experience	Age Group
1	1 year full-time, 1 year part-time	Under 25
2	1 year full-time	26 - 35
3	5 years, full-time	36 - 45
4	15 years, full-time	36 - 45
5	28 years, full-time	46 - 55

10.2.2 Procedure

All participants gave written, informed consent to participate in the focus group and be recorded. All participants then submitted personal data including age and length of service in order to give an impression of the different range of skills and experiences of the participants. This personal data was collected anonymously

Two main activities took place during the focus group. A general discussion followed by the research discussion.

General Discussion

The general discussion fulfilled a number of requirements. Critically, all the participants were encouraged to think and talk about space, describing different features that would be important to them in an operational context. In addition, the general discussion encouraged the group to get used to talking to each other in the presence of the tape recorder and the moderator. An exploratory approach was taken in writing up the results of this discussion. Interesting and relevant themes emerged about the ways in which space is partitioned and thought about by firefighters during an incident.

Participants divided themselves into two groups. Two participants became the 'talkers' and three became the 'sketchers'. Two photographs of the outside environment (Figure 10.3 and Figure 10.4) were given to the talkers and concealed from the sketchers. The area selected contained a complex series of routes which had generated navigation difficulties for participants in experiment three. Different ground cover, paths crossing at angles and buildings in a variety of positions make this environment challenging to describe. The photographs were A4 size and laminated. Large sheets of paper and coloured pens were freely available to the sketchers and no other instruction except the required orientation of the sketch was given. The talkers were asked to describe the environment shown in the photograph to the sketchers who were then required to draw the scene, firstly as an elevation and then as a plan view. Sketchers could ask questions of the talkers but the talkers could not indicate whether a particular drawing was correct or not.

The process continued until the moderator judged that new information delivered by the talkers was not improving the drawings produced by the sketchers. After approximately 25 minutes, the moderator stopped the process and allowed both groups to compare and discuss the maps.

Research Discussion

Following the general discussion, the research discussion was started. Spatial information corresponding to the environment shown in the photographs was presented to the firefighters (Figure 10.5). Like the photographs, the spatial information was enlarged and presented on laminated A4 sheets.

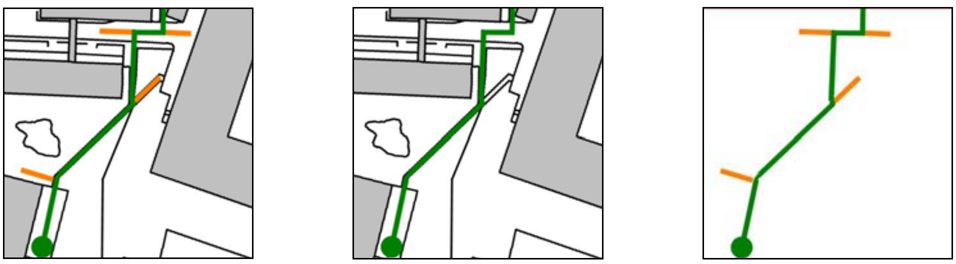
The route information was first presented followed by the enhanced information and finally the simplified information. Discussion about which features would be useful or distracting for navigation was encouraged by the moderator. In addition, firefighters were asked about how the different types of information would fulfil navigation requirements in an operational context. In order to stimulate and encourage discussion, participants were free to draw and mark all materials to make points to the rest of the group.

Navigation outside was discussed first, followed by navigation inside. Participants were introduced to the photograph of the inside environment (Figure 10.6) and then to the spatial information specific to the inside environment (Figure 10.7). The same discussion themes were encouraged as with the outside environment.

Figure 10.3 Photograph 1 of the environment to be sketched

Figure 10.4 Photograph 2 of the environment to be sketched

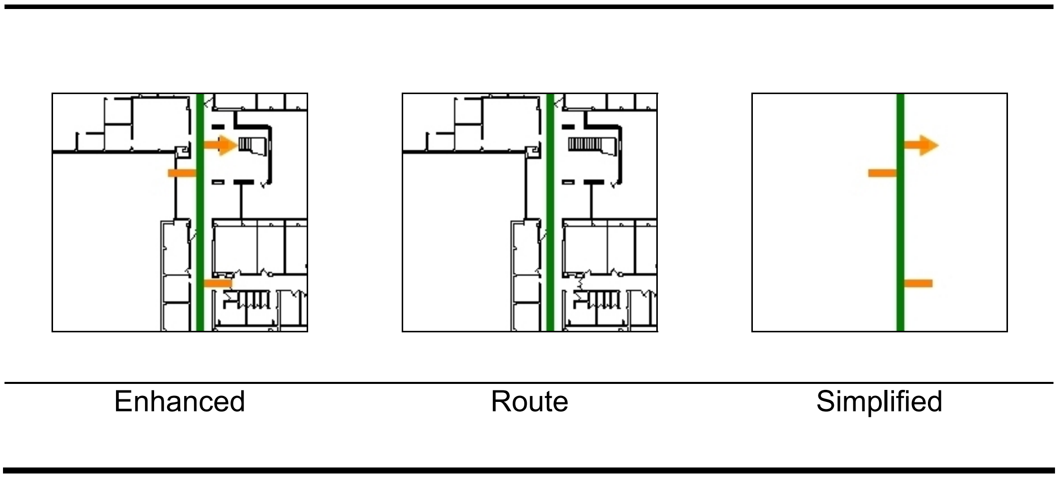
Figure 10.5 Spatial information corresponding to the outside location used in the discussion



Enhanced	Route	Simplified

Figure 10.6 Photograph of the inside environment used in the research discussion

Figure 10.7 Spatial information corresponding to the inside environment used in the discussion

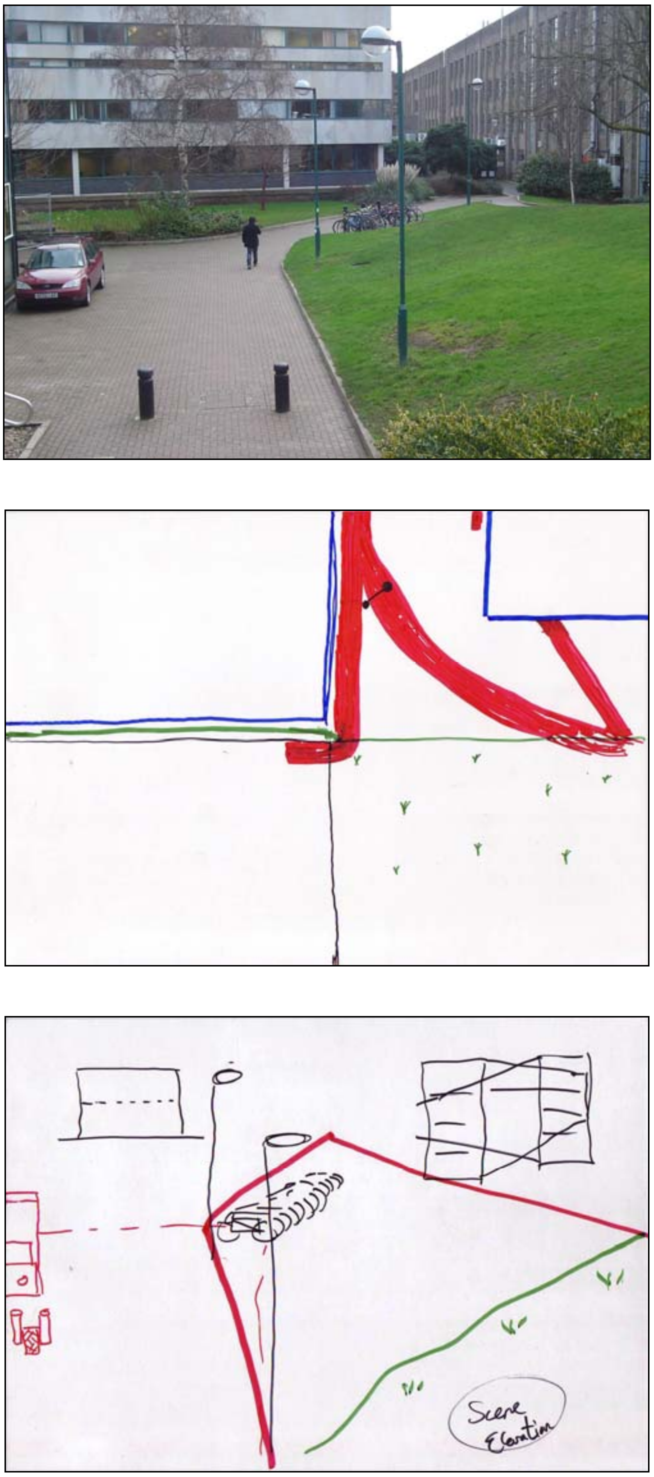


10.3 Results

10.3.1 General discussion

The final drawings produced by the participants together with the environment photograph for comparison is shown in Figure 10.8. Overall, the sketchers made a good attempt to draw the scene and included all major features: paths, lamp-posts and buildings.

Figure 10.8 Drawings produced by participants: (top to bottom) photograph of environment, plan, elevation



Common to both drawings is path detail, drawn in red, buildings and different types of ground cover. Descriptions of the environment tended not to focus on the paths running through the environments but on the overall area and different sections of the drawings. Both talkers used these kinds of descriptions:

> *"Right [Name]. I'm gonna talk to you like we're in gazetteer so we've got one, two, three, four [quadrants] OK. My picture is just a closer up image of quadrant two. Now in quadrant three on my close up image. That path that's continuing round which I'd say 2 ½ to 3 metres in width but on scale here you're looking at 6 inches is continuing from the bottom of quadrant three to about middle of quadrant four OK?"*

The area was divided into quadrants by the talkers and these quadrants used as reference points throughout the description. The quadrants tended to be described as one, two, three, and four following a clockwise circular pattern from the top left. All firefighters seemed to grasp the direction that the quadrants were described in and were happy to partition the environment in this way.

Following description of the quadrants and the nature of the ground cover in them the large buildings and major paths were described to the sketcher:

> *"Building facing me, a building to my right side, hard standing on the left I've got green on the right so I've sectorised it straight away. In this area the hard standing opens up in the middle to become footpath which goes from left to right to feed down between the two buildings that I'm looking at"*

The buildings and paths required significant amount of description and underlined how difficult complex paths and varied ground cover are to describe verbally. Distance is also used to frame and scale the various features in the photograph:

> *"Where the path separates. Right start again. Imagine you're at the bottom of quadrant three, on that main road going from the bottom of quadrant*

three going across into quadrant four. Now, 10 ft in, imagine we're doing it in real time, in a scale of I'd say 5 inches, if you imagine to the left there's a path that goes straight on along side the end of the building in quadrant one. A small walk path. That hits an additional building that we haven't seen because the view of this and a brick wall that covers. So that path, that small walk path there goes…it's a building…quadrant one…a brick wall that covers all of quadrant one… OK.. Happy with that?"

Other descriptions were very similar in content and comprised of clarifying details, especially the positions of buildings which are at odd angles to the paths:

"So this is right is it? Upper right? [inaudible] so the building goes in perspective so you've got the face of it and then it runs away …there. Ah Jesus. So it runs like that, there"

Both sketchers and drawers were surprised at the difficulty of the task given the small area required to be described. The general discussion was successful in getting the group thinking about and describing space and encouraging discussion about elements and features in space.

10.3.2 Research discussion: route Information

All participants found the route information maps straightforward. All participants understood the green marker line indicated the route that should be taken. The description of the map closely followed the descriptions in the general discussion:

"Building facing me, a building to my right side, hard standing on the left … I've sectorised it straight away. In this area the hard standing opens up in

the middle to become footpath which goes from left to right to feed down between the two buildings that I'm looking at…"

When asked about significant features displayed on the map, permanent structures were preferred, especially buildings, which usually maintain their structural integrity regardless of the severity of the incident.

"… obviously landscaping is something which can change so they're sort of semi-permanent but what…what's more permanent are the buildings so they are the most significant features to me as they're the least likely to change. As I say, the most significant features are the buildings."

Participants agreed that since permanent structures were of critical importance, they would be the features that should be augmented with other information such as height or number of storeys. This information would also assist in verbal descriptions to other crew members:

"And certainly the size of [the building] you would relay that information so but obviously a plan won't reflect the number of storeys ...so information like that is perhaps…I don't know. The physical length and the width of it is probably the most striking feature if you got a plan"

Several features were not felt to be useful. Features referred to in the quotes are shown in Figure 10.9. The identity of many features was not clear from the map:

"What's that? [refers to pond] Is that water?"

This same problem with a circular feature in a different location was experienced by participants using a map section in the previous study (Section 9.5, Figure 9.15, p269). In Chapter 9, the circular feature was tree cover, underlining the ambiguity associated with these features.

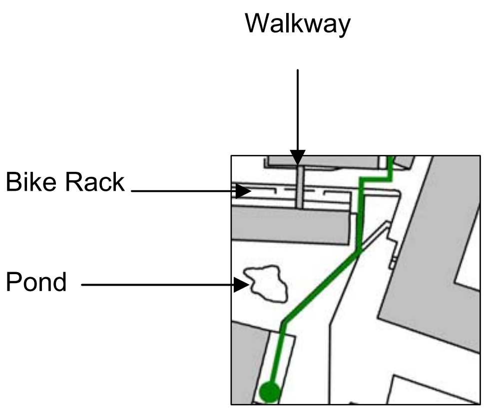
Also, details such as the bike rack were not helpful since they did not contribute to any understanding of the space as a whole:

> *"You don't need none of this detail here [bike rack], all you need is the outline of the buildings where you're not going to be able to go irrespective of where it is.*

Another issue raised were features that were not on the same level such as the walkway. As in the previous study, certain features require height information to be able to be quickly understandable. In the absence of height information, many features become distracting rather than imparting any new knowledge about the area displayed:

> *"Is this a walk-over [JN: yes] you see that's not necessary is it…"*

Figure 10.9 Ambiguous features



10.3.3 Research discussion: enhanced Information

The meaning of the green line was clear from reviewing the presentation of the route information. For both the inside and environments, discussion centred on the actual meaning of the decision point marker. Participants correctly judged the general meaning of the orange markers:

"Are you saying someone could easily walk straight on rather than turning off?"

"To me that says the paths continue there [Indicating orange markers] and the green one says that's the one to go for."

Further discussion revealed a number a number of varied interpretations of the meanings of the markers. The markers indicate viable paths that should not be taken in order to continue on the correct route. A frequent interpretation was change in direction:

"I know how you've broken it up, change of direction every time"

"…but are these paths or are they just breaks of change of direction. I think they're breaks, change of direction aren't they?"

Another interpretation was the indication of viable alternative paths. This interpretation is particularly inappropriate in an operational context since no such inference is intended, paths may exists but not be viable:

"See that to me is easily readable…extra routes an so forth"

"It would be more useful because if you find that you can't go down there for some reason it may suggest an alternative. And like you say, at that point, you've got to make a decision whether to go there or go here if this isn't accessible you know when you're halfway down there well actually I could have down near there so it gives you an alternative rather than having the feeling of being stuck there with no alternative you've at least got more information…"

> *"… you have to alter direction for some reason at that point so there may be an alternative for you to use and it's just another thing in the back of your mind that you think right, OK, we've tried that, we might be able to do this"*

When the precise meaning of the markers was communicated to participants they all indicated the need to be trained in precisely what the markers were showing.

> *"I've not been trained to know what they are. It's just a reference point with no path there?"*
>
> *"…but the orange, like my colleague said- I'll possibly be confused about because I've not been trained as to what they're about"*

The underlying assumption that decision points are the major features used when describing or navigating a route may not be warranted. Navigation decisions use of other features as well. Inside, this may be doors or staircases inside or buildings and changes in heading outside. The information may not be limited to decision points and paths:

> *"I can understand that they're all the nodes but like we were talking earlier that is that all one road. And that's telling me that I've made a decision, decision three, decision four there. Where' as if I look at that I come down there and perhaps I want to step in front of this I come down there hit the building veer off to the right, hit another building, down the side of it. Straight over turn right, I'm looking for a gap between the buildings again. I've talked my way through three four points changes…"*

Participants did indicate that they frequently had similar information but not in a visual form where spatial information is organised along paths and decision points:

> *"Bear in mind that what you have here is a similar system to what we have on the trucks called the left and right book from out the station: turn left, second right, fourth left, junction straight over we already got nodes written down like that in our [Microsoft] Word version and you got it in a map version."*

Participants also noted that using the current, text based system made error recovery very challenging; dynamic, visual information was judged to improve the situation:

> *"If we follow nodes and take a wrong turning we're stuffed. If we've got a picture like my colleague says the TomTom, if you go past it you can see an alternative if you go left and right and you take the wrong left - you're reading off a script, the scripts gone."*

10.3.4 Research discussion: simplified Information

All participants voiced strong opinions about the simplified information. Very different opinions emerged about how useful the information would be in the different environments. Opinions about using the simplified information in the outside environment were negative. The lack of scale was indicated to be a problem:

> *"That could be like 3 miles or 50 yards Whereas here you've got some reference to paths and the corner of the building for example so you know that the corner of the building is halfway along there, that sort of thing. I think the lack of any distance, actual physical measurement on there…it would be a benefit."*

Lack of major features, especially buildings was viewed as problematic, especially when assessing progress along the route:

> *"So there are no reference points on there other than your turning points. You gotta have a reference point as you shown me that and told me it's*

that. You need a reference point i.e. there's a building there, there's a building there."

Participants also indicated the need to know about the nature of the route itself. Outside, equipment may have to be moved or driven to an incident requiring specific types or quality of route:

"You don't know what's a road or what's a path, it could be a main road with a roundabout on it for all I know"

In the inside environment, the simplified information was viewed positively. Participants felt that a reduction in distracting features was useful and could speed up navigation:

"Looks very tom-tom-ish. But it looks very effective cos it cuts out alot of the noise, if you like unnecessary detail and says you need to go down there if you like. It does the job and it works."

"What you've drawn there is only the relevant things, you don't need anything else. Anymore and all they're doing is verifying there's something there and that you don't need to do, it's slowing you down."

Participants also felt that the features depicted, stairways and decision points were critical during inside navigation:

"I think it comes down to major reference points don't it. You say right there's a stairway, when you get there it's two steps forward"

Participants indicated that these kinds of reference points were used at the moment to describe buildings and structures. The point that reference points should be solid and immovable was returned to:

"Yes…they are certainly reference points we use, changes of height also usually changes of direction… doorways but certainly stairs absolutely...it's got to be a solid, immovable reference point"

[All agree]

10.4 Conclusions

"You give us too much, we'll lose something…too much information"

Table 10.2 shows the general direction of opinion for each type of spatial information.

Table 10.2 General direction of opinion for each type of spatial information in each environment

	Enhanced	**Route**	**Simplified**
Inside Environment	😐	😐	☺
Outside Environment	😐	☺	☹

The route information type was well received in the external environment. Participants mentioned that appropriate, immovable features would assist navigation. Problems concerned the inclusion of ambiguous features which could cause confusion and difficulty in interpreting the information. Other problems included the inclusion of features that require height information in order for interpretation to take place. Route information of this type was viewed as adequate in the inside environment.

The enhanced spatial information received a lukewarm reception for both types of environment. The positive aspects were the level of detail, particularly in the outside environment. The main problem associated with this information type was the precise meaning of the decision point markers. Participants generated several meanings including direction changes and alternative paths. In an operational setting, the level of ambiguity generated by this type of information may be problematic. In addition participants commented that navigation decisions do not simply concern decision points but may include passing buildings or other features. Forcing firefighters to use a consistent, although arbitrary, set of decision markers may reduce the efficiency of navigation.

The simplified information was viewed as useful when supporting navigation in the inside environment. The group felt that navigation would be well supported by the features displayed: decision points and staircases. Participants felt that this type of simplification had the potential to speed up navigation. In the outside environment, participants felt that the simplified information was insufficient to support navigation. Participants felt that more landmark information was needed, large buildings or features, to successfully support navigation. The simplified information does not show the nature of routes which could be a footpath or a road. This was also a concern since this type of information is necessary for planning access to vehicles and crew.

A key theme occurring thought the discussion was presentation of the correct features in order to support successful navigation. Reduction in information was viewed positively so long as the appropriate information was retained. In the inside environment, the simplified information delivered sufficient information with which to navigate. In the outside environment, more information was needed. However, further reduction in features would be possible without affecting overall navigation success.

10.4.1 Relationship to experimental work

The results of this study support the experimental work conducted in Chapters 6 and 7. The simplified information is associated with lower workload and faster completion time in inside environments. In outside environments, lower mental demand was associated with both the route and enhanced information types.

Chapter 11 Discussion

11.1 Introduction

This chapter describes how work presented in this thesis has met the original aims outlined in Chapter 1. An executive summary and suggestions for further research is also presented.

The original thesis aims were:

1. To examine how mobile LBS could be used in a real-world context and to evaluate experimental findings in conjunction with the real-world context.

2. To Investigate how different ways of presenting spatial information and how different types of spatial information affect navigation.

3. To suggest human factors guidelines that could be used in the development of mobile, location-based navigation support.

4. To develop experimental methods for human factors research into mobile LBS.

11.2 To examine how mobile LBS could be used in a real-world context and to evaluate experimental findings in conjunction with the real-world context.

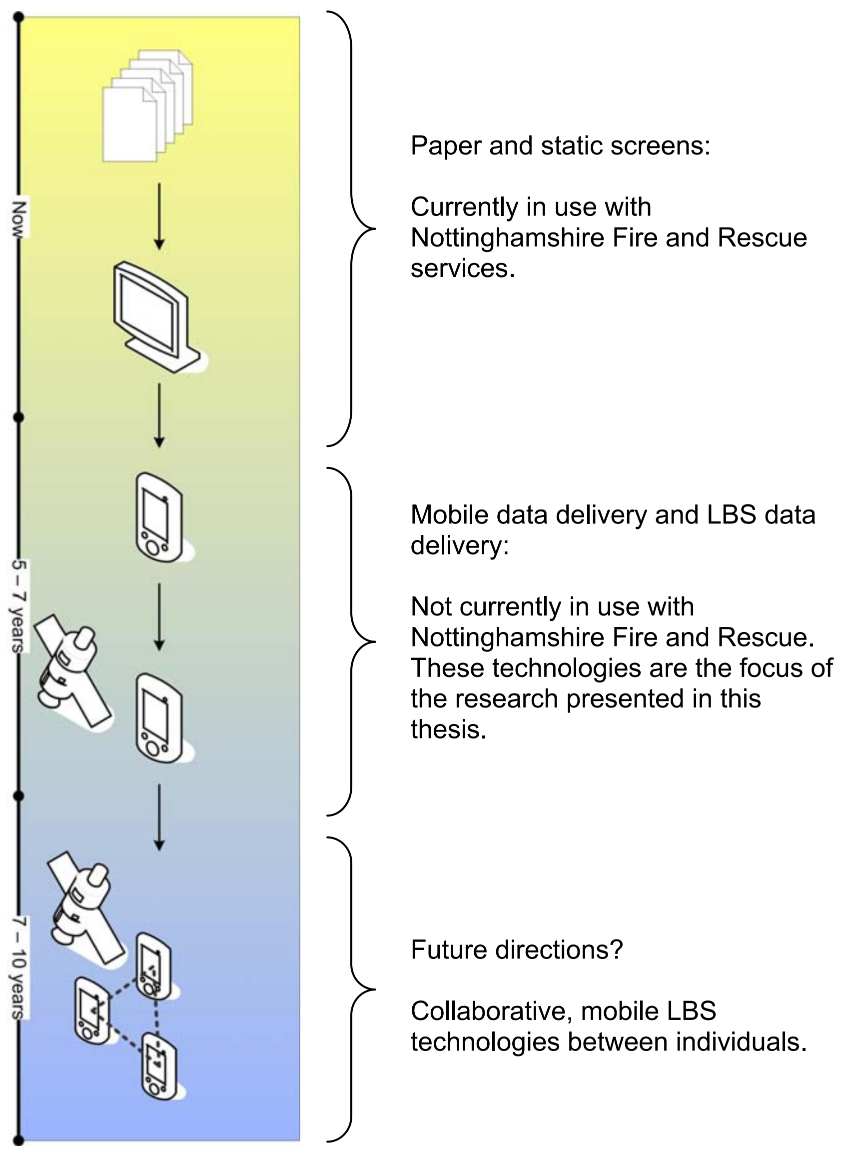
11.2.1 Key findings

- Firefighters use a variety of methods to communicate information during an incident
- Mobile LBS has the potential to streamline communication of information so that the correct information can be delivered quickly and to the right person
- Information should be speedily delivered by mobile LBS and be relevant and clear
- A variety of applications of mobile LBS exist for both specific tasks, and more strategic command level activities
- Firefighters prefer the simplified information used in experiments two and three for inside navigation and the route information showing significant environmental features for outside navigation
- Firefighters views support and validate the conclusions found in the experimental work performed

11.2.2 Introduction

Figure 11.1 shows the current methods of communication used in the fire service and potential future technologies that could be employed. Current technologies, paper and static information delivery are shown at the yellow end of the scale. Mobile information display, for example operating procedures or web-enabled delivery of information follows. Towards the blue end of the scale is mobile LBS; contextually relevant information presented in a mobile context which is the focus of research in this thesis. At the far blue end is a potential future scenario where collaboration between many mobile LBS is possible, opening further possibilities for information delivery to assist decision making.

Figure 11.1 Technologies used in the fire service: present and future



Nottinghamshire fire and rescue service uses both traditional paper based and electronic methods of information dissemination during an incident. Written risk assessment and paper based information collected from industry and fire officer visits is available but may not be immediately accessible during an incident itself.

Nottinghamshire fire and rescue have installed fixed mobile data terminals (MDTs). These small screens are the first sign of electronic information delivery. Increasingly, previously paper based information can be delivered and queried on the MDTs. The immediacy of electronic delivery means that key crew members can access information about sites; hydrant location or hazards, on the way to an incident. The MDT is a positive step forward in just-in-time delivery of information to crews since it makes large amounts of information available at the scene of an incident. However, often the information displayed is not optimised for this form of delivery. Many 3D CAD plans of large buildings are available for the Nottingham City area but these plans can be very challenging to interpret effectively and difficult to remember. All available information is frequently presented resulting in an information-rich and cluttered display. Although complex queries can allow focused information to be displayed, the time taken to input a query may not be available during an incident. A location-based service could reduce the amount of information made available or simplify the structure of a query allowing full use to be made of the stored information.

11.2.3 Information delivery

Mobile LBS offers an alternative way of delivering relevant, clear information quickly when it is required. The key requirements of delivering information using mobile LBS in the fire service are summarised below:

Speed

Information that may have passed through a chain of command could be made available to a number of individuals immediately. Incidents can change quickly. New information delivered to the right people immediately can match and follow the changing nature of an incident over time.

Relevance

Interoperable data sources and sensor networks could deliver information relevant to specific crew members in specific locations. For example, a firefighter may need immediate hazard information in the local area whereas an incident commander may need a higher level overview.

Clarity

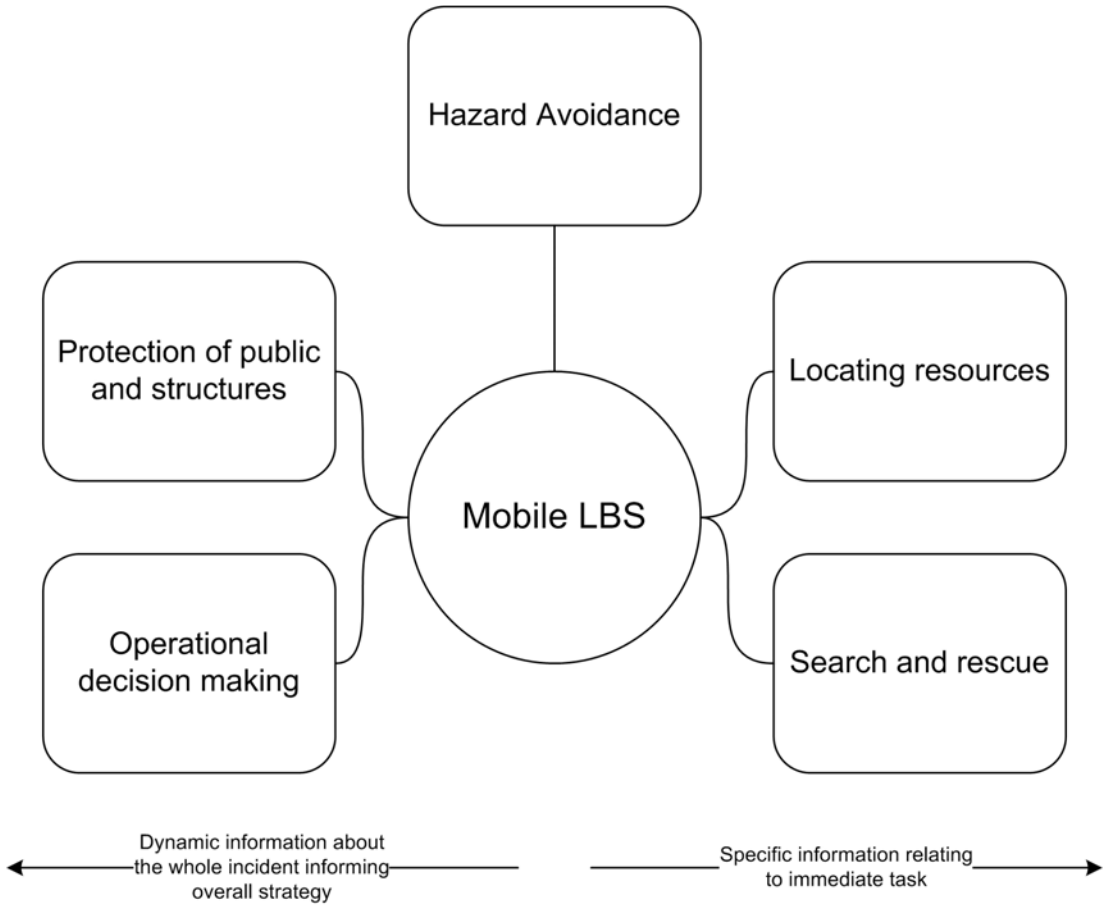
Highly relevant information may be delivered to crew in specific locations. The location element would define and constrain the information delivered: removing redundant information focusing attention on specific information, relevant to the context.

Overall, a combination of speed, relevance and clarity may reduce cognitive burden experienced during tasks by delivering context specific information about an immediate area, minimising the chance of information overload. Task performance may also improve. Delivering information in this way may speed up task completion owing to a reduction in unnecessary tasks, for example avoiding unnecessary search of a building or being guided to the most appropriate hydrant for an incident rather than having to interpret and act on many different data sources or displays.

11.2.4 Applications of mobile LBS

Overall applications that emerged as critical from the research are shown in Figure 11.2.

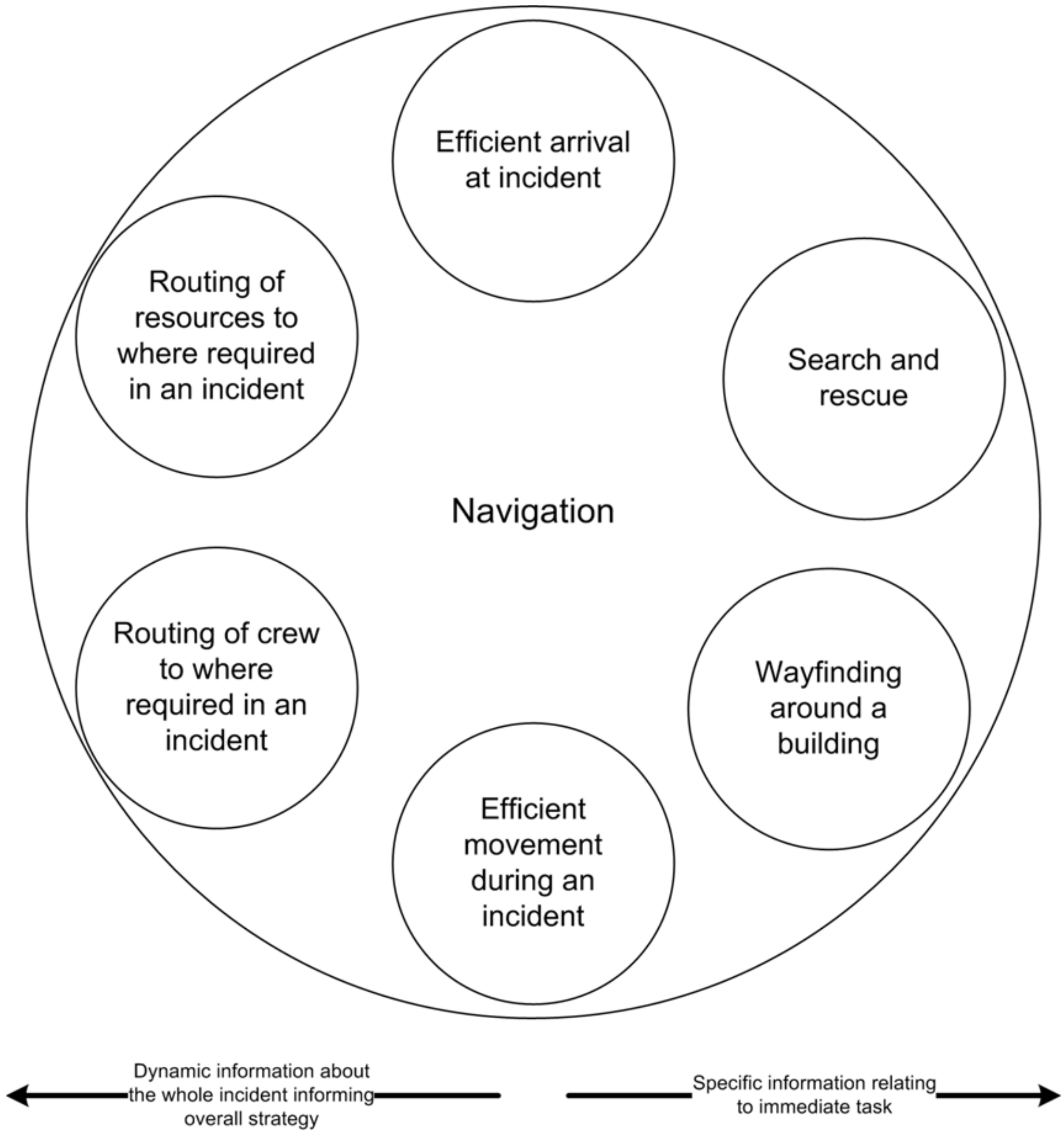
Figure 11.2 Applications of LBS in the fire service



The applications are broadly divided into two regions: whole incident strategy (left) and task specific information (right). This division is arbitrary since although there are crew members who take on a specifically strategic role, for example an incident commander, more often, crew requirements change as an incident progresses. Nevertheless, a variety of important application areas that would benefit from relevant, clear and speedily delivered information have been indentified in these two areas, which have very different information requirements.

The focus of this thesis has been navigation. During the interviews with the firefighters, a recurring theme was the task of navigation. This theme was explored in detail and a variety of tasks that require navigation were indentified. These tasks are summarised in Figure 11.3.

Figure 11.3 Navigation in the fire service



As with Figure 11.2, Figure 11.3 has been divided into overall strategy and task specific navigation. The overall strategy (left) concerns decision making about navigation: planning routes for resources or crew or moving groups of people. Personal navigation or search and rescue are categorised as immediate navigation tasks (right). Again, general movement around and incident and arrival at an incident are important for both specific tasks and overall strategy. Navigation is a challenging task, especially in the context of a complex or geographically distributed incident. Many crews without local knowledge of an area may be engaged in the incident. Clear information which supports navigation in these larger incidents would benefit firefighters who do not have local knowledge to rely on.

11.2.5 Validation of experimental results

A series of major experiments were conducted, the results of which are described and discussed in Section 11.3. The types of spatial information and their corresponding environment were presented to a group of firefighters for evaluation and discussion.

Firefighters indicated different preferences for spatial information in the inside and outside environments. Their preferences correspond with the overall findings from experiments two and three. A comparison of the key differences in mental workload and average speed between information types found in the experimental work and the conclusions of the focus group are shown in Table 11.1.

Table 11.1 Summary and comparison of evaluation with experimental findings

	Inside Environment	**Outside Environment**
Evaluation	Show simplified information using permanent, structural features of a building such as corridors and stairs	Show two or three permanent features such as large buildings or area of specific land type. Show paths were not defined by the environment
Experimental findings	Lower workload and higher average speed using simplified information compared to the route or enhanced information	Lower workload using the route or enhanced information compared to the simplified information

The evaluation conducted in Chapter 10 and summarised here is very much a first stage review. The findings in the focus group should be used as a basis for future empirical work, for example varying the features displayed in the outside environment and assessing the effect on navigation. Different types of behaviour supported by mobile LBS require further research for example search and rescue operations rather than navigation alone. Any of the applications shown towards the strategic side of Figure 11.3 would benefit from further research into how firefighters perceive and segment space, touched on at the start of the evaluation.

11.3 To Investigate how different ways of presenting spatial information and how different types of spatial information affect navigation.

11.3.1 Key findings

- A single type of information presented in different ways may change navigation performance or workload
- Different types of environment may require different information to be presented to ensure efficient navigation
- Navigation may be more successful if the information presented is closer to the way that the environment is perceived and therefore matched to the expected image.
- Successful navigation using an external representation could be explained by effective encoding of spatial information leading to a faster match between the perceived and expected environments

11.3.2 Theoretical position

Navigation in this section will be related to the model proposed by Passini (1992). This model is discussed extensively in Section 2.3.3 (p41). The two basic principles relevant to this section are:

- Navigation is a series of spatial decisions
- Navigation fails when an individual's expectation of an environment does not match the actual environment perceived.

Experiment one delivered the same spatial information using different methods of presentation. This experiment showed that paper plan or map information cannot be transferred directly to a mobile device; the type of information displayed must be changed to ensure efficient navigation. Experiments two and three show that the type of information displayed can change navigation performance using the same presentation method. Broadly results suggest that the simplified information type consisting of route and decision point markers elicits faster navigation times and lower mental workload in the inside environment. In the outside environment, higher workloads are generated when the simplified information is presented. Experiment three did not uncover any differences in route completion time. These findings are summarised in Table 11.2.

Table 11.2 Comparison of mental workload and route completion times for all types of spatial information in all environments tested

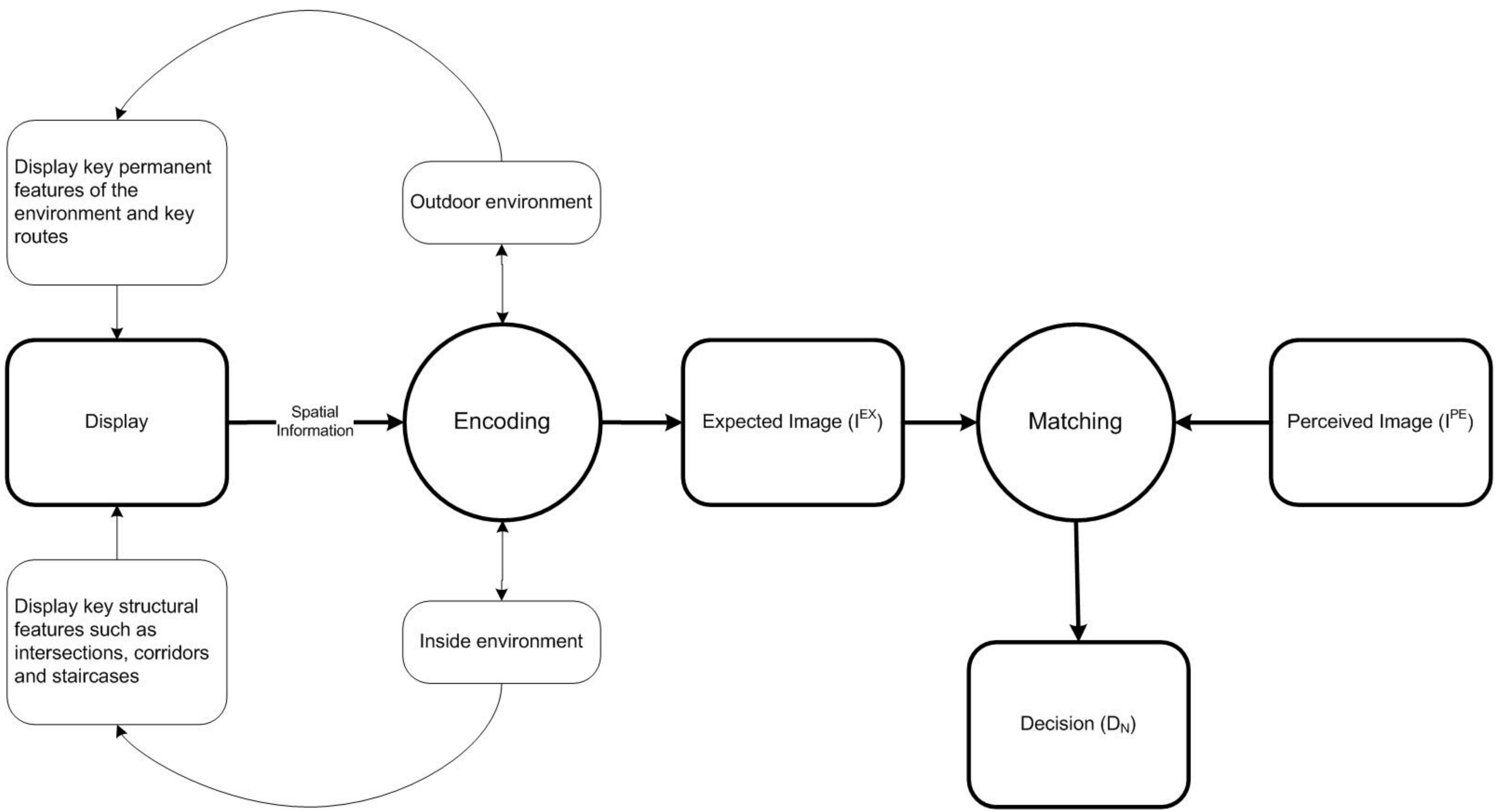
	Enhanced		**Route**		**Simplified**	
	Workload	Route completion time	Workload	Route completion time	Workload	Route completion time
Inside Environment	↑	↑	↑	↑	↓	↓
Outside Environment	↓	-	↓	-	↑	-

Figure 11.4 shows a model derived from Passini's decision model to explain the results found in experiments two and three. At the heart of the model is the matching between the expected and perceived environments. The expected environment can be specified by knowledge in long term memory or by external representations of the environment such as maps or plans. The critical stage of this process is the encoding of the spatial information presented in order to generate the expected

image ready to match to the real environment when encountered. Superior encoding of the spatial information leads to better navigation performance (Meilinger et al., 2006) and may reduce mental workload since the expected and perceived images can be matched more quickly with fewer cognitive resources being allocated. The type of information displayed is critical for efficient encoding and is different for different environments (Mallot and Gillner, 2000;Stankiewicz and Kalia, 2007).

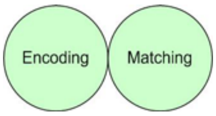
The more closely the external representation matches what is immediately attended to and processed in the real environment, the more efficient navigation will be. This approach also explains why different types of information must be presented in different environments. In man-made structures such as buildings the salient features which are used for navigation are permanent structures such as staircases, corridors or route intersections. The outside environment is more difficult to define being developed more organically through time. In this environment, presentation of permanent structural features and key route enable effective encoding and efficient navigation. Stankiewicz and Kalia (2007) suggest a framework which is synonymous with this part of the model and the overall experimental findings of the thesis. Another experimental finding which supports the model is the significant positive correlation between the memory sub-scale on the INQ and route completion time. Participants who reported good memory of the route tended to navigate more quickly. Mallot and Gillner (2000) suggest that certain features of the environment, particularly intersections are more easily recalled. The more efficient navigation seen in participants scoring higher on this subscale may indicate effective encoding of the spatial information due to highly relevant features being displayed for a particular environment.

Figure 11.4 Derived model for displaying different types of spatial information in different environments

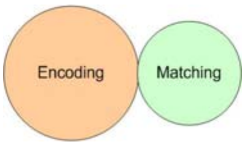


11.3.3 Key predictions of the model

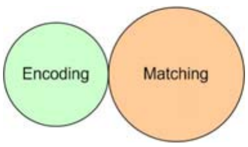
The two key stages of the model are the encoding of the spatial information displayed on the device and the matching of the encoded information (expected image) with the actual environment perceived (perceived image). The following four examples show how workload and performance are affected by differences in matching and encoding:



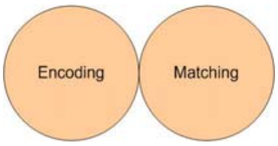
In this situation the encoded spatial information generating the expected image is well matched to the perceived image. Lower workload and improved performance will result from this combination. Research presented in this thesis shows that in order to achieve this ideal combination of encoding and matching, the type of spatial information displayed must be considered in conjunction with the context or environment that the spatial information is used in.



Higher workload and increased route completion times are generated at the encoding stage of the model. A large amount of information presented on the display may generate this combination. The user would have to encode more information to form the expected image to then match to the perceived image. This situation arose when presenting the enhanced information to participants navigating in the inside environment in experiment two.



Higher workload and increased route completion times are generated at the matching stage of the model. An insufficient amount, or inappropriate type of information presented on the display may generate this situation. The user would encode the information quickly enough, but experience difficulty when matching the encoded information to the environment. An example of this combination was presenting the simplified information to participants navigating in the outside environment in experiment three.



This scenario would generate the highest workload and poorest performance. Not only is a large amount of information displayed, the information is not appropriate or sufficient to match with the perceived environment. This combination may have occurred in experiment one. Certain display configurations displayed large quantities of spatial information to encode, but this information, even after encoding, was still difficult to match to the perceived environment.

11.4 To suggest human factors guidelines that could be used in the development of mobile, location-based navigation support.

This section presents ten human factors guidelines developed from research conducted in this thesis. A list of guidelines is shown below in section 11.4.1 and detailed explanations of each guidelines are presented in sections 11.4.2 to 11.4.11.

11.4.1 Summary of guidelines

A summary of guidelines is shown in Table 11.3. Guidelines are developed specifically from research performed in this thesis and this fact should be considered if applying the guidelines to other applications.

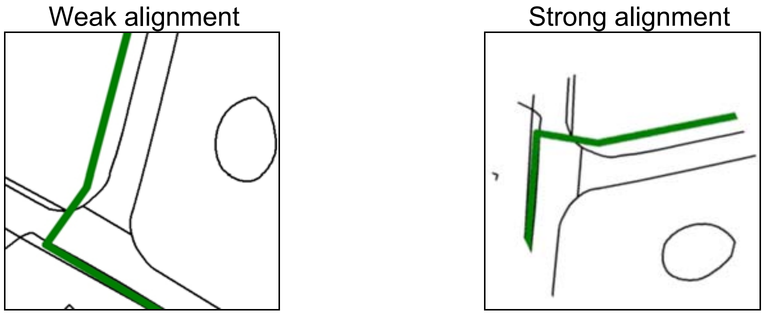
Table 11.3 Summary of guidelines and the studies from which they were derived

Guideline	Study
Use a strong track-up alignment wherever possible	Adding GPS
Show the start of a route at the lowest point on the display	Experiment two, Adding GPS
Display minimum information in the inside environment	Experiment two
Take a light-touch approach to information presented for outside navigation: permanent, conspicuous features should be displayed	Experiment three, Adding GPS
Avoid augmenting information at decision points in the outside environment	Experiment three
Avoid complex route configurations on a single screen: divide into more screens to reduce complexity	Experiments one, two and three
Take into account the geography of the outside environment: less information is required when paths are strongly defined	Experiment three, Adding GPS
Avoid presenting ambiguous features	Experiments one, two and three, Adding GPS
Provide orientation support on demand	Adding GPS
Increase support on presentation of a new map	Experiment one, Adding GPS

11.4.2 Use a strong track-up alignment wherever possible

Figure 11.5 shows an example of a map segment that begins the route at the bottom of the screen but then veers to the left. A preferable, strong alignment is shown where the line is following the direction that participants are walking in rather than a compromise between the geography of the area and the egocentric viewpoint.

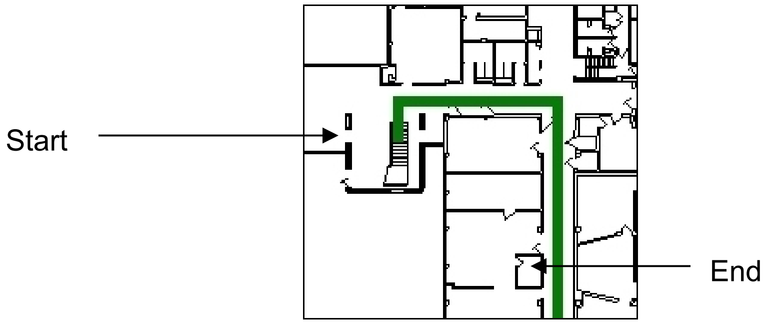
Figure 11.5 Examples of the same map showing a strong and weak track-up alignment



11.4.3 Always show the start of a route at the lowest point on the display

Figure 11.6 shows a map segment which breaks this rule. In the experiment this segment caused confusion when navigating. Despite all other information presented on the floor plan, participants frequently believed that the end of the route was the start given its lower position. One solution to this particular segment would be to divide the plan into two further segments, presented the start of the route always at the bottom of the screen.

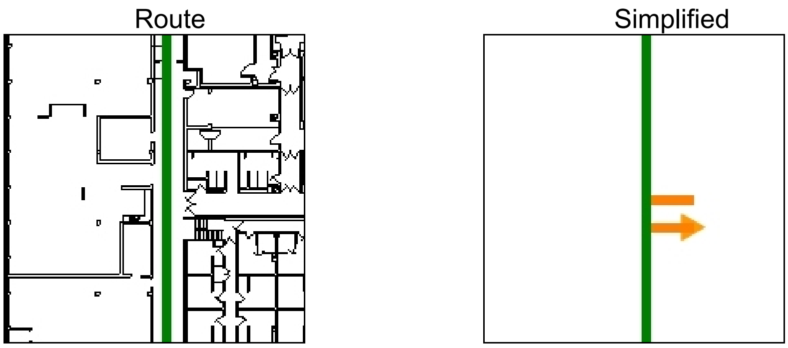
Figure 11.6 A map segment that shows the end point of the route at the bottom of the display



11.4.4 Display minimum information in the inside environment

The inside environment can be defined for navigation using the minimum number of features. Permanent features such as corridors and staircases should always be shown (Figure 11.7).

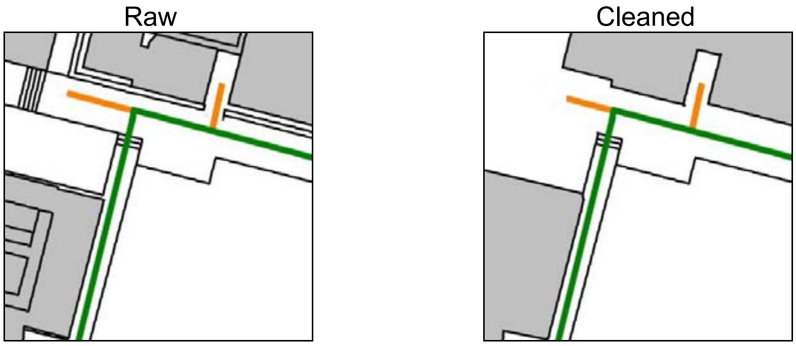
Figure 11.7 Comparison of a floor plan with a marked route and simplified information showing the same route



11.4.5 Take a light-touch approach to information presented for outside navigation: permanent, conspicuous features should be displayed

Not all features are necessary for effective navigation. Figure 11.8 shows a raw map segment with a route marked on. The cleaned version contains only features likely to be seen by a pedestrian while navigating the route. All details which would not be visible: roof details on buildings, building configuration has been removed. Path detail which does not directly inform the route has also been removed.

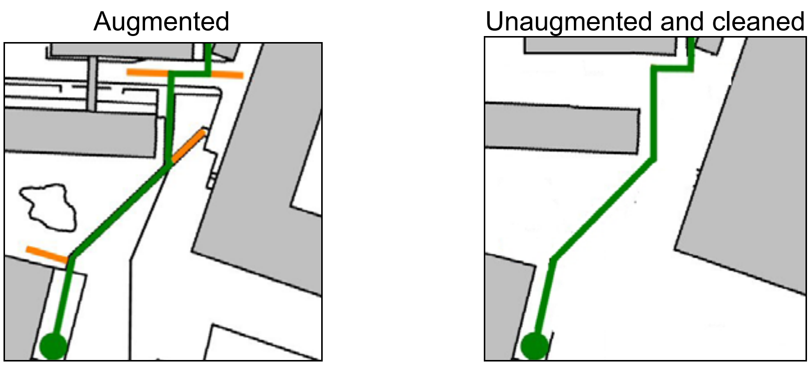
Figure 11.8 A raw and cleaned map segment



11.4.6 Do not augment information at decision points in the outside environment

No navigation advantage was found when increased information was presented at decision points. Not including this information reduced the amount of information displayed and this is important when considering limited screen sizes. Figure 11.9 shows a comparison between an augmented and unaugmented map segment. The unaugmented map segment has been cleaned as per guideline 11.4.5 showing the reduction in clutter that application of these two guidelines can achieve.

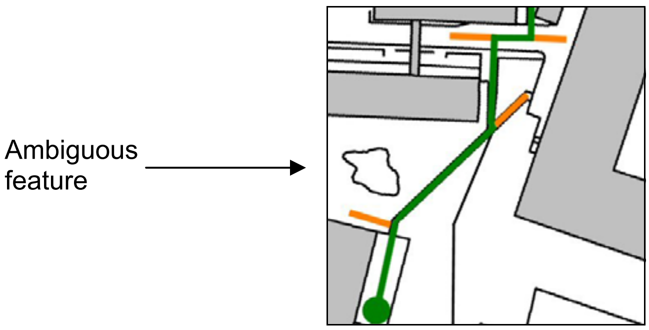
Figure 11.9 Augmented and unaugmented information at decision points



11.4.7 Avoid complex route configurations on a single screen: divide into more screens to reduce complexity

Figure 11.10 shows an example of a complex route configuration. The route changes direction four times in one screen. This particular map is rich in features and contains strongly defined paths, reducing the ambiguity. However, high number of features may not always be present. Under these conditions confusion and higher workload may result. The map shown would be better divided into further segments to reduce the number of direction changes to no more than two. Also of note is another ambiguous feature. In this case, the irregular circular feature denotes an ornamental stone feature.

Figure 11.10 Example of a complex route configuration



11.4.8 Take into account the geography of the outside environment: less information is required when paths are strongly defined

Where paths are very clear in the environment less information needs to be displayed compared to open terrain or weakly defined routes. More support in the form of landmarks of significant features would be required when navigating the environment shown in Figure 11.11. The environment shown in Figure 11.12 would require fewer features since the paths is strongly defined; when participants are routed in his direction they simply follow the path until a spatial decision point occurs.

Figure 11.11 Weakly defined environment

Figure 11.12 Strongly defined environment

11.4.9 Avoid presenting ambiguous features

Figure 11.13 shows an example of an ambiguous feature, often mistaken for a pond or area of water. Ideally such features should be removed as frequently they are not critical for navigation as other features such as buildings or paths can define the route. An intermediate solution is to clarify the feature. Figure 11.14 shows the featured coloured according to a population stereotype. The blue indicates water whereas the speckled green indicates tree cover. This kind of modification may be far from ideal possibly requiring more attention and subsequent elevation in mental demand when navigating

Figure 11.13 Example of an ambiguous feature

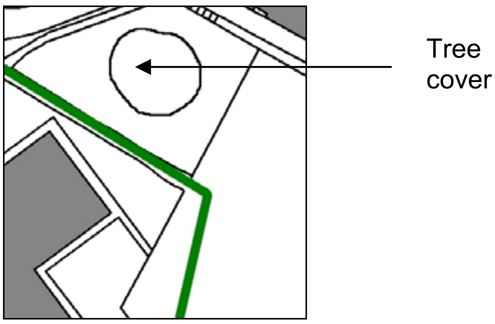
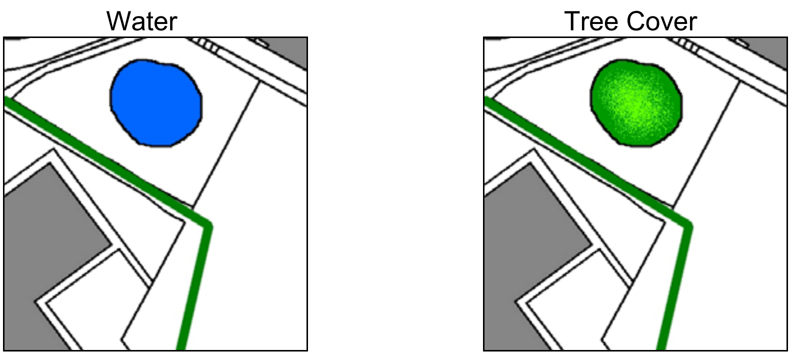


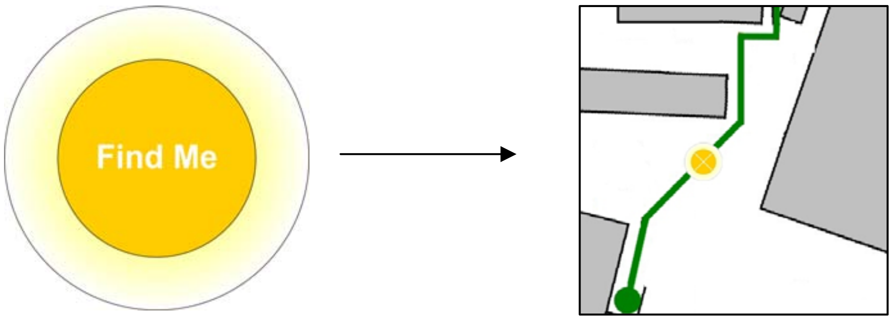
Figure 11.14 Clarification of features



11.4.10 Provide orientation support on demand

A user can become disoriented at any time for a number of reasons. Providing an on-demand ‘find me’ service would assist users to relocate. A conspicuous symbol could then be shown in the display indicating a user’s current location (Figure 11.15).

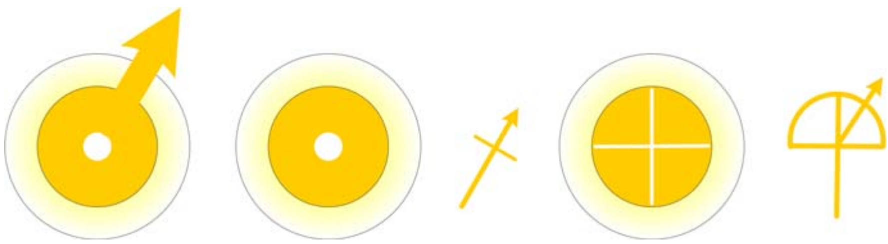
Figure 11.15 An example of on-demand user support



11.4.11 Increase support on presentation of a new map

Displaying a conspicuous you-are-here (YAH) symbols would assist orientation on presentation of a new map or plan. Development of such a symbol should be informed by research but various options are shown in Figure 11.16.

Figure 11.16 Possible YAH symbols



11.5 To develop experimental methods for human factors research into mobile LBS

11.5.1 Key findings

- Careful consideration should be given as to whether a controlled quantitative experiment is necessary or desirable given the high variation in key performance indicators.
- If a controlled quantitative experiment is selected, methods to reduce between subject variation should be employed
- The results of an experiment should be viewed critically in conjunction with an assessment of the environment that participants are exposed to during a field trial

11.5.2 Experimental methods

One of the problems with classical psychological approaches to navigation is their applicability outside of the laboratory. In order to explore how space is represented or how specific spatial tasks are approached and solved, the laboratory approach is an ideal setting in which to answer these questions. Transferring these laboratory findings to real and complex environments can be problematic.

The experiments in this thesis sought to strike a balance between the highly controlled laboratory settings and the highly variable environment encountered while conducting field trials. The approach has been broadly successful but not without a significant learning curve, inevitable in developing new research methods. Throughout the experimental work, reigning in sources of unwanted variation has been a key aim. Every human engages in navigation in a variety of contexts. Experimental manipulation of navigation must somehow affect navigation systematically regardless of the haze of different experiences and levels of ability. This section presents a critical summary of major considerations when conducting controlled field trials that have gone some way towards achieving a realistic level of experimental control when examining navigation.

Avoiding a controlled experiment

The most straightforward way in which to avoid the problems of experimental control is to avoid conducting an experiment. In Chapters 3, 9 and 10, many valid conclusions and recommendations have been derived from a more straightforward, in depth study using qualitative, observational data. Other research questions demand an experimental approach. For example when presenting different types of spatial information displayed in different ways manipulation of key independent variables benefits from a more controlled study but nevertheless careful consideration of whether a controlled experiment is strictly necessary may pay dividends.

Individual differences

A source of variation encountered in any experiment involving human participants is individual differences. Research presented in this thesis shows mixed success when using methods to control individual differences. One obvious method is the use of a within-subjects design but this design is not without its limitations (discussed below). Controlling for individual differences statistically was successful in reducing between-subjects variation in experiment one but no significant linear combination was found between the SDS and dependent variables in experiment two precluding the option of a statistical approach in this case.

One reason for this variation in success may be the difficulty in identifying specific abilities which directly affect navigational behaviour. High success on specific cognitive abilities such as mental rotation (Shepard and Metzler, 1971) does not necessarily translate into improved ability in real world navigation (Hegarty and Waller, 2004). Indeed, it is telling that the most successful measure of individual differences is individual's self-perception of their ability to navigate. Across the whole data set (Chapter 8) this individual difference is correlated with the main objective measure of performance used in this thesis, average walking speed.

Selection of the route

When conducted either a controlled field trial or a field trial, selection of a route that participants should navigate is a core consideration. Often the choice of environment will be dictated by the research and the application. For example, in this thesis, the application was navigation in the fire service. Routes in large commercial buildings and complex outside area of the campus were intentionally selected to represent the kind of environment where mobile LBS would be most useful as a navigation aid. The length of the route is important. A shorter route may exaggerate otherwise insignificant differences in walking speed. The route length used in experiment two, 301m should be considered the minimum permissible in order to give the best possible chance of reducing variation, unaccounted for by the independent variables of interest.

Consideration of the environment

It is not sufficient to assume that rigorous selection of the environment or counterbalancing of environmental exposure is sufficient when explaining results from controlled studies. Often, the structure and features of the environment can explain anomalous results. Many of the guidelines outlined in Section 11.4 have been derived from examining the local environment where differences in behaviour or navigation performance have been consistently observed.

Between or within?

A tension in designing experiments for exploring navigation is the decision to use between or within subjects design. A within subjects design would reduce the high between-subjects variation observed in between subjects designs. However, using this design exposure to the environment or route would create unacceptable carry-over effects; participants would have no need to use navigation support due to their familiarity with the route from previous trials.

Experiment three partly resolves this issue by dividing the environment into segments of similar length and then counterbalances exposure to these environments and information type. In a sense, the counterbalancing worked too well in this diverse environment. The different responses to different environments experienced during the route may have confounded differences due to the independent variable: spatial information type. This technique may only be suitable for highly consistent environments, inviting the criticism that such an experiment may have reduced ecological validity.

Between subjects designs do not have the problems of carry over effects but the higher variability can require larger sample sizes. Managing field trials with high sample sizes is not especially straightforward and increased resources may be required to pay for travel time to the experimental site.

Simulation of mobile LBS

The simulation of mobile LBS has been the key to achieving a significant degree of experimental control. Being able to present location specific information at exact locations has been valuable when designing experiments. The variability encountered when using GNSS positioning systems is not appropriate for many controlled experiments. The focus of the studies presented in this thesis was information display and type, not system design or performance. As such simulation of LBS is ideal for the research questions posed.

11.6 Conclusions

11.6.1 Executive summary of main findings

- There are many applications for mobile LBS fire service which could reduce mental workload and improve performance in individuals, teams or across the whole incident.
- Different display methods require different types of information to support navigation. As single type of information does not fit all methods of presentation on a mobile device.
- Different types of information differentially affect navigation. Different environments require different types of information to be displayed. Structural features should be used in the inside environment whereas a small number of large, permanent features and key routes should be used in the outside environment.

11.6.2 Further research

This research presents a first step in proposing user requirements for mobile LBS, evaluating methods and types of display and the developing experimental and evaluative methods. The constantly evolving nature of LBS technologies and positioning systems means that new challenges will always require new research.

Methods of presenting information and what information to present is wide open for further research. This thesis has focused on presenting information on a handheld device. Complex and novel display technologies such as e-paper or 3D displays present different opportunities and methods to present spatial information and will certainly require human factors input in order to ensure user acceptance and ultimate commercial success.

The model presented in Figure 11.4 makes a number of predictions about the type of information displayed. The hypothesis that effective spatial encoding generates improved matching requires significant further testing. In this thesis two distinct environments are used: inside and built up outside. Many other forms of environments and landscapes exist, but may require different information to be displayed for effective navigation. A framework for environments and landscapes which can ‘plug into’ this model would help define further research in this area.

A recurring theme in the discussion has been the consideration of the whole incident and organisational factors. Research presented in this thesis has concentrated on *one* user interacting with *one* display performing *one* task. This approach was necessary since the user response to the presentation method and information types displayed was of interest. However, these technologies cannot be considered in a vacuum. Mobile LBS may be developed for many uses and many users in the fire service, from incident command to a single team. The way in which these technologies change decision making or affect team responses must be understood for the technologies to be truly enabling, rather than an optional extra.

Finally, design guidelines and principles should ideally be incorporated into services automatically. The technological challenges involved in an operation which is straightforward for a human such as recognising the type of environment or paying attention to significant features poses enormous challenges to the structured world of geospatial information processing. New algorithms incorporating user research would have to be included in software to ensure that the appropriate information is delivered for the environment in which user’s find themselves in and the task they are performing.

11.6.3 Concluding statement

Research presented in his thesis has shown that navigation is a challenging task for the fire service when engaged in incidents Delivering location-based spatial information visually to support navigation in large incidents may improve performance of this task. The type of information presented can be constrained and sometimes reduced in order to elicit successful navigation with minimal wayfinding errors. The research has also shown that the spatial information presented and the types of environment interact. In order to maintain the highest performance, the type of information should be changed depending on the user's environment to ensure continued successful navigation.

Regardless of the application, incorporating human factors research and design guidelines into the development of mobile LBS will ensure user acceptance. The resulting commercial success that will hopefully follow strong user acceptance will ensure that further innovative technologies that use and deliver geospatial data will continue to be developed in the future.

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Appendix

A.1 Thesis information

A.1.1 Details

Word length (including references):	73619
Number of pages:	375
Number of figures:	139
Number of tables:	75

A.1.2 Literature

Figure A.1 Breakdown by subject area of source

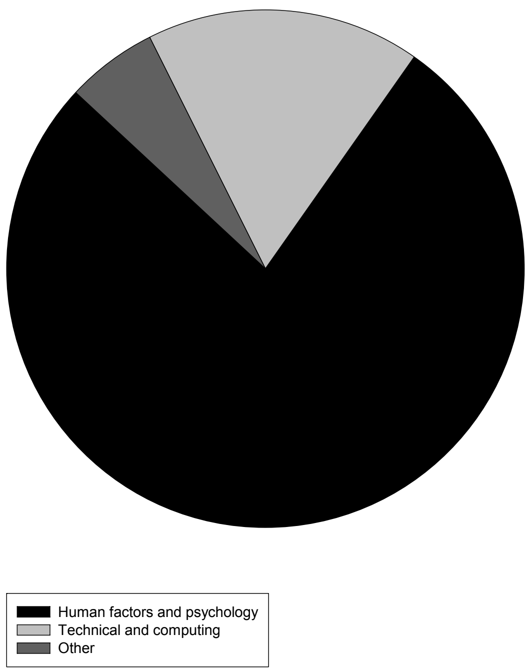
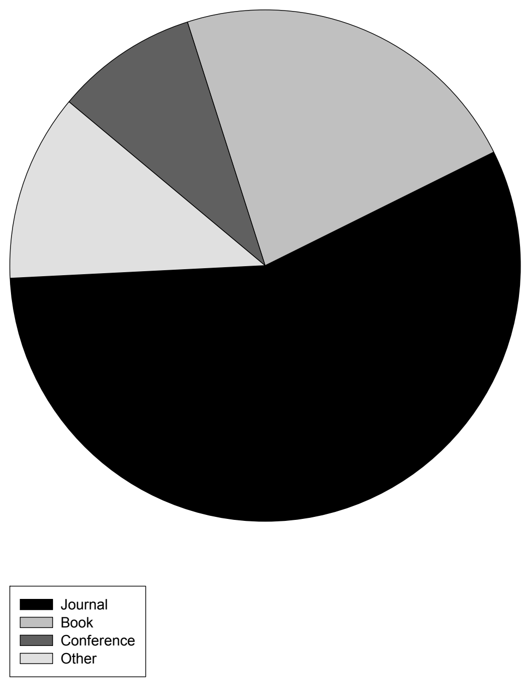


Figure A.2 Breakdown by type of source



A.2 Software

Table A.1 shows the software used to produce this thesis

Table A.1 Software used in the preparation of this thesis:

Application	Programme	Company
Word Processing	Microsoft Word 2003	Microsoft
Reference Management	Endnote 9	Thomson
Data Management	Microsoft Excel 2003	Microsoft
Data Analysis (Quantitative)	SPSS 14	SPSS
Data Analysis (Qualitative)	NVIVO 2	QSR
Power Calculation	G*Power 3.0	Univeristät Kiel
Graphs	SigmaPlot 9	Systat
Diagrams	Microsoft Visio 2003	Microsoft
Image Processing and manipulation	Paintshop Pro 8	Corel
	Adobe Photoshop CS	Adobe
Programming	Visual Studio 2003	Microsoft
	Visual Studio 2005	Microsoft
GIS	Arc Info 9.2	ESRI
Screen Capture (PDA)	HauteCapture 2	Volker Voecking
GPS Signal Processing (PDA)	GPS Tools.net	Franson
Image Viewer (PDA)	Photoviewer 2	Resco