The Effects of Route Guidance Information upon Travellers' Wayfinding and Navigation Ability.

Paul G. Jackson

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University of London Centre for Transport Studies,
Imperial College of Science Technology and Medicine,
London, England.

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ABSTRACT

Developments in information and communications technologies have made it possible to provide drivers with dynamic route guidance and information with the aim of enabling them to make informed route choice decisions leading to an overall reduction in traffic congestion. However, little is known about the effect that providing this information will have upon drivers' underlying cognitive processes: in particular the process by which we acquire, encode, store, decode and recall information about our spatial surroundings, commonly known as cognitive mapping. To improve our understanding of the effects of these information systems upon underlying cognitive processes, and to improve the information presented to drivers, this dissertation addresses three specific research questions:

1. What impact will listening to audible instructions have on the cognitive mapping process?
2. Are all groups equally capable of using auditory route guidance information?
3. In order to improve on existing human factors research the dissertation compares different levels and types of audible information and asks whether the detailed instructions currently in use in route guidance systems the most effective?

Literature reviews identify gaps in the transport, ergonomics and cognitive mapping literature and as a result a set of testable hypotheses were constructed. These hypotheses were addressed in two experiments involving a total of 213 subjects watching video film of three routes through an unfamiliar area. Research questions 1 and 2 were addressed by experiment 1 which involved 133 subjects who saw the videos in one of four conditions. A control group heard nothing, a second group heard route guidance instructions, a third heard a talk radio broadcast, while a fourth group heard a combination of route guidance and radio. A range of tasks was employed to test:

a) knowledge acquired of each individual route; and
b) ability to integrate the information acquired from each separate route into a configurational representation of the area as a whole.

The results of experiment 1 provide strong evidence for an age-related decline in spatial ability, with elderly subjects performing very poorly at the tasks. Ability to drive was also found to have an effect upon task performance, with drivers being more accurate in the majority of tasks. No evidence was found, however, to support the prediction of transportation researchers, that route guidance information can improve spatial knowledge.

In response to these findings a second experiment was carried out with the aim of improving upon existing route guidance instructions. Using the same procedure 40 male and 40 female drivers aged 18-35 watched the videos while hearing various forms of route guidance instructions. Two new information conditions were created which made specific reference to landmarks occurring in the vicinity of choice points, in an effort to strengthen the association between route and landmarks. It was hypothesised that these amended instructions would enable subjects to form a more complete cognitive representation of the area. Results were inconclusive. Although there was some evidence to suggest that those who heard directions followed by landmark information (e.g. "Turn left at the garage") performed better than the control group (who heard nothing) post-hoc analysis failed to identify significance. Other results suggested that attending to audible information can have a detrimental effect on time and distance estimation. As a result of the research the dissertation concludes with a list of recommendations for route guidance and information system designers.

Glossary of Acronyms

ACC	Adaptive Cruise Control
ADEPT	Automatic Debiting and Electronic Payment for Transport
ADIS	Advanced Driver Information Systems
ALI-SCOUT	An infrastructure-based dynamic guidance system using infrared communications, installed for trial in Berlin, by Siemens, Blaupunkt and the German Government.
AMTICS	Advanced Mobile Traffic Information and Communication System
ARI	A traffic service information system (Autofahrer Rundfunk Information) used in Germany, Austria, Switzerland and parts of the USA.
ARIAM	Improved version of ARI, using an automatic data collection system and automatic processing of traffic messages ready for dissemination.
ATMS	Advanced Traffic Management Systems
AVCS	Automatic Vehicle Control Systems
CACS	Comprehensive Automobile Traffic Control
DRG	Dynamic Route Guidance
DRIVE	Dedicated Road Infrastructure for Vehicle Safety in Europe. An initiative of the Commission of the European Communities for improving road safety efficiency and reducing pollution through RTI applications.
ERGS	Electronic Route Guidance System
ITS	Intelligent Transport Systems
IVRGIS	In-Vehicle Route Guidance and Information Systems
IVHS	Intelligent Vehicle Highway Systems
LISB	Leit und Information System, Berlin
PGI	Parking Guidance Information
PROMETHEUS	Programme for a European Traffic with Highest Efficiency and Unprecedented Safety.
RTI	Road Transport Information and Telecommunications (Telematics) Technology
VICS	Vehicle Information and Communication Systems
VMS	Variable Message Signs

1 INTRODUCTION

1.1 Background: traffic congestion in the modern era

Increasing traffic congestion in urban areas has been the cause of concern since the early 1950s, when the industrialised world went through a period of rapid urbanisation and increased economic growth, (Buchanan, 1963). As far back as 1958, Buchanan argued that dealing with the massive increase in traffic on British roads was not simply a matter of building a few new roads, but would require us to respond to a whole new social situation. Buchanan emphasised that there was a conflict between the many benefits of widespread car ownership and its many negative effects. In the 40 years since that book was published the traffic congestion problem has been well documented and researched, but the various approaches adopted to change the situation have met with little success. Improvements to highways, traffic control systems and to the vehicles themselves have all gone some way to raising the quality of the driving environment, but have had a minimal impact on the traffic congestion which blights modern urban areas across the world. In the UK there has been a tenfold increase in the distances travelled by car since 1960 (Houghton. 1994) and in the last decade alone road traffic in the UK has increased from 325 to 442 billion vehicle kilometres per annum (TSO, 1997).

The Royal Commission on Environmental Pollution's 18th report, *Transport and the Environment* (Houghton, 1994) considers the causes and effects of the traffic problem which faces the developed world. Houghton (1994) cites increased mobility, changes in work practices, demographic changes and changes in lifestyle as contributing to the congestion problem.

The Institution of Civil Engineers' report on Congestion (ICE, 1989) cites the following as social problems which can arise from congestion in any transport system:

- Delays and unreliability. Congestion causes delays, but because the delays are unpredictable additional time must be allowed for the completion of all journeys. Unreliability caused by congestion is a major problem for the public and industry. The costs of delays to road users and operators and increased running costs at slow speeds in congested conditions has been estimated to cost £19.1 billion per year at 1994 prices (Newbery, 1995; Maddison *et al.*, 1996 both cited in Houghton, 1997).
- Loss of efficiency. Congestion reduces the output of a transportation system, leaving it less able to deal with the increased numbers. As congestion increases, output decreases. Once congestion is endemic in a transport system, random events such as

accidents, breakdowns or repairs cause paralysis;

- Massive costs through wasted resources;
- Overcrowding results in loss of comfort;
- Environmental damage caused by pollution, noise and visual intrusion;
- Reduced safety. On public transport overcrowding increases evacuation times and exposes passengers to greater risk of injury; response time by emergency services is greatly increased as congestion impedes rescue service.
- Restriction of growth. Congestion, by impeding access of employees and increasing distribution costs of firms, can restrict growth.

ICE, (1989) p.7

1.1.1 Other effects: driver stress

For the individual driver, driving in congested networks can be an extremely stressful experience, associated with increased heart rate and high blood pressure (Littler, Honour and Sleight (1973); Rutley and Mace, 1970). Driver stress has been the subject of a number of intensive studies which have attempted to establish the dimensions and correlates of driver stress (e.g. Gulian *et al.*, 1989; Matthews, Dorn and Glendon, 1991; Novaco, Stokols and Milanesi, 1990), whilst media reports have highlighted the apparent increase in *road rage*.

Furthermore, traffic congestion and its effects are no longer exclusive to the traditionally congested cities and urban areas of the industrialised world. Thirty years ago traffic congestion was a problem associated with only the largest conurbations. Today, most commuter drivers are familiar with traffic congestion (albeit on a smaller scale) whether they live in a major city or a small town (ICE, 1989).

Whilst the developed nations of the world have begun to recognise the harmful effects of traffic congestion on individuals, communities, the environment and on society as a whole, the same scenario has begun to be repeated in developing areas rushing to embrace industrialisation. In third world areas, the prevalence of western culture in media and advertising emphasise the benefits of car ownership with little regard for the negative impacts. The situation in Asian countries is summed up by Midgley in the World Bank Technical Report "Urban Transport in Asia":

> "As a result of the large and growing population of poorly maintained vehicles with minimal, if any, pollution controls, powered by unusually dirty fuels, most major cities of Asia are already experiencing serious motor vehicle related air

pollution,"

Midgley (1994), p.18

As a consequence, the damage both to the environment and to the health of individual citizens caused by car-related pollution could be of an order many times worse than that experienced thus far in Western society.

The problem of traffic congestion is further compounded by the fact that poor route knowledge leads to drivers taking inefficient routes, thus wasting time and other resources in unnecessary mileage. Research has tried to quantify the extent of this inefficient usage of the road networks. King (1986) found that about 6 per cent of all distance was wasted, while King and Mast (1987) found that as much as 12 per cent of all travel time is similarly inefficient. Others have reported a range of values: Jeffery (1986) for example estimated this excess travel distance to be 6 per cent while Wootton *et al.*, (1981) suggest greater variation, putting the figure as being between 2% to 12% of the current total mileage and time spent on the road.

1.2 ITS - A possible solution?

Recent technological advances have offered transportation researchers and planners a possible means of significantly improving the efficiency of the transportation network, resulting in reductions in congestion levels, improvements in the levels of safety and generally raising the quality of the driving experience. The technology expected to have such an effect on these problems, is known by the generic term ' Intelligent Transport Systems' (ITS).

The term ITS covers a wide range of technologies including variable message signs (VMS), parking guidance and information (PGI) systems, and in-vehicle route guidance and information systems (IVRGIS). Whilst the focus of these systems is varied, they share the common aims of improving the quality of the driving environment experienced by the individual traveller, maximising the efficiency of the road transport network and thus producing a consequent improvement to the transportation system as a whole. The implementation of these technologies throughout the transportation system has been predicted to offer many benefits both to the individual driver and to the road system as a whole, by affecting key elements of the traveller's journey such as speed, cost, route and access whilst providing information about alternative travel modes (Bonsall, Pickup and Stathopoulos, 1991). With regard to the problems encountered

specifically by road users, the provision of information via such a system is considered to have two specific advantages (Ben-Akiva, de Palma and Kaysi, 1991):

i) Driver knowledge of travel conditions and congestion problems for the day would be increased.

ii) The provision of information would have the potential of reducing poor route choices and diminishing excess travel time.

This dissertation specifically focuses upon IVRGIS. These are a special case among the various applications offered by modern communications and information technologies, in that they reside in the vehicle. Consequently they offer the potential to have a more direct impact on driver behaviour. The nature of IVRGIS has led to researchers from two particular disciplines focusing on distinct issues:

- the potential to have a direct impact on driver behaviour has led transportation researchers to focus upon characteristics of the information and the extent of its effect on driver behaviour. Issues that have been considered include: the type of information which should be supplied (both to address the individual drivers' needs and to address the problems and limitations of the transport network as a whole); individuals' responses to this information; and the extent to which individuals will comply with the information supplied. These and related issues are discussed in chapter 2.

- the presence of IVRGIS in the vehicle has led human factors researchers to explore safety issues such as: the possible distraction caused by the presence of a screen display; the additional cognitive load associated with using such systems; and ability to use IVRGIS whilst maintaining safe control of the vehicle. These and related issues are discussed in chapter 3.

These two separate strands of research have greatly improved our understanding of the issues considered, but within each discipline there are areas left either unconsidered or inadequately considered.

1.2.1 Limitations of existing transportation research and issues to be considered

With regard to transportation research, recognition of the potential benefits to the transportation system that might result from widespread adoption and use of IVRGIS has led researchers to focus

on estimating the scale of these benefits and devising ever more complex models to describe the possible transport scenarios that might develop. Whilst some transportation researchers have considered possible negative aspects of IVRGIS (e.g. Arnott *et al.*, 1991; Ben Akiva *et al.*, 1991; de Palma, 1992; Emmerink, 1996) the focus of this research has been at the network level[1], rather than the possible impact on individual drivers. There has been little discussion of the impact of IVRGIS on the cognitive processes that underpin spatial behaviours such as navigation and wayfinding, and the consequent impact that this will have on driver behaviour. To date behavioural analysis in this field has been dominated by predictions that drivers will be better informed and therefore will be in a position to make informed decisions regarding route, mode and departure time. This is certainly a central aim of IVRGIS – but it is by no means certain that this will be the result of widespread uptake of such systems.

ITS development has reached the stage whereby the traditional models used to describe and predict human behaviour are no longer sufficient to cope with the complex nature of such problems. Transportation researchers have begun to recognise that in order to improve existing models it may be necessary to include within them a richer consideration of the cognitive process. Thus, whilst researchers continue to attempt to create models which accurately reflect human behaviour in the transport environment, the perennial problem of simulations which employ models of human behaviour - to what extent can they really model human behaviour? - has prompted calls for behavioural scientists to become involved:

> "A wealth of behavioural questions arise from the study of driver information systems. This calls for an in-depth study of real-life responses, possibly delving into the cognitive processes which underlie our behaviour.....Because of the difficulty in monitoring real-life behaviour and allowing for the influence of the many external factors, a current trend is for researchers to opt instead for the controlled environment of a driving simulator...While these may be of value for initial exploration, their ability to induce real-life responses remains in question - very little validation work has been carried out on them."
>
> (Watling, 1994, p.24.)

Requests for the participation of behavioural scientists are gradually being answered. To date, however, the majority of the behavioural research to date has focused on safety and design aspects of ITS. Dingus and Hulse (1993), for example, have looked at human factors issues which need to be considered to enable the driver to use IVRGIS effectively, efficiently and safely. Of course, in

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Ben Akiva *et al.*, (1991) mention three potential adverse effects of information provision: oversaturation, overreaction and concentration. These are discussed briefly in chapter 2.

developing complex in-vehicle information systems it is right that the first priority should be safety issues. But to understand the potential impact of IVRGIS it is essential that research focuses not just on short term effects that can be readily observed. As Watling (1994) asserts, the impact of these technologies upon the underlying cognitive processes that govern travel behaviour has to be considered.

It is clear that transportation researchers recognise a need for more in-depth research into the behavioural impact of IVRGIS. But what are the underlying cognitive processes that should be studied, and how does one investigate the impacts of technology on cognitive processes which, by their very nature, cannot readily be observed? This thesis takes the view that wayfinding, navigation and travel behaviour are all examples of spatial problem solving behaviours (Arthur and Passini, 1992). The cognitive process that underpins them is known as spatial cognition, which is defined as:

> "the knowledge and internal or cognitive representation of the structure, entities and relations of space; in other words, the internalized reflection and reconstruction of space and thought"
>
> Hart and Moore (1973) p.248

The process by which this knowledge is represented in the mind is known as *cognitive mapping*:

> "a process composed of a series of psychological transformations by which an individual acquires, stores, recalls and decodes information about the relative locations and attributes of the phenomena in his everyday spatial environment."
>
> Downs and Stea (1973), p.7

It has been argued (Arthur and Passini, 1992) that cognitive maps are fundamental to all spatial problem solving behaviour. Hence, it is logical to consider the impact that IVRGIS has on the cognitive mapping process. Transportation researchers have begun to recognise the significance of the cognitive mapping process to travel behaviour research, and a number of authors have suggested that the impact of IVRGIS on cognitive maps might be very positive:

> "Human knowledge of the spatial environment, the cognitive map, is based on an often limited mental representation of route locations and the physical environment. Cognitive maps influence travel behavior; for example, the propensity to divert in the face of congestion is related to the number of routes known to a person. People differ widely in their ability to understand and utilize spatial information. The potential for expanding and enriching cognitive maps through ATIS (advanced traveller information systems) may be substantial and the value of doing so needs to be explored."
>
> Schofer, Khattak and Koppelman (1993), p.108

The issues raised by this quotation are central to understanding the importance of cognitive maps to ITS. The quotation has two particular elements that will be addressed in this dissertation. These are:

i) "Cognitive maps influence travel behaviour...."

Chapter 4 will consider the cognitive mapping process, by which we acquire knowledge of our spatial surroundings, and will attempt to demonstrate the significance of this process to transportation research. Schofer *et al.*, are correct in their assertion that cognitive maps influence travel behaviour, but make the mistake of focusing on the product rather than the underlying process which shapes and creates that product. Chapter 4 focuses not on cognitive maps, but on the cognitive mapping process, for it is the effects of information on this process that needs to be better understood. Schofer *et al.*, go on to assert that

ii) the provision of additional information is capable of "expanding and enriching cognitive maps".

This is an oversimplification of the cognitive processes involved when we encounter new environments and when we are faced with additional information about those environments. In particular, it shows a lack of understanding of the relative importance of information acquired through direct contact with an environment, and how this differs from information about an environment acquired from a source other than the environment itself. Moreover, because additional information is provided, it does not necessarily follow that this information will be used by individuals. To enable transportation professionals to make more informed assessments of the potential benefits of route guidance systems, chapter 4 aims to provide a detailed description of the processes involved when individuals are faced with novel environments and wayfinding decisions.

In addition, the review of cognitive mapping research in chapter 4 will attempt to inform our understanding of the kind of information that individuals require to enable them to acquire a cognitive map of an unfamiliar area. To date the instructions issued by IVRGIS have been devised from a human factors perspective, with a consequent emphasis upon reducing the possible distraction caused by the information. Clearly, safety must be of paramount importance, but to maximise the behaviour-modifying potential of guidance information it is essential that human

factors specialists work together with those in human navigation and wayfinding to construct route guidance instructions that safely encourage spatial knowledge acquisition.

1.2.2 Limitations of existing human factors research and issues to be considered

Whilst human factors researchers have considered the problems associated with introducing complex navigation equipment into the car, much of this research to date has focused on the potential distraction of an in-vehicle computer screen. Wierwille (1993), for example, has reviewed the possible increases on a driver's workload resulting from the introduction of such complex equipment into the vehicle. It has also been suggested that some user groups (particularly older drivers) spend more time looking at navigation displays to process the same information than younger drivers (Dingus *et al.*, 1989). The possibility that this visual distraction might have an impact on driver safety has prompted systems designers to incorporate an auditory interface, providing verbal guidance instructions, in an effort to share some of the cognitive load between available resources. To date, research has failed to consider the possible distraction which might be caused by attending to *audible* route guidance instructions. Moreover, although there is now a code of practice for designers of route guidance instructions (Southall and Robertson, 1994) and guidelines for information presentation by IVRGIS (Ross *et al.*, 1995; Green et al., 1995) these fail to sufficiently address the *behavioural* impact of audible guidance instructions – their main focus is the possible distraction caused by screen-based systems, and the recommendation that audible guidance is incorporated into systems as a means of reducing this distraction. Audible guidance is seen as a solution to an existing problem rather than a solution that carries with it new problems. Research is needed that specifically focuses upon the possible distraction that might arise from use of audible guidance instructions.

1.3 Research questions addressed by this thesis

This dissertation attempts to address three specific research questions:

1. In order to improve upon existing transportation research, the dissertation considers the impact that IVRGIS supplying audible guidance instructions will have on the underlying cognitive processes that govern spatial behaviour. The research therefore asks - what impact will listening to audible instructions have on the cognitive mapping process? Because the focus is on underlying cognitive processes, the research will consider the effects of information not on existing knowledge, which would be

influenced by past experience, goals and a range of individual and environmental factors, but on the process of acquiring spatial knowledge of an unfamiliar area.

2. Are all groups equally capable of using audible route guidance information? A recent FHWA report (Wochinger *et al.*, 1995) concluded that in-vehicle route guidance has the potential to enhance the navigational performance of drivers of *all* ages and levels of spatial ability. The present research challenges this conclusion. Whilst age-related deterioration in spatial ability suggests that elderly[2] drivers may have diminished navigational ability (Kirasic, 1991, Wochinger *et al.*, 1995, see also section 3.7.3), it does not follow that elderly drivers will necessarily benefit from attending to audible guidance. The present research maintains that, just as senior drivers suffer impaired navigational ability, they are also less able to process additional information and are thus less likely to derive benefit from IVRGIS. The human factors research reviewed in chapter 3 will explore this and related issues and identify groups that will be the focus of the research.

3. In order to improve on existing human factors research the dissertation compares different levels and types of audible information and asks whether the detailed instructions currently in use in route guidance systems are the most effective. Do different types, levels and amounts of audible information have different effects on the user? Does the presence of non-salient information (i.e. information not relevant to the particular task being carried out) have a different effect on the individual than salient information? Can the effectiveness of audible guidance be improved, and does cognitive mapping research have anything to say about the content of messages that has been overlooked by human factors specialists? Chapter 3 considers the impact of information on workload and attention, while chapter 4 considers the same issue but with respect to the cognitive mapping process.

Whilst the focus will be the impact of audible instructions presented via ITS on cognitive processes, the impact of secondary information (i.e. not acquired through one's own direct experience with an environment) is an important issue above and beyond the present application.

[2] Elderly is defined as age 65 years or older. This is the most commonly used definition in the literature on the mobility and safety of elderly persons.

The fundamental importance of the cognitive mapping process to the successful evolution of the human race as a problem solving organism (discussed in chapter 4) makes it imperative that we gain a better understanding of the impact of route guidance systems on this process. Cognitive mapping research to date has not considered the impact of listening to information on ability to form a cognitive map. Moreover, modern society in the late 20th Century is characterised by the ever increasing influence of information technology on human activities and behaviour. It is timely, therefore, that researchers should consider the possible impacts of information on all aspects of our everyday experience.

1.4 Structure of the thesis

In order to answer the above research questions the thesis is comprised of a number of steps which together make up the research methodology:

i) The first step is to review existing literature in relevant fields which informs our understanding of the impact of audible guidance on underlying cognitive processes. Chapters 2,3 and 4 review the literature and research in three areas. Chapter 2 considers the history of ITS generally, focusing specifically upon in-vehicle route guidance systems. Due to the paucity of research into behavioural effects of IVRGIS relevant studies of associated technologies such as Parking Guidance Information (PGI) systems, are also considered, as these help us to understand the potential impact of higher order systems such as IVRGIS. The main purpose of this chapter is to give the reader some idea of the functions, scope and nature of the technologies being considered. Chapter 3 focuses more specifically upon ergonomic issues surrounding ITS, and reviews work on associated technologies such as in-car telephones, which also introduce an additional cognitive load to the driving environment. This chapter will highlight the lack of research into the effects of audible guidance.

Chapter 4 considers research into cognitive mapping and cognitive maps. The section begins with an explanation of the relevance of cognitive maps to transportation research, and particularly, to wayfinding and navigation. Major theoretical approaches to understanding the process by which we acquire, encode, store, recall and use mental representations of our spatial environment are reviewed, in order to improve our understanding of the effects that widespread deployment of route guidance and navigation systems might have on these processes. Finally, chapter 4 discusses

some of the factors which can affect cognitive map acquisition in order to improve understanding of the effects of presenting different types of information.

ii) Step two is the identification of gaps and weaknesses in the existing research in these areas, and the creation of hypotheses which can be tested through a series of suitable experiments.

iii) The third step is to design an experiment suitable for investigating the possible effects of audible guidance on these processes. The experiment should be performed in a safe, controlled environment, while preserving as much realism as possible. Having discussed the theory on which the research is based, chapter 5 reviews previous methods employed to study the cognitive mapping process. The chapter emphasises the many problems which surround studies of cognitive maps, and discusses methods which have been used to solve these problems. Chapter 6 presents a description of the experimental procedures used to investigate the various research questions. A series of pilot studies were organised using a variety of methods. These are also reported, and the resulting amendments made to the experimental design are discussed.

iv) The final step is to use this experiment to study the effects of different types of audible guidance instructions upon the cognitive mapping process. Two experiments were conducted: experiment I considered the impact of audible guidance on the cognitive mapping process and compared differences between groups in their ability to acquire a cognitive map of an unfamiliar area. The experimental design is based on a dual-task paradigm (see chapter 3) whereby subjects are asked to concentrate on acquiring a cognitive map whilst watching films of routes through an area (the primary task). Some groups also listen to additional information (a secondary task) to see whether their cognitive mapping ability is enhanced (as predicted by transportation researchers), impaired or unaffected by this extra requirement. Chapter 7 presents the results of experiment I and is organised around the first research question described in section 1.3. Chapter 7 also discusses the limitations of experiment I. As a consequence of these findings and in order to address problems identified in the experimental design, a second phase of experiments was conducted which focused on a subset of respondents and concentrated specifically on the route guidance instructions given to them. The main focus of chapter 8 is to determine whether guidance instructions which make specific reference to visible environmental elements might be more beneficial than the existing route guidance instructions. Finally, chapter 9 presents the conclusions of the project, discusses their significance to the future development and widespread deployment of IVRGIS and relates the findings back to the original research questions and objectives.

2 INTELLIGENT TRANSPORT SYSTEMS

2.1 Introduction

This chapter describes the development of Intelligent Transport Systems (ITS), in particular In-Vehicle Route Guidance and Information Systems (IVRGIS). The chapter is divided into three main sections. Section 2.2 presents a history of the development of ITS, from the initial research trials carried out in America in the 1960's, to present day real-world applications in Japan. The purpose of this section is to familiarise the reader with the types of system which come under the heading ITS. Section 2.3 reviews transportation research which has considered behavioural responses to ITS. This section considers research looking at lower order systems such as Parking Guidance and Information (PGI) systems and Variable Message Sign (VMS) systems, which are already in operation. Many of the issues considered by such studies are of direct relevance to IVRGIS, in that, like IVRGIS, they involve the presentation of additional information to drivers, which is expected to have an effect upon driver behaviour. Hence, this section aims to inform our understanding of the behavioural issues relevant to the introduction of IVRGIS into vehicles. The chapter concludes with a discussion of the benefits which transportation professionals have predicted will result from widespread adoption and use of IVRGIS. Section 2.4 critically evaluates these predictions and argues that they are based on limited research, and that the understanding of cognitive maps which underpins them is flawed. This section suggests that predictions of the improvements to the transport network are based upon misunderstandings about the way cognitive maps are constructed, and erroneous assumptions about the way in which information is acquired by travellers when making their way through a novel environment.

2.2 The history of Intelligent Transport Systems

2.2.1 What are Intelligent Transport Systems?

The term Intelligent Transport Systems (ITS) covers a number of technologically advanced techniques for providing drivers with motoring information via a combination of information and telecommunication technologies. A range of methods for providing information exist, including: television and radio channels dedicated to broadcasting traffic information; electronic pre-trip route planning systems; on-board navigation systems; roadside variable message signs (VMS); parking guidance and information (PGI) systems and dynamic route guidance (DRG) systems. The primary concern of this thesis is the development in route guidance and navigation

systems. However, research related to the associated technologies has contributed to an understanding of driver behaviour in response to information when using ITS and so is discussed in some detail.

The ERTICO report "Recommended Definitions of Transport Telematics Functions and Subfunctions" (Ertico, 1994) provides a comprehensive list of the various functions offered by advanced transport telematics. The full range of services offered is as follows:

- Road Management and Logistics;
- Demand management;
- Traffic management;
- Parking management;
- Public transport management;
- Traffic information;
- Travel information;
- Freight and fleet management;
- Vehicle control;
- Internal services;

However, for the purposes of the present research, the following is a simpler categorisation, covering three generic functional areas:

- Advanced Traffic Management Systems (ATMS) - e.g. automatic toll billing, automatic incident detection;

- Advanced Driver Information Systems (ADIS) - which include In-Vehicle Route Guidance and Information Systems (IVRGIS), discussed in more detail below; and

- Automatic Vehicle Control Systems (AVCS) - which include collision avoidance systems, and speed and direction maintenance systems.

(US DOT, 1989).

The technology required for ATMS is now available, and evaluation trials are already established . In Europe, for example, a consortium of partners from the UK, Greece, Finland and Sweden are

currently involved in a European Union project "Automatic Debiting and Electronic Payment for Transport" (ADEPT II). In contrast, AVCS are in the early stages of development (for examples of systems currently in development, see Williams, 1996), and to an extent their continued development is dependent upon the successful deployment and widespread acceptance of ADIS. Consequently, it could be argued that if drivers prove unwilling to rely on ADIS and associated technologies for route guidance information, they are unlikely to be willing to rely on AVCS to determine and maintain speed and direction. Hence, the successful deployment of the most basic forms of in-vehicle ITS - navigation systems - could have a crucial impact upon the long term success or failure of the technology as a whole.

2.2.2 The development of IVRGIS

French (1986) provides a comprehensive overview of the history of navigation systems for both cars and trucks, which charts the development of the system through research projects in America, Japan and Germany. The first attempt to develop a navigation system for vehicles was the U.S Department of Transportation's development of an electronic route guidance system (ERGS) which commenced in 1967. Five phases were planned but the programme was terminated in 1970 after three phases had been completed, partly due to the inability of the software technology of the time to cope with the information required to provide the service envisaged (Rosen *et al.*, 1970). However, despite its premature demise, the project highlighted a number of issues which shaped subsequent research, particularly the problems of advising drivers unfamiliar with an area of the best route to a given destination (i.e. the provision of "static" information) and the problem of advising familiar and unfamiliar drivers of the quickest (in terms of time saved) route based on the state of the network at a particular time and day (i.e. the provision of "dynamic" information) (Boyce, 1988).

The Japanese "Comprehensive Automobile Traffic Control" (CACS) project (Kawashima, 1990), which ran from 1973 to 1979, was an ambitious attempt to develop an integrated system with four main objectives:

- the reduction of traffic congestion;
- reduction of exhaust fumes;
- prevention of traffic accidents; and
- the enhancement of the public and social role of automobiles.

These objectives were to be achieved by: providing route guidance; diverting traffic away from highly polluted areas; providing traffic regulation information; giving road priority to public or emergency vehicles; and providing information promptly to drivers in the event of an emergency (Yumoto *et al.*, 1979). To evaluate the project a pilot study was carried out involving 1330 in-vehicle units in an area of Tokyo. Results of the route guidance experiment showed that out of a sample of 161 trials, the guided vehicles reached their destination earlier than non-guided vehicles in 135 cases, their journey times having been reduced by an average of 11%. As a result of the success of the CACS project, a number of other foundations have been created which run similar joint ventures between government and private industry to develop the systems to higher levels. The AMTICS (Advanced Mobile Traffic Information and Communication System) project is a prime example of the potential of such collaboration. AMTICS incorporates a compact disc (CD-ROM) system and screen-based display for static information such as road maps, traffic regulations, tourist information etc., with real time (dynamic) traffic information such as congestion and weather reports and availability of parking spaces fed to the vehicle via the "Teleterminal system", a cellular mobile communication system (Kawashima, 1990). Today, Japan is at the forefront of ITS technology, with research studies gradually giving way to practical applications in some of the major areas. One example of current developments is VICS, organised by The Metropolitan Expressway Public Corporation (MEPC). VICS is discussed in more detail in section 2.2.3 below.

In Europe, the preponderance of driver information systems being developed separately throughout the various member states of the European Community, operating in isolation and utilising different technologies, led to the formation of the DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) programme. This was an initiative of the European Commission for improving road efficiency and safety and consequently reducing pollution through ITS applications (Everts, 1993). The DRIVE I project V1024 "Driver Information Systems", which ran from January 1989 until December 1991, involved seven European institutions combining their research and development skills towards a common aim of establishing a Community wide set of standards for design, performance and process (a quality test for the system as a whole). A survey of the 77 systems in operation throughout the world (of which 23 were in-vehicle) was undertaken to integrate the best features of all into one overall system, so as to prevent the need to develop new technology. The ALI Destination Guidance System, designed by the Blaupunkt/Bosch Group had been field tested between 1979-1982 and had proved very successful, as a result of which a more advanced system (ALI-SCOUT) using infrared technology was developed. Meanwhile, the European Union initiated three research projects with the aim of

providing experience and essential data relating to the implementation of the systems. In Berlin the LISB (Leit und Information System Berlin) project has been field testing the ALI-SCOUT system on a large scale; in England AUTOGUIDE, again using the beacon approach whereby all equipped cars passing a certain point are sent the same data set of information, has been demonstrated in the London area (for details see Jeffrey, Russam and Robertson, 1987), while in France the ULLISSE project was commenced but is no longer in existence. The LISB project is an ongoing field trial of the ALI-SCOUT system which has provided a wealth of data regarding drivers' reactions to dynamic in-vehicle route guidance. Questionnaire surveys of 300 private car drivers were conducted after they had used the equipment for over a year and the results used to determine how drivers used the systems (Bonsall and Joint, 1991). The results of the LISB questionnaire survey are reviewed in detail in section 2.3.4.

The projects described above are representative of the range of developments which have taken place in the field of ITS over the last twenty years. A number of other systems have been developed, in Europe: ARIAM in Germany; ARISE in Sweden; and the DRIVE project SOCRATES, utilising two-way cellular radio technology; and the PROMETHEUS research programme, led by a group of major European automobile manufacturers); in Japan (e.g. RACS); and in America (e.g. the ETAK electronic map system, and the more advanced PATHFINDER system using a dynamic information version of ETAK). Future technologies are also the subject of ongoing research. The ADEPT II project, for example, organised under the EU DRIVE II program, aims to explore the potential deployment of transponder-based services such as toll collection, parking management, road-use pricing and road-to-vehicle information systems. As with many of the projects organised in Europe, one of the central concerns is the successful implementation of a European-wide system. Thus, ADEPT II aims to develop, test and validate a specification which will ensure the interoperability and compatibility of a common payment system and smart card.

2.2.3 Recent developments: Vehicle Information and Communication Systems (VICS)

The Japanese Metropolitan Expressway Public Corporation (MEPC) has recently developed and started operating the Vehicle Information and Communication System (VICS) Centre to supply information to car navigation systems through radio beacons installed along its highways. This system provides users with up-to-the-minute digital traffic information with the aim of redirecting the flow of traffic and contributing to safer and smoother traffic conditions. The VICS Centre processes, edits and distributes information received from the Japan Road Traffic Information Centre, the Public Safety Commission Road administrators (providing current journey time,

traffic, accident and roadworks information), and other information sources (giving parking information). The VICS Centre launched its service in the spring of 1996. The first stage of the launch was to make the service available to eight administrative jurisdictions in the Tokyo and Osaka areas, and Aichi prefecture, with plans to gradually extend the service to highways.

VICS integrates the full range of regular traffic information services: roadside traffic information boards graphically display traffic conditions; travel time information boards give travel times to destinations using differing routes; variable message signs display traffic conditions on the expressways, and the data is updated every minute. The VICS Centre and the services it aims to provide demonstrate the potential of an integrated ITS system, but as is the case elsewhere, very little research has considered the potential impact of such systems upon cognitive function, and the consequent effect upon driver behaviour.

2.3 Behavioural responses to Intelligent Transport Systems

In addition to the potential benefits to the transport system as a whole, it is important to consider how drivers will respond to being given such information. Of course, until ITS are actually in widespread operation it is difficult to predict what their effects will be, and how drivers will respond to traffic information. A combination of ethical, cost and safety considerations preclude the testing of large numbers of in-vehicle units in real-world field trials, as these would require that drivers use the systems unsupervised (i.e. under natural conditions) on standard roads, which, from an ethical standpoint, would be unacceptable until the impact of IVRGIS upon cognitive function is better understood. To date research has failed to address this issue. Consequently, it is necessary to consider research in other areas which might inform our understanding of the central issues. The aim of this part of the review is to draw out of previous research lessons which might inform our understanding of the potential impact of IVRGIS. Consequently, this section considers studies which have looked at behavioural responses to information provision from four perspectives:

- Research using lower order systems such as parking guidance systems which involve similar decision making processes;
- Research using simulations and mock ups of ITS to study drivers' responses;
- Results of questionnaire surveys focusing on drivers' route choice behaviour and how information via ITS might affect these choices;

- Questionnaire surveys conducted of participants of the LISB research programme.

2.3.1 Parking Guidance and Information studies

Parking Guidance and Information (PGI) systems deal with the management of parking facilities and the provision of information to drivers about the availability and location of parking space. This may be based on VMS systems as well as wireless communication systems. There are three categories of parking guidance. *Dynamic parking guidance* provides drivers with information on real time parking space availability. *Network parking guidance* provides wide-area guidance information related to parking facilities with available spaces. *Final destination guidance* offers guidance within a parking facility to the parking space assigned to the vehicle (Ertico, 1994).

Research undertaken to assess the effects of PGI systems is particularly useful for studying behavioural effects of ITS:

- the systems are already in general use and so provide a rich and easily available source of data from real world settings;

- the decision and choice making processes which drivers employ when provided with parking guidance information are, in the opinion of the author, likely to be similar to those employed when provided with other forms of driving-related information;

- in the opinion of this author, the relationship between PGI systems and the individual is similar to that between IVRGIS and system users. Both systems provide drivers with additional information, in the case of PGI, about the availability of parking facilities, and in the case of IVRGIS , with information about alternative routes. For either system to be successful drivers must process additional information, incorporate it into an existing knowledge base and use it to make informed decisions about future behaviour. Hence, whilst the two systems are quite different in terms of the technology they employ, in terms of the underlying psychological mechanisms which might be affected, the two systems are comparable.

Whilst PGI systems offer potential benefits both to the user and to the system as a whole, for them to be effective as a management tool, user compliance has to be encouraged. Therefore, a trade-off between user and system requirements has to be made (Allen, 1993). This is usually achieved by balancing the degree of information which is prescriptive (i.e. giving only restricted

information in order to control car park choices) and that which is descriptive (i.e. providing comprehensive information with no attempt to control drivers' choices). This distinction between types of information equates to the difference between ITS which recommend alternative routes and those which simply provide information and allow the driver to make the decision. Consequently, studies of drivers' responses to prescriptive and descriptive information can provide useful indicators as to drivers' likely responses to route guidance and information provision respectively.

Parking guidance information is usually presented to the driver via one of two methods: Variable Message Signs (VMS) displaying dynamic information regarding the availability of parking spaces either in the area or for a particular facility; and information presented via radio broadcasts. Results of studies of drivers' responses to such systems (e.g. Owens, 1980; Dudek and Huchingson, 1982; Polak, Vythoulkas, Khattak and Chartfield, 1991; Polak and Khattak, 1991; Allen, 1993,) suggest a number of points relevant to behavioural effects of route guidance and information systems:

- Drivers' willingness to use PGI is very time-dependent - being most effective at peak periods when drivers' uncertainty as to the availability of parking is at its highest level (Allen, 1993).
- Additionally, both VMS use (Allen, 1993) and use of broadcast information (Dudek and Huchingson, 1982) may vary according to a driver's level of local knowledge, those who are unfamiliar are more likely to divert in response to broadcast information than drivers who are familiar with the network.
- Whilst it is argued that positive diversion advice is more useful to drivers than factual information (Owens, 1980) this can be affected if VMS systems displaying prescriptive information assume a level of local knowledge by displaying named alternatives without offering directions.
- Compliance may also be affected by drivers' ability to comprehend the information when travelling at speed (Owens, 1980). This is influenced by the positioning of the signs, the content of the message and display characteristics.

Evaluations of broadcast based services (Dudek and Huchingson, 1982; Polak *et al.*., 1991; Polak and Khattak, 1991) offer further clues as to possible behavioural responses to IVRGIS. These studies have identified a number of behavioural factors as contributing to parking congestion:

- parking choices are made at the pre-trip stage (Polak *et al.*, 1991);

- knowledge of available city centre facilities tends to be partial and inaccurate (Polak and Khattak, 1991);

- travellers are willing to spend large amounts of time searching or queuing for the parking of their choice (Polak *et al.*, 1991). Furthermore, having established a pattern of behaviour, drivers are unwilling to change this course of action.

From the above one can conclude that drivers could potentially benefit from using the additional information provided to them by PGI, VMS and IVRGIS. However, it is also apparent that many drivers are likely to be unwilling to use additional information, particularly prescriptive advice, preferring to follow their own knowledge rather than that provided by ITS. The next section considers simulation studies which have explored these issues.

2.3.2 Behavioural data obtained from results of ITS simulations

Due to the ethical and safety considerations surrounding field trials of ITS, a number of studies have analyzed drivers' behaviour in response to route guidance using simulations of the driving experience or some aspect thereof (Adler, Recker and McNally 1992a; 1992b; 1993; Bonsall and Parry, 1991; Gotts and Bonsall, 1993; Polak and Jones, 1991, Rothengatter *et al.*, 1995). Simulator studies are used as a complement to on-road studies with the aim of replicating the experience of receiving traffic information while performing a simulation of a driving task. One of the advantages of simulations is that they enable researchers to study the effects of route guidance systems under highly controlled circumstances and in standardised settings.

In reviewing the results of simulations which have employed real participants receiving information in a simulated network, it is clear that whilst methodologies may vary, the findings do show a degree of consistency - certain factors being repeatedly identified as significant in drivers' route choice behaviour. The increase in compliance due to situational uncertainty and lack of network familiarity identified in surveys of drivers' responses to PGI systems has been supported by a number of ITS simulations: drivers show a tendency to stick to main (familiar) routes (Gotts and Bonsall, 1993); acceptance of advice varies according to drivers' network familiarity (Bonsall, 1992) and familiarity with the suggested alternative routes (Adler *et al.*, 1993); while prior knowledge and experience contribute to drivers' overall route choice (Bonsall and Parry, 1990).

Bonsall and Parry also found that drivers do not decide simply to use or not to use advice from the start of their journey, rather a driver might change his or her mind depending on prevailing traffic conditions. Bonsall (1992) supports this - users of the IGOR (Interactive Guidance On Routes) interactive route choice simulator were found to use the information provided selectively, 27% of all information was rejected and the probability of advice being rejected varied according to objective measures of its quality. This notion of selective processing of travel information is supported by a simulation study of travellers' likely use of home based pre-trip information systems (Polak and Jones, 1991), which suggests that travellers' information acquisition is guided by the use of simple heuristics to minimise the amount of information not relevant to the individual. Travellers wanted information about other available modes of transport and their current conditions rather than uni-modal information, perhaps to enable them to rationalise their decision by comparing the various options available. The presence of corroborating information was found to increase the likelihood of drivers accepting advice, while they are more willing to accept the advice if it is perceived as *credible* and *salient* to their individual situation, factors which are affected by the driver's previous experience of receiving information. En-route, this requirement for corroboration extends to following advice when it is clear that other drivers are taking the suggested route, but rejecting it when it appears to be taking the driver away from his intended destination (Bonsall and Parry, 1990). These findings offer an interesting insight into driver behaviour. The research suggests that not only do drivers favour their own experience and knowledge (which might be expected), but they may also value the behaviour of other drivers above the advice given by the route guidance system.

In critically reviewing simulator-based research, it is important to raise a central concern which has shaped the present research, and in particular the choice of methodology. When this research project was initiated, a number of the simulations discussed above were considered by the author as a means of presenting routes to be learned to respondents. Computer-based travel simulators such as the UDS (urban driving simulator) Leiser and Stern (1988), FASTCARS, (Adler *et al.*, 1993) and IGOR (Bonsall, 1992), were evaluated for their potential suitability for the project, but were rejected because they lacked the level of realism required for the present study. UDS and FASTCARS both display a simple network in plan view, which was also considered problematic. In carrying out that review (Jackson, 1994) the author came to the conclusion that the simulations then being used to evaluate the effects of guidance instructions were flawed at a basic level: they purported to simulate the experience of making route choice decisions, but in effect were lacking in external validity. As a consequence, the choices and decisions made by respondents taking part in experiments involving these simulators could be

argued to have little bearing on the decisions that these same individuals would make in a real-world situation. Lack of realism was not the only problem – to enable a number of days to be simulated, simulations of this type tend to employ accelerated time - a 20 minute experiment simulating the experience of making a commuting journey on 15 or 20 consecutive days. Such simulations are widespread in transportation research, but in the opinion of this author they are overly simplistic, and bear little relevance to the decision making processes that would be made in reality. One could argue that the experimental set-up has little similarity with the experience of travelling the same route for 20 consecutive 'real time' days. For these reasons the use of a computer simulation was rejected as a methodology, and the results of simulator studies, whilst informative and interesting, should be treated with a degree of caution.

2.3.3 Surveys of drivers' route choice behaviour.

Drivers' route choice behaviour has been the subject of surveys and questionnaires for as long as traffic congestion has been a recognised problem. Ideally, surveys measure the observed behaviour of large numbers of individuals in their real world settings. However, where this is impossible, researchers have to rely either on subjects' reports of past experiences, on stated preference studies - which place the respondent in a hypothetical situation and ask them how they would behave - or on self-reporting of behaviour via travel diaries. Retrospective questionnaires are problematic: discrepancies between true and reported behaviour may arise through respondents' memory loss, poor or erroneous recall or through discrepancies between the researcher's and respondent's interpretation of a question's meaning. Stated preference (SP) studies have the distinct advantage that they enable hypothetical situations to be researched: this is especially relevant to the study of technologies that are not yet in existence. SP studies rely on respondents' ability to imagine themselves in the hypothetical situation. However, it could be argued that it is impossible to do this with any degree of reliability, particularly when the hypothetical situation has never been experienced by the individual. Moreover, even if the individual is able to project themselves into such a situation, there is no way of knowing whether they would behave in the way stated when faced with the real world situation. As with simulations, it is easy to criticise the use of these techniques for lacking realism, but one should be aware that predicting the behavioural response of individuals to a system which has not been implemented is in itself a most difficult exercise, requiring alternative methods to be used to elicit data that might improve our understanding of the behavioural impacts of ITS.

Early studies of driver behaviour (e.g. Wachs, 1967; Ueberschaer, 1971) identified a range of factors as being influential in route choice, (e.g. road type, avoidance of traffic signals and stops,

time minimisation). Additionally, studies of route diversion behaviour identified a range of factors which affect drivers' willingness to divert from their customary route such as: longer expected delays or congestion on usual route (Heathington, Worrall and Hoff, 1971); familiarity with the alternative (Huchingson *et al.*, 1977) and longer travel times on the preferred route (Mannering, 1989). Additionally, drivers who have more flexibility of arrival time (Mahmassani *et al.*, 1990), or who are younger, male and unmarried are all more likely to divert (Allen *et al.*, 1991; Mannering, 1989; Mahmassani *et al.*, 1990). However, a comparison of drivers' route choice criteria carried out in four European cities (Bonsall and Parry, 1990) suggests that drivers place most emphasis upon congestion avoidance and certainty of arrival time.

Survey findings suggest that drivers' knowledge of alternative routes is fairly limited (Benshoof, 1970; Wright and Orrom, 1976) while recent studies (Horowitz, 1984; Huff and Hanson, 1990) argue that this is due to the *habitual* nature of drivers' behaviour, characterised as being borne out of past travel experience, resulting in the choice of a route which satisfices (Simon, 1955) rather than optimises certain route choice criteria. Surveys suggest that drivers are fairly confident about their ability to navigate without the assistance of guidance and information systems (King, 1986). Research (e.g. Bonsall and Parry, 1990) suggests that drivers view route guidance systems with suspicion, showing a preference for descriptive information rather than guidance, and are unwilling to surrender the perceived control which makes driving such an attractive mode of transport. If drivers are to use ITS then the credibility of the information provided is crucial (Shirazi, Anderson and Stesney, 1988). Indeed attitudinal surveys carried out in Europe (Bonsall and Parry, 1990) suggest that many drivers would be reluctant to accept guidance from a computer on their familiar and habitual route, feeling that they would know of "rat runs" and back routes unfamiliar to the system. The credibility factor is one which may necessitate a trade off between the various aims of the transport planner and those of the intended ITS user. Unless the system is equipped to provide information about side roads and minor routes then the familiar driver's route knowledge will exceed that of the computer, but should the system provide such information when one of its aims may well be to encourage safe driving and to divert traffic away from environmentally sensitive areas?

Aside from the methodological problems of these studies, there is another criticism which could be levelled at many surveys and stated preference research into driver behaviour. The studies detailed above have tended to focus on elements within the environment which affect driver behaviour, with little consideration of aspects within the individual which might explain their actions. In particular, there is little consideration of differences between: drivers with varying

levels of driving experience; of different age groups; or between drivers with different trip purposes.

Travel diaries detailing a respondent's real life travel behaviour over a set period of time have the advantage of being based on current or recent events and so reduce the possibility of recall error. They provide rich data on real world behaviour, and if completed in sufficient detail, can offer an insight into the travel behaviour of an individual for a prolonged period rather than the "snapshot" that a one-off questionnaire provides. However, travel diaries are time consuming, expensive to administer, and rely on the respondent's honesty and ability to recall all the journeys made throughout the period. Moreover, their ability to provide data on past experience is of little use in analyzing driver guidance and information systems which are as yet largely untested. However, the travel diary approach has been used to explore drivers' responses to radio traffic broadcast information (Khattak, Schofer and Koppelman, 1993) and recent work has used diary data to evaluate the direct impact of traffic information by modelling commuter patterns and then incorporating drivers' attitudes and perceptions obtained from survey data (Polydoropoulou, Ben-Akiva and Kaysi, 1994). This approach has enabled the identification of factors which affect the acquisition of traffic information via radio broadcasts. As with previous research (e.g. Polak and Jones, 1991) the perceived credibility and relevance of the information were found to be of particular importance, as were the driver's own observations of traffic conditions. Indeed, en-route diverting was found to be influenced by a combination of attitudinal factors and the information acquired, a finding which has important implications for the design and implementation of route guidance systems.

Within the field of ITS research questionnaire surveys are increasingly being used in conjunction with stated preference studies so that reported and stated behaviour can be compared. A section requesting demographic details also allows an analysis of various groups' (e.g. age, gender, socio-economic status) reaction to the system. A recent example is Khattak, Kanafani and Le Colletter's (1994) survey of travel behaviour in the Bay Area of San Francisco. This study used a questionnaire combining questions on present commuter patterns with stated preference questions exploring how traffic information might affect their decision to divert to a suitable alternative route. The stated preference questions enabled Khattak *et al.*, to study drivers' stated reactions to various levels of information, and thus allowed them to test previous research which has suggested that drivers prefer descriptive to prescriptive information. It was found that, when faced with unexpected congestion, the more complete the information provided the higher the proportion of commuters who would divert. Most respondents favoured a system which provided them with real

time quantitative information regarding their own route in addition to information about travel times on the best alternative.

2.3.4 Surveys conducted of LISB users

Whilst stated preference studies and questionnaires which attempt to predict drivers' responses to ITS may be very useful, they are a poor substitute for surveys of drivers who have actually used the systems over the course of a field trial. Such data is now available as a result of the LISB field trial in Berlin (Bonsall 1991a; 1991b; Bonsall *et al.*, 1991). A questionnaire was distributed before the trial, again after 5 months of static guidance information and again after a further 6 months during which time the system provided dynamic route guidance. This methodology enabled a comparison of drivers' responses to the system before, during and after exposure to using an IVRGIS in a real world setting.

Prior to using LISB respondents had rather high expectations of its capabilities, particularly with regard to the amount of time that it would save, drivers predicted savings of between 20% and 30% of their journey time. They also expected the system to be capable of always finding the route with the quickest journey time, despite having previously been satisfied with finding a straightforward route. Having used the system for about 5 months, during which time it gave static guidance advice, about 20% of the participants changed their normal route to or from work to that suggested by LISB. However, a similar number said that they would not change routes even if LISB had advised them to. For regular journeys about 40% said they could find a better route than that suggested, but about half the sample also said that the system had taught them new routes. Drivers' faith in their own judgement and inherent suspicion of the system was manifested in their tendency to deviate from the advised route when it appeared to have ignored shortcuts, about two thirds of the sample deviated from advised routes for this reason.

Survey results for the period of dynamic guidance showed that LISB usage declined somewhat and drivers were far more likely to use the system for unfamiliar routes. Indeed, an analysis of respondents' ratings of the system showed that it was not seen as particularly useful for frequently used routes, but was rated well on most counts for unfamiliar journeys. These findings were reinforced in the survey conducted at the end of the trial. By this time, although most users still felt they could save time with LISB use in unfamiliar areas, only a minority continued to use it on their journey to work.

"Drivers seemed quite happy to rely on its advice when their own knowledge was

> deficient but when they were in a familiar area they found its advice often lacked credibility. If its advice conflicted with their own perception of the correct route in the prevailing circumstances they would have little hesitation in deviating from the advised route."
>
> Bonsall, (1991a), p.5

This concludes the review of research on drivers' behavioural responses to ITS. While a wide range of methodologies have been employed, all of which have benefits and drawbacks, there is a consistency about some of the findings which suggests that tentative predictions can be made as to drivers' responses to the provision of traffic information and route guidance. These are summarised below:

- Driver behaviour can be characterised as habitual. Drivers follow particular routes with which they are familiar and from which they are unwilling to deviate even when they are aware of alternatives;

- On these familiar routes drivers are unwilling to use advice, but may accept real-time information from which they can make their own judgements;

- Habitual behaviour, formed from previous, limited experience of the available routes, shapes a driver's perception of alternative routes and information offered about both the habitual and other routes;

- In situations of increased uncertainty, for example, lack of familiarity with the network, unexpected heavy congestion, or in particularly complex networks, drivers perceived control of their situation decreases, and they are therefore more willing to use guidance and information, and are more likely to comply with the advice supplied;

- Drivers tend to be very confident of their own abilities with regard to route navigation, particularly when on familiar routes. This self belief explains drivers' suspicion of IVRGIS systems, there is a definite 'driver knows best' element involved;

- This belief in drivers' abilities extends beyond the individual's self image, to the extent that drivers are more likely to accept advice if the route recommended appears to be popular with other drivers, and are likely to reject a suggested route when few drivers are using it;

- Drivers' past experience of the reliability of guidance is likely to affect their acceptance of current advice. If they have previously received advice which proved accurate and reliable they tend to be more trusting of the occasional piece of bad advice. Recent experience has more influence than past experiences.

2.3.5 Predicted benefits of IVRGIS

As a result of his research into the behavioural effects of IVRGIS Bonsall (1992) summarises the claimed benefits of providing information to drivers:

- "Firstly and most fundamentally, by improving people's knowledge of the network and by assisting them to find efficient routes, some of the resources currently wasted in unnecessary time and mileage can be recovered.

- Secondly, it is thought that by reducing unnecessary mileage, traffic volumes, and hence congestion, can be reduced.

- Thirdly, it is thought that by linking IVRGIS with traffic control... and perhaps road pricing systems... all three systems could become more effective.

- Fourthly, it is suggested that, by manipulating the information or guidance provided to drivers it might be possible to discourage them from using routes which are environmentally sensitive and that it might be possible to bring about routing patterns that are more globally efficient (the so called 'system optimum')."

Bonsall (1992), p.2

The present research challenges these predictions. This chapter has reviewed a range of research which has considered driver behaviour in response to information. One of the clearest messages to come out of this research is that drivers are unwilling to accept advice on routes familiar to them. On these routes they prefer to rely upon their own past experience, and even on other drivers' actions. This issue has important implications for the benefits that are predicted to arise from IVRGIS. These benefits rest on the assumption that drivers will choose to adhere to the advice offered by the IVRGIS, when in fact the findings of a wide range of studies: research into the effects of PGI systems (Allen, 1993); broadcast-based services (Dudek and Huchingson, 1982); simulator studies (Bonsall, 1992; Bonsall and Parry, 1990); and the LISB study (Bonsall, 1991a)

have all come to a similar conclusion – in familiar environments, drivers will be less willing to follow the advice and may instead choose to rely on their own past experience. Moreover, when faced with information that contradicts their own experience, they will ignore it. For IVRGIS to be successful (in terms of diverting drivers from habitual routes, and thus spreading traffic equally across the available routes within the network) the information they supply and the advice offered regarding alternative routes must be adhered to by a majority of drivers. Yet the aforementioned research suggests that this is unlikely to be the case. Certainly drivers will be willing to adhere to advice offered in unfamiliar networks, but the congestion problem stems from drivers' habitual use of familiar routes for journeys they make regularly.

At the heart of these predicted benefits lies the assertion (point one in the Bonsall quote above) that people's knowledge of networks will be improved by using IVRGIS. Certainly, the presence of an IVRGIS offers the individual the potential to be better informed about the possible routes available, in much the same way as owning a London "A to Z" offers the individual the potential to be better informed about the routes in London. However, there is no guarantee that owning an IVRGIS will lead to more informed drivers: indeed, it could be argued that reliance upon IVRGIS will remove the need to learn the network at all. This might at first appear to be a trivial issue, but as chapter 4 will aim to show, simply replacing the natural process of spatial knowledge acquisition with a machine issuing directions will remove the essential element of experience that shapes our route choice and wayfinding behaviour. This thesis argues that predictions of the potential benefits of IVRGIS are based on an oversimplified view of the underlying cognitive processes responsible for spatial behaviour.

2.3.6 Possible adverse effects of IVRGIS

It should also be noted that some transportation researchers have recognised the potential for adverse effects to arise from driver information systems (e.g. Arnott *et al.*, 1991; Ben-Akiva *et al.*, 1991; de Palma, 1992; Emmerink, 1996). The issues raised by these authors are quite distinct from the cognitive issues considered in this thesis, however, they do raise some interesting points regarding driver behaviour. Ben-Akiva *et al.*, (1991) discuss three potential adverse effects of information provision:

- Oversaturation
- Overreaction
- Concentration

Oversaturation refers to the possibility that the driver may become overloaded by the

information being provided to him causing distraction, impaired driver safety and preventing the driver from selecting an optimal route. Overreaction relates to a situation when a significant proportion of drivers respond to the same information by deviating to the suggested route, causing congestion to transfer from one road to another. Ben-Akiva et al., (1991) point out that overreaction arises if drivers fail to take into account the response of the other road users to the information provided. It need not arise if a significant proportion of informed drivers correctly anticipate a rush of other drivers to the suggested route and consequently choose to remain on their present route. Similarly, if the information provider anticipates the likely reaction of drivers and incorporates this into the advice given, then overreaction need not necessarily arise. Finally, concentration refers to a situation whereby differences between drivers are reduced through information:

> "Information tends to reduce the variations among drivers because it increases uniformity of perceptions of network conditions around the true values. As a result a greater number of drivers may select the best alternatives (from their individual point of view) and consequently drivers with similar preferences will tend to concentrate on the same routes during the same departure times."
>
> Ben-Akiva *et al.*, (1991) p.254

These three adverse effects relate to the behaviour of individual drivers, but the focus of the research is their impact upon the network as a whole. Oversaturation is a human factors issue, although Ben-Akiva *et al.*, (1991) are primarily concerned with its effect on route selection, rather than distraction and safety issues. These issues are discussed in chapter 3. Overreaction and concentration are network issues, and are not discussed here. Overall, transportation research has tended to concentrate upon the possible benefits rather than the potential adverse effects of providing motorists with information. This review has highlighted a need for a more detailed consideration of the impact of the information supplied by IVRGIS at the individual level, with particular attention to effects upon different groups of driver.

2.4 Conclusions

This chapter has considered transportation research into the possible impact of IVRGIS. From this review it is clear that the majority of this research has attempted to understand the impact of IVRGIS on drivers' route choice behaviour. This is understandable when one considers the transportation problems which persist in modern societies, and the fact that ITS are seen to offer a potential solution to these problems. Transportation research has concentrated on understanding how ITS might be used to change drivers' habitual route choice behaviour, how additional

information might improve route choice decisions, and how, ultimately, ITS might improve the state of the transport system. It is also apparent, however, that there has been little consideration of the impact of IVRGIS on cognitive aspects of spatial behaviour: in particular, how IVRGIS might affect underlying cognitive processes, such as how we learn new routes, how we store, recall and use route knowledge, and how new information is incorporated into existing mental representations of our spatial environment. These are important issues which need to be addressed, for they are fundamental to understanding the full impact of ITS, and IVRGIS in particular. The next two chapters will attempt to rectify this situation.

Many transportation researchers clearly consider ITS to offer enormous potential, but these predicted benefits are based upon limited research which has not addressed the full range of driver behaviour. Bonsall, like Schofer *et al.*, (1993) (see p.18) considers the provision of better information to be fundamental to solving transport problems - by improving their knowledge of available routes drivers will be in a position to make informed route choices. Like Schofer *et al.*, Bonsall (1992) suggests that inefficient route choice is largely the result of a lack of knowledge, and therefore, more information is a good thing. However, section 2.3.3 in this chapter, which summarised previous research looking at driver behaviour, suggests that, whilst driver's route choice behaviour may not be optimal, it serves a particular purpose, is habitual and thus resistant to change. From this research it is by no means certain that all drivers will be willing or able to use additional information in preference to their own knowledge. In order to test whether listening to route guidance information leads to increased knowledge about an unfamiliar area the research will test the following hypothesis, suggested by transportation researchers such as Schofer *et al.*,:

Hypothesis 1

H_1: The spatial knowledge acquired by subjects who hear audible route guidance information will be superior[1] to that of subjects who do not hear route guidance information.

H_0: There will be no significant differences in the spatial knowledge acquired by subjects regardless of information condition.

The following chapter concentrates upon human factors issues relevant to the introduction of new technologies to the vehicle. The first part of the chapter, which reviews existing research, emphasises the lack of research which has considered the impact of audible guidance instructions.

[1] Chapter 4 will explain the issue of comparing different individuals' spatial knowledge in more detail. Objective measures of "superiority" will need to be established before experiments are run.

As a means of addressing this deficiency, the chapter then goes on to consider research in associated areas that inform our understanding of the effect that such systems might have on attention and workload, and the impact of IVRGIS upon different user groups. This is achieved by first focusing upon the issues of workload and attention, which human factors specialists use to assess the impact of tasks and new technologies upon cognitive processes and function. The discussion then focuses upon past research into other technologies which have been introduced into the vehicle, specifically, the use of in-car telephones.

Following on from this, chapter 4 concentrates upon the cognitive mapping process, and will attempt to show that transportation researchers have oversimplified what is a complex process: one characterised by distortions, inefficiencies, and above all, a process shaped by the individual's purposes with respect to the environment in question. Chapters 5 and 6 will then establish suitable methods that will enable the testing of the above hypothesis and others formulated in the next chapters.

3 HUMAN FACTORS ISSUES RELEVANT TO IVRGIS

3.1 Introduction

The previous chapter considered IVRGIS research and noted that, although a considerable body of work exists which has looked at behavioural aspects of these systems, much of this work has concentrated on characteristics of the information supplied, drivers' perceptions of this information and its effect on route choice behaviour. There is a lack of research concentrating upon the cognitive aspects of IVRGIS – how using route guidance information will affect cognitive processes such as learning, memory and the development and performance of cognitive skills. Two issues are of central importance in this regard: first, the extent to which the introduction of IVRGIS into vehicles might impact on the drivers' safe performance of the driving task and second, whether all groups will be equally able to process additional information whilst maintaining safe control of the vehicle. Furthermore, the majority of the research considered in this chapter has concentrated upon the effects of screen-based information, to date there has been little consideration of the possible impact of *audible* guidance. Consequently, this chapter has three primary aims:

1. To improve our understanding of the possible impact of IVRGIS upon cognitive workload;
2. To improve our understanding of the *differential* effects of IVRGIS on various groups within the population:
3. To improve our understanding of the potential distraction caused by *audible* guidance (as opposed to visual guidance).

In order to address these aims the chapter is structured as follows. Section 3.2 first explains the importance of cognitive workload, then describes models proposed to explain the relationship between workload, resources and attention (section 3.2.1). These models are then used to make predictions of the effect that using IVRGIS might have upon performance of a primary task such as driving (section 3.2.2).

Section 3.3 focuses upon the second of the above aims. First, Anderson's (1982) model of the development of skill is discussed. This model is important because it provides an account of how cognitive skills develop with increased experience and highlights differences between skilled and unskilled operators (e.g. learner drivers and experienced drivers) that might affect ability to effectively use the information provided by IVRGIS. This section also describes evaluations of existing IVRGIS (section 3.3.1).

This section would have been equally at home in chapter 2, but it was decided that it should be included in the present chapter, as the research concentrated on differences between groups in their ability to use IVRGIS. As such the findings are directly relevant to the group differences research question. Section 3.4 addresses the third of the aims. Although there has been little research exploring the impact of audible guidance upon the driving task there is a considerable body of research which has considered a closely related issue: the effects of using in-car telephones upon driver safety. This is an area which has received considerable attention in the last decade, with the development of mobile telephone technology. The issues considered by researchers in this field are directly relevant to the present research as, like IVRGIS, the use of an in-car telephone involves the utilisation of a cognitive resource (auditory) which is not used to any great degree in the driving task.

Finally, section 3.5 summarises the various findings, considers existing design guidelines in light of the research reviewed (section 3.5.1) and provides conclusions that can be drawn from the research.

3.2 Workload, resources and attention

It has been estimated that as many as 95% of traffic accidents involve a degree of human error with distraction and lack of attention being identified as major contributory factors in nearly half of these cases (Rumar, 1988). The visual sense is clearly of central importance to driving (Wierda and Aasman, 1992). Indeed, research suggests that 30% of all accidents are due to visual perception errors (Staughton and Storie, 1977). Furthermore, Wierda and Aasman (1992) have argued that the visual skills that enable drivers to anticipate situations and take the necessary action are not present in learner drivers, but develop with increased experience. Hence, the primary concern for designers of any in-vehicle system must be to minimise the interference between use of the system and the primary task of safe driving (Burnett and Joyner, 1995). In this regard the concepts of mental workload, resources and attention are of central importance.

The concept of mental workload encompasses a wide variety of aspects of work: task performance; discrepancies between actual and expected performance; the cost to the individual of carrying out a specific task; as well as the concept of task difficulty (Gopher and Donchin, 1986). Measuring the difficulty experienced in undertaking a task is a complex operation. Subjects asked to rate their own performance might vary in this assessment from situation to situation. Nor are individuals constant in their performance of a task. Repeating a task under different conditions

creates problems of learning: the subject might learn to do the task more efficiently (Gopher and Braune, 1984); attempt a different strategy, or change their performance criteria (Wickens, 1984). Nor are all operators uniform - some will have more ability or available resources than others (Wickens, 1991). For these reasons the direct measurement of workload is most problematic. As with other areas of cognitive psychology which attempt to study cognitive processes which are not directly observable, the conventional solution is to study the effects upon performance of some observable task which is known to involve facets of the cognitive ability under test.

The possible distraction and increase upon drivers' workload caused by IVRGIS has been the main focus of human factors research. Dingus and Hulse (1993) emphasise the need to minimise visual attention demand and, in keeping with research carried out by Wetherell (1981) and Verwey (1993), suggest that one way to achieve this is to allocate certain tasks to the auditory modality:

> "A major advantage of auditory information presentation in the driving environment is efficient allocation of information processing resources. Allocating supplemental tasks to the auditory modality (particularly in situations of high visual attentional demand) has the potential for making the composite task of driving easier and safer."
>
> Dingus and Hulse (1993), p.123

To understand the theory behind these conclusions it is necessary to consider the various models that have been proposed to explain the demands of simultaneously carrying out two tasks (dual-task performance). Dingus and Hulse's assertion regarding the potential advantages of auditory information is based on a multiple resource model (Wickens, 1980), but there are other models which should be considered. The next section discusses the two main approaches which have shaped human factors research into these issues.

3.2.1 Models proposed to explain the relationship between Attention, Resources and Mental Workload

In performing any task we carry out a range of different mental operations - perceiving, responding, rehearsing etc. (Wickens, 1992). Performance of each of these operations places demands upon the operator's limited processing resources. When we are called upon to concurrently perform more than one task these tasks will compete for a share of available resources. A number of models have been proposed to explain the relationship between attention, resources and mental workload. Primary among these are *central capacity interference (or single resource) models* (Moray, 1967; Kahneman, 1973; Norman and Bobrow, 1975; Navon and

Gopher, 1979) and *multiple resource models* (Baddeley and Hitch, 1974; Allport, 1980; Wickens, 1980). The two types of model predict quite different outcomes arising from IVRGIS use and are considered separately below.

a) Central Capacity Interference (Single Resource) Models

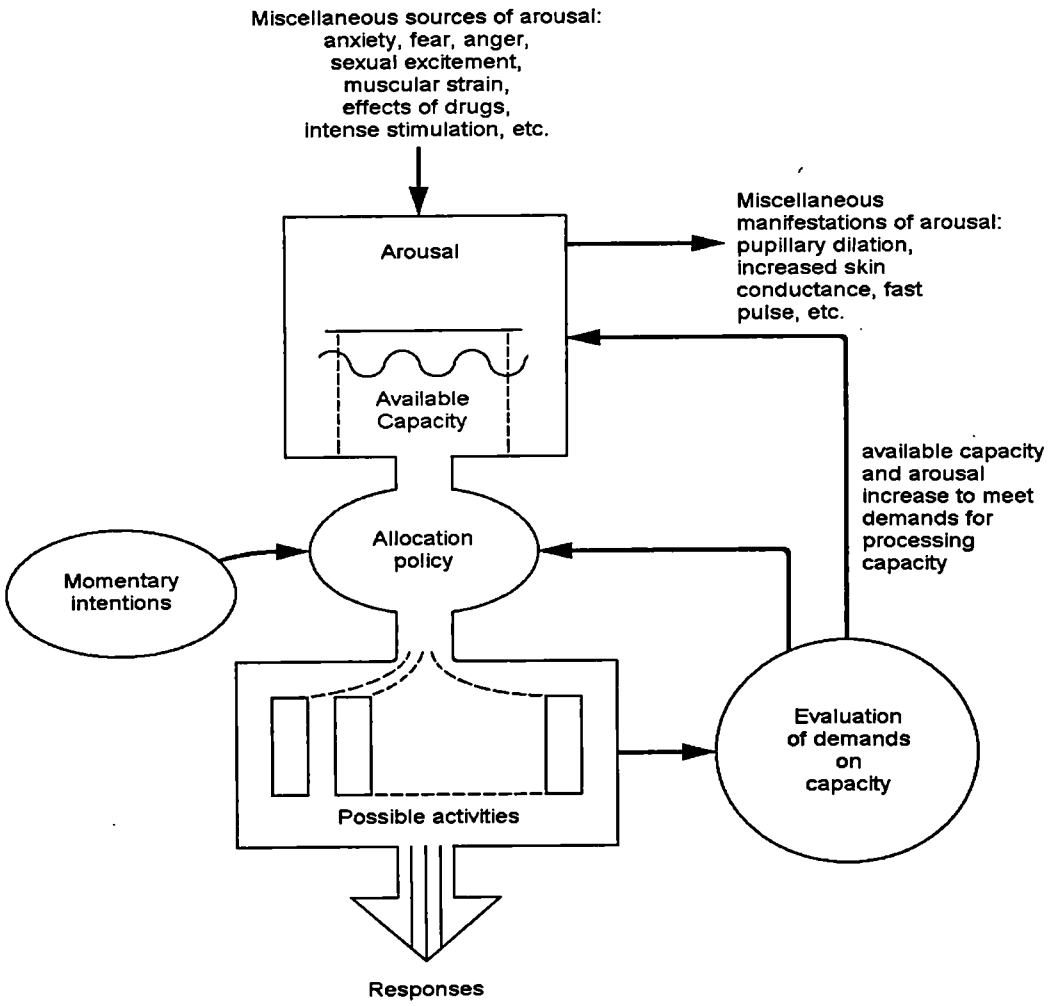
Moray (1967) was the first to consider the quantitative properties of attention, proposing that attention be considered a flexible, sharable, processing resource of limited availability (Moray, 1967). An important element of this approach is the idea that, as task difficulty increases, so more demands are made for available resources. Out of this seminal work arose a number of models (e.g. Kahneman, 1973; Norman and Bobrow, 1975). Kahneman (1973) proposed a single, undifferentiated pool of resources available to all tasks. As task demands increase (either due to increasing the difficulty of the task, or to increasing the number of tasks to be completed) physiological arousal mechanisms produce an increase in the supply of resources. However, this increase cannot fully compensate for the increased resource demands, due to the finite nature of resource availability, with the result that task performance is impaired. Figure 3.1 shows the relationship between capacity demands, arousal and performance predicted by central resource models.

A major problem with central resource models is their inability to account for the results of dual-task interference studies (Wickens, 1980, 1984). In these studies subjects are given two tasks to perform simultaneously. Central resource theories predict that as the difficulty of one task increases it demands more resources (assuming it is performed at the same level of performance) producing a consequent decline in performance of the second task. However, Wickens has found examples in which increases in the difficulty of one task, which should consequently consume more resources, fail to degrade the performance of the second task (see for example, Wickens, 1976; Wickens, Sandry and Vidulich, 1983). Wickens terms this concept *difficulty insensitivity.*

Another set of results which central resource theories fail to predict are those in which two tasks that both demand attention can be performed with no disruption of either task by the other. For example, Allport, Antonis and Reynolds (1972) showed that skilled pianists can sight-read music and engage in verbal shadowing with no effect upon either task. In such situations the tasks are considered to be *perfectly time-shared.* One could argue that a particularly skilled operator has learned one or other task so well that it has become automatic, leaving spare mental capacity for the performance of the second task (see section 3.3.1 for a more complete description of this issue). However, this explanation would not account for other findings where the task

difficulty is maintained, but the input mechanism is altered. For example, Wickens *et al.*,(1983) asked subjects to perform a tracking task concurrently with a reaction time task. They found that interference was reduced when the input of the reaction time task was changed from visual to auditory and when the response was changed from manual to vocal. Clearly if there was a single pool of available resources then changes made to the input or response modality would not have any effect upon task interference. In the years since Moray (1967) first proposed the concept of an undifferentiated central resource, research findings such as those described above have caused researchers to seriously reconsider the concept. As a result of these findings a number of researchers (Allport, 1980; Schneider and Shiffrin, 1977; Wickens, 1980) have proposed *multiple resource approaches* to human attention.

Figure 3.1 **Relationship between capacity demands, arousal and performance as predicted by central resource interference models. (Source: Kahneman, 1973)**



b) Multiple resource models

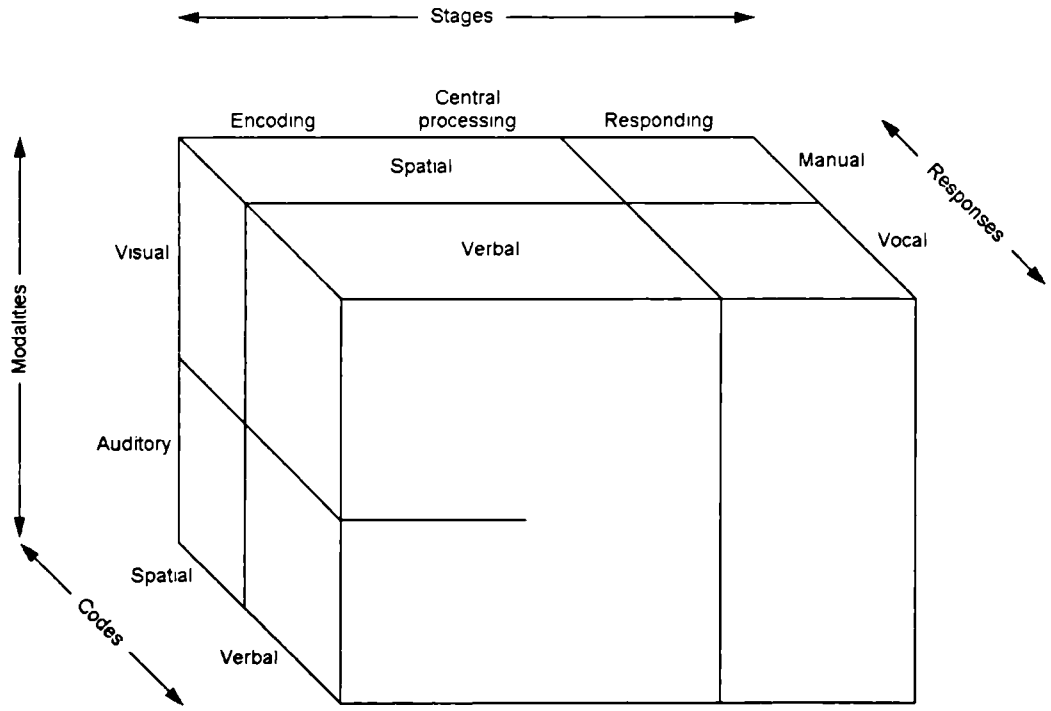
Disenchantment with the notion of a central capacity has prompted some researchers to argue that no such system exists. Allport (1980) proposed that there are several different specific resources or processing mechanisms. Such a conception explains why the degree of similarity between tasks is important – similar tasks will naturally place demands upon the same resources, thus producing mutual interference, whereas dissimilar tasks involve different resources and so may not interfere with each other at all (Eysenck, 1984). However, a system in which resources are operating independent of one another is likely to result in chaos. Multiple resource approaches overcome this problem by proposing some form of central executive co-ordinating the various processing systems. Baddeley and Hitch (1974), for example, proposed two specific processing systems (the articulatory loop and the visuospatial sketch pad) which operate in conjunction with a modality-free central processor. More recently, Wickens (1980, 1984), proposed that instead of a single supply of undifferentiated resources, there are multiple channels available to the individual, which are independent of each other. Wickens (1984) concluded that interference during simultaneous performance of two tasks will be dictated by the similarity of the tasks: the extent to which the tasks have the same stimulus modality (e.g. auditory or visual), make use of the same stages of processing (input, internal processing and output) and rely on related memory codes (e.g. verbal or visual). Wickens' model has received considerable attention in human factors research and is frequently used to justify the use of audible guidance in IVRGIS and is consequently the focus of this section. Figure 3.2 below shows the relationships that Wickens proposes exist between the perceptual modalities (auditory and visual), stages of processing (early and late) and the processing codes (spatial and verbal) involved in attention. Multiple Resource Theory is widely accepted within human factors research, particularly in the USA. Yet although the theory is persuasive it is perhaps accorded more weight than is healthy within a discipline concerned with human safety.

Multiple Resource Theory has been applied extensively in the design of aircraft control panels, where the pilot is required to attend to and process multiple sources of information (e.g. Wickens, Sandry and Vidulich, 1983). Similarly, in the design of IVRGIS, researchers' adherence to Multiple Resource Theory has led to the development of systems which make use of the auditory sense, as this is not utilised to any great extent in the driving task. Parkes and Coleman (1990) found that route guidance presented auditorily interfered less with performance of a simulator-based driving task than visually presented information. However, it should be noted that many of the findings cited in support of Multiple Resource Theory (e.g. dual-task studies) have involved highly accomplished or practised subjects, such as the pianists studied by Allport *et al.*, (1972).

Similarly, Parkes and Coleman (1990) used drivers who were entirely familiar with the driving task. It could be argued that these individuals are so skilled at the primary task that it has become automated and requires minimal effort. Hence, the primary task places few demands upon available resources, freeing them up to perform the secondary task. It may also be the case that differences between individuals in time-sharing efficiency are due to differences in the extent to which they have automated the primary task. Damos (1978) for example, noted that flight instructors have greater reserve capacity than novices, as measured by simultaneous performance of a secondary task. Experienced flight instructors had automated the flight task to the extent that they could easily perform the secondary task with no interference to either.

A further issue to be considered here is the complexity or difficulty of each of the tasks. This is an issue of direct relevance to the possible impact of audible guidance. Research (e.g. Sullivan, 1976) suggests that increasing the salience of the secondary task may affect performance of a primary task. Sullivan (1976) gave subjects two tasks: shadowing (i.e. repeating) an auditory message, and detecting target words in a non-shadowed message. When the difficulty of the shadowing task was increased by making the non-shadowed message less redundant (i.e. more relevant) fewer targets were detected on the non-shadowed message. It has also been shown (e.g.

Figure 3.2 Structure of processing resources as proposed by Wickens (1984).



Duncan, 1979) that two tasks performed concurrently demand resources over and above the demands of each individual task. For example, simultaneous task performance may require resources to enable co-ordination and avoidance of interference.

3.2.2 Predictions of the impact of IVRGIS made by each model

It is useful to consider and compare the predictions that each class of model make about the impact of IVRGIS upon driver workload. If we adopt a single undifferentiated resource perspective then the first prediction that can be made is that the resources required to attend to the IVRGIS will be taken from the same single pool of resources used to perform the driving task. From this perspective, as the difficulty of one task increases more resources will be supplied to enable performance of this task. This approach predicts that, because there is a finite source of resources available to perform tasks concurrently, as task difficulty increases this available source will become overstretched with the result that task performance will be impaired. Clearly, driving is the primary task in this case, therefore in difficult driving conditions the driver will divert attention away from the IVRGIS to enable safe performance of the driving task, with a consequent reduction in attendance to the information supplied by the IVRGIS. Moreover, from this perspective it does not matter whether the IVRGIS supplies visual or audible information: the effect will be the same – attending to the information will require a share of available resources and this will leave less resources available to perform the primary task.

Multiple Resource Theory predicts that, in situations where two tasks involve separate resources on any of the three dimensions, three phenomena will occur:

1. Time sharing will be more efficient;
2. Changes in the difficulty of one task will have little impact upon performance of the other;
3. It will not be possible to divert resources from one task to the advantage of the other, because each utilises different resources.

(Wickens, 1984)

So, from a multiple resource perspective it is clear that the use of audible instructions in IVRGIS is preferable, the tasks will draw upon separate pools of resources and so there will be no interference between the two tasks. Moreover, as task difficulty increases there will still be no interference. In response to research which highlighted the potential distraction that might arise from using screen-based instructions (Verwey, 1989; Wierwille, 1993), IVRGIS development has adopted a multiple resource approach, with the consequent development of the audible interface.

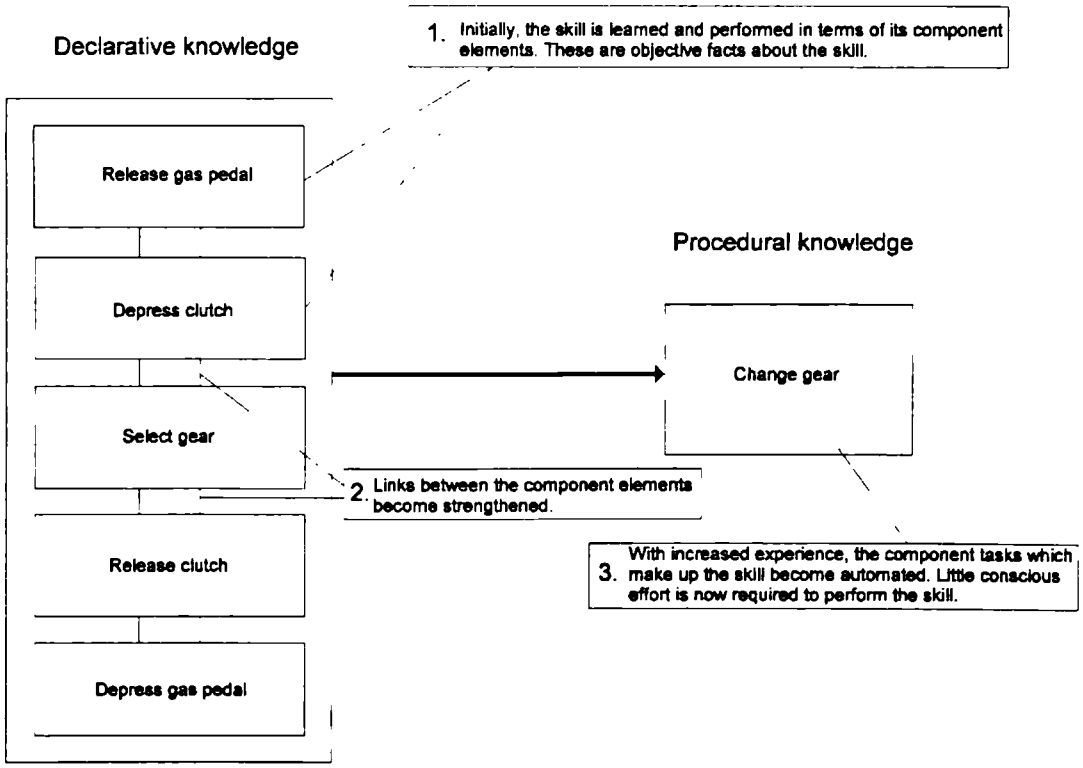
However, results used to support the notion of cross-modal time sharing have usually involved skilled operators (e.g. Allport *et al.*, 1972; Parkes and Coleman, 1990). Little research has involved newly qualified or inexperienced subjects. This is a major weakness of IVRGIS research to date, and is an issue that the present research will attempt to resolve. Consequently, the research will consider the impact of attending to audible guidance upon drivers of differing levels of driving experience. To this end, the next section starts with a description of the development of skills such as driving, as proposed by Anderson (1982). This model is important to the present research because it emphasises that newly qualified drivers do not have the skills that develop through extensive driving experience. To really understand the impact of IVRGIS we must explore their potential impact upon all levels of driver: an issue which has been largely ignored by human factors research to date.

3.3 Group differences in ability to use IVRGIS

J. R. Anderson provides an excellent model to help us understand the development of skills such as driving. Anderson (1982) distinguishes between 2 major stages in development: a declarative stage, involving the interpretation of facts about the skill; and a procedural stage, in which the aforementioned knowledge is combined into a set of procedures which enable the performance of the skill (see figure 3.3). The ability to drive, for example, is initially in the form of declarative knowledge: a list of component steps which, when combined and carried out in sequence, enable us to perform the specific driving task. Learners and newly qualified drivers have to recall the individual steps which make up the various component tasks of driving (e.g. changing gear, changing lane etc.). With more experience this declarative knowledge becomes increasingly proceduralised or automated: we are able to carry out the majority of the driving task with minimal conscious effort. This process involves the gradual forging of links between the various sub-component tasks that make up each aspect of the driving task as a whole. For example, figure 3.3 shows how one aspect of the driving task – changing gear – develops from first experience. The new driver has to run through each stage of the whole process to change gear, for example by reciting each stage in the process. With increased experience changing gear becomes automated - the driver no longer has to break the task into its components, and gear changing can be carried out with minimal conscious effort. The same pattern occurs for all aspects of the driving task, to the point where the driving task itself becomes fully automated. It is not uncommon for experienced drivers to remark that they suddenly realised they had been driving for some distance without consciously attending to what they were doing.

Once the driving task has become largely proceduralised, the individual has more attention available to perform other tasks. Drivers are frequently called upon to estimate distances and directions. They must be able to quickly and accurately estimate the width of gaps, the speed of oncoming traffic, and maintain distances between self and other vehicles. In addition, drivers also have to scan the numerous roadside signs to perceive and process information relevant to them. This process of actively searching out information, processing the information and making judgements as to its relevance, develops and improves with experience (Wierda and Aasman, 1992). The experienced driver is able to actively search out roadside information, conduct a conversation with a passenger, or perform more complex spatial tasks such as navigation with relative ease. However, in the first years after passing the driving test, wayfinding whilst driving can cause problems in terms of switching attention between tasks. This attention switching is made more problematic under difficult driving conditions (Wierwille, 1993).

Figure 3.3 The development of cognitive skill from declarative to procedural knowledge (Adapted from Anderson, 1982)



Under such circumstances drivers tend to divert all their attention resources to the primary task of controlling the vehicle. This is the case for even the most experienced of drivers. From this

perspective it is clear that the debate between advocates of single and multiple resource theories is only part of the story. For experienced drivers, for the majority of the time, the multiple resource approach is probably correct. In difficult driving conditions, and for novice drivers in particular, however, it is likely that the driving task will take up a disproportionate amount of available resources (Wierwille, 1993). Although multiple resource approaches predict that no interference will arise because the two tasks (driving and attending to audible instructions) utilise different resource modalities (visual and auditory) the present research argues that this is only the case with experienced drivers under normal driving conditions.

There is support for this view in the human factors research. Wierwille (1993) reviewed the possible effects on various aspects of a driver's mental workload resulting from the introduction of complex equipment into the vehicle. Wierwille describes resources which the driving task requires and which route guidance systems will also utilise. In order of importance to driving, visual, manual, cognitive and auditory resources are identified as the main resources utilised. Wierwille's primary concern was with the demand that a route guidance system might place upon available visual and manual resources. With regard to cognitive load, Wierwille makes the point that, whilst under normal driving conditions the cognitive load of driving will be relatively small, in other situations (e.g. trying to make sense of confusing signs) cognitive load can be high:

> "On first examination it might appear that cognitive load is not very important, because a driver can easily shift attention to the primary task of driving, provided that a hazard has been detected by either visual or auditory means. If this is so, then it would appear that cognitive load, though heavy, has little bearing on safety or accident rate. Closer examination indicates otherwise. Cognitive load can result in perceptual narrowing and temporary rejection of apparently irrelevant stimulus information (Broadbent, 1958; Moray, 1981). Cognitive load is also likely to draw foveal vision to a specific area or device, thereby temporarily suppressing visual scanning, which may be needed for hazard detection. Thus sharing cognitive resources can reduce the margin of safety."
>
> Wierwille (1993), p.135

With regard to attendance to auditory messages Wierwille suggests this same perceptual narrowing effect might also arise. Moreover, in discussing the possible effects of receiving auditory guidance Wierwille makes the important point that:

> "commanded guidance does not provide the driver with a so-called "cognitive map" (Neisser, 1976). In other words, the driver does not gain a spatial image of the road network or the spatial relationship between present vehicle position and destination. Advocates of auditory commands for navigation and traffic advisory have tended to overlook the potential importance of driver spatial information gathering in keeping the driver appraised."
>
> Wierwille (1993), p.141

This is one of the issues of central concern to the present thesis, it will be returned to in more detail in the next chapter.

3.3.1 Group differences indicated by evaluations of existing route guidance systems

During the DRIVE II programme of research studies, a series of evaluation studies tested safety and usability aspects of some of the earlier incarnations of the latest route guidance systems (Ståhl *et al.*, 1994; Oxley *et al.*, 1994a; Oxley *et al.*, 1994b). As part of the DRIVE II project V2031 (Elderly and disabled drivers Information Telematics), a series of evaluation studies were carried out. These looked at three devices: the Phillips Carin, Bosch Travelpilot and the Motorola route guidance systems. Separate trials were run with approximately 30 subjects aged 65 and over driving an equipped car. The Motorola and Phillips systems were equipped with voice instructions in addition to the visual display. Overall impressions of the three systems were positive, with the majority of subjects rating the systems as easy to use. A minority in each trial felt that their mobility would be enhanced through using such a system, with some users more likely to drive more frequently, and others more likely to travel unfamiliar routes. For the majority, use of the system had no discernible effect on driving performance or driver safety. However, the driving performance of a minority of subjects in both the Motorola and Bosch trials was adversely affected. The authors attribute this to the drivers being unfamiliar with the equipment and suggest that driving performance would return to normal with increased familiarity. However, they also speculate that:

> "It might be hypothesised...that this result....suggests that if the use of a route guidance system does cause any reduction in driving safety, it is likely to do so among those drivers who are of below average ability."
>
> Oxley *et al.*, (1994b) p.17

This is one of very few studies which have looked at the ability of older individuals to use IVRGIS. However, the research was primarily concerned with drivers' evaluations of the various systems, and how much they would be prepared to pay for them. The authors assume that poor performance was merely due to unfamiliarity with the equipment and that it would improve with increased exposure but no evidence is provided which would account for this conclusion. In addition, the small size of the samples involved in this series of studies make it difficult to draw any firm conclusions regarding the effects that using these systems might have on the performance or safety of the wider population of older drivers.

A series of studies carried out under the DRIVE II project V2002 HOPES (Horizontal Project for

the Evaluation of Safety) (Rothengatter, Carsten and Labiale, 1995) recently considered the effects of driving with route guidance information with respect to:

i) visual search behaviour of drivers whilst using the system;
ii) vehicle control and driver workload, comparing the use of map-based information with using a route guidance system; and
iii) the effects of different types of systems on driver interactions and conflict.

The project considered screen-based displays using simple arrows with and without landmark information. The systems considered did not present verbal instructions, hence the main focus of the research was a consideration of the effects of visual distraction upon driver safety. The studies used a variety of variables: glance duration; navigation errors; subjective preferences; speed choice and variation; lateral position control; workload measures; driver comfort measures; driver interaction and conflict measures and general assessment scales. The following results were obtained:

- Navigation information provided by means of a route guidance system produced less navigation errors and less experienced workload than the same information presented on a conventional map. However, it should be noted that this conclusion only applies to the type of systems tested, i.e. those displaying distance information with an arrow indicating the direction of turn or other manoeuvre;

- Increased information complexity had a marginal effect on navigation performance, but a negative effect upon visual search and the performance of the manoeuvring task;

- Group differences in ability to process the information displayed were also observed. Elderly drivers were found to require longer to process the information. Females performed better than males, which the authors suggest may be due to females rating the experienced workload as higher than males, consequently the presence of additional route guidance information may serve to reduce the perceived workload.

Whereas Ståhl *et al.*, (1994); Oxley *et al.*, (1994a) and Oxley *et al.*, (1994b) concluded that elderly drivers have little difficulty using IVRGIS, the HOPES study suggests that elderly individuals might have difficulty in processing the information displayed. Although the focus of their research was screen-based information, the point is that, for elderly individuals, it is the ability to process

the information, not ability to perceive or comprehend the information which is the cause for concern.

The issue of divided attention in relation to elderly drivers has also been studied by van Wolffelaar, Brouwer and Rothengatter (1990) using a computer simulation. This project was organised within the framework of the project V1006 'Factors in elderly people's driving abilities' within the DRIVE programme of the Commission of European Communities. The project specifically focused on elderly drivers' driving capabilities, performance and problems, with a view to developing technologies that might overcome some of these problems. The research was laboratory-based, and used a computer-based lane tracking task (to simulate the driving task) in conjunction with cognitive tasks such as dot counting and serial addition tasks (to simulate attending to guidance instructions). Groups of young and elderly drivers were compared. Both tasks were displayed on the same screen as a means of studying the impact of divided attention. Again, this research has a number of limitations: the group sizes were small (12 in each condition); the driving task could be criticised for lacking realism; while the secondary tasks in some cases were overly complex. Despite these limitations, the project made some important conclusions regarding the impact of dividing attention between multiple tasks. In particular, the research found that, as the difficulty of the driving task increased, elderly drivers' ability to attend to the IVRGIS task was impaired.

Other researchers (Rothe, 1990; Burns and Galer-Flyte, 1996) have focused on the wayfinding problems experienced by elderly individuals, and how these might be addressed by information technology. Rothe (1990) conducted interviews with elderly drivers regarding their collision experiences, and reported that it was quite common for those involved in collisions to have been searching for a particular street, road sign, house number or business establishment when the incident occurred. A number of other factors such as being in strange neighbourhoods, searching for anticipated but unknown freeways, or rushing to find shortcuts as contributory distracting factors that caused collisions. Burns and Galer-Flyte (1996) conducted a series of focus group discussions and a questionnaire survey with groups of young (24-47 years) and elderly (59-82 years) drivers in an attempt to determine the nature and amount of navigational assistance that older drivers require. Although the sample was small (30 participants split into four groups) the discussions identified a range of wayfinding strategies, which varied according to trip type. Contrary to the findings of other studies no age group differences were found in wayfinding strategies, although older drivers emphasised the importance of seeing an overview of the route before setting out. Both young and elderly groups experienced similar wayfinding problems.

Older drivers expressed a need for more information to support their wayfinding decisions, and tended to be less confident than younger drivers in their wayfinding ability. They cited misunderstanding of road signs as the most common reason for wayfinding errors. With regard to the possible introduction of IVRGIS, elderly drivers expressed interest in the technologies, but only if they were simple and non-distracting. A common concern amongst the elderly drivers was that the system would be difficult to operate and to program, and too distracting to use while driving. Their preferred mode of presentation was for a guidance system that provided only verbal instructions when the car was moving.

In a follow up study, (Burns, 1997) a postal survey of young and elderly drivers was conducted which concentrated upon the strategies adopted and information requirements when wayfinding on unfamiliar routes. A total of 1184 replies were received and these showed a difference between the two groups in terms of the kind of information they considered useful: elderly drivers favoured street names, place names and road number, whereas younger drivers wanted street names, landmarks and lane position and relied more on memory to retain information.

Previous work on the behavioural effects of route guidance and information systems has provided data about drivers' route choice behaviour and preferences regarding both the way in which information is presented and the nature of the information itself. Recent work (Burns and Galer-Flyte, 1996, Burns, 1997) has started to explore the wayfinding requirements and problems experienced by elderly drivers and how these differ from younger drivers. However, this work is at an early stage of development, and has not yet been turned into recommendations for the development of future systems. Although the picture is not yet clear, the weight of evidence suggests that elderly drivers experience age-related problems with regard to wayfinding, and lack confidence in their own judgement. Generally, technologies that might address some of these problems are viewed favourably, but with the proviso that the information provided is simple to understand and the systems that provide it are easy to operate. The recent work of Burns (1997) suggests that route guidance instructions should include features such as landmarks, lane position information and should ideally allow the individual to tailor the instructions to suit their particular needs.

To date, systems manufacturers have not taken these issues into consideration in designing new systems. The information they provide is standard, and cannot be tailored to the particular comfort levels of the individual. There remains a need for further behavioural research which concentrates upon drivers' internal cognitive processes so that we can better understand how drivers acquire,

encode, process, mentally represent and recall information presented to them. With the notable exceptions of work by Verwey and Wierwille discussed above, in the area of route guidance systems there has been little research aimed at unravelling the possible effects of using route guidance information upon cognitive workload, particularly with regard to drivers of different levels of experience or ability. The research which has considered these issues in any degree has involved small sample sizes, has concentrated upon drivers' evaluations rather than systematic assessments of the effects upon their safety, and has predominantly been focused upon screen-based information. In part this is due to the recency of these latest developments – systems incorporating audible guidance instructions have only been available for the last 3 years. However, one could also argue that, having acknowledged the distraction capabilities of screen-based guidance, and having responded by incorporating an audible interface, systems manufacturers will be impatient for a return on their investment and unwilling to fund further research into the possible distraction that might arise from this latest development.

3.4 Safety implications of in-car telephone use

A body of research work does exist, however, which has specifically considered the problem of increased cognitive load and distraction caused by the presence of in-vehicle audible devices. The effect of using a telephone whilst driving has been the subject of research since the late 1960's (e.g. Brown, Tickner and Simmonds, 1969; Kames, 1978; Mikkonen and Backman, 1988; Zwahlen *et al.*, 1988; Brookhuis *et al.*, 1991; McKnight and McKnight, 1991, Nilsson and Alm, 1991). This research has highlighted a number of issues.

First, there is clear agreement amongst experts working in this field that:

> "The interference of two simultaneous human activities creates performance problems when neither of these activities is completely automatic and when they both make use of the same sensory receptors, the same motor groups and the same psychological processes"
>
> Petica (1995), p.1714

In his review of the possible effects of widespread car-phone usage, Petica (1995) considers the theoretical aspects involved in the problem. This discussion is especially pertinent to the present research problem and consequently is covered in some detail.

The driving task can be separated into partially automatic psycho-motor functions and more

complex cognitive processes. The psycho-motor functions require visual, auditive and kinaesthetic perception mechanisms. The complex cognitive processes require analysis of situations, the processing of information and decision making. However, the combination of these two aspects involves more specific mental/functional mechanisms which relate to anticipation, identification, interpretation and assigning significance. The extent to which a driver is able to successfully integrate these two aspects of the driving task will, to a large extent, influence their reaction time, speed of information processing and analysis and precision in making complex manoeuvres (Petica, 1995).

Clearly, car phone use is a secondary task, and from a multiple resource perspective, it utilises different resources to those normally assigned to the driving task. However, as researchers in this field have long maintained, the problem is only likely to manifest itself in situations requiring additional concentration (e.g. difficult intersections).

> "A conflict may appear which causes a reduction of adaptive capacity and behavioural effectiveness. The risk of an accident under such conditions can obviously no longer be ignored."
>
> Petica (1995), p.1714

From a theoretical perspective, therefore, there are important similarities between car phone use and the presence of IVRGIS in the car. The previous research in this area reflects the change in technology which has come about over the past thirty years. In common with route guidance systems, the main focus of human factors research has moved through distinct phases. The problem was first highlighted by Brown *et al.*, (1969) who, as a result of experimental studies, concluded that car phone use could have a serious impact upon perception and decision making, although its impact upon driving under normal conditions would probably be negligible. With Kames' (1978) study of the ergonomic design aspects of the handsets used in car phones, the research emphasis switched to design criteria. Kames showed that much of the negative impact of car phone use could be alleviated by bringing the handset within reach of the driver, removing the dialling element from the task and improving the design of the handset by incorporating a push button keyboard. Many of these original problems have now been addressed, and recent research has concentrated on differences between users in their ability to cope with this secondary task whilst maintaining safe control of their vehicle.

Other studies using car simulators (e.g. Alm and Nilsson, 1990) have shown that it is not just the dialling function which causes problems. This study showed that even simple tasks like talking on

the telephone whilst driving can have an impact upon reaction times, even of experienced drivers. However, it should also be noted that familiarity with the road can lessen this impact. Mikkonen and Backman (1988) found that vigilance and anticipation increased when driving on familiar roads whilst using a car phone, and that this increased attention reduced the need for braking. In the same study however, inexperienced users stated that using the car phone seriously impaired driving and increased risk, even though their performance was actually comparable with more experienced users. It would appear, therefore, that the subjective workload for inexperienced users is rated as much higher than that of those familiar with using a car phone. As a result of this study the authors warned that a rapid increase in the number of car phones in use might result in a short term reduction in road safety, as a result of drivers' lack of experience and familiarity with the device.

Alm and Nilsson (1990) also compared drivers' ability to safely use a car phone under a variety of different driving conditions: in low traffic on a motorway; in dense traffic on a four lane road; and in urban traffic conditions. Using the NASA-TLX subjective workload assessment tool (Hart and Staveland, 1988) drivers rated the subjective effort of using mobile phones of both the hands-free and handset types. In addition, a range of physiological measures including pulse rate and blood pressure were considered. This study showed that telephoning can have a significant impact upon driving and especially upon driver effort. In addition it showed that the circumstances under which the car phone is used are most important in determining the extent of any safety risk.

Finally, a number of studies (Nilsson and Alm, 1991; McKnight and McKnight, 1991) have considered the effects of age upon ability to use a car phone. Nilsson and Alm (1991) compared the reaction times, ability to maintain lane position, speed and subjective workload as rated by groups of young and older users. This study showed that reaction times were significantly slower when the driver was using a car phone. Older drivers' reaction times to unexpected events were 0.40 seconds slower than those of younger subjects. Older drivers also showed greater variation in lane position and rated the workload of using the car phone as higher. Interestingly, this same group appeared to compensate for this by slowing down when making a telephone call. Other studies offer support for these findings. McKnight and McKnight, (1991), for example concluded that any telephoning activity leads to a significant increase in both failures to react to traffic conditions and reaction times. Moreover, in subjects aged over 50 this distraction was found to be between 2 and 3 times greater than that for younger people.

To summarise, early research into safety implications of in-car telephone use (e.g. Brown *et al.*,

1969) identified a potential for distraction arising from using a telephone in the vehicle. Many of the issues raised by this work were addressed throughout the 1970's by attending to design aspects of in-vehicle telephones. More recent research, however, suggests that even simple tasks requiring little attention to the unit itself (e.g. talking on the telephone whilst driving) may impact on reaction times (Alm and Nilsson, 1990) and that inexperienced drivers in particular may suffer impaired driving and increased risk (Mikkonen and Backman, 1988). Under normal driving conditions most experienced drivers can use a telephone whilst driving with little effect upon safety, (it is more likely that their conversation will suffer before their driving performance) but under more difficult driving conditions, or when undertaking complex manoeuvres, using an in-car telephone may have an effect on safety (Alm and Nilsson, 1990). Research has also shown that two groups in particular: the elderly (Nilsson and Alm, 1991; McKnight and McKnight, 1991) and inexperienced drivers (Mikkonen and Backman, 1988) are at risk from using in-car telephones. These results have important implications for the introduction of IVRGIS and other in-vehicle systems that place additional demands on the driver's available attention resources. While much of the research has been undertaken with small sample sizes, in a laboratory environment, or with mock-ups or simulations of the driving task, there is a consistency in the findings that should not be ignored.

3.5 Conclusions

This concludes the review of the existing behavioural literature relating to route guidance systems and other associated technologies. From this review it is possible to conclude the following:

- Early IVRGIS research quickly identified the potential for distraction of screen-based systems, with the consequent development of an audible interface. There is considerable research (e.g. Verwey, 1989; Wierwille, 1993; Dingus and Hulse, 1993; to suggest that screen-based information distracts drivers. The subsequent development of the audible interface has proceeded ahead with little further research. The predominance of the multiple resource model of resources has led to a research environment which has been too accepting of the concept of separate resources, with little research considering the impact of such systems upon underlying cognitive processes. The present research attempts to redress this situation by focusing upon the impact of audible guidance instructions upon performance of a primary (visual) task.

From a multiple resource theory perspective the following testable hypothesis is suggested:

Hypothesis 2a

H_1: The primary task performance of subjects listening to audible route guidance will be superior to that of subjects who hear nothing, or listen to radio (non-relevant information), regardless of task complexity, as the two tasks utilise different resources[1].

H_0: There will be no difference between the primary task performance of all groups regardless of information condition.

But from a central resource theory perspective:

Hypothesis 2b

H_1: The primary task performance of subjects listening to audible information will be inferior to that of subjects who hear nothing or radio.

H_0: There will be no difference between the primary task performance of all groups regardless of information condition.

From this perspective the extent to which audible guidance interferes with the primary task will depend upon the complexity of the information contained in the secondary task, and its salience to the primary task. This suggests that non-relevant information (e.g. a radio broadcast) that does not require the subject to respond will place lower demands on the individual's pool of resources and so will not interfere with primary task performance to the same degree. Hence, central resource theory makes the additional prediction that:

Hypothesis 3

H_1: The primary task performance of subjects listening to radio will be superior to that of subjects listening to salient information.

From both perspectives the null hypothesis is the same:

H_0: There will be no significant differences between the performance of groups at the various tasks measuring spatial knowledge, regardless of information condition.

- Anderson's (1982) model of the development of skills suggests that there are differences between inexperienced and experienced drivers in their ability to perform tasks whilst

[1] It should be noted that this hypothesis makes the assumption that attending to audible guidance has the capacity to enhance performance of the primary task.

maintaining control of the vehicle. This suggests that newly qualified drivers are an important group to be considered in evaluating the impacts of IVRGIS. The present research notes that this group have, thus far, received very limited attention. The research seeks to redress this balance by including groups of non-drivers, newly qualified drivers as well as experienced drivers, to compare the effects of listening to IVRGIS on each group's performance of the various tasks. Because the present research does not employ a driving task it is not possible to directly test hypotheses relating to the impact on driving performance. However, Anderson's model suggests that experienced drivers will have gained more experience of the sort of wayfinding exercise employed in the present research (because they will have more resources available to perform other tasks whilst driving). Consequently, the present research tests the following hypothesis:

Hypothesis 4

H_1: Performance of tasks measuring spatial knowledge will be significantly correlated with ability to drive.

H_0: There will be no significant differences between drivers and non-drivers in their performance of these tasks.

- Research relating to in-car use of telephones (Petica, 1995; Alm and Nilsson, 1990) suggests that too much emphasis has been placed on the fact that the tasks utilise separate resources. Attending to audible route guidance information may still place an additional cognitive load upon the individual, regardless of the source of the incoming information. The extent to which this might impair performance of a primary task (e.g. driving) will depend upon characteristics of: the information; the individual; and the demands placed upon the individual by situational requirements. The present research will compare different types of information (e.g. information that has no relevance to the primary task, such as a radio broadcast and route guidance information) to see whether situational salience plays a part in distraction. This will permit the testing of the following hypothesis:

Hypothesis 5

H_1: Subjects' performance of the primary task will be adversely affected by attending to salient information but not by attending to non-salient information (e.g. radio).

H_0: There will be no significant differences in performance of the primary task between groups hearing salient or non-salient information.

- Research from a variety of areas (use of in-car telephones: Nilsson and Alm, 1991; McKnight and McKnight, 1991; previous evaluations of IVRGIS: Ståhl *et al.*, 1994; Oxley *et al.*, 1994a; Oxley *et al.*, 1994b; and laboratory studies: Wolffelaar *et al.*, 1990; Rothengatter *et al.*, 1995) all point to possible age group differences with regard to ability to process information supplied by IVRGIS. The present research will compare different age groups in their ability to perform a cognitive task whilst attending to audible guidance instructions. The following hypothesis will be tested:

Hypothesis 6

H_1: The quality of subjects' performance at the tasks measuring spatial knowledge will be negatively correlated with age.

H_0: There will be no correlation between age and task performance.

The following sub-section considers current codes of practice (Southall and Robertson, 1994) and existing design guidelines for designers of IVRGIS (Ross *et al.*, 1995) in light of these conclusions.

3.5.1 Existing IVRGIS design guidelines and audible instructions

At the time of writing three sets of design guidelines (Southall and Robertson, 1994; Green *et al.*, 1995; Ross *et al.*, 1995) address driver information systems and the information they provide. Of these guidelines, one set was prepared for the Department of Transport in Britain (Southall and Robertson, 1994), one formed part of the European Union HARDIE (Harmonisation of ATT Roadside and Driver Information in Europe) project (Ross *et al.*, 1995) while Green *et al.*, (1995) were jointly funded by the Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration in the USA.

Southall and Robertson (1994) is very general in scope and has little content specific to vehicles or in-vehicle devices. The guidelines consider the presentation of information, the design and location of the driver interface and associated controls and a range of issues related to the assessment of such systems, but contain limited references. The guidelines briefly discuss the use of auditory displays, but concentrate upon the use of auditory signals to draw the driver's attention to the visual display. It is a measure of the rapid development of IVRGIS that, despite being published in 1994, Southall and Robertson make no reference to the use of audible guidance, or their possible impact upon the driver.

The HARDIE guidelines (Ross *et al.*, 1995) set out to be a reference source for designers and aimed to summarise best human factors practice. The first part of the guidelines review existing sources of information and, as a result, identify issues for which no design support is available. Ross *et al.*, (1995) identify the following five areas:

- Choice of information presentation mode;
- Design of information presentation mode;
- Optimum timing of guidance instructions;
- Orientation and harmonisation of vehicle and road information; and
- Driver/system interaction.

Like Southall and Robertson (1994), Ross *et al.*, (1995) offer an extensive set of design recommendations, but these are supported by a complete list of references. The guidelines are well set out, and would certainly be a useful aid for systems designers. The guidelines consider audible guidance and compare instructions composed either of auditory or visual information or a combination of the two. As a result of their review Ross *et al.*, (1995) recommend a combination of visual with auditory instructions. Their recommendation is based in part upon the distracting nature of visual information, and partly upon Wickens' Multiple Resource Theory, discussed earlier in this chapter. As discussed in section 3.2.1, there has been little validation of Wickens' theory with regard to audible information presented by IVRGIS, and this is clearly a weakness of existing human factors research in this area.

Green *et al.*, (1995) produced a valuable set of guidelines, based on field and laboratory experience with pre-competitive interface designs, as well as human factors literature. They begin with basic design principles, then general guidelines regarding input and output, and then focus on system-specific guidelines for navigation systems. The guidelines are set out with two key principles in mind: first that they should be developed from design decisions, and second, that they should be kept short. Green *et al.*, (1995) are the most detailed of the existing guidelines with regard to auditory output, and list 7 recommendations:

1. Auditory instructions should be limited to four chunks in all cases, three or less in most cases. Each chunk is a distinct and separate piece of information.
2. If a series of three messages about a manoeuvre is given, the information should be presented in three stages: "early" information, "preparation" information and "approaching" information: for example,

Early: *In 3.5 miles at Green Street, bear left.*

Prepare: *In 1 mile at the traffic light at Green Street, bear left.*

Approaching: *Approaching Green Street, at the traffic light at Green Street, bear left.*

3. Where timing permits, each decision point should have its own instruction.
4. When a street name changes, tell drivers "(Street name) has changed to new street name."
5. When travelling on city streets, tell drivers "entering (city name)" when they cross a political boundary.
6. There may be instances when "continue" messages are desired.
7. Provide drivers the capability to activate and deactivate auditory prompts and directions.

Adapted from Green *et al.*, 1995 pp.48-52

Points 1, and 2 are necessary recommendations aimed at reducing driver workload. Points 3, 4 and 5 may reduce confusion, but may also add to the amount of information the driver has to deal with, and so a trade-off may be required. Points 6 and 7 are not necessary but would enhance user satisfaction with the device. Indeed, recommendations 6 and 7 are now standard for many IVRGIS. On the whole, the recommendations are clear, but guidelines 1 and 2 are potentially problematic. The major problem relates to the recommendation that up to four chunks of information can be supplied in one message. For the three types of message suggested (early, prepare and approaching) they suggest that the information be presented as in table 3.4.

These are useful recommendations where the manoeuvre is simple, but may be less so under more complex situations. Even the example cited by Green *et al.*, could be criticised for providing more information than is strictly necessary for a simple manoeuvre. The final message, designed as "a last minute reminder" before the driver misses the intended turn, is far too long to be of much use in this situation. The example used is also simplistic, involving only one street name throughout. A more complex example (e.g. where more than one street name is required to make sense) would highlight the problem of using four "chunks" of information. There is also a potential problem regarding the order in which this information is presented. This recommendation was based on the idea that a recency effect is involved in short term memory, and so the most important aspect (the action) should come last. From a psychological perspective this sudden reference to short term memory has the feel of a convenient add-on, rather than the result of considered, objective research. Moreover, it is a gross simplification of a highly complex, poorly understood cognitive process. Whilst there is evidence that a recency effect exists, there are many other factors that need to be considered, such as word length, sentence length, salience of message, and individual characteristics. One could also argue that if

the driver is required to process three other pieces of information before being given the vital instruction then they may miss this information all together. The present research will investigate differences in word order of instructions, as this recommendation appears not to be based on empirical findings.

Message type	**Information provided**
Early (*always given*)	"In" {distance} "at" {location}{action}
Prepare (*only given if enough distance after early message*).	{distance}{location}{action} or {distance} {landmark}{location}{action}
Approaching (*always given*)	"approaching" {location}{action} or "approaching" {landmark}{location}{action}

Table 3.1: Recommendations for audible guidance (from Green *et al.*, 1995)

There are a number of other problems with the auditory guidelines suggested by Green *et al.*, Some of the language recommended is potentially ambiguous, for example, does "bear left" mean get in the left hand lane, *prepare* to take a left turn or turn left? (For further discussion of this issue see the final appendix in this thesis). Green *et al.*, recommend that key information elements should include direction of turn (left or right), distance to turn and associated road name. Streeter, Vitello and Wonsiewicz, (1985) make a similar recommendation but add the important caveat that the information supplied should be kept to the minimum required to carry out the manoeuvre. Green *et al.*, recommend that landmark information be included to aid comprehension, but limit their suggestion for landmarks to traffic lights, stop signs and underpasses, which may be too narrow to encompass the full range of situations that might arise. However, Green *et al.*, (1995) do raise an important issue which will become more relevant as the number and range of in-vehicle devices increases. The extent to which new systems can (or should) be integrated with existing non-IVHS interfaces such as displays (speedometer, fuel gauge, etc.) is an issue of concern for designers of future vehicles.

In summary, existing guidelines have begun to consider audible guidance, but as yet have been limited to design issues such as type of information to be presented, timing of presentation and information content. To date guidelines have paid little attention to the potential distraction that might arise from listening to audible guidance beyond recommending that audible instructions

might reduce some of this distraction. Whilst the present research accepts this to be largely true, there is an implicit assumption that audible instructions will place a minimal additional load on the individual. This issue has not been tested and needs to be addressed before firm recommendations regarding the relative benefits of visual and audible guidance can be made.

3.5.2 Conclusions regarding tasks to be employed to address research questions

- In order to enable comparisons to be made of the effects of different types of information it is essential that all participants are exposed to the same situation. This necessitates the use of laboratory based studies, as real-world environments will vary significantly between individuals. A real-world test environment will not provide the degree of control required - it would change due to hour of day (e.g. in terms of traffic flows), day of week, as well as due to seasonal variations (e.g. school holidays).

- There is also the ethical problem of safety: it is not feasible to allow drivers to drive around a real network whilst exposing them to an additional cognitive load which might affect their safety.

For these reasons, and because of the limitations of using car simulators, the present research will employ some other cognitive task, performance of which can be easily compared between subjects and groups. The task to be employed is the ability to acquire a cognitive map of an unfamiliar area. There are a number of reasons for selecting this task:

1. First, as was discussed in chapter 1, the primary aim of this research is to inform our understanding of the impact of IVRGIS upon underlying cognitive processes. Spatial cognition, and specifically cognitive mapping, is increasingly recognised as being of fundamental importance to spatial behaviour (Bovy and Stern, 1990; Schofer, Khattak and Koppelman, 1993), and is the cognitive process that underpins spatial behaviours such as travel, navigation and wayfinding (Arthur and Passini, 1992; Neisser, 1976;).

2. It is difficult to investigate directly the effects of information upon underlying cognitive processes, for the simple reason that they are unseen and their existence can only be inferred. Cognitive psychologists regularly have to deal with this problem, and the conventional solution is to find test variables that it is widely agreed have some resemblance to (or dependency upon) the underlying processes being investigated. The contents of an individual's cognitive representation of an environment have a direct impact upon their behaviour within that environment (this is discussed in detail in the next chapter) and so it is relevant to compare externally elicited representations produced by different individuals exposed to the same environment.

3. The information provided by IVRGIS may impact upon driver behaviour. However, if we were to simply compare drivers' navigation performance with and without IVRGIS we would ignore a whole range of personal and situational factors that could account for the results. Differences in driving ability, familiarity with the test environment, differences in the environment caused by time of day etc. could all contribute to the findings. How would performance be measured - Time taken to complete the navigation task? Number of errors made? Adherence and compliance to the advice? In all of these cases the dependent variables could be influenced by factors outside the experimenter's control. It is essential that experimenter control is maximised if we are to explore the effects of IVRGIS.

4. From a human factors perspective the cognitive mapping task can be considered to be a primary task, with attending to audible guidance instructions a secondary task that is varied in complexity. In this way the experiments can address human factors issues while focusing upon the main issue: the impact of listening to guidance on underlying cognitive processes.

For these reasons the present research considers the effect that audible instructions as delivered by IVRGIS have upon ability to acquire a cognitive map of an unfamiliar area. Chapter 4 will now review existing research in this discipline, to improve and clarify our understanding of this important process, and as a means of identifying the most suitable means of testing and comparing the elicited representations of these cognitive structures.

4 COGNITIVE MAPPING: THE PROCESS OF SPATIAL KNOWLEDGE ACQUISITION

4.1 Introduction

Imagine these scenes: a stranger asks you for directions to the nearest post office in your home town; you start a new job and are trying to figure out the quickest route to your new destination; or maybe you are just trying to remember where it was that you saw that new clothes shop. In the absence of any external assistance (map, compass etc.) solving spatial problems such as these relies on internal representations of previously acquired spatial knowledge. These internal representations of our environment are commonly referred to as 'cognitive maps' (Tolman, 1948) and are seen to play a major role in influencing behaviour (Downs and Stea, 1973). In particular, 'spatial problem solving behaviour' such as wayfinding and navigation (Arthur and Passini, 1992) depends upon the ability to acquire, store, retrieve and manipulate these cognitive spatial representations. We are all familiar with using cognitive representations of our surroundings and, if prompted, can readily recall representations of places with which we are familiar. Indeed, people's decisions and behaviour within an environment are widely held to be a function of their cognitive representation of that environment (Golledge, Smith, Pellegrino, Doherty and Marshall, 1985).

Previous sections (in particular sections 1.2.1 and 3.3) emphasised that transportation researchers have begun to recognise the importance of cognitive maps to research related to spatial behaviour. However it was also noted that transportation researchers have tended to oversimplify what is a most complex process. Consequently, this chapter has the following aims:

- To improve understanding of the cognitive mapping process by providing a review of previous research in key areas relevant to the introduction of IVRGIS;
- To emphasise the significance of cognitive maps to transportation research;
- To consider the validity of predictions made by Schofer *et al.*(1993) – that providing additional information is capable of expanding and enriching cognitive maps. In particular, there seems to be a discrepancy between these predicted benefits, and the possible negative outcomes of extensive reliance upon IVRGIS, as hypothesised by Wierwille (1993). This chapter will try to determine what effect additional information will have upon the process

In order to address these issues the chapter first provides definitions of cognitive maps and cognitive mapping (section 4.1.1), then discusses their relevance and importance to transportation studies relating to spatial behaviour (section 4.1.2). The remainder of the chapter is divided into sections which address issues specifically relevant to the aims of the chapter and to the research questions outlined in chapter 1. These issues and the structure of the rest of the chapter are outlined in section 4.2.1.

4.1.1 Definitions

Throughout the spatial knowledge literature authors regularly refer to 'cognitive representations of the environment'. There is potential confusion surrounding use of this term, its synonym cognitive maps and the term mental maps. It should be noted that, despite their similarity, the terms cognitive map and mental map refer to distinctly different processes. Mental maps refer to subjective evaluations of, or preferences about environments, an area of research not discussed here. The term cognitive map was originally coined by Tolman (1948) to describe the process by which rats learnt a maze. This use of cognitive map was a metaphor for the process by which the rats came to learn the correct route - in that they appeared to develop an internal map-like representation of the environment (Tolman, 1948). While useful as a metaphor, Tolman's use of 'map' has been criticised for giving the impression that cognitive maps bear some resemblance to cartographic maps, and thus suggests an ordered, organised representation of spatial information. On the contrary, research suggests that, unlike real maps, cognitive maps are likely to be distorted and fragmented (Appleyard, 1970; Stevens and Coupe, 1978; Tversky, 1981). For the purposes of this thesis, cognitive representations refer to a hypothetical construct (MacCorquodale and Meehl, 1953): - a useful means of describing how we come to know the environment. It is accepted that, although we cannot observe the processes which take place, it is reasonable to believe that they do exist and that their organisational structure bears some resemblance to the way in which such information is organised in the world about us (Moore and Golledge, 1976b). Whilst there is some objection to the use of the term cognitive map, it is widely used and recognised (if not always widely understood). Hence, after providing a definition of its intended meaning it will be used throughout this thesis.

The process by which we come to form knowledge of our environment is called cognitive mapping. The generally accepted definition of cognitive mapping is that proposed by Downs and Stea (1973):

> "cognitive mapping is a process composed of a series of psychological transformations by which an individual acquires, stores, recalls and decodes information about the relative locations and attributes of the phenomena in his

everyday spatial environment"

Downs and Stea (1973), p.7

Cognitive maps are therefore the products of this process of cognitive mapping. They are the mental representations which we form out of the information we perceive through our everyday transactions with our environment. Cognitive maps play a major role in influencing an individual's behaviour (Downs and Stea, 1973), they allow the perception, prediction and evaluation of possible courses of action and are seen as coping mechanisms which enable the individual, faced with a vast amount of information, to establish both the location of valued articles and a means of getting to them from the individual's present location (Kaplan, 1973). This definition highlights the importance of cognitive maps to spatial behaviour, in particular behaviour involving travel from a present location to a destination.

Cognitive maps enable us to construct a mental representation of an environment which cannot be seen from one vantage point alone (Arthur and Passini, 1992) and so they enable us to build a meaningful whole from the various parts which have been previously perceived. This definition is important because it emphasises the *subjective meaning* that the individual attaches to the representation. The cognitive map is formed through perception of environmental features, but the contents of the cognitive map are shaped by the individuals' purposes, goals, past experiences and future objectives with regard to the environment in question. Consequently, cognitive maps are likely to contain features which make the map meaningful to that individual. This viewpoint echoes the 'constructivist' approach to the cognitive mapping process proposed by Siegel and White (1975). The purposive nature of the cognitive mapping process is an essential element in that it emphasises that cognitive maps are often formed to meet a specific requirement. Information previously acquired (perhaps from a number of separate sources and at different times) is combined to solve a specific problem:

> "Fundamental to all constructivist-representational frameworks is the assumption that individuals actively construct a cognitive representation of the environment on the basis of perceptual and motor experience."
>
> Kirasic (1991), p.10

Kirasic's definition also highlights another important feature of the cognitive mapping process: that it is not a passive process, nor do we passively soak up knowledge about our surroundings. Rather, we seek out information in the environment which has some relevance to us, either at that particular point in time, or as a function of our own goals, aims and needs. This information is stored and, when required, is retrieved to construct a cognitive map which will be used for

some specific purpose. Hence, cognitive mapping is an active, purpose-driven, process and the representations we construct are put together in order to address a particular need.

4.1.2 Why are cognitive maps relevant to transportation and IVRGIS research?

Wayfinding has been conceptualised as a process involving three distinct stages: information processing, decision making and decision execution (Arthur and Passini, 1992). These stages are represented in figure 4.1. During the information processing stage we gather information about the journey to be made, and organise this along with previously acquired information. This information is formalised in the form of a cognitive map. At the decision making stage, we form a plan of action which will guide our activities, then at the decision execution stage we adopt appropriate behaviour in accordance with this plan of action. From this perspective it is easy to see how one might assume that by making more information available at the information processing stage one would improve the quality of a cognitive map. However, this differences between information acquired from the environment as a result of self-driven action, and that acquired passively from secondary sources such as an IVRGIS.

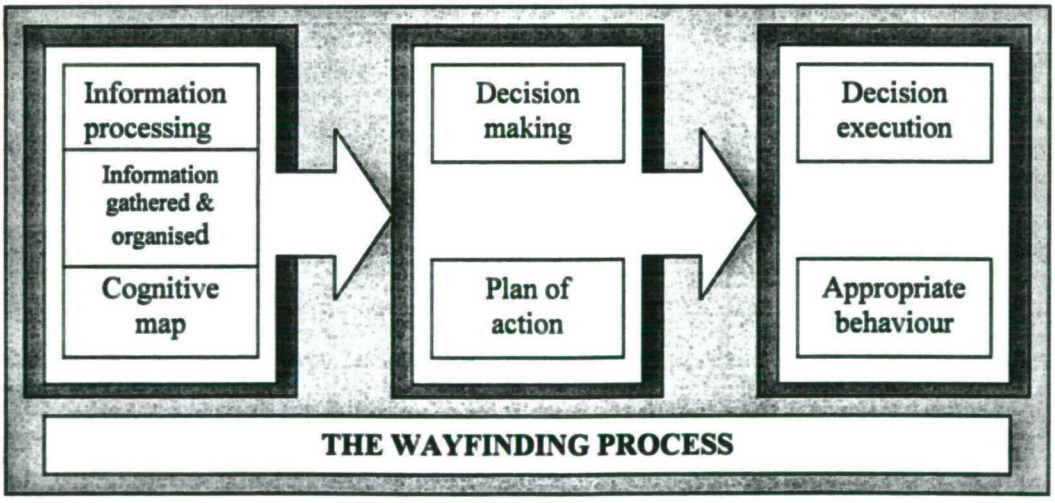


Figure 4.1: The wayfinding process, as conceptualised by Arthur and Passini (1992).

Researchers working within transportation are becoming increasingly aware that research looking at the impact of new technologies upon spatial behaviours such as wayfinding and navigation should include an analysis of the impact upon the underlying cognitive processes which govern such behaviours. Bovy and Stern (1991) for example, in their book *Route Choice:*

Wayfinding in Transport Networks, written from a transportation perspective, state that it is:

> "generally accepted that spatial behaviour is a direct function of the extent of learning about the environment in which we act"
>
> Bovy and Stern (1991) p.35

Bovy and Stern take the view that, in order to provide answers to questions about peoples' route choice behaviour it is essential that we first gain a better understanding of how people choose routes, what they know about the routes they take, and what characteristics of the network they consider to be important (Bovy and Stern, 1991). These questions are rooted in spatial behaviour and have received considerable attention from researchers in psychology and geography over the past thirty years. Bovy and Stern's book was the first (and to date, the only) attempt by transportation researchers to raise awareness of the importance of cognitive maps to travel behaviour. Sadly, the book suffers from poor editing and translation, is somewhat selective in its choice of reference materials, and the wide range of issues addressed require that cognitive mapping theory and research are given only superficial consideration. Moreover, for Bovy and Stern, the aim of route choice research is to enable the design of

> "quantitative models aimed at predicting the use of routes dependent on the characteristics of the routes, those of the surrounding environment, and those of the travelers. In this way, traffic flows in the network can be calculated and the network performance can be evaluated."
>
> Bovy and Stern (1991), p.ix

With regard to IVRGIS, there is the risk that placing such an emphasis upon the identification and extraction of quantitative data might lead transportation researchers to focus upon environmental elements (which are much easier to quantify than elements located within the individual) at the expense of the behavioural element, with the result that individual differences with respect to IVRGIS are ignored.

Chapter 2 showed that, within transportation research, the introduction of IVRGIS is widely predicted to have an impact upon route choice behaviour (Ben Akiva *et al.,* 1991; Bonsall, 1992; Schofer *et al.,* 1993). The majority of these predictions are positive (see chapter 2). However, whilst transportation researchers have been quick to espouse the potential for improvements to the network that IVRGIS might provide, some of the leading experts in other fields have raised serious doubts.

Wierwille (1993), for example, makes the point that, whereas self-navigation results in the development of a robust and useful cognitive map, commanded guidance does not provide the

driver with a cognitive map (see p.54). This is an issue of fundamental importance, for the very benefits that are predicted to arise from widespread use of IVRGIS are based upon their assumed ability to expand and enrich the contents of individuals' cognitive maps (see figure 4.2). The previous section emphasised that under natural conditions the cognitive mapping process involves an active search for information salient to the individual. The construction of the cognitive map, similarly, is dependent upon the retrieval of previously acquired and stored information.

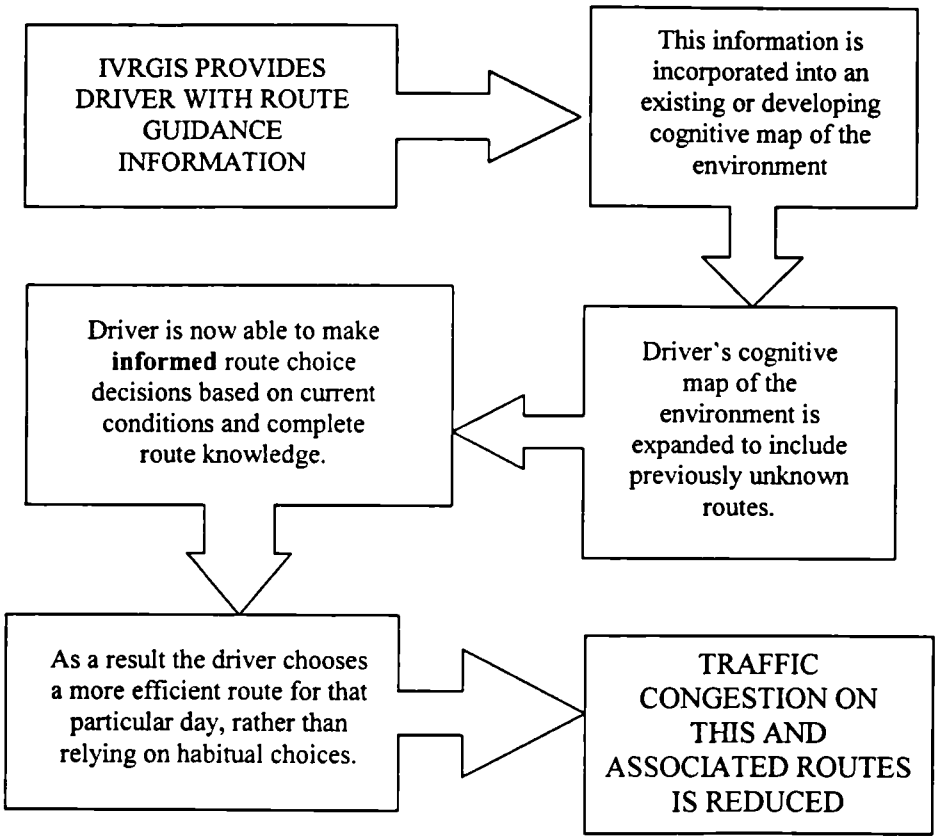


Figure 4.2: The relationship between IVRGIS, cognitive maps and congestion

Schofer *et al.*, (1993) discuss the effect of information on cognitive maps. However, this misses the point of cognitive maps. They are simply a product of an underlying process. Rather than considering the effects of information upon this product, we should be considering the impact upon the processes that shape the product: the various stages of spatial knowledge that comprise the cognitive mapping process. For this reason this project will consider the impact of listening to information on the lower order aspects of spatial knowledge: landmark knowledge and route knowledge, which are combined to produce configurational knowledge and will focus on the development of spatial knowledge rather than the effects of information upon existing

knowledge. This chapter reviews theories which have attempted to explain the cognitive mapping process.

4.1.3 Structure of the remainder of the chapter

This thesis argues that there is a fundamental difference between the information acquisition process, central to natural cognitive mapping and the way in which additional information is provided and acquired via IVRGIS. 'Natural' wayfinding involves active participation and an active search process, and thus leads to the construction of strong, durable, personally-salient cognitive maps. IVRGIS-led wayfinding is largely passive, and the resulting cognitive maps are weak, less durable and not tailored to the specific requirements of the individual.

Current predictions of the possible benefits to be derived from IVRGIS make no allowance for the difference between active and passive cognitive mapping: the provision of information is considered sufficient to enhance and enrich cognitive maps. To date, research has not addressed the issue of whether differences exist between cognitive maps that result from self-navigation and those formed as a result of commanded guidance. Given the importance of cognitive maps to all aspects of spatial behaviour, this is an issue that must be addressed before accurate predictions of the possible benefits to be derived from mass uptake of IVRGIS can be made. The remainder of this chapter is organised around key questions, answers to which will address the aims stated in the introduction. The questions that this chapter addresses are:

i) How and why have we evolved such a complex representation system?

In order to understand the possible long term impact of route guidance upon an individual's cognitive maps and mapping, it is relevant to first examine the reasons for having such a system in the first place. Stephen Kaplan's theories of functional adaptation (Kaplan, 1973, 1976) offer a plausible explanation of how humans came to evolve such a highly developed and complex system of cognitive representation. Kaplan considers the reasons for the development of this spatial representation system and the needs and purposes it addressed. Consequently, Kaplan's theory of functional adaptation is reviewed in section 4.2. In addition, Kaplan suggested the idea of generic spatial knowledge, by which we abstract from previous experiences to help us cope with new situations. This theory (and other, similar theories also considered in this section) may have relevance to the introduction of IVRGIS: differences may exist between the way in which this information is understood and used by those with some prior experience of similar environments and those with no such experience.

ii) How does spatial knowledge develop?

Developmental psychologists have long been interested in the development of spatial knowledge in infants and young children. It has been proposed that, with regard to spatial knowledge acquisition, the development of spatial knowledge in adults closely follows the comparable process in children. There are differences, however, in the two processes. Moreover, it is important for us to understand how spatial knowledge develops across the lifecycle. Consequently, the major theories which have been proposed to explain the acquisition of spatial knowledge both in childhood and adult life are considered in section 4.3.

This section also considers alternatives to the developmental approach, in particular information processing approaches. Cognitive mapping is by no means a random process. On the contrary, there is substantial evidence to suggest that individuals are selective in the information which they acquire and store in their cognitive maps of environments. The sheer range and quantity of spatial information with which we daily have to deal implies that some selection process is essential to enable us to cope. Information processing approaches offer an alternative but compatible explanation to developmental approaches. Information processing approaches have the advantage that they can account for the wide individual differences which are apparent in cognitive mapping ability, whilst explaining the hierarchical structure which, it is now commonly accepted, must exist to enable economical storage of information. Hence, this section also summarises Golledge's Anchor Point Theory (Golledge, 1978), one of the most widely accepted explanations proposed within an information processing framework.

iii) What factors affect the process of spatial knowledge acquisition?

It is clear that we do not all develop spatial knowledge at an equal or comparable rate. Two people who have lived in the same area for an equal length of time may develop very different representations of this same area. What accounts for these differences? Section 4.4 considers this question from two perspectives. First, factors within the environment which have been found to have an impact upon the cognitive mapping process are discussed. Second, factors within the individual which have been identified as affecting the rate, quantity and type of spatial information acquired are considered. In addition, this section considers the effect that information has upon the temporal and distance information contained in people's cognitive maps.

Finally, section 4.5 summarises the major findings discussed in the body of the review, and draws conclusions with the aim of offering assistance and relevant information for those involved in the design of route guidance systems. The conclusions also reconsider the claims of

Schofer *et al.*, in the light of the research discussed.

4.2 The evolution of the cognitive mapping system

Wayfinding and navigation through familiar and unfamiliar environments can be seen as examples of spatial problem solving (Arthur and Passini, 1992). Clearly, the successful resolution of such problems is highly dependent upon the information available to the individual. When faced with a new environment, however, we are bombarded with stimuli through all the senses - how do we manage to make sense of this wealth of available information and know what information to retain and what to ignore? Moreover, how did we come to acquire such a complex system as cognitive mapping? What function did it meet in our ancestors' times? Kaplan (1973, 1976) proposed a convincing theory which explains how humans came to develop these complex spatial systems.

Kaplan hypothesised that the cognitive mechanisms we employ during problem solving exercises, such as wayfinding, evolved because of their importance to the survival of the organism. Thus, our present day ability to build cognitive maps arose through this evolutionary process. Our primitive ancestors were ill-equipped to fight against faster animals with better sensory capacities of sight, hearing, sense of smell and the protection afforded by claws, fangs and thick skins. To compensate, these first 'humans' had to develop systems to enable them to compete on near equal terms. Kaplan proposes that the systems which developed were oriented towards processing and making sense of the enormous amount of spatial information available. Thus, early Man evolved strategies, speed of thought and the ability to differentiate, select and process relevant cues from the much wider barrage of available but irrelevant information. Kaplan proposes that the necessity for strategy and speed of thought and action, coupled with the relative scarcity of salient information led to the evolution of the following capacities:

- Anticipation;
- Abstraction and generalisation;
- Responsible innovation.

The organism needed the ability to *anticipate* future events to enable intelligent decisions to be made quickly. Furthermore, when faced with a novel situation it was necessary to be able to *abstract* from previous situations to enable the transfer of prior experience to the present. This in turn required the ability to *generalise* from situation to situation. However, whilst such abilities would be important, they alone would not be sufficient to enable competition on equal terms. The success of the species was dependent upon the ability to come up with appropriate

solutions to problems never before encountered: *responsible innovation.* Kaplan proposes a number of mechanisms which might deal with these requirements.

4.2.1 Anticipation

The ability to anticipate events is of central importance to functioning in the environment. However, having encountered a particular event, a huge number of possible sequences could arise from its occurrence. Such a multitude of possibilities requires an economical coding system. Kaplan proposes that such economy would be best handled by a system which allows considerable overlap. This would ensure economy both of storage and also of experience: a cognitive map, built up from many different sources, would enable access to the representation from a large number of experiences.

4.2.2 Abstraction: the need for a hierarchical structure

Abstraction is aided by a number of mechanisms which aim to reduce the mass of information with which the individual is faced. First, in recognising an object and creating a representation, only the object's most salient and frequently occurring features will be included. Second, the representation must enable generalisation to a large number of circumstances and not solely those which gave rise to it. Abstraction is further aided by the capacity to shift scale; we are capable of making the cognitive leap from a representation of a room in a house, to a representation of a whole town, with little effort. Although we take this process for granted it is most important in reducing detail and enabling abstraction. Kaplan proposes that, in order to cope with the amount of information present in the environment, it is essential that the system of storage should be hierarchical. A hierarchical system of storage would enable access to the representation from any one of a number of access points.

Empirical evidence (e.g. Hirtle and Jonides, 1985; McNamara, 1986; McNamara *et al.*, 1989; Stevens and Coupe, 1978) offers strong support for the existence of a hierarchical structure. Stevens and Coupe (1978) found that subjects judged Reno in Nevada to be east of San Diego, California, despite it actually being further west. Stevens and Coupe hypothesised that this was because subjects encoded California as lying west of Nevada and hence inferred that cities in California would be west of cities in Nevada. Clearly, such a finding points to the existence of a hierarchical structure whereby decisions about cities are made by reference to their membership of a higher order categorisation ("States of the USA"). McNamara (1986) distinguishes between theories which propose that spatial knowledge is stored in analog form such as images

or networks (non-hierarchical theories) and those which maintain that we encode environments in terms of regions. These latter (hierarchical) theories propose that spatial knowledge is stored in a hierarchical, compartmentalised manner. McNamara used priming tasks to test his theory. In his experiments (McNamara, 1986) one group of subjects studied maps of objects placed in an area divided into four equal squares. A second group studied the same objects in a similarly shaped real space. Pairs of objects were located either in the same quadrant or in different quadrants, and were either far apart or close together. Using a priming task to elicit item recognition, McNamara demonstrated that subjects recognised objects faster when they were primed by objects from the same quadrant. It was also found that subjects' estimates of distances between pairs of items were underestimated when the items were in the same quadrant. These findings offer strong support for the view that spatial information is encoded in a hierarchically structured representation.

Hierarchy is clearly an essential characteristic of cognitive maps, allowing for economy of storage, flexibility of use and the ability to infer relationships between separately encoded representations. Indeed, McNamara *et al.*, (1989) have shown that subjects tend to impose a hierarchical structure on spatial layouts to be remembered even when none is apparent, suggesting that hierarchical encoding facilitates storage and memory of larger amounts of information and is "a fundamental property of spatial memory" (McDonald and Pellegrino, 1993, p.72). The evidence discussed above suggests that hierarchy is not just a storage facilitator, but also plays an important part in retention. For IVRGIS to be effective they must be capable of providing drivers with information about their spatial surroundings in a form which is easily understood. Moreover, the information should be in a format compatible with the knowledge acquired from other sources, in order that this new information can be incorporated quickly, efficiently and effectively within the structure of an existing cognitive map. In situations where a new cognitive map is being created to address a specific spatial problem, information will be acquired from disparate sources. In such situations the information provided by IVRGIS must be as accessible as information acquired from direct experience.

4.2.3 Responsible innovation and generic spatial knowledge

The mechanisms discussed thus far and the processes which they are considered to enable, deal with speed of action and the reduction of information. In reality, however, perhaps the most challenging cognitive exercise is one which requires intelligent decision making in the face of novel circumstances. Clearly, this is a process faced daily by travellers wayfinding through new environments. Where there is no prior experience to fall back on, the individual must make a

decision which not only fulfils the requirements of the situation, but which does not endanger the individual.

Kaplan proposes the 'responsible innovation' mechanism to address this problem. This uses prior experience by seeking a solution to a novel problem utilising representations acquired through past, similar experiences. To this extent the process is not random, but it is nevertheless innovative in that it involves the creation of new connections between the present and past experience. Central to the notion of responsible innovation is the ability to use generic knowledge.

A distinction needs to be made between the knowledge we acquire of likely spatial layouts and the memories we have for specific places and routes. Kaplan describes how human beings have evolved a number of strategies which enabled our primitive ancestors to compete with better equipped animals on near equal terms. Whilst these evolutionary abilities enabled our ancestors to survive, they enable their modern day counterparts to function within society by teaching spatial patterns and the behaviour deemed appropriate for particular settings. This important element of Kaplan's theory is the idea of "generic knowledge". Concerned with the requirements for economy, flexibility and efficiency of the system, Kaplan proposes that not all of our representations need to be of specific places:

> "Rather, knowledge can be viewed on a continuum ranging from the specific on one end to the completely generic on the other. ... Generic knowledge provides a basis for comprehending new environments based on prior experience with reasonably similar environments."
>
> Kaplan (1976), p.42

We learn patterns of probable spatial arrangements through sensory and perceptual experience - associations between spatial features are built up and strengthened through repeated exposure to particular patterns of spatial arrangements. In addition, our experience within a particular culture exposes us to culture-specific spatial arrangements (e.g. the American grid system, or the prevalence and consistency of spatial layout and content of a High Street in British towns). Prolonged experience of such culture-specific norms teaches us what to expect when faced with a particular view. Thus, one aspect of spatial knowledge is *generic spatial knowledge*, enabling us to predict likely spatial arrangements of upcoming features based on past experience. Such knowledge is not dependent upon direct (primary) experience of a specific route or place, but arises out of primary experience of similar spatial settings.

Kaplan's theory of generic spatial knowledge is similar to other theories that have emphasised the importance of prior experience in memory. Bartlett (1932) for example proposed that subjects remember new material in terms of existing structures which he termed schemas or schemata. Bartlett suggested that schemas help us to organise our knowledge and expectations of aspects of our world, and serve as models of parts of our environment and experience. For Bartlett, remembering and learning are active processes, with the individual constantly endeavouring to place meaning upon experience. Applying existing schema to new situations helps us to understand these new situations, or, if the new situation does not agree with our existing schema, distortions will occur which give rise either to modifications to the existing schema, or the development of new schema. In the mid-1970's a number of theories (Minsky, 1975; Rumelhart, 1975, Schank, 1975) were proposed that echoed Bartlett's basic principle - that knowledge structures extend beyond the level of an individual concept. These three theories use different terminology (frames, schema and scripts respectively) but essentially refer to a similar idea: that past experience (and thus memory) of similar events or situations is used by individuals to cope with the requirements of a present situation. Schank and Abelson (1977) for example, proposed scripts, that apply to particular situations. These enable us to predict the behaviour that is expected in similar situations, and allow us to fill in much of the detail not specified. However, whilst the various approaches are certainly compatible, Kaplan's theory is more directly relevant to the present research in that the other theories tend to refer to social situations (e.g. visiting a restaurant) or to the way in which our previous experiences enable us to fill in the gaps in a description of events, while Kaplan focused specifically on the influence of previous spatial behaviour and its effect upon present experience.

With regard to the introduction of IVRGIS, it is possible that generic spatial knowledge could play a part in ability to use route guidance information. At present route guidance systems provide information which cannot be tailored to the particular needs or existing knowledge of the individual. However, one of the intended markets for IVRGIS is car rental firms, particularly those based at airports. Clearly, tourists arriving in a foreign country using rental vehicles are a logical target market for manufacturers of route guidance systems. However, if the instructions provided to them have been written by inhabitants of a particular country, who through having lived in that country all their lives have acquired a particular level of generic knowledge of that environment, it is possible that the writers are subconsciously using generic spatial knowledge in determining the meaning intended by the instructions. Other members of the same community, who have acquired a similar level of generic spatial knowledge as a result of extensive experience of similar spatial layouts, are likely to impose the same meaning on these instructions. Overseas visitors, however, may not have the same frames of reference to

refer to, thus what might appear totally unambiguous to an indigenous member of the society may have different connotations for the overseas visitor. Although this might appear a trivial point, it is important when one considers that the same instructions will be used by all groups, regardless of their origins. Moreover, the instructions, by their very nature, will be adhered to in good faith. Given the importance of removing potential ambiguity, research is required that considers the differential effects of guidance information upon indigenous and non-indigenous populations.

4.3 Theoretical approaches to the process of spatial knowledge acquisition

Over the past forty years surprisingly few new theories have been proposed to explain the acquisition development of spatial knowledge. Early theorists (e.g. Lynch, 1960; Appleyard, 1969) were primarily concerned with identifying environmental features that are important in the cognitive mapping process. It was not until the 1970's that formal attempts were made to describe the process. The first attempts were made by developmental psychologists. Two theoretical approaches in particular have been pre-eminent in the cognitive mapping field, and are still widely accepted as being reasonably accurate, (although recently criticisms have started to appear). These theories are described below.

4.3.1 Developmental approaches

In discussing development it is common to think in terms of an "ontogenetic process" - occurring across the lifespan from birth, through infancy and childhood, and on to adolescence and adulthood. However, development is also seen as a process of increased organisation which comes about as a function of interaction between the present level of organisation and discrepancy with the environment (Hart and Moore, 1973; Piaget, 1963; Werner, 1948). Thus, studies of development are concerned with identifying characteristics of these levels of organisation, explaining relationships between these levels, and the process of transformation which takes place from one level to another (Hart and Moore, 1973; Werner, 1948; Piaget, 1963). With regard to the development of spatial knowledge, the majority of approaches have been directly or indirectly influenced by Piaget's theories of child development. Piaget and his colleagues were particularly concerned with the development of the child's cognitive processes. This led to a consideration of the specific area of spatial cognition (Piaget and Inhelder, 1967), a work which has been most influential in the field of environmental cognition. Hart and Moore (1973) combined the stages of cognitive development proposed by Piaget with Werner's

'organismic developmental theory of space' (Werner, 1948; 1957). Werner emphasised that the process of development of spatial cognition can take place at any stage of life and is a process of increased differentiation and hierarchic integration. Werner also pointed out that the developmental progression of microgenesis (short term exposure to selected stimuli, as might be experienced by a driver provided with information about the road network) and of ontogenesis, proceed in the same ordered sequence of stages and so are directly comparable.

4.3.2 The development of spatial knowledge in children

Hart and Moore's (1973) approach can be seen as *transactional constructivism* (Pick, 1976). Transactionalist in that they assert that we cannot understand how spatial cognition works until we understand the transactions that occur between individuals and their environments, and constructivist in that we construct the world from data we have gleaned about it.

As a result of their review of the work of Werner and of Piaget, Hart and Moore proposed three levels of development wherein the child uses an increasingly organised system of reference to make judgements about surroundings. According to Piaget, our earliest forms of spatial awareness consist of overt activities directed at features of our immediate environment. Similarly, Werner maintained that the infant is unable to differentiate between self and environment and reacts passively to stimuli. Consequently, objects are located by their position relevant to the child's own body. Hart and Moore refer to this as an **'egocentric reference system'** which characterises the early infant's view of the world from birth to about 2 years of age[1]. Evidence for the presence of such a system has been provided by a number of studies (Acredolo, 1976; Bremner and Bryant, 1977). Such studies usually involve an infant having to locate an object under one of two pieces of cloth, or a similar arrangement. Having learnt the position of the object (i.e. the cloth under which it is to be found), the infant is then rotated 180 degrees and presented with the same situation. If the object is under the left piece of cloth an infant responding in an egocentric manner will again turn to the left after rotation, responding to the object's position relative to self.

As the child develops more abstract thought (between the ages of 2 and 7) a greater awareness of the relationships among environmental features develops. In early infancy the child is only aware of features with respect to his or her own body, but with the development of an **'allocentric reference system'**(Hart and Moore, 1973), the child becomes more aware of the

[1] Developmental theorists from Werner to Piaget to Hart and Moore emphasise that the exact stage at which each of these stages takes place is of little interest by comparison with how the development takes place. As such, the ages quoted are no more than rough guides.

spatial positions of features in the environment distinct from self. The child becomes increasingly active in initiating actions and is able to differentiate between his own viewpoint and that of others (Werner and Kaplan, 1963). Thus, in the above experiment, after rotation a child responding according to an allocentric frame of reference will this time turn to the right, aware that they, rather than the object, have moved. Hart and Moore propose that through increased experience in the environment the child becomes more aware of fixed points of reference between which (s)he is able to differentiate, but which (s)he is unable to integrate. By age 7 the child has developed an awareness of 'clusters' of features within the environment but is unable to coordinate connections between these clusters; the child has achieved differentiation without integration.

The final level of development of spatial cognition arises by around age 8 or 9. At about this age a level of abstract thought has been developed which allows the child to actively construct knowledge about the world (Werner and Kaplan, 1963). The child is increasingly able to clearly differentiate and integrate a wide range of means and ends and can now adopt the perspectives of others as well as his/her own. This leads to an overall '**coordinated reference system**' whereby the child is able to attach distance and direction to points. Thus, by this stage, the system of reference employed is no longer dependent upon the child's actions. Moreover, the system has become fully integrated, allowing for abstractions across representations and thus enabling wayfinding between places within the environment (Hart and Moore, 1973).

The age at which development from egocentric to allocentric thinking takes place appears to be dependent upon a number of environmental factors. Acredolo and Evans (1980) for example, were able to facilitate allocentric responding in infants as young as 6 months of age, by the use of salient landmarks which facilitate differentiation of the two cloths. Other studies have shown that allocentric responding can be enhanced by: testing the infant in a secure environment, such as the home (Acredolo, 1979); by allowing increased interaction between mother, infant and experimenter prior to testing (Acredolo, 1982); and by rotating the child through 90 rather than 180 degrees (Rieser, 1979). Whilst research (e.g. Evans, 1980) generally supports the Piagetian model of Hart and Moore, a number of researchers have pointed to the possibility that the emphasis on laboratory based studies may have underestimated children's abilities (Spencer and Darvizeh, 1981). Biel (1982), for example, has shown that children as young as 6 years old can make spatial judgements which appear to require perspective taking when using aerial maps. Neisser (1976) suggests that our underestimation of these abilities lies in the fact that children's spatial knowledge at this stage exceeds their verbal abilities.

An alternative view, again following the constructivist assumption that all spatial thought and behaviour is underpinned by spatial representations which undergo a series of transformations, is that of Siegel and White (1975). Their model deals with the organisation and development of psychological systems which enable us to solve problems such as wayfinding.

4.3.3 The development of spatial knowledge in adults

Although Hart and Moore emphasised that ontogenetic and microgenetic development are comparable, their model is primarily concerned with the development of spatial knowledge in the child. Siegel and White also emphasise the comparability between child and adult development of spatial knowledge but, unlike Hart and Moore, specifically outline the development of spatial knowledge in adults.

There are three primary elements to Siegel and White's model, knowledge of which proceeds in a hierarchically ordered manner. The predominant elements are landmarks and routes. When we first encounter a new environment we first identify landmarks. Primarily used as reference points in navigating, landmarks form the beginnings and ends of journeys, help us maintain direction and form frames of reference from which other landmarks can be identified. One's conscious knowledge of where one is going is based on landmark knowledge (Siegel and White, 1975).

The second major element of this model is routes. Whereas landmarks are predominantly visual, routes are considered to be essentially sensorimotor. Between any two landmarks there may be innumerable routes, but efficiency and plausibility reduce this number to just a few. Routes are important in that they give shape to the spatial representation, they represent habitual lines of movement and familiar lines of travel (Lynch, 1960).

Finally, what makes a representation more than a simplified form of map is knowledge of configurations (Siegel and White, 1975). Through experience, the routes which have been learned become integrated into a configurational representation which enables the relationships between landmarks and routes to become co-ordinated into an overview of a region of the environment (Siegel and White, 1975). Such knowledge enhances wayfinding and may be a necessary condition for the invention of new routes. Configurational knowledge, as defined by Lindberg (1984)

"makes it possible to relate oneself spatially to distant landmarks not only by

> means of particular locomotion paths (as would be the case with a so called route map representation), but also in terms of directions and crowflight distances."
>
> Lindberg (1984), p.13

4.3.4 Evidence for the existence of a developmental sequence

Although the approaches discussed differ (for example, Heft and Wohlwill (1986) point out that the knowledge of sequences of landmarks along a route is peculiar to Siegel and White, reflecting the greater emphasis they place upon wayfinding), they are essentially compatible: both adopt a constructivist perspective; both maintain that we rely on environmental features at an early stage of knowledge acquisition; and both see the attainment of configurational knowledge as the final level of achievement.

The existence of different stages of spatial knowledge development is supported by a number of studies. Herman and Siegel (1978), for example, showed that children's ability to construct a model of their environment is dependent upon their developmental level, while Cousins, Siegel and Maxwell (1983) found that children's ability to estimate distance and direction, a task which should require configurational knowledge, was strongly affected by their developmental level: older children being much more capable of completing such a task. Additionally, in their comparison of the methods used to judge distance and direction, Foley and Cohen (1984) showed that subjects more familiar with the test environment are more likely to use map-like imagery in making their estimates, indicating that the spatial cognition of these subjects has reached a level of development whereby they are capable of using configurational knowledge. More recent research (Blades and Medlicott, 1992) has shown developmental differences in childrens' and adults' ability to give route directions from a map. Younger children are found to rely more on landmarks whereas adults and children over the age of 12 include information about type of road junction and road sequences. Younger children are unable to give coherent directions suggesting that their spatial cognition abilities are as yet insufficiently developed to perform such tasks.

There is strong evidence (Shemyakin, 1962; Appleyard, 1970; Evans, Marrero and Butler, 1981) that this developmental sequence proceeds from basic spatial knowledge to a more structured and integrated form. The developmental progression from route to configurational knowledge equates with the distinction made by Shemyakin (1962) between two types of representations: route maps, and the developmentally superior survey maps. Survey maps were characterised by an increase in configurational elements. Appleyard (1969, 1970), in his examination of the maps of residents of Ciudad Guyana, a new industrial city in Venezuela,

asked residents to draw maps of both the whole city and their own particular neighbourhood. From these, Appleyard was able to distinguish between 'sequentially dominant' and 'spatially dominant' maps, the latter, more developed form being evident in neighbourhood maps. Evans, Marrero and Butler (1981) showed that students' drawings of their college campuses started with landmarks acting as anchor points, from which a network of paths evolved which gradually became more and more complex over the course of the year. Whilst various researchers at different times have used different phraseology, the similarities suggest a developmental sequence from basic landmark knowledge through to a more complex and detailed portrayal of the spatial environment.

4.3.5 Information processing approaches to spatial knowledge acquisition

An alternative to the developmental approaches which takes account of both the need for a hierarchical storage system and the psychological development which occurs across the lifecycle has been proposed by Golledge (Golledge, 1978). This approach, the 'Anchor Point Theory', has been developed within an information processing framework which allows for differences between individuals with regard to spatial abilities. The developmental theories outlined above emphasised the importance of the various developmental stages through which spatial knowledge progresses. Increased spatial understanding brings increased awareness of the way that places, which previously were unconnected, are linked together to gradually form a coherent whole (configurational spatial knowledge). Golledge's anchor point theory adopts a similar view, but places far more emphasis upon individual purpose, thus allowing for individual differences within the same environment, and with similar environmental familiarity. Despite adopting a different terminology. (locations, paths and areas substituting for landmarks, routes and configurational knowledge) the basic principles of anchor point theory are similar to those of developmental approaches. The main diversion from developmental theory is that anchor point theory emphasises the relative significance that environmental features have for the individual. Places of significance (home, work, shopping places) anchor the information acquired by the individual and determine the search for paths which connect these *primary nodes* or *anchorpoints*. In addition, the individual gains knowledge of the immediate vicinity surrounding these areas (referred to as spatial generalisation). This is known as first stage areal knowledge. With increased experience in the area the individual becomes aware of second, third and lower order nodes extending out from, and connected to one of these primary nodes. In this way spatial knowledge develops in a hierarchically structured manner. When searching for a specific location, the individual identifies a path, node or area and seeks links to the nearest primary node. These primary nodes, according to the Anchor Point Theory, root or anchor the

cognitive map, and together with the routes which link them, form the basic framework upon which spatial information is represented. The information stored therein can be efficiently searched using a spreading activation process:

> "Proximity to an anchor point, measured in terms of the length and number of path segments connecting such nodes to other related bits of information, will influence accuracy of recall, and ability to make judgements concerning the spatial relations of selected subsets of that stored information. Distance up or down a hierarchy ... will influence fuzziness and distortion components associated with the stored information."
>
> Golledge (1990), p.155

One of the advantages of such a structure is that errors made by an individual (e.g. distance and direction errors, inefficient or unexpected path selection) can be interpreted in terms of the underlying connecting structure contained within the individual's spatial representation (Golledge, 1990).

Golledge's theory is firmly rooted in behavioural geography, placing emphasis both upon features of the environment and their significance to the individual. As such, anchor point theory advances existing theories, because it recognises that environments have different meaning and significance for different individuals. This view is much closer to the transactionalist approach adopted by environmental psychologists, which stresses the importance of purposive evaluation (Canter, 1986). From this perspective it is not sufficient to consider the impact of human behaviour upon environments, nor to consider the impact of environments upon human behaviour. Rather, one must consider the *transactions* which take place between people and environments and in order to do so it is necessary to understand the meaning that people attach to environments as well as the behaviour which is expected within those environments.

4.3.6 Critical appraisal of the theories

The present research considers the various theories proposed to explain the process of spatial knowledge acquisition to be in broad agreement, differences between the approaches tend to be refinements rather than changes to the basic theory. There have been few major theoretical developments in this area in the past 20 years. To some extent this suggests that the theories are accepted by the majority of those working in the field as being accurate, but it is also indicative of the change in research emphasis that has occurred over this period, from attempts to identify environmental features which determine the content of cognitive maps, to a more in-depth

consideration of the cognitive processes underpinning spatial knowledge acquisition.

Developmental approaches to the process of spatial knowledge acquisition have made an important contribution to our understanding of the processes involved in cognitive mapping. Over the past 20 years the developmental approach has provided a useful framework for a wide range of research. The main criticism which could be levelled at developmental approaches is that they have tried to specify a rigid sequence of developmental stages through which all spatial knowledge acquisition progresses. The weakness of this approach is shown by the number of studies which have contradicted this view (e.g. Herman, Kail and Siegel, 1979; Evans, Marrero and Butler, 1981; Lindberg and Gärling, 1983). The aforementioned research has suggested that routes are learned before or at least at the same time as landmarks. Others have shown that extensive experience in an environment does not necessarily result in configurational knowledge (e.g. Moeser, 1988). Such studies suggest that situational circumstances and individual requirements (e.g. purposes with respect to an environment) may play a major part in determining the exact type and sequence of information learned. Hence, it is probable that the exact sequence of spatial knowledge acquisition is by no means as rigid as suggested by developmental theorists, at least not in adults. This rigid sequence has opened up developmental approaches to criticism.

Montello (1997), for example, argues that there is no stage in which only pure landmark or pure route knowledge exists. Furthermore, whereas developmental theorists have tended to argue that at early stages of development little metric knowledge is encoded, Montello argues that metric knowledge is acquired from the outset, and is refined over time. Hence, we start acquiring configurational knowledge from our first exposure to an environment, this knowledge is continuously increased in terms of quantity, accuracy and completeness. From this perspective the process of acquiring spatial knowledge is:

> "one of quantitative accumulation of metric information and its consequent refinement rather than a qualitative shift from nonmetric to metric forms"
>
> Golledge and Stimson (1997)

In light of research which has provided contradictory evidence, Montello's criticisms are valid, but in the view of this author, should be considered as refinements to a well-established and largely robust theory, rather than a rejection of the theory *per se*. The present thesis favours Siegel and White's conceptualisation of landmark, route and configurational knowledge as a logical progression from limited to more in-depth knowledge. It is interesting to note that,

whilst within cognitive mapping research much debate has centred on refining details such as the exact sequence of knowledge acquisition and the ages at which these changes occur, outside the discipline it is still common to see Lynch's (1960) typology portrayed as the last word on the matter (e.g. Daimon, Kawashima and Akamatsu, 1997).

Anchor point theory has improved our understanding of the impact of previous experience and meaning on the cognitive mapping process, and as such is an important development in cognitive mapping research. However, for the present research anchor point theory is less useful in that it focuses on past experience and familiar environments. The present research, concerned with the development of spatial knowledge in unfamiliar environments, requires a model of the process that charts the development of knowledge from totally unfamiliar through to full and detailed knowledge. For this reason the research follows Siegel and White's approach.

4.4 Factors affecting the contents of cognitive maps

This section reviews findings regarding the contents of cognitive maps and factors which might affect the acquisition and development of spatial knowledge. Section 4.4.1 concentrates upon features of the environment which are memorable and what makes these features memorable. Section 4.4.2 considers the impact of visual and audible environmental information upon distance and time estimates and discusses the attentional allocation model (Thomas and Weaver, 1975) which has been proposed to explain the process by which we perceive and estimate time. Section 4.4.3 is concerned with factors within the individual which affect the contents of their cognitive maps.

4.4.1 Environmental factors

While it is important to know how cognitive maps develop, it would be helpful for route guidance system designers to know what features of an environment are retained and how these are organised in an individual's cognitive map, in order that route guidance and information can be based around the most memorable features. Cognitive maps develop not only in terms of the quantity of information they contain, but more importantly in terms of the quality of the detail contained. Indeed, developmental theorists emphasise that development is a process of increased differentiation and organisation. The development of spatial knowledge results from a discrepancy between what is observed in an environment and what has been stored in the

individual's cognitive map of that environment (Hart and Moore, 1973; Moar and Carleton, 1982; Siegel and White, 1975; Thorndyke and Hayes-Roth, 1982).

The content of an individual's initial representations of a new environment have been the subject of much debate. Early theories (e.g. Siegel and White, 1975) suggested that route schemata were essential to the acquisition of cognitive maps. Our initial representations are composed of distinctive landmarks within the environment, but with very little information regarding the spatial relations between landmarks. With increased experience, more knowledge is acquired of the sequential order of landmarks along a route and eventually the routes learned may become integrated into a configurational representation of the environment, what is referred to as 'survey knowledge' (Siegel and White, 1975).

Siegel and White emphasised the importance of routes in the development of spatial knowledge. They were seen as the building blocks of cognitive maps because each route caused a new representation to be formed and through increased experience these separate representations became incorporated into one overall representation of an area. However, some have argued (Byrne, 1979; Moar and Carleton, 1982) that the emphasis upon routes was perhaps overstated. Rather than having to acquire a separate schemata for each route and then combining them into a more global picture, Moar and Carleton (1982) found that if the routes intersect in an obvious manner a cognitive map may be formed which is based on the network of routes rather than separate schemata for each.

What makes a landmark?

Clearly, some environmental features will be more memorable than others, but the extent to which these can be identified as universal constants is questionable. Early research such as that by Lynch (1960) concentrated upon the identification of distinctive features of the environment. In his seminal work on environmental cognition, Lynch (1960) proposed a five element classification system for investigating the contents of cognitive maps of familiar urban environments. These five elements were landmarks, nodes, paths, edges and districts. Lynch used these elements to examine people's elicited representations (sketch maps, verbal descriptions, lists) of their home city.

Landmarks are defined as easily identified elements of the environment (Lynch, 1960), they can be natural (e.g. a large, distinctive tree) or man-made (e.g. statues, tall distinctive buildings). Paths are channels allowing mobility either on foot or in some vehicle. Nodes are focal points such as roundabouts at which behavioural decisions have to be made. Edges are seen as barriers

(such as rivers, railway lines) which divide the city into areas or districts, sharing some common characteristics (e.g. business and residential districts). A problem with this classification system, however, is the difficulty of identifying universally accepted distinctive landmarks.

Appleyard (1969), in his research into why buildings are known, took distinctiveness a stage further by incorporating societal and cultural context, as well as historical and local significance as features which might influence recognition. More recent work (Kaplan, 1976; Gärling, Böök and Lindberg, 1984; Golledge, 1978; Mainardi-Peron, Baroni, Job and Salmaso, 1990) supports Appleyard's suggestion that distinctiveness is not limited solely to the physical features of a landmark. Certainly a building which is visually distinctive will be perceived more readily, but this is affected by the landmark's *inferred* distinctiveness: a building may stand out from other features in an environment because we know something about its structure which sets it apart from its neighbours, despite visual similarities. This would imply that inferred distinctiveness is highly subjective, based upon the individual's past experiences, whereas a landmark which is truly visually distinctive would be so for all who view it. Furthermore, a building may be perceived as functionally distinctive, having some particular salience for the individual, or serving a particular function. This element of subjective salience is likely to produce a cognitive map which, in addition to features of the environment such as routes and landmarks, will also include non-spatial information (Gärling, Böök and Lindberg, 1984; Golledge, 1978; Hirtle and Jonides, 1985).

In addition to distance, direction and landmark information, an individual's cognitive map of a familiar area might contain information such as availability of different resources (e.g. leisure facilities in the area), socio-economic and demographic information regarding the likely population of the area, public transport information such as bus routes, and journey times which might be expected. A particularly well developed cognitive map of a familiar area is likely also to have imprinted upon it the fluctuations in traffic (human as well as motorised) which might occur due to time of day, day of week and seasonal variations such as school holidays. A point to emphasise here is that differences between the cognitive maps of individuals familiar with an environment are likely to result from the different lifestyles, goals and aims, environmental roles, cultural and socio-economic differences of the various actors within that environment. As a consequence, it is difficult to draw firm conclusions regarding these differences when dealing with environments familiar to the individuals under investigation. For this reason (amongst others) the present research will focus upon an environment unfamiliar to the subjects.

Several recent European projects (Alm, 1990; Alm and Berlin, 1991; Burnett, May and Ross,

1994) have attempted to specify features to which IVRGIS instructions should refer and which will be distinctive for all who observe them. As a result of work investigating drivers' cognitive models of routes, Alm (1990) suggested that traffic lights, orientation and traffic signs, petrol stations and shops would be the most suitable for route guidance. A follow-up field study (Alm and Berlin, 1991) indicated that the inclusion of landmarks in a guidance system can have positive effects on a driver's ability to follow a route. Alm and Berlin (1991) suggest that a reduction in perceived workload, increased confidence in the location of the next turn and reduced navigational errors might all arise from including landmarks in route guidance instructions. However, it should be noted that Alm's work pre-dates the inclusion of audible guidance and therefore refers to the use of screen-based landmarks. Consequently, perceived workload was measured by comparison with screen-based instructions, and as such is of less relevance than more recent work discussed below.

As part of a study aiming to improve the quality of information provided by route guidance systems Burnett *et al.*,(1994) found that for route guidance purposes the most suitable landmarks for the UK were traffic lights, pelican crossings, bridges over the current road and petrol stations. However, of more importance for the present study are the reasons cited by Burnett *et al.*, (1994) for these being 'good landmarks'. They cite the following :

- permanence;
- visibility;
- predictability in appearance and location;
- uniqueness;
- degree of separation;
- usefulness of location.

Although at first sight the landmarks selected as most suitable seem to paint rather a dull picture of the urban landscape of British towns and cities, in relation to the provision of route guidance information it is clear that these are good choices. In particular, their permanence and predictability of appearance ensure that they will probably still be present in the future, and will still look the same. These are issues directly relevant to designers of route guidance systems, for whom the credibility, salience and reliability of information are of utmost importance.

Affordances

Gibson (1966, 1979), in proposing his alternative theory of visual perception, introduced the idea of 'affordances' - the *functional* significance and meaning an environment is perceived to hold for the viewer. As goal seeking is an essential part of automobile travel (Appleyard, Lynch

Lynch and Myer, 1964) it is important to consider the affordances that an environment, or any aspect of that environment (such as an IVRGIS) provides an individual, as they will naturally affect the individual's behaviour in that environment. The concept of affordances is central to a transactionalist approach to person-environment relationships in that it recognises that an environment may offer and signify different things to individuals dependent upon their purposes for being in that environment. In this way the transactionalist nature of such relationships is emphasised: the environment offers the individual opportunities for activity and behaviour, while individuals bring a range of purposes with them to the environment which will shape their interpretation of that environment and the extent to which they perceive these affordances within the environment.

4.4.2 Distance and time estimation and the effect of environmental features

Distance estimates made by subjects using their encoded mental representations have been shown to be influenced by (amongst other things) the amount of spatial detail encountered along the route. The number of turns and route sections encountered (Briggs, 1973; Byrne, 1979; Thorndyke, 1981), barriers such as rivers that are traversed (Canter and Tagg, 1975; Milgram and Jodelet (1976), or for train and underground travellers, the number of stations passed through, (Canter, 1977) may all influence estimates of distance travelled.

A similar effect may be at work with regard to journey time estimations. In the small scale environment of a laboratory set up, temporal judgements have been shown to be dependent upon the spatial context in which they occur (a phenomenon known as the Kappa effect, see Cohen and Cooper, 1962; Cohen *et al.*, 1963). For example, when two lights are flashed and subjects have to estimate the time lag between the two flashes the distance of separation between the two lights has a strong influence upon the temporal estimate made. Similarly, laboratory experiments have shown the reverse to hold true, that spatial judgements such as length are dependent upon their temporal context (the Tau effect) (Cohen and Cooper, 1962; Cohen *et al.*, 1963). Whilst many of these observations have been made with regard to estimations of short lengths and durations and under laboratory conditions, the interdependency of spatial and temporal judgements may well apply over longer durations and in natural conditions. Studies of spatial knowledge provide indirect support for this view.

It is possible that a large scale space version of the Kappa effect exists, i.e. the estimates we make of journey times are influenced by the spatial context in which they are made. Rarely do we know the length in distance of a route or journey to any degree of accuracy. Time

estimations are even less certain - whilst the distance travelled over a particular route may not vary from day to day, the time taken to travel that distance may vary dramatically between separate experiences. Thus, when called upon to make estimates of journey time, it is likely that we use all information available to us, inferring journey times by using information about the distance and speed travelled. In making time judgements we are essentially recalling our representation of the journey and estimating duration from this. The existence of the Kappa effect would imply that these temporal judgements are dependent upon the amount of spatial detail present. Of course, the main aim of our cognitive processes in making such estimates is to make as good an estimate as possible based on a 'most likely' heuristic, thus in the majority of situations, the presence in the representation of more spatial information is a good indicator of having travelled further and for a longer duration. Encoding spatially dense or complex journeys requires more information processing which takes longer, as does the recall process, leading to overestimates of journey time.

This view is in broad agreement with the dominant model of the perception and estimation of time, the attentional allocation model (Thomas and Weaver, 1975). This model states that temporal information is obtained from both an internal timer and a visual information processor, which share attention. The output of the timer becomes less reliable as the visual information processor captures more attention. Thus, as the amount of information to be perceived increases this requires more processing and so less attention is available to focus on the temporal information. As a consequence, ability to estimate time will be impaired. This has the effect that, during tasks which require a lot of attention, such as complex or absorbing and interesting tasks, we tend to underestimate time, whereas during boring, easy tasks we tend to have more attention available to focus upon the timer and thus times are overestimated. Clearly this has important ramifications for studies which require subjects to estimate duration whilst performing another task. If the task is visually complex and requires a lot of attention, then the accuracy of subjects' temporal estimates are likely to suffer as a result. To date, however, research has only considered the impact of visual information upon the temporal processing mechanism. The present study will attempt to advance our understanding of these processes and offer further support for the attentional allocation model by providing individuals with additional audible information in addition to the visual information which all subjects are exposed to. Thomas and Weaver's model suggests that subjects required to attend to verbal messages will have less attention available for the temporal processor and consequently will make more inaccurate estimates of duration.

In natural situations a similar effect may be apparent. The spatial detail present in an environment requires information processing, particularly when we are driving. Thus, the visual information processor will capture more attention than the temporal information processor when we are travelling through an environment. Of course, as Thomas and Weaver (1975) point out, for longer durations it may be possible to switch attention between the two processors, thereby re-establishing the accuracy of the timer. However, when driving, the demands placed upon the driver (controlling the vehicle, maintaining course, navigating, avoiding other vehicles etc.) and the information processing demands that they place upon the individual, suggest that the timer will receive very little attention over the course of a journey. It would be interesting to compare journey time estimates of passengers and drivers travelling in the same vehicle: if the above hypothesis is correct passengers should make more accurate estimates of journey time than their drivers.

4.4.3 Factors located in the individual

From an information processing perspective, wayfinding and navigation can be broken down into a number of interrelated processes: an information gathering and organising stage which leads to the development of a cognitive map; the formation of an action or travel plan; and finally, the execution of the travel plan (Gärling, Böök and Lindberg, 1985). Central to each of these processes is the information available to the individual. Information about the environment can be obtained from various sources: relevant media; word of mouth; direct observation; and from the individual's cognitive map of the environment. We have seen that a number of cognitive mechanisms are employed to reduce and select information. However, one of the most important aspects of cognitive maps, and one which has all too often been overlooked by researchers from all disciplines, is the extent to which an individual's cognitive map of an environment reflects his or her purposes within that environment. In related areas, Canter (1983) emphasised the purposive nature of people's evaluations of places, Ittelson (1973) pointed out the extent to which perception directs purposeful actions, and previously Gibson (1966, 1979) argued that people perceive environments within the framework of 'affordances'- the functional significance and meaning an environment holds for the perceiver, i.e. how the environment is seen to be able to assist the individual in the completion of personal aims. Clearly, such evaluations will be highly dependent upon the individual's reasons and purposes for being in the environment: these will influence the meaning and significance the individual attaches to the particular setting and will consequently shape the individual's behaviour in that environment.

Environmental roles

The interactions which take place between people and environments are ongoing activities and are thus difficult to specify for any given point in time (Canter, 1977). Similarly, with respect to cognitive maps, whilst research has attempted to identify specific features which can be predicted to be included in an individual's cognitive map of an environment (reviewed by Evans, 1980), the wide variation of factors identified suggests that this may be more difficult than was originally thought. Certainly, it would be useful for IVRGIS designers to know which environmental features are most 'memorable', so that such features can be included when giving route directions, but the point is that such features are not *universally* memorable. Rather than trying to identify specific aspects of the environment or the individual which might affect environmental cognition, an alternative approach is to consider the pattern of interactions that an individual has in a particular place. It was noted earlier that much of our behaviour is strongly goal orientated, and thus we base our evaluations of an environment partly upon the extent to which it facilitates these goals. Consequently, the role that an individual has in, and with regard to, a particular setting - their environmental role (Canter, 1977) - will have a major influence on the way that they conceptualise that setting. Unlike observations of behaviour made at a specific time which might be in isolation, a person's environmental role is likely to be built up over a much longer period of time, reinforced by repeated occurrences and as such is likely to be a good predictor of their likely behaviour in that particular setting (Canter, 1986).

This is a key concept which has direct significance for route guidance system research. Goal seeking is an essential part of automobile travel (Appleyard, Lynch and Myer, 1964). Therefore, it is important to consider an individual's purposes with respect to the environment and the consequent affordances that environment is perceived to provide, as these will naturally affect the individual's conceptions of, and behaviour in, that environment. Clearly, a driver's evaluation of an environment can be expected to differ from that of a pedestrian. Similarly, in providing the driver with information about the route, features considered obvious, memorable and salient when *standing* at a particular vantage point may not be so considered when moving through the environment in a car travelling at speed. Additionally, recognition of purposes and affordances helps us to understand the ways in which different *groups* of drivers evaluate driving and the particular network on which they habitually travel. For a commuter driver, the primary aim is to reach their workplace by a specific time, and therefore the car, the network and the prevailing conditions thereon will be evaluated in terms of the extent to which these hinder or facilitate this goal. By contrast, for a driver who uses the car as part of their job, such as a taxi driver or sales representative, for a large part of the day the car is their workplace. For such drivers, their evaluation of driving and of the network will be shaped by the extent to

which these make performance of the job easier or more difficult (Jackson, 1992). This is an important concept for IVRGIS design, suggesting that designers should consider different drivers' goals, how the environment facilitates or hinders these goals, and how guidance information should be tailored to suit these goals.

A good example of the influential nature of environmental role and of the affordances offered by an environment is provided by Moeser (1988). In her study of nurses' knowledge of a complex hospital setting Moeser (1988) showed that nurses who had been working at the hospital for two years had developed good route knowledge but had very limited configurational knowledge. By contrast, she demonstrated that a group of subjects with no prior experience of the hospital could develop good configurational knowledge after an intensive training program involving learning floor plans of the building. If we consider the environmental role of each group, the reasons for the results become clearer. The environmental role of the established nurses would have been shaped by the extent to which the hospital facilitated their work. The spatial representation they formed of the environment was specifically aimed at enabling them to achieve their primary objectives in relation to that environment, consequently they obtained excellent knowledge of the routes between places which they traversed daily. As such, their representation would have been particularly strong with respect to these routes. This was sufficient for them to perform their duties efficiently. Configurational knowledge was not acquired because such a depth of knowledge was not required, indeed learning such detail could have had a detrimental effect upon their primary task, that of carrying out their nursing duties.

By contrast, the naive group - psychology students fulfilling part of their course requirements - would have had a relatively weak environmental role. They had a clear motivation for performing well and indeed were subjected to the procedure until such time as they had obtained a perfect score, the lack of a relationship with the test environment turns the exercise into little more than a memory testing exercise for the naive subjects. The clearest point to emerge from the study is that rather than indiscriminate learning taking place, individuals adopt a purposive approach to learning about their surroundings; their learning is specifically oriented to the goals which they have to achieve with respect to the environment. For the naive subjects this entailed acquiring a comprehensive configurational knowledge of the environment. For the nurses learning the spatial environment was only important in the extent to which it allowed them to competently perform their nursing duties.

Familiarity

Whilst Moeser (1988) demonstrates the modulating effects of environmental role on the influence of familiarity in spatial cognition, it is clear that familiarity does play a significant role in the process. As we become more familiar with an environment our experience of the area increases not just the amount of information we obtain, but also the differentiation and integration of that information. Appleyard (1970) found that with increasing length of residence (and thus increased familiarity) the use and frequency of spatially dominant maps increased. Similar results have been reported by Evans *et al.*, (1981). More recently, a number of studies (Gale, Golledge, Pellegrino and Doherty 1990; Mainardi-Peron, Baroni, Job and Salmaso 1985, 1990) have offered further support for the influential nature of familiarity and in doing so have explored the concept in more detail. Gale *et al.*, (1990) argue that familiarity exists along four dimensions: locational knowledge, visual recognition, place name recognition and interaction with the place. A further distinction is made by Mainardi-Peron *et al.*, (1985) in differentiating between acquaintance and functional familiarity, the latter referring to repeated contact with a place for a specific purpose - goals being attained through activity occurring in the place.

Other factors

In his review of environmental cognition research, Evans (1980) identified a number of factors within the individual which could account for differences in cognitive mapping ability. The wide range of methods which have been employed at various stages of experiments however, (e.g. source of information, methods used to elicit representation) could account for much of the variation between studies. Two potential factors have prompted a large body of research in associated areas. In particular, spatial ability studies have concentrated upon gender- and age-related differences in spatial abilities.

Gender

It is a commonly held belief that males are in some way inherently superior to females in wayfinding and navigation ability. Studies of gender differences in spatial ability have shown less conclusive results, although Maccoby and Jacklin (1974) in their review of the research carried out prior to 1974 also drew the conclusion that males exhibit superior performance at spatial tasks. Subsequent analysis using sophisticated meta-analysis techniques has prompted a re-evaluation of previous research. Meta-analysis allows the researcher to summarise the results of a number of studies with a single estimate of effect size (in this case, the mean standardized difference between male and female scores on each particular test). Hyde (1981), for example, found that gender accounted for only 5% of the variance in the spatial tasks sampled by Maccoby and Jacklin. More recently, Linn and Petersen (1985) carried out a meta-analysis of

the effect sizes in the spatial ability studies carried out since Maccoby and Jacklin's review. As a result, they proposed three categories of spatial tests: spatial perception (ability to detect spatial relations amongst distracting information); mental rotation (ability to quickly and accurately mentally rotate two- and three-dimensional figures); and spatial visualisation (ability to manipulate complex spatial information across a number of stages to produce a correct solution). Linn and Petersen (1985) concluded that gender differences were only significant in tests involving spatial perception and mental rotation, hence the nature of the tasks used may have a strong influence upon results.

Others (e.g. Fairweather 1976; Caplan, MacPherson and Tobin 1985; Feingold 1988) however, have argued that a range of other factors might account for differences in spatial ability. Fairweather (1976), in considering spatial abilities in infants, suggests that factors such as the maturation rate, birth order and being left or right handed might all play a part. Caplan *et al.*, (1985) argued that the lack of a common agreement as to the nature of spatial abilities could account for gender differences, while Feingold (1988) suggests that changes in attitudes towards women over the last 30 years have reduced spatial ability differences between the sexes.

Recent meta-analysis carried out on 286 effect sizes from a variety of spatial ability tests (Voyer, Voyer and Bryden 1995) supports partitioning of the various tasks according to homogeneity of effect size as proposed by Linn and Petersen (1985). As a result of their meta-analysis, Voyer *et al.* (1995) conclude that

> "sex differences are most compelling for tests in their (Linn and Petersen's) mental rotation category, large but less consistent for their spatial perception category, and highly variable and frequently non-significant for tests in their spatial visualisation category"
>
> Voyer, Voyer and Bryden (1995), p.262

With regard to wayfinding studies, the conflicting results that have been reported suggest that differences between men and women are predominantly stylistic and dependent upon the situational requirements of the experiment. Men have been found to be more accurate in their ability to locate the direction of landmarks (e.g., Bryant, 1982; Galea and Kimura, 1993; Holding and Holding, 1989), more likely to include more roads and paths in giving directions (McGuiness and Sparks, 1983) and more likely to give directions in terms of the cardinal points and mileage (Ward, Newcombe and Overton, 1986). Women are more likely to refer to landmarks when giving directions (Miller and Santoni, 1986), are more accurate in their recall

of landmarks (Galea and Kimura, 1993) and, in giving directions, are likely to include more items and show a more accurate sense of distance (McGuiness and Sparks, 1983).

Recent research involving wayfinding behaviour in an unfamiliar indoor environment (Lawton, Charleston and Zieles, 1996) showed no gender differences in wayfinding pattern, or in time taken to complete the task, but did show that women made significantly more errors on a direction estimation task than men. Another recent study (Devlin and Bernstein, 1995) showed that men made significantly fewer errors on a wayfinding test and displayed more confidence in their own abilities.

The wide range of results shown in these studies suggest that whilst gender differences do exist with regard to spatial ability, these differences are related more to the style of wayfinding favoured by men and women respectively rather than being indicative of a gender-related superiority in spatial ability. Few of the studies have looked at gender differences in adults. Indeed, Voyer *et al.*, (1995) note that of the 286 studies they included in their meta-analysis relatively few included participants aged 30 or over. Consequently, developmental differences could account for some of the effect. Another important factor is the different way that boys and girls have, until recently, been socialised into the cultural values expected of male and female children. Ladd (1970), for example, found that whereas male children were allowed to roam quite some way from their homes and were encouraged to play in games and activities which develop spatial ability, girls were kept near the home and encouraged to take part in 'female' activities such as playing at cooking and 'keeping house' etc. Recent changes in society have certainly reduced the differences in the way that male and female children are treated. Parents' safety concerns mean that children of both genders are less likely to be allowed to walk to and from school, take public transport, or explore their neighbourhoods alone (Hillman *et al.*, 1990).

It is also interesting to note how few studies have questioned subjects about their driving experience. If motion and activity in the environment are as important to cognitive mapping as has been suggested (Carr and Schissler, 1969; Cohen and Cohen, 1982; Heft and Wohlwill, 1986; Miller and Santoni, 1986) then it is reasonable to assume that navigating and wayfinding whilst driving would enhance these skills, regardless of the gender of the driver. From this perspective, gender differences in spatial ability identified in earlier studies would be accounted for by the disproportionate number of female non-drivers in the adult population. The increase in the number of females who now drive (see chapter 1) would imply that there should be no gender differences between young male and female drivers who have been driving for comparable lengths of time.

Age

Age-related decrements in abilities have been the focus of a large body of research activity and it is accepted that our available cognitive resources decline with age. In particular, activities which require elements of memory are subject to deterioration in performance over the lifecycle. Baddeley (1986) proposed working memory as the general cognitive resource which enables us to simultaneously store information whilst carrying out complex functions. It has been shown that this resource declines with age, and thus it is reasonable to assume that activities which place demands upon working memory will exhibit declines in performance with advancing age. Researchers have considered the effects of *ageing* upon a wide range of activities requiring elements of spatial ability and memory. Kirasic (1991) suggests a useful means of classifying such research. Kirasic considers past research on age-related decrements in spatial abilities in terms of the developmental stages of spatial knowledge acquisition proposed by Siegel and White (1975). Hence, Kirasic considers the effects of age upon the process involved in the acquisition of landmark knowledge, route knowledge and configurational knowledge.

Effects of ageing upon landmark knowledge.

Kirasic characterises landmark knowledge as recognition-in-context memory. Early research in recognition memory (e.g. Botwinick and Storandt, 1974; Drachman and Leavitt, 1972) suggested a fairly stable process showing little decline across the lifespan. However, more recent studies have shown that situational circumstances (particularly context and task complexity) may have an impact upon performance. Perlmutter, Metzger, Nezworski and Miller (1981), for example, showed an age-related decline in ability to recognise features on a simple map. They suggest that ageing affects the encoding of certain information previously considered to be acquired automatically (i.e. requiring no effort on the part of the individual). Other studies which have tested memory for objects in an array (Waddell and Rogoff, 1981), and memory for letters, words and objects in matrices (Pezdek, 1983) also indicate that age affects performance.

Effects of ageing upon route knowledge

In acquiring route knowledge we are identifying a sequence of associations between features perceived in the environment and specific motor actions. Hence, in learning a route, we identify a landmark and learn that at this landmark we must make a left turn. Consequently, route learning relies upon our ability to learn a series of paired associations. Laboratory studies using serial and paired associate learning again suggest that there is an age-related decline in performance. However, as Kirasic (1991) points out, studies of route learning in natural situations are rare. Ohta (1983) compared ability to learn an environment by viewing a

videotaped tour of a model of the area with ability to learn the environment simply by viewing the model from various viewpoints. Under both conditions, Ohta found older subjects took longer to learn the relationships between landmarks and locations, suggesting that route learning in a novel environment would pose more problems for older than younger adults.

Effects of ageing upon acquisition of configurational knowledge

One of the characteristics of configurational knowledge is the ability to infer new routes between untravelled locations within an area. This ability has received more direct attention from cognitive mapping researchers. Research (e.g., Herman and Coyne, 1980) has shown that older adults have difficulty acquiring and manipulating multiple perspectives of large-scale environments. The complexity of the operations required to produce configurational knowledge may account for this difficulty. Configurational knowledge requires a number of simultaneous operations to be performed. First, previously acquired multiple perspectives of an area must be retrieved from long term memory. Second, these separate representations must be held in a temporary memory store, whilst being manipulated to identify possible common parts. Once these common links are identified, true configurational knowledge is evidenced by the ability to infer new routes between previously unconnected locations within the area. Clearly, these complex cognitive operations will place additional demands upon a number of available cognitive resources. It is reasonable to assume, therefore, that, as with landmark and route knowledge, configurational knowledge will be subject to age-related decrements in performance. Moreover, the complex nature of the varied operations required to produce configurational knowledge suggest that configurational knowledge will show a greater age-related deficit than either landmark or route knowledge.

In her study of young (mean age 24.3 years) and elderly (mean age 70.1 years) women's performance on a range of wayfinding-related tasks, Kirasic (1991) tested subjects in familiar and unfamiliar shopping environments. She found little evidence for a general age-related deficit in spatial cognition: in the familiar environment elderly adults were found to perform as accurately as young adults on tasks involving route execution, distance ranking and map placement. Kirasic did find some evidence for an age-related decrease in the efficiency of spatial learning: in two tasks which had been hypothesised to place significant demands upon working memory, elderly adults performed more accurately in the familiar than the non-familiar environment. Kirasic accounts for these findings with reference to the cognitive resources available to the elderly wayfinder:

> "The effect of environmental familiarity on elderly adults' performance in these tasks is consistent with the interpretation that the combined storage and transformation demands of these tasks in the novel setting strained available cognitive resources, whereas the accessibility of locational information from long-term memory prevented such strain when the tasks were performed in the familiar setting."
>
> Kirasic (1991), p.16

4.5 Summary and conclusions

This section has reviewed research into cognitive mapping carried out over the last 40 years. The review has summarised: how and why the human cognitive mapping system evolved; how spatial knowledge develops both in children and in adults; the representational format in which spatial information we acquire about environments is stored; the cognitive structure of this information; and finally, factors which affect the acquisition of spatial knowledge.

The following is a summary of the most important of these findings.

4.5.1 Cognitive maps and cognitive mapping

- Cognitive mapping is a process through which we acquire, encode, store, manipulate, recall and use information about our spatial surroundings.

- Having reviewed the various theoretical approaches to the acquisition of cognitive maps, the framework adopted for this research is the constructivist-representational theoretical perspective proposed by Siegel and White (1975). This approach considers cognitive mapping to be a process whereby individuals actively construct knowledge of the environment from a wide variety of sources into a representation of that environment.

- Cognitive maps develop from a basic knowledge of key points such as landmarks, to a knowledge of the surrounding area and then to knowledge of the routes which connect these primary nodes with lower order nodes. With extensive experience in an environment a higher level of spatial knowledge, configurational (or survey) knowledge may develop, although this need not necessarily be the case. Similarly, the sequence of knowledge acquisition (Landmarks-routes-configurations) may differ from individual to individual and from situation to situation depending upon the specific aims of the individual with respect to the environment in question.

The importance of landmarks in forming cognitive maps suggests the following hypothesis:

Hypothesis 7

H_1: Subjects hearing route guidance which makes reference to salient landmarks visible in the immediate vicinity of turns will perform significantly better than the control group (who hear nothing) at the cross route pointing task.

H_0: There will be no significant differences between subjects in their performance of tasks regardless of the type of information they hear.

- It is likely that spatial information is stored in a hierarchically structured format. With increased experience in an environment this information is subject to a process of increased organisation and differentiation.

- The cognitive mapping process is purposive. We acquire information from a range of diverse sources, which is stored in long term memory until such time as it is required. Cognitive maps are created using information acquired over time, in order to solve specific problems, such as a navigation or wayfinding exercise. The nature of the problem defines the content of the cognitive map formed.

- Cognitive maps are liable to distortions and errors. Some have argued that these distortions are the result of the method used to elicit the external representation, others that they are caused by necessary heuristics which are used to help us cope with the vast amount of spatial information we are faced with on a daily basis.

4.5.2 Factors which affect the cognitive mapping process

A number of factors were identified which could account for differences between individuals in the quality of their cognitive maps. Apart from differences in ability to produce an external representation of the contents of our minds (e.g. differences in drawing ability, developmental level, ability to understand the instructions) there are also a range of factors both within the individual and in the environment which will affect the process.

- The main environmental factor identified is the presence and distinctiveness of environmental features, particularly landmarks. Landmarks can be visually or functionally

distinctive, although it is only with extensive experience within an area that functionally distinctive landmarks might be identified.

- Estimates of distance and time are also subject to error. Research has shown that, the amount of spatial information present, particularly the presence of 'barriers' (e.g. rivers, railway tracks, motorways) can affect distance estimates.

- The prevalent model of the time estimation process suggests that time estimates might be less accurate in the presence of more information, due to the increased cognitive load associated with attending to multiple sources of information.

The review of the time estimation literature therefore suggests the following hypothesis to be tested:

Hypothesis 8

H_1: Subjects who are required to listen to full route guidance instructions will make less accurate estimates of journey time than those who hear nothing or non-salient information.

H_0: There will be no significant differences between these groups in their time estimation ability.

Age- and gender-related differences in spatial ability have been proposed but the picture is unclear. With regard to gender differences in spatial ability there is some evidence to show that men and women differ not so much in spatial ability but in the strategies they adopt to tackle wayfinding problems. Consequently the present research will not test a gender-related hypothesis. The same could be said with regard to elderly people's use of landmarks for wayfinding: in addition to the aforementioned environmental factors, there is some evidence that elderly subjects place more significance on landmarks with historical importance. However, this aside, age-related differences in spatial ability have shown more consistent results.

- It is widely accepted by gerontologists that there is some decline in spatial ability with age, but the extent to which this will manifest itself is dependent upon the complexity of the task situation, the nature of the environments being tested, the level of familiarity that the individuals have with the test environment and the means used to elicit spatial knowledge.

- Working memory theory (Baddeley, 1986) and research suggests that this decline in spatial ability may result from an age-related deficit in working memory, the cognitive resource

enabling simultaneous storage and operations functions. Working memory can be considered a resource essential to successful configurational learning. Any deficit in working memory is likely to have a consequent effect upon configurational learning.

These two points together suggest a further hypothesis that can be tested:

Hypothesis 9

H_1: Elderly subjects will perform poorly at tasks measuring configurational knowledge, regardless of their performance at tasks measuring lower order spatial knowledge.

H_0 Elderly subjects' performance at tasks measuring configurational knowledge will be correlated with their performance of lower order tasks.

4.5.3 Is IVRGIS capable of expanding and enriching cognitive maps?

Chapter 1 divided Schofer *et al.* 's quote into two parts. The first of these stated that cognitive maps influence spatial behaviour. The research reviewed in this chapter certainly supports this proposition (see for example, sections 4.1.1 and 4.1.2). The second half of the quotation referred to the assumption that Schofer *et al.*, make regarding the ability of IVRGIS to expand and enrich cognitive maps. The simplest answer to this question is that at present we just don't know, and further research is required to enable us to answer the question. However, section 4.1.2 emphasised that one of the problems of the predictions made by Schofer *et al.*, was that they talk of the impact that information will have on cognitive maps rather than on the cognitive mapping process. The research reviewed suggests that the cognitive mapping process is far more complex than the model suggested by Schofer *et al.*, acknowledges. Cognitive maps are the product of an underlying process that involves stages in which different aspects of knowledge are acquired. Whilst it is argued (e.g. Montello, 1997) that there is no stage in which only pure landmark or pure route knowledge exists, it is clear that both aspects of knowledge are required to enable configurational knowledge, and that these three aspects of spatial knowledge together make up the cognitive mapping process. A cognitive map may not necessarily have all of these aspects of spatial knowledge present, whereas the cognitive mapping process is clearly comprised of these aspects of spatial knowledge. It is therefore the process which it is important to study.

The research considered in this and the previous chapter strongly suggests that differences exist between groups in their ability to process additional information (see chapter two) and in their cognitive mapping ability (see this chapter). Consequently, any effects on the cognitive mapping process are unlikely to be constant across all groups. Taking the human factors and

cognitive mapping research together a pattern does seem to appear. In particular, human factors research has shown that elderly subjects require longer to process information (Rothengatter *et al.*, 1995) while cognitive mapping research has shown deficits at all stages of the cognitive mapping process: landmark recognition (e.g. Perlmutter *et al.*, 1981) route learning (Ohta, 1983) and integrating this information into a configurational representation (e.g. Herman and Coyne, 1980). From this research it would appear that this group might well be best placed to benefit most from IVRGIS but are least able to use the information effectively. The picture is much less clear with regard to other groups (e.g. younger subjects, subjects with different levels of driving experience, indigenous and non-indigenous subjects), a situation that the present research aims to address.

Spatial knowledge develops as a result of discrepancies between stored knowledge and information present in the observed environment (Hart and Moore, 1973; Piaget, 1963; Werner, 1948) and therefore, providing information alone is insufficient to lead to more complete cognitive maps. Fundamental to this process is a purposive element: we actively construct our cognitive maps to address specific needs. Unless IVRGIS can be tailored to provide individual-specific information they are unlikely to be capable of providing information that is capable of enriching and expanding existing cognitive maps.

The review chapters have met the first two research objectives of this thesis, namely to identify and review research which can inform our understanding of the possible impact of audible information, and to design hypotheses that can be tested through a series of suitable experiments. The next chapter will tackle the third research objective by reviewing methodologies available for the study of the cognitive mapping acquisition process in order to design an experiment suitable for investigating the possible effects of audible guidance on these processes.

5 A REVIEW OF EXPERIMENTAL METHODS USED TO STUDY THE COGNITIVE MAPPING PROCESS

5.1 Introduction

This thesis considers the effect that hearing route guidance information about an unfamiliar area will have upon an individual's ability to acquire a cognitive map of that area. The method adopted to study this issue clearly needs to have the potential to provide subjects with an adequate knowledge of the study area. In addition, however, subjects need to be provided with additional information as would be the case if they were using a route guidance system. This is a research issue which has not been studied previously. Consequently, there is no standard method which can be used, and so a review of previous research methods used to study the acquisition of spatial knowledge was undertaken. This chapter discusses these various approaches (section 5.2) with a view to selecting one suitable for the present experiments. A full description of the research method finally adopted can be found in the next chapter. Before discussing previously used methods, however, the chapter begins with a discussion of the problems which surround cognitive mapping research and considers ways of solving these problems.

5.1.1 The problematic nature of cognitive mapping studies

Cognitive maps are, by their very nature, highly problematic structures to study. The cognitive map is a hypothetical construct (MacCorquodale and Meehl, 1953) which it is assumed exists, but evidence of its existence can only be inferred from external versions (e.g. sketch maps) of this cognitive representation. However, although we cannot categorically verify its existence, it is beyond question that some form of cognitive structure containing spatial information exists.

The study of the properties of mental representations, by necessity, involves making inferences from the observable product of some cognitive task. Moreover, the form taken by the presented information will affect what is processed and how it is processed (McNamara, 1991). This makes the study of cognitive maps highly problematic: we make inferences about the cognitive processes taking place on the basis of elicited representations; but the elicited representation depends firstly upon the internal representation from which it is derived, and secondly from the manner in which it is elicited; moreover the internal representation formed is dependent upon the information originally presented to the individual. These three elements: information presented; knowledge acquired; and representation or knowledge elicited; need to be considered before any conclusions

can be drawn.

5.1.2 Type of information presented: primary versus secondary learning

Under natural circumstances we draw on a wide range of diverse sources for the information we will use for wayfinding and navigation, and store as cognitive representations. In this respect, a distinction has been made (Presson and Hazelrigg, 1984) between two types of learning which are a function of the type of information available to the individual. When we come into direct contact with an environment, for example through wayfinding or directly navigating a route, the knowledge we gain is acquired through *primary learning*. By contrast, *secondary learning* occurs when we acquire knowledge about an environment via some source other than the environment itself, for example via a map, model, verbal or written instructions, video or photographic slides. The central issues here relate to the extent to which experimental studies employing indirect experience of an environment can replicate, or at least approximate, the natural acquisition process, and the extent to which the information thus acquired can be compared to that gained as a result of direct experience.

Ideally, the study of the acquisition of cognitive maps would involve people naturally acquiring knowledge about real areas through direct contact with the environment in question. In reality however, such a procedure would prove problematic. Cognitive maps are exclusive to the individual: two people experiencing an environment will form a cognitive representation with some shared features, but each will have different emphases depending upon the particular purposes of the individual. In other words, although the information available to each individual may be the same, the information selected for inclusion in the cognitive map of each individual may be very different. In an effort to control such potentially wide variations researchers have attempted to standardise the information given to the individuals by the use of secondary learning sources. Of course, the use of secondary sources is also more convenient, more economical and less time consuming than exposing large numbers of subjects to a specific natural environment. Research employing these indirect experiences of an environment aims to maintain the realism of direct experience, but with additional experimental control.

A review of previous approaches employed suggests that there is some disagreement regarding the ability of subjects to acquire spatial knowledge from secondary learning techniques. While a number of studies (Allen, Siegel and Rosinski, 1978; Cornell and Hay, 1984) have shown that it is difficult to obtain configurational knowledge from secondary learning alone, other studies have

suggested that subjects can acquire good configurational knowledge as a result of a combination of secondary learning and exposure to the test environment. Hunt (1984) has shown that subjects who have experienced an environment via video simulation in conjunction with viewing a model of that environment, can develop good wayfinding abilities. Moeser (1988) demonstrated that configurational knowledge could be acquired in a short space of time through intensive learning involving studying floor plans of the building. Hunt's and Moeser's results have been offered as examples of situations where configurational knowledge obtained through secondary learning can be used in the real environment (McDonald and Pellegrino. 1993). In both cases, however, it should be noted that, in addition to the knowledge gained from some form of secondary learning, both Hunt's and Moeser's secondary learning groups were given additional help which could be construed as varying forms of direct or primary experience of the environment. In particular, Moeser's naive group were given a tour of the hospital, which could have helped to articulate the spatial representation they acquired through studying the floor plans, in much the same way that conventional primary learning would contribute to the development of an internal representation. This objection apart, the study does demonstrate that configurational knowledge does not *necessarily* develop as a result of prolonged experience in an environment.

5.1.3 Type of knowledge acquired

Procedural versus declarative knowledge

Section 3.3 discussed Anderson's (1978, 1982) theory of skill acquisition, with regard to the development of driving skill. With regard to wayfinding and navigation, salient objects are represented in the form of declarative spatial knowledge and enable the individual to know of, and recognise these features upon encountering them. Declarative knowledge is the precursor to procedural route knowledge. When given directions to get to a new destination, we learn these directions and instructions in much the same way as we would any other list. Consequently, it is only through repeated practice that this declarative knowledge is turned into procedural route knowledge. Routes that we are familiar with, on the other hand, being composed of a series of decision points, are represented as procedural spatial knowledge (Gärling and Golledge, 1989). Procedural route knowledge

> "...consists of well-learned response patterns which exist in a functionally compact or 'compiled' form that may be relatively inaccessible to conscious processes."
>
> McDonald and Pellegrino (1993) p.56

Initially, our route knowledge is in the form of declarative knowledge: a list of objective facts

which, when combined, enable us to get from one place to another (e.g. Turn left, walk 100 metres, turn right etc.). To travel the route we need to recall these instructions in the correct sequence. With more experience this declarative knowledge becomes increasingly proceduralised: knowledge of the route becomes more and more automated, and eventually we are able to navigate the route with minimal conscious effort.

Procedural knowledge tends to be more abstract in nature than declarative knowledge, concerned with identifying appropriate behaviour for a given situation. It is reasonable to assume that such knowledge will be more difficult to represent in an image format than objective facts about the world. However, whilst it is tempting to assume that declarative knowledge will be stored in the form of images, and procedural knowledge in the form of propositional statements, it is unlikely that such a clear cut distinction exists. Some items will be more amenable to being represented in visual imagery, while abstract concepts will perhaps rely upon propositions to encode the information. Moreover, an individual's total knowledge about an item is likely to be made up of a wide range of images and propositional statements, accumulating over the course of one's experience.

One can 'know' an environment through direct exposure, but this is not necessarily sufficient if one is unaware of the cultural norms and the constructs which impose order within that culture: hence true knowledge of an environment involves giving meaning through imposing order (Rapoport, 1976). It is the cultural norms we learn from previous experience of similar spatial layouts that constitute this meaning. Thus, configurational knowledge is likely to involve the integration of declarative and procedural knowledge bases. In addition, Anderson (1982) suggests that, once proceduralised, further learning processes operate on the skill to strengthen the productions and to enable them to be applied to a wider range of situations. In this sense, the theory has close links to Kaplan's functional adaptation theory of the development of spatial knowledge, discussed in section 4.2.3.

Differences in knowledge arising from primary and secondary learning

Cognitive maps arising from primary learning tend to be full of detail, imprecise, subject to distortions caused by heuristic methods used during the encoding process - (for examples, see Byrne, 1979; Stevens and Coupe, 1978; Tversky, 1981) - and are capable of being manipulated when recalled to suit the needs of the situation (Evans and Pezdek, 1980). In contrast, where we have not experienced the environment directly, for example, when someone describes a route for

us, the cognitive representation formed will normally contain sparse detail. However, at this point a distinction should be made between map-based knowledge (referred to as 'survey knowledge' by Shemyakin, 1962) and other forms of secondary learning. Research suggests that a representation formed from a map in a particular orientation is orientation-specific – i.e. it is retrievable only in this format (Evans and Pezdek, 1980; Presson and Hazelrigg, 1984; Sholl, 1987; Thorndyke and Hayes-Roth, 1982). The success as a wayfinding tool of a mental representation formed as a result of studying a map will therefore depend upon our ability to translate this information into another, more flexible format, one which could be usefully retrieved and utilised at some later date. Research has shown that if locations are learnt from a map, one is likely to make more accurate evaluations of spatial relations (such as distance estimations) connecting the various spatial components than if this information has been acquired by walking through the environment (MacEachren, 1992; Golledge, Dougherty and Bell, 1995). However, this is not to say that map-based knowledge is superior to that acquired from direct experience. The problem solving tasks used to compare the two forms of knowledge frequently favour the map learning subjects. Tasks which compare speed of recall necessarily require only the limited information available within the secondary source (e.g. Moeser, 1988) and thus favour the map learning subjects, whose recall is not delayed by having to sift through other information irrelevant to the task at hand. Similarly, distance and direction estimation tasks favour map learners because these subjects have had a view of the environment as a whole, rather than having to piece together a succession of views of the environment. Moreover, research has shown that it is easier to learn information when it is bounded by some spatial frame of reference (Peruch and Lapin, 1993). A map has clear boundaries which limit the amount of information the individual is exposed to. By contrast, information-limiting boundaries in the real world are far less distinct.

The knowledge gained from prolonged experience within an environment is purpose-driven, that is, it is shaped by the individual's purposes with respect to that environment. This is an essential coping strategy to enable the individual to have any chance of making sense of the vast amount of information available. Consequently, the information about an area contained in a number of its residents' cognitive maps is likely to be very diverse: each shaped by the subjective meaning imposed on the environment and the particular needs and goals of the individual. By contrast, the knowledge acquired from map reading tasks is a function of the knowledge available: the limited information presented produces a limited but accurate representation, but cannot be compared with the vast amount of information available to someone directly experiencing an environment.

A number of studies have attempted to provide configurational spatial knowledge via other forms of secondary learning. Hunt (1984) employed a 3D computer simulation in conjunction with a model of the environment, Cornell and Hay (1984) compared slides and videos with direct experience, while Pearson and Ialongo (1986) used a slide presentation as their source of route knowledge. Recently, Golledge, Dougherty and Bell (1995) have used a 3D computer simulation and compared the knowledge acquired from this with that acquired via a map. Hunt (1984) suggests that subjects can acquire a good degree of configurational knowledge from indirect experience of an environment, as long as the representation they are to learn closely resembles the real environment (e.g. video or 3D computer simulation) and is not limited to one viewpoint. In their comparison of the types of spatial knowledge acquired from maps and slides of a route, Hirtle and Hudson (1991) provide support for Hunt's argument. Subjects found it difficult to obtain configurational knowledge solely from a slide presentation of the route. Hirtle and Hudson (1991) suggest that because the route was presented in a linear sequence, the subjects formed a linear representation and thus it was difficult for them to do the extra processing required to produce configurational knowledge. Map learning subjects, however, had all the information presented to them in one view, thus making it easier for them to gain a configurational representation of the area.

Spatial knowledge acquired from maps would appear to be represented differently from that acquired either from primary learning or from other forms of secondary learning. The survey view of the environment that one acquires from a map does not compare with the front ahead view one has when moving through the environment. It has been suggested that locomotion in space is an almost essential condition for the formation of spatial representations (Lynch, 1960; Carr and Schissler, 1969; Bovy and Stern, 1991). The internal representation acquired as a result of traversing an environment requires the integration of successive views of the environment. Consequently, any attempt to provide spatial knowledge via a secondary source should adopt a front forward view as a means of simulating movement through the environment.

5.1.4 Type of representation elicited

Having discussed the input and the internal processes which operate upon this information, attention must now focus upon the product: the spatial information elicited from the individual. The main problem surrounding any elicited representation of a cognitive map, regardless of how it has been obtained, is whether it can be considered to be an accurate representation of what is actually stored in the mind. This elicited knowledge, be it a sketch map, distance or direction estimation, verbal or written report or model, may only partially reflect what is stored in memory. The information used by a subject during performance of a task designed to measure spatial knowledge by no means includes all that is known by the subject about that environment. Indeed, it has been suggested that an active or working representation is constructed by the subject to complete the specific task in hand (Foley and Cohen, 1984). Alternatively, what has been produced may have been distorted during the encoding or retrieval processes with the consequence that the representation again bears only partial resemblance to what is stored in memory.

This section has attempted to highlight the many pitfalls surrounding the study of cognitive maps. Apart from making research difficult, these pitfalls emphasise how risky it is to make generalisations from one study to other situations. The next section considers the various approaches which have attempted to study environmental cognition while maintaining an awareness of the problems discussed above.

5.2 Methods previously employed to study the development of cognitive maps.

The methods employed to study cognitive maps and the acquisition of spatial knowledge can be divided into three broad categories (Golledge, 1976):

- Experimenter observation of subjects' behaviour;
- Analysis of external representations;
- Indirect judgement tasks.

A number of other methodologies have been employed, (e.g. phenomenological approaches such as analysis of novels, poems, film, paintings etc.) however, these are more concerned with environmental perceptions, attitudes and preferences, rather than environmental cognition per se. Clearly, preference plays a part in choice, but one must first know of an entity's existence to be

able to prefer it. Consequently, such approaches will not be considered here - the present discussion specifically concentrates upon the aforementioned approaches.

5.2.1 Experimenter observation of subjects' behaviour

With regard to observations made of subjects' behaviour two scenarios exist: behaviour exhibited in naturalistic environments and behaviour in response to controlled settings. Behavioural observation has been used extensively to enable researchers to evaluate the effectiveness of signage in natural environments such as nature parks (R. Kaplan, 1976). Similarly, in urban settings, behavioural observation is a useful tool to enable researchers to monitor subjects' natural behaviour and to study the effectiveness of building design (e.g. Uzzell, 1987).

Whilst observation of behaviour in naturalistic environments is preferable in that it concentrates upon natural behaviour in a natural environment, it also carries with it the attendant problem of reduced experimental control. As a consequence many early research studies looked at subjects' behaviour in controlled environments (laboratory based studies). This method has proved particularly useful for studying the development of spatial knowledge in infants and young children (e.g. Acredolo, 1976; 1977; 1978; Herman and Siegel, 1978; Piaget and Inhelder, 1967) where small scale environments can be created and the child's response studied in isolation. Of course, whilst such studies benefit from an increase in experimenter control they do sacrifice the naturalism of field studies. In addition, one should bear in mind the objections raised above regarding spatial frames of reference. Whilst behavioural observation offers a high degree of validity in studying natural behaviour it is less useful in studies which focus upon the development of cognitive maps: clearly behavioural observation alone would not be sufficient, an external representation of the cognitive map has to be elicited. An additional drawback of experimenter observation studies is their reliance upon experimenters' interpretations of behaviour. For these reasons they were rejected as a possible method for the present study.

5.2.2 Analysis of external representations

An alternative method is to allow subjects to 'self-report' the knowledge they have acquired. Self-reports draw on psychomotor, affective and cognitive skills and employ a range of techniques to depict the external representation, for example verbal and written reports, sketches, map and model making (Golledge, 1976). As has been discussed, the form of this external representation will be heavily influenced by the mode of presentation of environmental information.

Early contemporary research (e.g. Lynch, 1960; Shemyakin, 1962; Appleyard, 1969; 1970; Ladd,

1970) relied heavily upon the use of subjects' sketch maps as a means of representing cognitive knowledge. However, the problematic nature of such methods has been emphasised. Problems commonly cited include: inter-subject differences in verbal and drawing skills; developmental differences in spatial abilities; the demand placed on subjects to produce a 2D aerial representation of a 3D environment; and the subjective nature of comparing and evaluating the sketch maps of different subjects. Another criticism of sketch studies centres on the chance errors which could occur during the sketching process. A slip of the pen could easily be misinterpreted as some distortion present in the subject's cognitive map. These problems prompted a search for alternative methods of investigation.

Initially, alternatives centred on removing the drawing element from the task by, for example, providing subjects with standard items to represent roads, buildings, etc. and asking them to construct a 'map' with these elements. This technique is still perhaps the simplest way of overcoming this objection. Another approach has been to try to standardise the task for all subjects by providing them with an 'environmental mapping language' (Wood and Beck, 1976) which could replace the wide semantic variations in people's sketch maps. However, whilst reported results (Beck and Wood, 1976) suggest that the technique is quite successful, the effort and time required to train subjects in the use of 'Environmental A', as Beck and Wood's methodology was known, have perhaps prevented it from becoming a standard within the field.

Recent research (Blades, 1990) however, has prompted a re-evaluation of the sketch map approach as a means of eliciting spatial knowledge from subjects. A number of commentators (notably Newcombe, 1985) have voiced their reservations about the proposed alternatives, suggesting that the backlash against sketch maps has been too long and too loud. Others have pointed to the advantages of sketch maps, for example the fact that most people are familiar with the idea of using sketch maps as a way to convey information (Psathas, 1979; Blades, 1990). In response to the debate, Blades (1990) tested the reliability of sketch maps by re-testing subjects after one week, to see whether the second sketch maps they drew differed from their first maps. Blades found a very high correlation between the two pairs of maps: an independent judge was able to match together 19 out of 20 pairs of maps (from which all idiosyncratic detail and handwriting had been removed). The results of this study suggest that, for studies involving adult participants sketch maps can be a reliable means of extracting spatial knowledge.

5.2.3 Indirect judgement tasks

Increasing use has been made of tasks which indirectly test individuals' spatial knowledge. At

present the most popular of these is a combination of distance and direction estimates (e.g. Golledge, Rivizzigno and Spector, 1975; Thorndyke and Hayes-Roth, 1982; Gärling, 1989; Golledge, Ruggles, Pellegrino and Gale, 1993) whereby the subject's spatial knowledge is revealed through an analysis of their estimations of distances between, and directions towards landmarks in the test area. Montello, (1991) has compared the various different methods of measuring 'cognitive distance' and distinguishes between five classes of methods: ratio scaling, interval/ordinal scaling, mapping, reproduction and route choice. As a result of this comparison of the relative merits and disadvantages of the various techniques, Montello concludes that three techniques are particularly useful: ratio scaling; reproduction techniques; and, to a lesser extent, mapping techniques. Ratio scaling (e.g. Byrne, 1979; Sadalla and Magel, 1980; Sadalla and Staplin, 1980) usually involves subjects being given a piece of paper with a line at the top representing a standard distance (e.g. the distance between two familiar landmarks) and then being asked to draw a line beneath to represent, on the same scale, the distance between two other known locations. Montello (1991) concludes that, when subjects are required to make independent pair-wise estimates in very large-scale spaces, ratio scaling is probably the most efficient method, but

> "one should not interpret data generated by them (ratio scaling techniques) in terms of absolute accuracy relative to actual physical distances. Conclusions about overestimation and underestimation of physical distances should thus be avoided, unless speaking relatively."
>
> Montello (1991), p.117)

In addition, ratio scaling techniques can be problematic in that they require subjects to make a ratio calculation between the length of the standard distance and the length of the test distance. Similarly, subjects must make a scale translation between the standard distance and the standard line. Subjects may be provided with the same standard line to represent a common distance, but there is no guarantee that all will encode the standards equally. Thus errors made during this encoding process could affect all subsequent estimations made by the subject.

Distance reproduction techniques (e.g. Sherman, Croxton and Giovanatto, 1979; Sadalla and Magel, 1980) typically involve subjects re-walking a straight-line distance which they consider to be the same as a test distance. For distance estimation in small scale spaces which can be traversed within a reasonable length of time the method is particularly useful. In developmental studies involving young children reproducing the route traversed is an easy concept for subjects to understand and does not require them to make ratio calculations or scale translations. In addition, of all the methods for measuring cognitive distance, generally speaking only reproduction

involves actual locomotor behaviour (Montello, 1991). Unfortunately, with the larger distances which will be used in the present experiment, the reproduction of the test distance is inappropriate.

Mapping basically refers to distance and direction estimates taken from sketch map techniques. The construction of a map or a model necessitates that subjects represent all of the distances between objects or places in a single consistent representation. The representation of both distances and directions may make estimates more accurate due to a cueing effect, or could result in less accurate estimates overall as a result of distortions caused by encoding heuristics (e.g. biases towards cardinal points and to right angles). Another potential problem is that each distance and direction represented on the sketch map may be affected by the placement of other elements. In mapping techniques the distance from point A to point B will always be represented as the same as the distance from point B to point A. Other techniques, such as ratio scaling, do not impose this Euclidean metric on pair-wise distance estimates. Mapping may thus mask subjective biases caused by direction and consequently suggest a stability which may not in fact exist in the subject's cognitive representation of distance.

Whilst popular, distance estimation tasks rest on the assumption that a subject who has acquired configurational knowledge of an environment will have the ability to infer spatial relationships between various parts of their cognitive map, which may or may not have been associated previously. One of the criticisms levelled at sketch map studies is that they test abilities other than spatial ability, for example drawing ability. One could argue, however, that inferring spatial knowledge from direction and distance estimates is also potentially flawed. Distance estimation tasks may, for example, confuse distance estimation with time estimation (Lloyd, 1989). This is especially plausible when one considers that, particularly in urban areas, we tend to refer to the time it takes to get somewhere, rather than the distance that it is: in large, congested cities travel time is a more meaningful measure than travel distance. If this is the case then it is possible that subjects estimating spatial distances between landmarks with which they are familiar recall the time it takes them to travel between these landmarks and infer distance from this. This could lead to errors: spatial distances on busy routes are likely to be overestimated because of the longer duration of the journey. A similar effect could arise if subjects base their distance estimates on the ease or difficulty associated with making a particular journey.

Past research provides ample evidence to support this hypothesis. Studies by Canter and Tagg (1975); Sadalla and Magel (1980); and Sadalla and Staplin (1980), for example, have all shown

that subjects overestimate distances on routes containing more turns, intersections and barriers to cross (e.g. rivers and railways). Moreover, work by Cohen, Baldwin and Sherman (1978) showed that both children and adults tend to base their distance estimates on ease of travel: the presence of elements which make travel more difficult (such as those aforementioned) leads to over-estimations. However, the clearest support comes from the work of Antes, McBride and Collins (1988) in their investigation of the effects of a new city route on the cognitive maps of its residents. The rationale behind distance and direction estimates is that a subject having obtained a good degree of configurational knowledge of an area should be able to infer straight line distance estimates to unseen locations. Using distance estimations as their cognitive task, Antes *et al.*, (1988) aimed to show that a new overpass which reduced the travel distance across a city would result in a reduction in straight line distance estimates made between landmarks in the affected area. Whilst the study failed to adequately support this hypothesis it did show that all subjects performed very poorly at the task, consistently overestimating straight line distances by as much as 60%. This raises the question of whether a task which is difficult for subjects to perform with any degree of accuracy should be used as an indicator of their spatial knowledge.

Direction estimations may also be prone to major errors, caused by the various encoding heuristics employed when acquiring spatial knowledge. We tend to encode turns as being left or right, (Byrne, 1979; Moar and Bower, 1983) with little consideration for the angles of turns: consequently the information available when making estimations of direction is itself likely to produce distortions. However, this does not necessarily mean that such spatial knowledge is inferior to the individual whose direction estimates are more accurate - it could simply mean that this individual is better at manipulating the spatial knowledge they have available: perhaps what is being tested is not spatial knowledge but the ability to solve abstract spatial problems.

5.2.4 Solving the problems

Section 5.1 highlighted the various problems associated with cognitive mapping research. Observed effects could be due to the information presented, the mental processes operating upon this information, (Anderson, 1978) or the methods used to elicit the information. As McNamara (1991) points out, the conventional solution to this problem is the use of converging operations (Garner, Hake and Eriksen, 1956).

> "if performance in several tasks is affected by a variable in the same way, then the likelihood is that these effects are caused by unique features of the tasks. If the only common feature of the tasks is the presumed mental representation that supports performance, then one

> can conclude with some confidence that the variable affects how information is mentally represented."
>
> McNamara (1991), p.148

McNamara suggests combining this approach with tasks which are easy to understand and are accomplished quickly and with little effort or conscious activity from the participants. Objections can be raised with regard to the majority of the approaches previously pursued, but it is hoped that some of these objections can be removed by attention to the areas deemed problematic, and the employment of a variety of experimental methods (converging operations) rather than the reliance upon one method in particular.

5.3 The use of slides and videotape to convey spatial information.

Whilst there are a range of different methods for studying the products of spatial knowledge acquisition, there are very few methods for conveying the spatial knowledge in the first place. The review of previous approaches suggested a method was required which would maximise experimental control, whilst preserving as much realism as possible. Consequently it was decided that a secondary learning technique should be adopted.

Recent research has made increasing use of secondary learning techniques in an attempt to provide individuals with spatial knowledge. Such techniques usually require subjects to integrate information acquired from viewing separate but partially overlapping routes into a configurational or 'survey' view of the area. The idea behind such experiments is that a subject who has acquired survey knowledge of the study area will be able to perform spatial tasks such as estimating distance and direction to unseen points. This ability is an accurate measure of survey knowledge because it requires the individual to take two pieces of information (in this case two routes) and integrate them, enabling new routes to be created despite these routes never having been experienced directly: the individual has abstracted them from the two separate pieces of information previously acquired. Hanley and Levine (1983) did this through a series of table-top experiments in which subjects were blindfolded and learned different paths by tracing them with a finger through a common environment. However, the most commonly used method has been the presentation of photographic slides, a technique popularised by Allen and his colleagues (Allen, Siegel and Rosinski, 1978; Allen, Kirasic, Siegel and Herman, 1979) subsequently used by Moar and Carleton (1982) and most recently by Golledge and his colleagues (Golledge, Ruggles, Pellegrino and Gale, 1993). The method involves taking a series of photographs at regular intervals along a route and showing them as a continuous slide sequence to subjects, thus

simulating the view one would have if one were making the journey. This technique has provided a strong body of previous research establishing slide presentations as a useful means of conveying spatial information in a controlled environment.

5.3.1 Rationale for using video in preference to slides

The use of slides clearly gives excellent experimental control whilst also giving the researcher a good deal of flexibility, particularly in the testing stages of an experiment, where a selection of the same slides can be used. However, for the present experiment there are a number of good reasons for using video in preference to slides. First, video has the advantage of presenting a more dynamic environment than slides. Photographic slides are still and show scenes at a specific moment in time. Whilst this has the advantage of maintaining experimental control, the static viewpoint conveys only limited information. When we travel through an environment movement is a rich source of perceptual information (Gibson, 1979; Siegel and White, 1975; Neisser, 1976):

> "Each of our perceptual systems has evolved to take advantage of the special kinds of information that motion makes available. Perceiving is often most effective during motion.."
>
> Neisser (1976), p108

and

> "action or locomotion in the locale adds to, enhances and articulates the spatial representation"
>
> Siegel and White (1975), p.26

From this perspective it is clear that filmed footage should convey a richer form of information, closer to the experience of moving through the environment itself. Moreover, whilst slides are proven as an excellent method for conveying route information, they are less efficient at providing a coherent combination of route and landmark information. The normal procedure for a slide presentation is for key landmarks along the route to be shown as they are encountered. With slides this entails interrupting the front ahead view and showing photographs taken at ninety degrees to the route in the direction of the landmark. Thus, although subjects will be aware that at a particular point they encountered a particular landmark, they may be less sure of whether the landmark was on the left or the right of the route. Similarly, at junctions at which changes of direction take place it is important to effectively convey the impression of movement around the corner. Such junctions serve as reference points to assist in orientation. The conventional solution to such problems is through the use of a succession of overlapping photographs which simulate

cornering or head movement to a landmark and back again to the direction of travel. However, whilst resolving the problem, such a solution breaks up the continuity of the route, with the possible effect that subjects lose track of the information they have previously received. Video has the advantage that a pan to the right or left can be experienced as just that, the continuity of image simulating the movement of the head to the side in question.

Aside from these objections to the use of slides, pilot studies were conducted as part of this project (reported in chapter 6) which included a small scale evaluation of slides as a possible presentation medium. The results of this pilot study highlighted a number of additional difficulties that had not been voiced by previous commentators. These are discussed on pages 134-136.

Very little research has attempted to provide subjects with configurational spatial knowledge via filmed footage. The slide method has been the standard approach over the last fifteen years. A number of studies have compared the spatial knowledge acquired from slides and video with direct experience of an environment (e.g. Cornell and Hay, 1984; Goldin and Thorndyke, 1982; Ohta, 1983). Cornell and Hay (1984) compared spatial knowledge acquired by children who either walked a route, or saw a film or a slide presentation of the route. They conclude that walking the route led to fewer errors but there was little difference in performance between the slide and video groups. However, subjects only saw the route once, and subjects who walked the route had the distinct advantage of being allowed to freely explore the environment. Ohta (1983) found little difference between the spatial knowledge acquired by a group who viewed a videotaped tour of a model town, with that of a group who simply viewed the model itself from a variety of perspectives. Goldin and Thorndyke (1982) found that performance on a range of tests was not affected by viewing medium. After either being taken on a bus tour or viewing a film of the same tour, performance on a landmark recognition test was significantly better for the film group than for the tour group. Similarly, film groups were more accurate than tour groups in their performance of location sequencing tasks, which measure subject's route (or procedural) knowledge. In all but one of the other 4 tests carried out there was no significant difference between the groups. The one exception was performance of the orientation task, although all subjects performed badly at this task. In summary, Goldin and Thorndyke (1982) offer clear support for the use of filmed footage of a journey, as a means of examining the processes operating during wayfinding and spatial knowledge acquisition.

Within the field of neuropsychology, video has been used in recent approaches to the study of

topographic disorientation (Barrow *et al.*, 1995). This study focused upon four subjects who, although showing no evidence of brain damage, reported longstanding problems of topographic disorientation. As part of the study subjects were shown a 5 minute video of just one route of about 0.75 miles. The route was quite complex, incorporating 10 changes of direction, and subjects were shown the film four times. They were then tested for scene recognition ability and ability to select the correct route at choice points. The use of one route, however, precludes a possible investigation of configurational knowledge, but the experimenters' aims were very different from our own.

5.3.2 The use of three routes

Previous research attempting to provide survey knowledge of an area has used two overlapping routes (e.g. Moar and Carleton, 1982; Golledge *et al.*, 1993). Whilst this approach has become standard, objections could be raised as to whether the knowledge acquired can really be considered to be survey knowledge. Moar and Carleton (1982), for example, used two very simple routes with only 2 turns each and approximately 240 metres in length. Photographs were taken every 8m and a total of 45 slides were taken on each route for presentation to subjects. Moar and Carleton's experimental design could be criticised for presenting too simple a study area (see figure 5.1) which does not really test subjects' ability to acquire a configurational representation of the area. Golledge *et al.*, (1993) improved upon this design by using two much longer routes (both just over 1 km) which had 5 and 6 turns respectively. However, although the routes had more turns, the routes are not more complex when complexity is measured in terms of turn density (i.e. metres per turn). By this measure the routes used by Moar and Carleton have a turn density of 120m, whereas Golledge *et al.*, used routes with a turn density of 200m and 167m.

Figure 5.1 shows examples of the routes used by the aforementioned studies. The present study aimed to address the issues raised above by using **three** interconnecting routes of moderate length, each with at least 4 turns, thus making the routes more complex in terms of greater turn density. The three routes were chosen because each traverses a different section of the study area. Thus, although each route on its own gives only partial information, the spatial knowledge acquired from viewing all three routes, if combined into a survey representation of the area, should be quite complete and should cover a much wider area than has been the case with previous research which has tended to concentrate upon a narrow corridor of the environment which bears little resemblance to the neighbourhood knowledge of individuals familiar with an area.

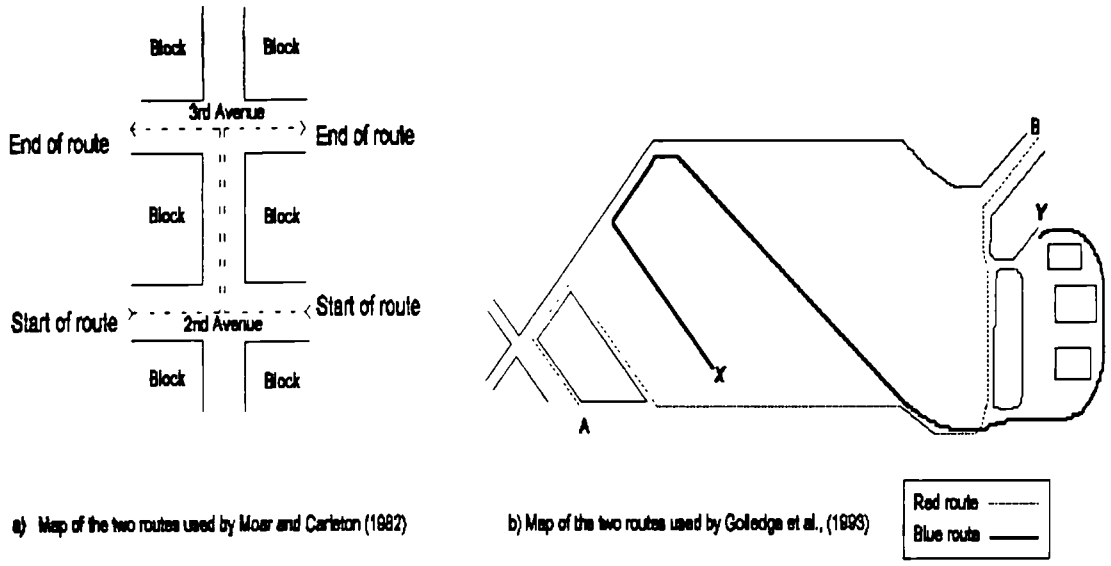


Figure 5.1: Examples of routes used in previous studies of the acquisition process

5.4 Summary and conclusions

This chapter has reviewed previous approaches to the study of the process by which we acquire spatial knowledge. From this review it is apparent that a range of methods have been used, some with more success than others. It should be noted that the methods deemed suitable for previous experiments have been influenced by the specific research focus of the experimenters, and so some methods, whilst methodologically acceptable (e.g. behavioural observation) are not appropriate to investigate the research questions posed by this thesis. The present research focuses upon subjects who are unfamiliar with the study area, in an effort to measure the development of spatial knowledge. The review highlighted the problematic nature of studies investigating the cognitive mapping process and noted that the manner in which information is presented and tested may influence results. The type of information presented may influence the information acquired; while the type of representation elicited might be influenced by the testing procedures used to elicit this representation. As a consequence, sections 5.4.1 and 5.4.2 below focus on conclusions regarding the presentation and testing methods that are to be adopted.

5.4.1 Presentation methods

The present study requires a methodology which maximises experimental control whilst preserving realism. It was concluded that the best way of meeting these two contrasting requirements was to use a secondary learning technique. Secondary learning is quicker, easier and much cheaper than exposing subjects to a real environment (which would involve transporting large numbers of people to the study area and back again), and enables the experimenter to maintain control over the study area itself. The main drawback with using a secondary learning technique is that such methods are less realistic. However, the other main requirement of the present research is that subjects are presented with information whilst being exposed to the study area. If participants were taken on a tour of the area this would require that they walk the routes whilst listening to the instructions on headphones. Apart from the potential safety implications, the main problem with this approach would be the loss of control over what each participant looked at whilst listening to the information. As a result of the first pilot study (see section 6.2) it was concluded that a more realistic sense of motion could be achieved through the use of video footage than the more conventional use of photographic slides. This method preserves the experimental control of photographic slides, but has the additional advantage of presenting a more dynamic version of the environment, one in which the individual experiences the environment in a similar way to reality. Having decided upon video, it was further decided that the study area should be conveyed via subjects watching films of *three* separate routes through the area. Previous research has only ever used two slides or film of one or two routes. This approach was criticised for conveying only a limited amount of information about the area. Watching film of three routes through the area should enable subjects to acquire a much more detailed cognitive map of a wider area, which is more like the neighbourhood knowledge that an individual acquires as a result of extensive experience in an environment.

5.4.2 Testing

A range of methods for testing the spatial knowledge acquired were considered. It was decided that the most reliable results would be achieved with a combination of tests, rather than relying upon one particular approach. As subjects will be viewing three different routes it was decided that there should be four stages of testing. The first three stages to occur one after each route, to test for route and landmark knowledge, followed by a fourth set of tasks which test for subjects' ability to integrate the information acquired from these separately experienced routes into a survey representation of the area as a whole. Consequently, the following tests were selected:

Tests of individual route knowledge

- Sequencing task
- Distancing task
- Time estimation
- Distance estimation
- Single route pointing task

Tests of configurational (survey) knowledge

- Cross route pointing task
- Sketch maps

These tasks and the experimental method are described in detail in chapter 6.

6 EXPERIMENTAL PROCEDURE

6.1 Introduction

This chapter describes the experimental procedure used in this research. Two experiments were carried out, henceforth referred to as experiment I and experiment II. Experiment I addressed the first two research questions and therefore focused on the impact that audible guidance has on cognitive processes (research question 1) and differences between groups in their ability to use this information (research question 2). To a lesser extent, experiment I also considers the third research question, in that different types of information were presented to subjects whilst watching the videos. Experiment II was designed in response to the findings of experiment I and specifically focuses on research question 3. The experimental procedure used for these two experiments was largely the same, although changes were introduced to specifically address the third research question. These amendments to the experimental design are described in chapter 8.

In order to investigate these research questions subjects are asked to carry out a cognitive task, which is representative of an underlying cognitive process, and their performance of this task measured using a variety of measures of performance. In order to investigate the effects of audible information upon cognitive processes, all subjects will perform the same task, but listen to different types of information whilst doing so. The cognitive process to be studied is spatial cognition. The representative task selected as the primary task is the ability to acquire spatial knowledge of an unfamiliar area (cognitive mapping) Thus, groups will be asked to listen to different types of information whilst attempting to acquire a cognitive map of an unfamiliar area. In order to investigate group differences in ability to perform the primary task whilst attending to audible information there are four information conditions and subjects are assigned to one of these conditions on the basis of their age, gender and driving ability. Hence the experiment has a 4 (information groups) x 3 (age groups) x 2 (gender) x 2 (driving ability) factorial design.

The remainder of this chapter is divided into four sub-sections. First, section 6.2 reports on the pilot studies that were run in the summer of 1994. As a result of these pilot studies a number of changes were made to the procedure, these are discussed in section 6.3. Section 6.4 discusses aspects of the experimental procedure that were made necessary because of the specific research focus of the experiments. Finally, section 6.5 describes the full experimental procedure as used for the two experiments.

6.2 Pilot studies

Two pilot studies were run in August and September 1994. An area of south west London was selected for convenience (being within driving distance of the author's home). First, the Ordnance Survey map of the area was enlarged and a number of potential study areas were identified. These areas were selected because they complied with the following criteria:

- They contained a mix of land uses, featuring residential, commercial and business properties;
- The areas allowed three routes of moderate length (500-1000m) to be plotted. These three routes should intersect at some point;
- The area should be neither too busy nor too quiet. A steady flow of traffic and people to show evidence of activity was acceptable, but not so much traffic that it obscured the view of the environment;
- There should be distinctive landmarks evident that would serve to identify each route.

Three areas were visited by car to gain an impression of the types of landmarks and building use present, the amount of traffic likely in the area, and the potential for route learning. One of the sites (see figure 6.1) appeared to have all the features required for the experiments, being composed of residential housing with a busy high street along the north side, containing many shops and businesses. There were also a number of distinctive landmarks in the area (a church, a railway bridge, a school, shops and other distinctive or historic buildings). By the time of the first pilot it had already been decided that 3 routes should be used, but the presentation medium had not yet been finalised. The first pilot study used photographic slides (after Golledge *et al.*, 1993) to represent the 3 routes. This involved a series of black and white photographs being taken along routes through the area (see examples in figure 6.2). With hindsight the use of black and white film was a mistake, as the presence of colour would have enhanced landmark identification and route learning. However, to save costs it had been decided that the films should be developed by the author, which required that black and white be used (no colour processing facilities being available in the college).

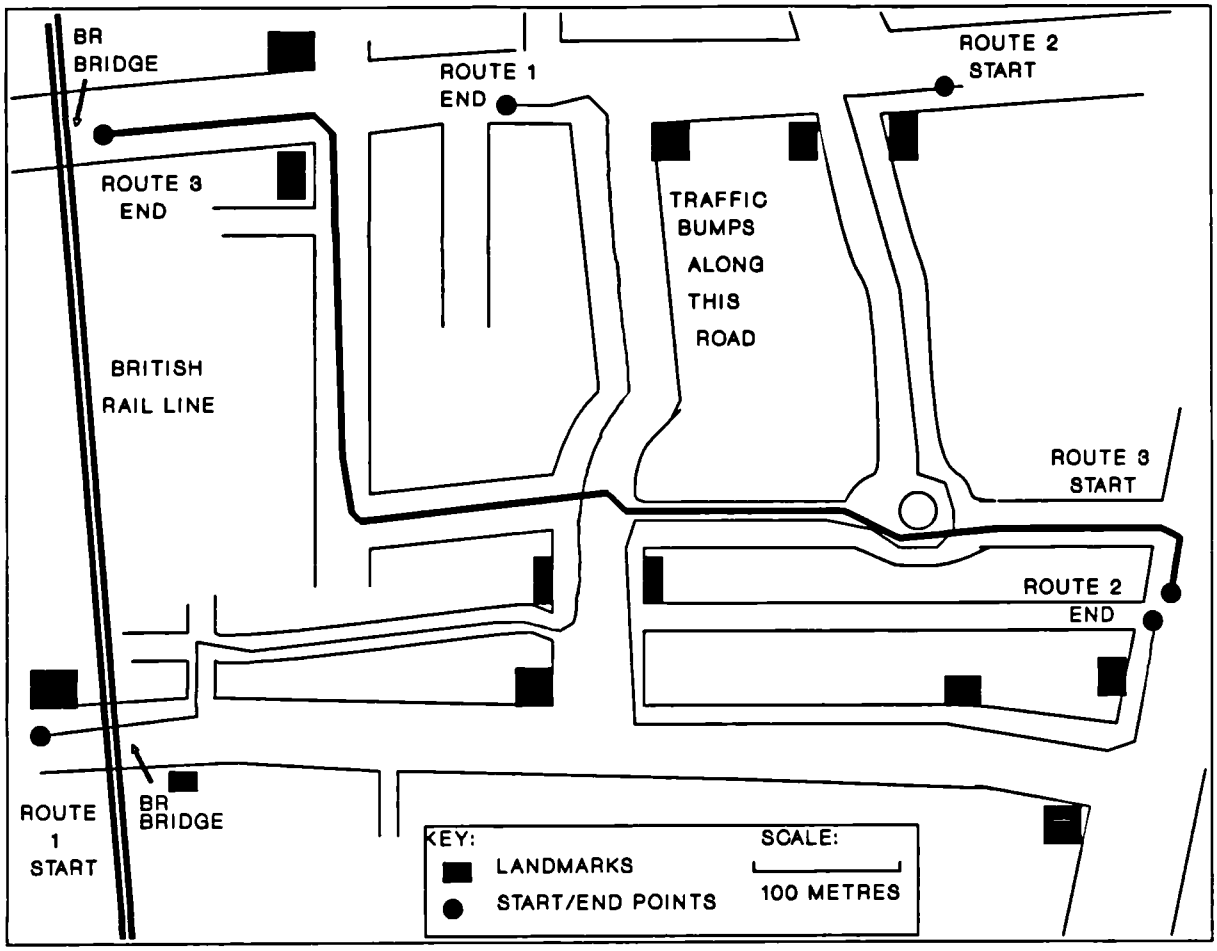


Figure 6.1 Areas used for the first pilot studies

The exercise was valuable, as other problems with the method soon became apparent. The author visited the chosen site and photographed the area, taking photographs at 10 metre intervals (the distance being measured using a metre wheel). To try and give a driver's perspective the photos were taken by standing in the road and photographing down the route. Once developed, a major problem with the use of photographic slides became apparent. Because of the nature of photographic film it was impossible to check the quality of each photograph until the whole film had been developed. The 3 routes made several changes of direction and consequently some photographs had to be taken facing into the sun. Inevitably, some photographs were found to be of substandard quality (due to overexposure) and would have to be retaken at a later date, causing problems of continuity with the existing images. To test the effectiveness of the slides for conveying route knowledge they were shown to a group of volunteers (5 researchers from the Centre for Transport Studies). The group agreed that it was difficult to learn the routes from these

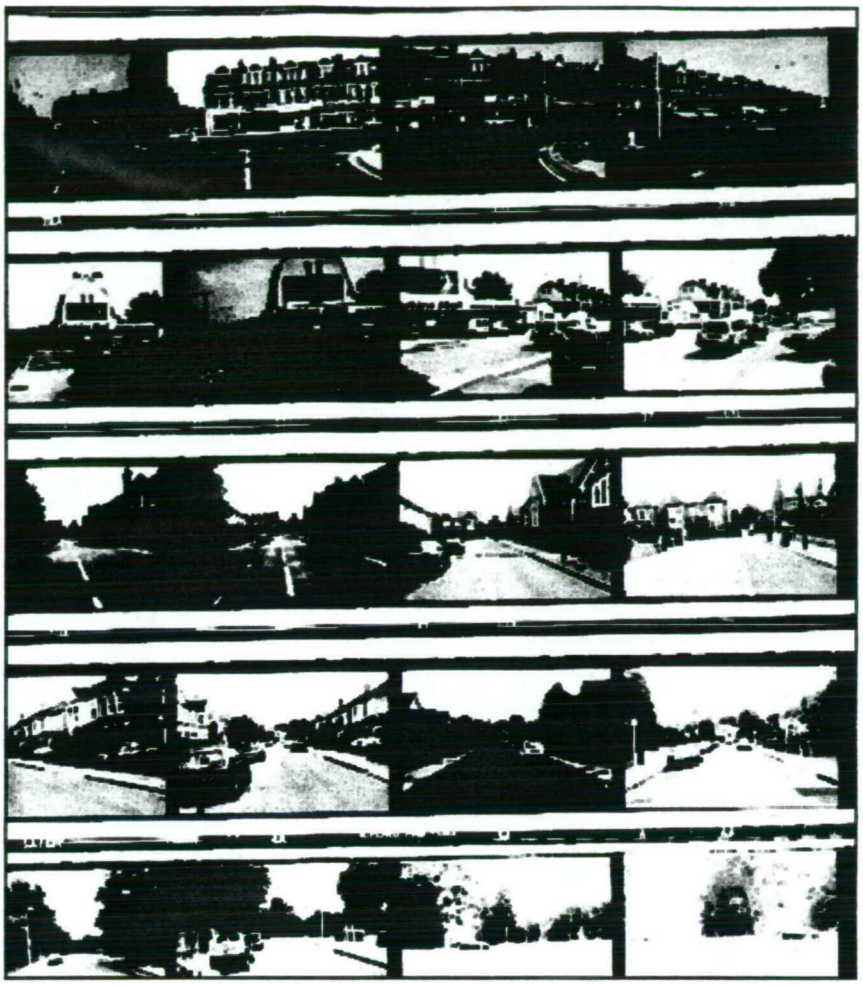


Figure 6.2 Contact sheet examples of photographs used in the pilot study.

slides as there was not enough variation either in the images or in the routes they portrayed and because there was not enough happening in the photographs to make them interesting.

As a result of this first pilot study it was decided that photographic slides were going to prove difficult to use effectively. Given the financial and temporal limitations of the research the potential costs and time required to do the method justice were not available and so an alternative method was sought. Although very few previous studies had used video footage it was felt that it had the potential to convey a far richer representation of the environment. Consequently, the second pilot study involved filming the same routes using video. A local video company known to the author agreed to take part in the research by supplying a camera (Sony Super 8), film and their editing services free of charge. In addition to providing professional video filming and editing services, the cameraman also happened to be a fully qualified driving instructor, and consequently contributed enormously at all stages of the experimental design. The same routes were travelled, but this time in a Nissan saloon car, with the cameraman standing in the front passenger seat and filming from out

of the sunroof. These films were then shown to another group of 5 volunteers from the Centre for Transport Studies who were asked to watch each film in turn, then draw each route. Having seen the three films, they were then asked to draw a sketch map of the study area as a whole. This would test their ability to integrate the information acquired from each film into a configurational representation. The volunteers made a number of comments about these films:

1. There was too much lateral camera movement (i.e. panning) during filming. This was particularly evident when the car travelled around corners – the cameraman had tried to film as much of the corner as possible, with the consequence that there was too much camera movement, resulting in subjects reporting a feeling of car sickness. The group felt it would be more beneficial to keep the camera fixed directly ahead for the majority of the time, except at landmarks. At landmarks the film should try to focus on the landmark from a distance and gradually pass it, focusing on it in passing. At junctions it was decided that a slow 180 degree sweep in the same direction as the turn would best convey the impression of movement around the corner.

2. The footage was filmed from too high above the vehicle, consequently giving an unnatural view of the road.

3. The routes should begin with a "180 degree orienting pan" to give the viewer some idea of where they were starting from. A more consistent method of panning to show landmarks was also required (the films panned from side to side too regularly, and with little purpose). As a consequence the films were viewed again by the author and the cameraman, and specific landmarks were identified as the focus of panning movements.

4. The car moved too quickly. Originally the car travelled at about 20 mph. The volunteers felt it should travel more slowly to enable the viewer to see the landmarks clearly.

5. Volunteers complained that the area was difficult to learn. Much of the area comprised residential roads, and subjects found it difficult to distinguish between the various roads, due to the similarity between buildings. Furthermore, although there were a number of distinct landmarks, they were mostly concentrated on one of the routes. In addition, the subjects found it difficult to orientate themselves at the start of each route, as there was no indication of where they were going or why they were travelling in a particular direction. Moreover, they had no idea what direction was being taken other than left or right. In real life wayfinding, they argued,

you would normally have a global appreciation of north, south, east and west, even if this was inaccurate.

6.3 Amendments made as a result of pilot studies

As a result of the pilot studies a new area was sought with the following criteria. The area should have a fairly simple route structure bounded by major routes clearly distinguishable from the minor roads of the study area. It should be large enough to enable three routes to be plotted through it, with prominent landmarks on each and with distinctly different patterns of land usage evident through the area as a whole. Experience of filming the first area also suggested that filming should take place very early on a Sunday morning, when traffic would be at a minimum. This was so that the filming could be continuous and would not be interrupted by stopping at junctions or having to wait for traffic. Following an incident with the local police force (a resident reported "two men stealing a video camera from a car, and then testing it out as they drove away...") it was also decided that the local constabulary should be informed of our activities prior to the day of filming. The following changes were made to the filming as a result of the pilot studies:

- The final videos would be filmed from a height of approximately 5' 8" to provide a more realistic viewing height and angle. Earlier versions were filmed from a front seat passenger's perspective (car body restricted view at corners) and from above the car, with the cameraman standing in the front passenger seat with head and body out of the sunroof (view unrealistically high above the car). The final view was obtained by the cameraman crouching in the front passenger seat and filming out of the sunroof.
- The car should move at a slow constant speed, stopping only at T-junctions. By using an automatic vehicle this was possible – the car had a gear setting that enabled the car to move at a constant speed of 10 miles per hour.
- The problems identified by volunteers regarding panning and simulating movement around corners led us to film 2 separate videos. These provided subjects with route and landmark knowledge separately rather than trying to combine the two elements on the same film. Two videos were created, the first maintaining a front-ahead view all the way along each of the 3 routes, while the second used this same film but with pan shots of the landmarks and other salient features spliced into the film at relevant points along the route. This served to locate the landmarks within the route as a whole. The 'salient features' included in the landmark film were selected from landmarks suggested by residents of the area (see below). This

additional film takes the place of the 'location referent' photographs used by Golledge *et al.*, (1993) to provide landmark information.

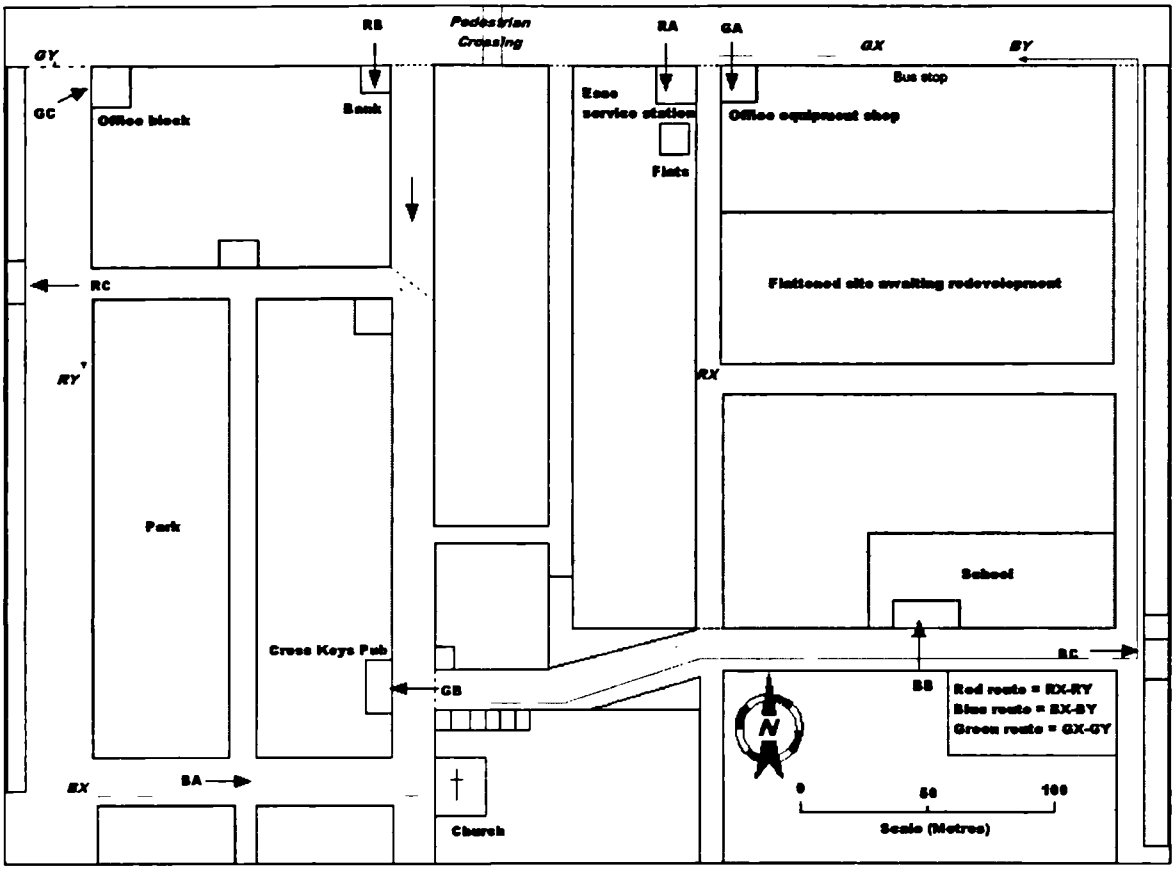


Figure 6.3 The study area showing landmarks and routes used

A study area which satisfied the above criteria was found in Stamford Brook, West London (Figure 6.3). The study area was bounded in the south by a major dual carriageway (inaccessible from the study area) and in the north by a busy high street. The site was selected because of the varied land uses evident in a small area. The area contained distinct areas of residential, commercial, industrial, educational and recreational land use which helped to distinguish each of the three routes. The routes were plotted to cross at a common point and to cover as much of the area as possible, but because three routes were used it was inevitable that there would also be some sections common to more than one route.

The new area was filmed using a Sony Super 8 camera fitted with a wide angle lens, giving a viewing angle of approximately 55 degrees. The film was shot between 06.45 and 08.15 on a Sunday morning in late September, when there was minimal traffic in the area. To retain the high

resolution obtained with Super 8 film, all editing was carried out on Super 8 and the finished product copied to videotapes. In order to select the landmarks that would be used in the experiment group interviews were held with a group of residents of the area who had been contacted via the local church and its affiliated school. Ten residents were recruited, all of whom had lived in the area for at least 5 years (range 5 – 27 years). They included teachers, cleaners, dinner staff and parents of children of the school, as well as members of the congregation of St. Peters' church. The group were shown an enlarged Ordnance Survey map of the area and were asked to list all the landmarks in the area. For the purposes of this exercise landmarks were defined simply as distinctive buildings or other features that they could recall. The ten subjects listed a total of 27 features, of which fourteen were listed by all ten subjects. These were designated as the pool of landmarks from which nine would be selected (3 per route) for the testing phase of the experiment. Selecting nine of these landmarks for the test materials was more difficult. First, they had to be reasonably spaced along each route and ideally would have to be unique to a particular route. In some cases this was not possible – the church for example is visible from most points within the area, but this was such a distinctive landmark that it was considered essential that it be included.

Two of the landmarks in the pool of possible landmarks were very close together (the bank and the post office) and so one had to be omitted from the list. Similarly, the landmark eventually designated as BC was next to another landmark from the pool (a company called Systemtext) and so one was omitted. The nine landmarks selected for the study originally included a landmark known locally as Ship House (because of its distinctive porthole-like windows), which is situated on the corner at a T-junction. As such this seemed to be a perfect landmark, it was certainly well known by the locals. However, when the experiment was piloted with a group of researchers from the Centre for Transport Studies, none of the group recognised the photograph of Ship House. The film of the route on which Ship House is located was viewed again and it became apparent that the pan shot of this landmark was rather quick, as the car immediately moved around the corner. Consequently a replacement landmark had to be used. The nine landmarks finally selected for the testing procedure were:

Red Route (RX-RY):		**Blue Route (BX-BY):**		**Green Route**	**(GX-GY):**
Garage	(RA)	Church	(BA)	Corner shop	(GA)
Bank	(RB)	School	(BB)	Public House	(GB)
Historic building	(RC)	Works	(BC)	Offices	(GC)

These are marked on figure 6.3 above. This completed the creation of the presentation materials. The next stage was to create the test materials. Three of the tasks that subjects are asked to complete involve photographs: the sequencing and distancing tasks and the pointing task. The sequencing

task tests subjects' route knowledge and requires them to place 10 photographs of each route into the order that they would be seen along that route. The distancing task is completed immediately after the sequencing task and requires subjects to space the same photographs the ratio-scaled distance apart that they would be seen along the route. The pointing task tests subjects' knowledge of the landmarks and their location within the study area. These and the other tasks employed in the experiments are all described in detail in section 6.5.

The sequencing task required a set of 10 route photographs for each of the three routes. The pointing task required a set of 9 landmark photographs (one for each of the landmarks listed above). These photographs were taken early the following Sunday morning to try to maintain consistency between the videos and the photographs. Fortunately, being a predominantly residential area, vehicles were parked in the same locations as when the videos were filmed the previous week. Weather and traffic conditions were also similar. The ten route photographs were taken at measured intervals along the route and the distance from the start of the route noted down for the distancing task. The arrows in figure 6.3 above show the direction in which the camera was pointing to take each photograph.

6.4 Aspects of the experimental procedure made necessary by the research focus

The specific focus of this research is the effect of audible guidance upon the cognitive mapping process. As a consequence a number of additional elements of the experiment need to be explained. First, the experiment attempted to simulate the experience of travelling through an unfamiliar area. A simulation was used in preference to real world experience for reasons of experimental control – in order that all subjects experienced the same environment under the same conditions. However, this was a more complex issue than originally envisaged. Section 6.4.1 below describes 3 problems that were identified with this method and how they were addressed. Second, the experiment had to provide subjects with navigation information about the environment which would simulate the experience of attending to audible guidance whilst travelling through an unfamiliar area. The information groups and the information provided to them are described in section 6.4.2.

6.4.1 Simulating the wayfinding process

While the experiment was being designed the author presented a paper at the Universities Transport Study Group Annual Conference, describing the intended experimental procedure. At this presentation Professor Peter Bonsall of the Institute for Transport Studies at Leeds raised an objection to the methodology as it stood at that time. Three problems were identified:

- First, under normal circumstances wayfinding is an active, information seeking process,

characterised by purposeful action and motivation. A subject simply viewing a film of a journey does not have this motivation. Consequently, on its own the video merely provides subjects with information about three routes through an area, it does not specifically include a search element.

- Second, in real-world wayfinding the individual normally has some wider spatial frame of reference which serves to locate the environment. An individual watching videos of routes is placed in an unnatural situation whereby they have no idea of the cardinal points, and no understanding of what is beyond the study area. This was a similar objection to that raised by subjects in the pilot studies, that there was no logic to the directions taken by the vehicle as they did not know where it was going or where it had started from.
- Third, providing subjects with additional route guidance information does not necessarily mean that they will actually attend to this information. There is no way of knowing whether or not they are using the information.

As a result of further discussions it was conceded that the experiment would have to incorporate devices that would address each of these problems. The first problem was relatively easy to solve by providing subjects with explicit instructions to watch the films as if they were being taken on a tour through the area, and that they would have to find their own way around the area at the end of the experiment. These "pre-trip instructions" direct subjects to obtain as much information as possible about the routes, the landmarks on those routes and the way the 3 routes link together. Prior to viewing the first video, subjects were given the following instructions encouraging them to seek out information in much the same way as a wayfinding exercise:

> "You are about to see films of three routes through an area. For each route you will first see a front-ahead view of the route, then you will see the same route again with the camera panning so that you can see relevant landmarks along the route. You are to imagine that you are being taken for a drive through the area and that later you will have to find your own way around the area. It will help you later if you can try and remember the 3 routes taken and the location of the various landmarks along each route. Your present position and your destination are shown on the simplified map you have been given."

Once subjects had read the instructions the experimenter went over them again to ensure that everyone understood the experiment and the tasks they would have to carry out. Particular care was taken to explain terms such as 'panning' and to describe the various stages of the experiment.

To address the second problem - the lack of a spatial frame of reference in which to locate the area -

a simple "map" was designed for each route. The relevant route map was given to each subject before watching that film. The simplified map is a rectangle representing the study area, containing two dots (see figure 6.4 for an example and appendix II for examples of all maps), one representing the subjects' starting position and the other representing their destination. Subjects were told that in each map the rectangle represented the same area, and that the only thing to change was the location of the origin and destination points of the route. The simplified map does not show the routes, nor does it show any spatial elements such as landmarks or buildings. This simplified figure is intended to give purpose to the subject's viewing of the videos. Experience gained from the pilot studies suggested that simply showing subjects each route would fail to accurately simulate wayfinding, as in reality one would have at least some idea of present location and intended destination. By giving subjects these details they might better understand the reasons for the route taking particular turns, however, the information given is not detailed enough to provide any additional information about the study area or the route to be taken.

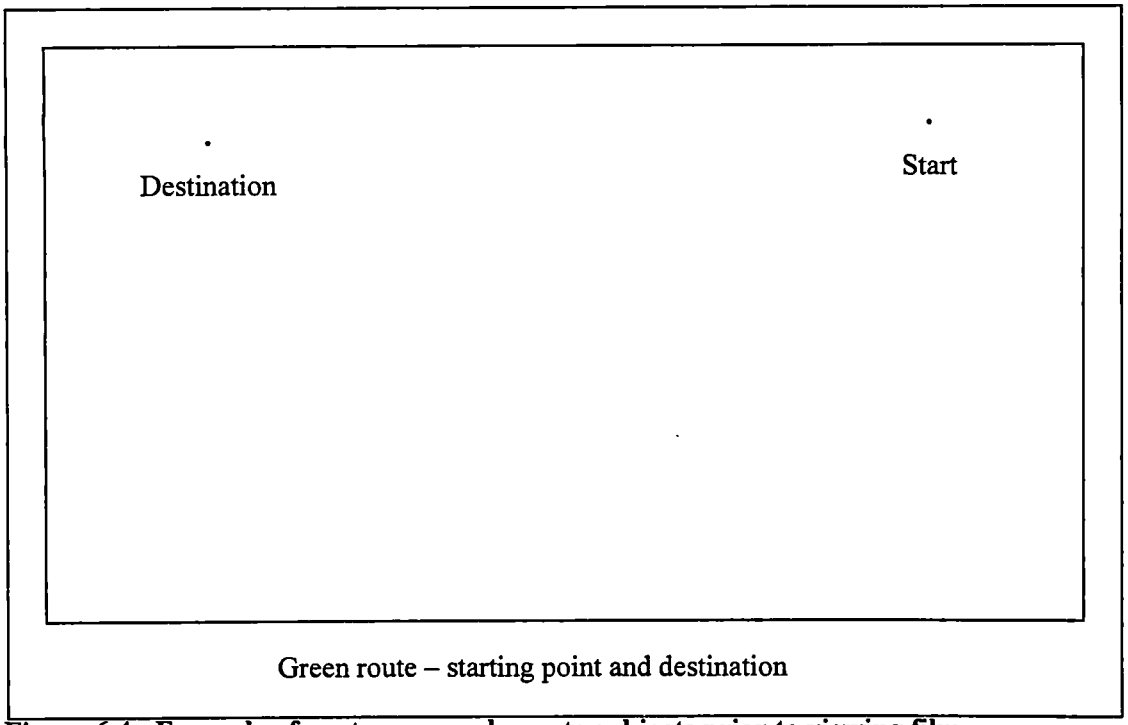


Figure 6.4 Example of route map as shown to subjects prior to viewing film

The final problem was to ensure that subjects attended to the audible information they were being presented with. To accurately simulate the experience of receiving guidance instructions it is essential that subjects actively attend to the information received. In a normal wayfinding situation

guidance instructions received would obviously have to be listened to for them to be of use. In the present experiment subjects have no control over the direction taken and so do not have to respond to the instructions to get from start to destination. Consequently, there is no way of knowing whether they have actually attended to the information received. This would be a serious flaw in an experiment designed to investigate the effect of receiving such instructions upon our ability to acquire spatial information. However, a task was designed to ensure that subjects attend to the instructions, or, if they fail to attend to them, that this can be detected.

An individual using a route guidance system in a real life situation responds to the guidance by making the adjustments necessary to produce the required change in direction (i.e. making a turn). In the laboratory situation it would be unrealistic to ask subjects to respond to the guidance instructions in a way comparable with reality, for example by having them turn a mock-up steering wheel. An alternative would be to have subjects sitting at computer terminals and having them press keys corresponding to the directions and headings that the guidance instructions give them. Although this could provide us with useful response time information, the logistics of having five subjects linked up to computers whilst also watching a video make this an unrealistic option in practice. However, given that the objective of this device is simply to ensure that subjects attend to the guidance instructions, it was decided that a simple task was appropriate. Thus, for each video, subjects in the guidance condition write down initial letters corresponding to the headings (N, S, E or W) and to the turns (L or R) that they are instructed to make. This simple device simulates reality in three important ways. First, it ensures that subjects attend to the information, second it ensures that they make a response to this information and third, it ensures that this response occurs in the same sequence and at the same time as would be the case under natural circumstances. Moreover, the list produced by subjects can be compared with the correct sequence to check for any effects that attending to the instructions might have upon attending to the video.

6.4.2 Simulating the provision of route guidance information

Simulating the experience of receiving route guidance instructions requires consideration of the various levels of information that could be provided. These range from no additional information to a level which could include present location, distance to turn, direction guidance, spatial detail such as location of landmarks, and revised position location as a result of turning. A typical sequence of instructions of this type would be "Current position heading west on King Street....50 metres to left turn....Turn left at the garage...turning left....new position, heading south on Lincoln Avenue.." etc). The review of IVRGIS and the kinds of information they aim to provide drivers (chapter 2) suggests that the amount of information provided to drivers in-transit should be limited to what is absolutely necessary due to the attention and information processing demands of the driving task

(Dingus and Hulse, 1993). With this in mind, subjects were provided with the minimum necessary information required to enable them to follow a route: details of the next turn, distance to this turn, what street to turn on and which direction to turn (Streeter *et al.*, 1985).

Information groups: experiment 1

The first experiment was designed to study the effect of listening to route guidance instructions upon ability to acquire a cognitive map of an unfamiliar area. The scripts of the full guidance instructions are shown in Appendix III. Subjects were assigned to one of the following groups:

Group I : Video group

This group acted as a control group and simply observed the films with no additional information.

Group II : Route guidance group

This group were provided with route guidance information via spoken instructions during the films

Group III : Radio group

A third group heard a recording of a radio broadcast, recorded from a news and traffic information radio station (Greater London Radio) during the rush hour.

Group IV : Radio plus route guidance group

Finally, a fourth group heard the same radio broadcast as group III, but this broadcast was interrupted by guidance information as and when necessary.

This experimental design allows a comparison of the effects of salient and non-salient information upon the cognitive mapping process. A number of possible scenarios can be considered.

a) If all groups' spatial knowledge is inferior to that of the video only group then the mere presence of a secondary information source, regardless of its content, can be considered to be placing extra demands on processing and is thus affecting the cognitive mapping process.

b) If the performance of those receiving route guidance (groups II and IV) is superior to that of the video only group, but the radio group's spatial knowledge is either the same as, or inferior to that of the video only group, then the presence of additional salient information can be seen to have had a positive effect upon the cognitive mapping process.

c) If the performance of those receiving route guidance (groups II and IV) is inferior to that of the other groups then it is likely that the extra processing required to attend to this additional information has had a detrimental effect upon cognitive mapping processes.

The presence of the fourth group enables us to consider the use of route guidance information

systems in a naturalistic situation whereby route guidance information is set up to override the radio broadcast. This tests subjects' ability to switch attention processes between incoming salient and non-salient information in addition to information provided by the visual sense. The simultaneous presence of three information sources should place additional attention demands upon subjects, testing whether they are able to attend to the two salient aspects equally while ignoring the non salient (radio) information.

6.5 Description of the experimental procedure

6.5.1 Experimental design

Studies which have employed secondary learning methods to provide subjects with spatial knowledge have varied considerably in the number of exposures to the learning medium deemed sufficient to produce a satisfactory level of knowledge. Clearly, the complexity of the route (number of turns, available landmarks and distance travelled) and the particular research aims of the experimenters will affect this. The number of trials used by slide studies have varied from one or two exposures (e.g. Allen, Kirasic, Siegel and Herman, 1979) to as many as 6 per route (Golledge *et al.*, 1993). The present study, utilising three routes, had to reduce the number of times each route was viewed, in order to bring the experiment down to a reasonable duration. The screening of each route lasts between 10 and 12 minutes depending on the route (the three route films last between 4 and 5 minutes each, the three landmark films last between 5 and 7 minutes each), but the additional time taken to view the third route, and the extra testing procedures required, would result in an experiment of excessive duration. A reduction in route exposures was not considered unduly problematic, as the three routes contained sections common to more than one route. Thus, although subjects would only traverse each route twice, the nature of the three routes meant that each viewing would provide information not only about the route being traversed, but also of parts of the other two routes. This reduction in viewing and testings brought the experiment length down to about 90 minutes.

Table 6.1 shows the sequence of trials and testing procedures which comprise this experiment. So that we could test possible order effects, the three routes were assigned the names of colours to allow presentation order to be varied across subjects (this would not have been possible had they been called routes 1, 2 and 3). Participants were randomly assigned to one of 6 presentation orders to enable all orders of video presentation to be considered. It was expected that the first route seen would be most difficult for subjects to learn, due to lack of familiarity with the test requirements. The red route was expected to prove most difficult for subjects to learn, because of its greater

complexity (6 turns as opposed to 5 on each of the other routes) and the greater distance travelled. In addition, an order effect was predicted, with performance improving as subjects saw more routes (and consequently acquired more knowledge of the area).

Table 6.1: Experimental protocol

1		2		3			
R1L1	Ts	R2L2	Ts	R3L3	Ts	Tcr	Tms

Key:

i) Presentation:

R1L1 Subjects see two versions of the first route: the route film followed by the landmark film.

R2L2 Subjects see two versions of the second route: the route film followed by the landmark film.

R3L3 Subjects see two versions of the third route: the route film followed by the landmark film.

ii) Testing:

Ts Single route tasks: a) sequencing and distancing tasks,
b) time and distance estimation and
c) Single route pointing task

Tcr Cross route pointing task

Tms Map sketching task

The experiment has a 4x3x2x2 factorial experimental design. Consequently a total of 48 different experimental conditions are possible. Within the time constraints of the thesis it was not feasible to include all 48 conditions (with a suitable size of sample) and so a statistical procedure was employed that reduces the number of conditions required and still enables the testing of the key combinations. This design was taken from Kocur *et al.*, (1981) and is an example of the catalogues developed and published by Hahn and Shapiro (1966). These were designed specifically to address the problems of orthogonal symmetric and asymmetric fractional factorial designs. The particular design chosen allows 16 of the 48 possible combinations to be tested. These are shown in table 6.2 below.

Table 6.2 Experimental design showing the 16 groups that make up the experiment

Group	Information condition	Age group	Gender group	Driving ability
1	Video only	18-21	Female	Drivers
	Video only	22-54	Male	Drivers
	Video only	22-54	Female	Non-Drivers
	Video only	55 and over	Male	Non-Drivers
2	Route Guidance	18-21	Male	Non-Drivers
	Route Guidance	22-54	Female	Non-Drivers
	Route Guidance	22-54	Male	Drivers
	Route Guidance	55 and over	Female	Drivers
3	Radio	18-21	Female	Non-Drivers
	Radio	22-54	Male	Non-Drivers
	Radio	22-54	Female	Drivers
	Radio	55 and over	Male	Drivers
4	Route guidance and radio	18-21	Male	Drivers
	Route guidance and radio	22-54	Female	Drivers
	Route guidance and radio	22-54	Male	Non-Drivers
	Route guidance and radio	55 and over	Female	Non-Drivers

As can be seen from this table, each information condition is presented to at least one group of subjects from each age range. Moreover, every possible combination of subject is represented at least once across the 4 information conditions. The experimental design is designed specifically to enable estimates of the performance of each group to be calculated across all conditions. In each condition there are also two groups from the same age and gender group, who only differ in terms of their driving ability. This allows the comparison of the performance of drivers and non-drivers in the same age group both within each information condition and across all four conditions. Clearly, there are limitations to this method of reducing the total combinations to a manageable number. The upper and lower age groups are only represented by one sub-group in each condition and this group is made up of subjects of one gender and of one level of driving experience. This means that it is not possible to compare directly the performance of, for example, male and female drivers aged 55 and over who listened to radio (as female drivers aged 55 and over were not included in this condition). To do so would require that all 48 possible combinations of group be tested. As this would have required that at least 240 subjects complete the experiment a trade-off was necessary between covering every possible combination and getting a reasonable sample size. Given the problems of finding subjects in the over 55 age group (particularly male non-drivers) it was felt that

obtaining a suitable sample size in each group was more important, and consequently the experiment was limited to 16 sub-groups spread across 4 information conditions. An alternative approach would have been to dispense with one of the categories, e.g. the male/female split. This would have instantly reduced the number of combinations to 24, which might have been manageable in the allotted time. However, the cognitive mapping literature reviewed in chapter 4 (see pages 100-102) suggests some confusion regarding gender differences in spatial ability. Much of this confusion can be attributed to differences in the tasks employed (cf. Voyer *et al.*, 1995, see p101). Given the lack of conclusive evidence regarding gender differences it was considered more worthwhile to try to make a contribution to this debate rather than ignore it. Furthermore, chapter 4 noted that previous research has tended to lack a consideration of the possible impact of driving experience upon performance of tasks requiring spatial ability. The present research is designed to allow the possible relationship between driving ability and gender to be investigated, which might clarify some of the existing work on gender differences in spatial ability.

Following the methodology of Golledge *et al.*, (1993) the present study uses a battery of tests designed first to help subjects organise the information acquired from the screening of each individual route (single route tasks), and second to test their ability to integrate the information acquired into a configurational representation of the area as a whole (cross route pointing task and map sketching task). With a few exceptions[1] the trials all took place in a lecture room in the Centre for Transport Studies at Imperial College, with groups of up to five subjects taking part at any one time. The additional information group listened to verbal instructions during the screening, the other groups heard either nothing (no information group) radio (radio group) or both radio and route instructions (radio plus information group). To maintain a consistent experimental procedure across all the trials an experiment checklist was designed, which is incorporated into the description below (***bold italics***). For simplicity the following describes an experiment in which subjects see first the red route, then the blue and finally the green. However, all combinations of the three routes were tested.

6.5.2 Description of experimental methodology

Having agreed to take part in the experiment subjects were assigned to the information groups based on their age, gender and driving ability. These groups were dictated by the experimental design described above.

[1] Experiments involving subjects recruited from external organisations were conducted at the meeting places

1 Give pre-trip instructions to subjects to read.

Upon arrival at the testing centre subjects were seated and given the pre-trip instructions to read (see section 6.4.1). Once they had finished, the instructions were collected and were explained in more detail by the experimenter, who clarified any questions the subjects had. For the presentation part of the experiment subjects were seated in a row at a workbench in front of the television screen (see figure 6.5). Subjects wearing watches were asked to remove them as all subjects would be required to estimate journey durations later.

2 Show simplified map for first route

Next, subjects were each given the simplified route map (figure 6.4) for the red route and were asked to study this while the video was set up. If the experimental condition was one of the route guidance conditions subjects were given a piece of paper approximately 10cms x 4cms on which to record the instructions they heard (section 6.4.1, page 140).

3 Show video of first route

The video of the red route was then played. The video first shows the route version (with the camera fixed straight ahead), and is then immediately followed by the landmark version (with the camera panning to show the landmarks and other features along the route).

4 Give subjects sequencing task materials (10 photographs)and explain task requirements

Having seen both the route and landmark films for the red route subjects were moved to a different part of the room where they were given instructions on how to carry out the sequencing task. An instruction sheet was created for this purpose but it was found to be easier for the experimenter to demonstrate the task requirements on the blackboard and to show the various materials to be used. Each subject was provided with a set of ten randomly shuffled photographs showing route scenes from the red route. Subjects were instructed to arrange these photographs in the order that they would be seen along the route, so that the first photograph in the pile was the first scene that would be seen on the route, and the photograph at the bottom of the pile was the last one seen. Tables were arranged so that each individuals' work was kept private.

5 Give subjects distancing task materials (metre strip, pen and ruler) and explain task.

Once all subjects were satisfied that the pictures were in the correct order they were given a strip of paper (1mx4cms) which they were told represented the distance of the route they had just seen if it were stretched out into one line. Hence, the beginning of the piece of paper represented the

of the organisations. In all cases the experimental set up was kept close to that used in the laboratory.

beginning of the route and the end of the paper represented the end of the route. They were then asked to take each photograph in turn and to place a horizontal line across the strip of paper to represent where the photograph was taken.

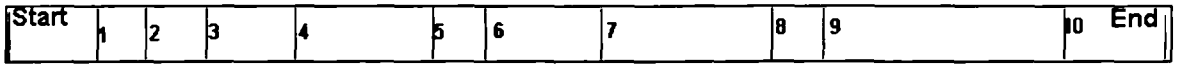


Figure 6.5 Example of a completed 1 metre strip as used in the distancing task.

So, if they thought the first photograph was taken very close to the start of the route they would draw a horizontal line near the end of the strip that they had designated as the start. The pilot trials had shown that a number of subjects forgot to treat the strip as the full length of the route, which required that the experimenter perform a ratio scaling calculation to obtain results. Others failed to indicate which was the start of the paper and which was the end. Consequently, subjects were asked to draw lines to indicate the beginning and end of the route and to write "Start" and "End" in the appropriate places on the paper. Despite these measures it was still necessary for the experimenter to check all subjects' work to ensure that they had complied with the instructions. Subjects were then asked to take each photograph in turn and to mark a vertical line on the paper where they thought the scene was located on the route. The photographs were to be placed at their correct (ratio scaled) distances along the route (the distancing task). Subjects were also required to number each line. Appendix IV shows the actual and ratio-scaled distances of each of the route photographs used in the sequencing and distancing tasks.

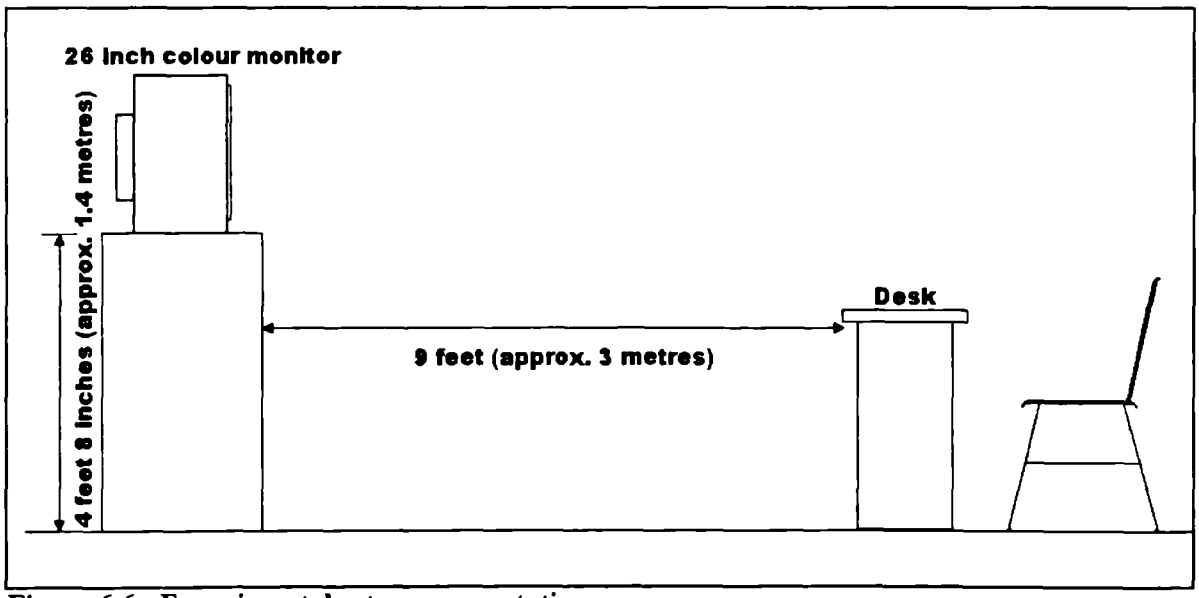


Figure 6.6 Experimental set up: presentation

Collect metre strips and photographs in the order they are set out

The sets of 10 photographs were collected and placed in a packet with the name of the subject and the relevant metre strip wrapped around the packet to identify each subjects' work.

6 Give subjects single route pointing task instructions

Subjects were given a booklet to be used for the pointing task. On the front of this booklet were the following questions:

Name.....

This is the	FIRST	SECOND	THIRD	route I have seen (circle one)
Name of route	RED ROUTE	BLUE ROUTE	GREEN ROUTE (circle one)	

Please estimate the length in metres of this route .....metres

And estimate the time that the journey took: The route film took .....mins.....seconds.

The landmark film took .....mins.....seconds.

Some subjects (particularly older subjects and Americans) voiced concern over the use of metres. They were instructed to use yards instead of metres, and told that the experimenter would calculate the equivalent in metres. As a consequence, all subjects from then on were told that they could use the unit of measurement with which they felt most comfortable.

8 Give subjects landmark photographs for this route

Subjects were given a set of 3 photographs of landmarks seen on the route (labelled A,B and C). The booklet mentioned above contained 6 sheets of paper, on each of which was a large circle with a dot at its centre and a direction arrow pointing to the top of the page (see appendix V). At the top of each page was a pair of letters which referred to the photographs. Taking each photograph in turn they were then asked to imagine that they were standing where the first photo was taken and that the dot on the page represented this position. They were then asked to "point" to the second landmark, by drawing a straight line from the dot in the direction of the second landmark. This procedure was repeated with each of the landmarks as targets and for each of the three landmarks acting as the origin or referent (a total of 6 direction estimates: A to B, A to C, B to A, B to C, C to A and C to B).

9 Collect photos and task book.

Once all 6 single route pointing tasks had been completed the landmark photographs and task

booklets were collected and subjects were taken back to the presentation area to view the route and landmark films for the blue route. The same viewing and testing procedures were repeated for both the blue and the green routes.

Once subjects had seen all three films and had completed all the tasks for testing single route knowledge, they were asked to perform the pointing task again, but this time imagining themselves at a point on one route and pointing to the landmarks on **the other routes**. This produced a total of 54 possible pointing estimations, however, it was decided that this would be prohibitively time consuming and so one of the landmark photographs for each route was dropped from this procedure. Thus, from each landmark site on each route subjects had to point to 4 other locations (2 for each of the other two routes) making a total of 24 cross route pointing estimations. The six landmark photographs retained for this procedure were RA, RC, BA, BB, GB, and GC. These were selected for their route exclusivity: i.e. the views of the landmarks portrayed in these photographs are exclusive to one particular route, thus the task tests subjects' ability to combine information acquired from different routes. Subjects were provided with the 6 labelled photographs and a booklet similar to those used for the single route pointing task, except with 24 pages. They then followed the same procedure as for the single route pointing tasks. Appendix V shows the instructions used for the single and cross route pointing tasks, and includes an example of one of the booklet pages. Appendix VI shows the correct angle measurements between all combinations of landmarks used in the single and cross route pointing tasks and also shows examples of the landmark photographs used in the study.

Finally, having completed the cross route pointing task and filled out a one page questionnaire (Appendix XII) requesting basic demographic details and details of driving experience, subjects were asked to draw a sketch map of the study area as a whole. They were provided with a pencil, ruler and as much paper as they required to do this, and told to take as much time as they needed until they were satisfied with their sketch maps. This concluded the experiments.

7 EXPERIMENT I: EFFECTS OF INFORMATION UPON COGNITIVE MAPPING ABILITY

7.1 Introduction

This chapter presents the findings of the first experiment, which concentrated on the effects of listening to audible route guidance information on ability to acquire spatial knowledge of an unfamiliar area, and on group differences with regards this ability (with and without additional information). Before presenting the results, the following two sections are included in order to clarify the research aims and how they are addressed by the various experimental tasks. Section 7.1.1 restates the research hypotheses identified in the preceding chapters under headings suggested by the research questions proposed in chapter 1. Section 7.1.2 then discusses the importance of the constituent elements that make up spatial knowledge, and which are addressed by the experimental tasks.

7.1.1 Summary of hypotheses to be tested by the present research

The review chapters (chapters 2, 3, and 4) identified key issues to be addressed by the research. These were expressed in the form of specific research hypotheses which were suggested and shaped by the research reviewed in each chapter. Consequently, while the reviews have focused upon work in different disciplines there is some similarity between the hypotheses suggested by each chapter. In particular, the possible impact that additional information might have upon underlying cognitive processes has been informed by research from 3 separate strands: transportation, human factors and spatial cognition.

Because of this overlap this section restates the hypotheses under three headings suggested by the original broad research questions:

- the effects of information;
- group differences;
- effectiveness of existing route guidance instructions.

a) The effects of information

The effect that listening to audible route guidance instructions might have upon spatial knowledge acquisition was discussed in all three review chapters, with 5 research hypotheses resulting. These were:

Hypothesis 1: (from chapter 2: transportation research)

H_1: The spatial knowledge acquired by subjects hearing audible route guidance information will be superior[1] to that of subjects who do not hear route guidance information.

Chapter 3 described two opposing theories of resources and mental workload. These led to two opposing hypotheses:

Hypothesis 2a: (from chapter 3: resources and workload research)

H_1 : If multiple resource theory is correct then the primary task performance of subjects listening to audible route guidance will be superior to that of subjects who hear nothing, or listen to radio (non-relevant information), regardless of task complexity, as the two tasks utilise different resources.

But if central resource theory is correct then:

Hypothesis 2b:

H_1: The primary task performance of subjects listening to audible route guidance information will be inferior to that of subjects who hear nothing, as resources are demanded from the same central pool.

However, the extent to which audible guidance interferes with the primary task will depend upon the complexity of the information contained in the secondary task, and its salience to the primary task. This suggests that non-relevant information (e.g. a radio broadcast) that does not require the subject to respond will place less demands on the individual's pool of resources and so will not interfere with primary task performance to the same degree. Hence, central resource theory also predicts that:

Hypothesis 3: (from chapter 3: resource and workload research)

H_1: The primary task performance of subjects listening to radio (i.e. non salient information) will be superior to that of subjects listening to salient information.

[1] Superior (i.e. configurational) spatial knowledge is defined in terms of performance at the cross route pointing task. This task requires subjects to integrate knowledge acquired from the three individual routes. In all hypotheses, unless otherwise stated, the main measure of performance is the mean error score achieved at this task.

Chapter 3 also considered research that had explored the possible impact of other in-vehicle devices upon attention, workload and safety, in particular carp phone research. This research suggested that attending to salient (relevant to the individual) information provided by such devices might distract from the primary task of controlling the vehicle. The present research does not consider driving performance, but substitutes another primary task that is safe, easy to control in the laboratory, and representative of the underlying cognitive processes involved in spatial tasks:

Hypothesis 5: (from chapter 3 – car phone research)

H_1: Subjects' performance of the primary task will be adversely affected by attending to salient information, but not by attending to non-salient information (e.g. radio).

Chapter 4 discussed research which has considered factors that can affect time estimation accuracy and concluded that the presence of information would have an effect upon this ability. The following hypothesis was proposed:

Hypothesis 8: (from chapter 4 – time estimation research)

H_1: Subjects required to listen to full route guidance instructions will make less accurate estimates of journey time than those who hear nothing or non-salient information.

b) Group differences

Group differences with regard to the development of skills such as wayfinding and navigation were discussed in chapters 3 and 4. From chapter 3 the following hypothesis was suggested:

Because the present research does not employ a driving task it is not possible to directly test hypotheses relating to the impact on driving performance. However, Anderson's model suggests that experienced drivers will have gained more experience of the sort of wayfinding exercise employed in the present research (because they will have more resources available to perform other tasks whilst driving). Consequently, the present research tests the following hypothesis:

Hypothesis 4: (from chapter 3 – development of skills)

H_1: Performance of tasks measuring spatial knowledge will be significantly correlated with ability to drive.

Chapter 3 also considered the effects of age upon the cognitive resource known as working

memory, as a result of which the following hypothesis was suggested:

Hypothesis 6: (from chapter 3 - effects of age upon working memory)

H_1: The quality of subjects' performance of tasks measuring spatial knowledge will be significantly correlated with age.

Chapter 4 also considered the effects of ageing, and noted that working memory was the resource required to enable the individual to integrate information from separate sources into a unitary whole. The deterioration in working memory suggests that, for older subjects, previous performance on the single route tasks will not be correlated with performance at the tasks measuring configurational knowledge:

Hypothesis 9: (from chapter 4 - effects of age upon configurational knowledge acquisition)

H_1: Elderly subjects will perform poorly at tasks measuring configurational knowledge, regardless of their performance at tasks measuring lower order spatial knowledge.

H_0 Elderly subjects' performance at tasks measuring configurational knowledge will be correlated with their performance of lower order tasks.

c) *Effectiveness of existing route guidance instructions*

The importance of landmarks to the cognitive map acquisition process suggests the following hypothesis:

Hypothesis 7: effects of instructions making reference to landmarks (from chapter 4)

H_1: Subjects who hear instructions containing references to visible landmarks should acquire superior spatial knowledge to those who hear information that makes no reference to landmarks.

This final hypothesis will be explored in detail in a second series of experiments (chapter 8).

7.1.2 Elements of Spatial Knowledge and tasks used to measure them

Before the results of the various tasks are described it is important to emphasise that acquisition of spatial knowledge is not just about being able to sketch a map of the study area. Rather, configurational knowledge of an area is dependent upon the individual having gained a good understanding of the routes in the area and how these are connected, and the locations of prominent landmarks on these routes. Thus, good route knowledge and landmark knowledge are the foundations of good configurational knowledge. This is not to say that good landmark and

route knowledge will *necessarily* result in good configurational knowledge, as this requires the ability to integrate the information acquired from separate routes into an overall representation of the study area.

However, in the present experiment the acquisition of configurational knowledge is the aim, and this is communicated to the subjects before starting the experiment. In this sense the experiment deviates from common experience, in that real world navigating and wayfinding, whilst goal-directed, rarely carries with it the specific, stated purpose of acquiring a cognitive map of an unfamiliar area. Whilst for this reason the experiment could be criticised for being somewhat unnatural, it is the cognitive processes that operate when we acquire spatial knowledge that are our primary concern, and in order to elicit these processes some minor degree of experimental manipulation was deemed necessary and acceptable.

A range of tasks were selected to measure subjects' acquisition of these constituent elements of spatial knowledge: knowledge of the routes (including time and distance information) and landmarks that constitute the area. Then, further tasks will measure subjects' ability to integrate this knowledge into a configurational representation. The experiments produce a dataset consisting of 282 variables. The dependent variables used in the analysis and the tasks which produced them are shown in Table 7.1. The complete list of variables and the SAS setup file which reads the raw data and produces the dataset is shown in Appendix VII.

Table 7.1: Tasks used, dependent variables produced and the aspect of spatial knowledge measured

Aspect of spatial knowledge being tested	Method of investigation	Dependent variables produced
Route knowledge	Sequencing task Distancing task	RScore, BScore, GScore d_err_R, d_err_B, d_err_G
Landmark and route knowledge	Single route pointing task	Red_Mean, Blu_Mean, Grn_Mean
Distance estimation	Route distance estimates	RRD, BRD, GRD R_Dseq, B_Dseq, G_Dseq
Time estimation	Journey time estimates	RRRT, RRLT, BRRT, BRLT, GRRT, GRLT R_TSeq, B_Tseq, G_Tseq
Configurational knowledge	Cross route pointing task Sketch map task	XRT_Mean Roads, Seqs, Landmarks, Correct, Total

7.1.3 Sample details

A total of 133 subjects took part in experiment 1 (68 female, 65 male). Subjects were recruited from a wide range of sources: advertisements in local newspapers; posters placed in academic departments, administration blocks, Students' Union, Junior Common Rooms and around the Imperial College campus; and to recruit older participants, a mailing of letters to 48 organisations (retired persons groups, clubs and societies, community centres, women's organisations such as Townswomen's Guilds and Women's Institutes). Participants were paid £5 each for taking part in the experiment. The list of organisations approached, and examples of the materials used to recruit subjects (posters, press release and letters sent out to organisations) are shown in Appendix VIII. The age range of subjects was 18 to 86 (mean age = 35.50). Subjects were assigned to the four information groups on the basis of three factors: their age (18-21, 22-54 and 55 and over), gender and driver status (driver or non-driver). The mean ages of the three age groups were: 19.71; 30.42 and 64.38 years. This produced a 4x3x2x2 experimental design (4 information groups, 3 age groups, 2 gender groups and 2 driving ability groups) which is shown in Appendix IX. The group composition, group numbers and mean ages of each group and sub-group are shown in Table 7.2. Driving experience ranged from 0-60 years (mean driving experience = 8.67 years). A list of subjects' professions are shown in Appendix X, while nationalities of the participants of both phases are listed in Appendix XI.

7.1.4 Route details

Table 7.1 shows details of the three routes. All routes were filmed at the same constant speed (10mph). The red route consists of 6 turns along an 800 metres route (Turn density = 133.33m) and is the longest of the three routes. The blue route is the least complex of the three routes, having only 4 turns over 600 metres (Turn density = 150m). The green route is 650 metres long and has 5 turns giving it a turn density of 130m.

Table 7.2: Details of the three routes

Route	Turns	Distance (metres)	Times (secs) Route	Landmark	Turn density (M/turn)
Red route	6	800	302	406	133.33m
Blue route	4	600	243	313	150m
Green route	5	650	275	376	130m

Thus, in terms of turn density, the green route is slightly more complex than the red route. The red route is longer, however, and requires 7 changes of orientation to the blue route's 5 and the green route's 6, so in this sense, the red route is the most complex.

7.1.5 Structure of the chapter

The remainder of this chapter is divided into three sections: results, summary and discussion. The results section is organised around tasks designed to measure the following aspects of spatial knowledge: route and landmark knowledge (7.2); subsidiary route information (distance and time estimates, section 7.3) and configurational knowledge (7.4). Sections 7.2.2 and 7.2.3 describe the results of the sequencing task; section 7.2.4 describes the distancing task, while section 7.2.5 considers the single route pointing task, designed to measure landmark and route knowledge. The next two sections are concerned with subsidiary information which is encoded as part of cognitive maps: section 7.3.1 reports on the distance estimation tasks, while 7.3.2 analyses subjects' ability to perceive and estimate journey duration. These tasks, in addition to testing subjects' knowledge of the individual routes, also help them to structure and organise the knowledge acquired and as such form part of the learning phase of the experiment.

Sections 7.4.1 and 7.4.2 report the results of tasks designed to test subjects' ability to integrate the information acquired from the three separate routes: their configurational knowledge. Section 7.4.1 considers the cross route pointing task while section 7.4.2 reports the results of the map drawing task. Section 7.5 summarises the results and considers the original hypotheses and how they are addressed by these results. Section 7.6 discusses the results, and section 7.7 offers conclusions and considers the limitations and problems of the experiment.

The results for each task are presented in a standard format: first, descriptive statistics are reported (group means, sample sizes, and other relevant information). Second, where applicable rank-order correlation coefficient analysis is described to show the independent variables which correlate with performance of a particular task. Third, the results of analysis of variance using the General Linear Models procedure are reported. Where a comparison of group means involves three or more levels (e.g. the independent variable age is divided into three groups) post hoc analysis using the Tukey procedure is used to provide evidence for differences between particular means. Finally, where applicable correlation coefficients which show a link between the current task and performance of other tasks are reported.

Table 7.3: Group composition and mean ages of constituent groups

Group	Information condition	Sub-group	n	Mean age
I	Video only	Female drivers 18-21	8	20.00
		Male drivers 22-54	8	26.50
		Male non-drivers 55 and over	7	65.28
		Female non-drivers 22-54	8	28.25
	Group Totals	Number of subjects	31	
		Group Mean age		33.97
II	Route guidance	Male non-drivers 18-21	9	19.67
		Male drivers 22-54	9	30.11
		Female drivers 55 and over	10	61.20
		Female non-drivers 22-54	8	26.12
	Group Totals	Number of subjects	36	
		Group Mean age		35.25
III	Radio	Female non-drivers 18-21	10	19.30
		Male non-drivers 22-54	8	27.25
		Male drivers 55 and over	8	63.62
		Female drivers 22-54	10	35.60
	Group Totals	Number of subjects	36	
		Group Mean age		35.44
IV	Route guidance/radio	Male drivers 18-21	8	20.00
		Female drivers 22-54	8	38.25
		Female non-drivers 55 and over	6	69.67
		Male non-drivers 22-54	8	30.00
	Group Totals	Number of subjects	30	
		Group Mean age		37.47
Total		Number of subjects	133	
		Sample Mean age		35.50

7.2 Results of tasks measuring single route knowledge

7.2.1 Order of presentation

Prior to the commencement of the experiments it was predicted that subjects' performance of some tasks would be affected by the order in which the three routes were presented. The single route tasks in particular were considered susceptible to the effects of order. However, preliminary analysis of the data quickly suggested that this was not the case, with the mean scores for all orders of presentation being quite similar for the sequencing, distancing and single route pointing tasks. Similar results were found for the distance and time estimation tasks as well as the cross route pointing and sketch map tasks. Further analysis using analysis of variance (General Linear Models procedure) showed that there were no significant differences between the 6 possible orders of presentation. Table 7.4 summarises the results of these analyses. Figures in brackets are standard deviations. It is clear from these figures that the different orders of viewing had little significant impact upon the ability to perform the tasks. Consequently, order of presentation is not discussed any further and will not be included as a variable in the second experiment.

7.2.2 Sequencing task

Having viewed both versions of a route, the first task performed is the sequencing task. This requires subjects to arrange 10 photographs into the correct sequence, i.e. as they would be experienced along the route. Hence, a score out of 10 is produced for each of the individual routes (variables RScore, BScore and GScore) for each subject, with a maximum overall sequencing task score (OScore) of 30 possible if all three routes are sequenced correctly. Each subject's sequencing task is turned into a series of 10 digits, each of which represents one of the 10 photographs. So, 1234567890 represents all 10 photographs being placed in the correct order. Similarly, 1234657890 represents the first 4 photographs in the correct order, photographs 5 and 6 transposed, and the remaining photographs in the correct order. In order to prevent the latter example receiving a score of 4 rather than 8 (two of the photographs in the wrong order), the sequencing task is scored using the following SAS routine contained within the SAS setup file:

For the red route sequencing task:

```
R_SeqOK = (Rorder = 1234567890);
RScore = 0;
do i=1 to 9;
if (int(Rorder/10**(10-i)) – int(Rorder/10**(11-i)*10) = i then Rscore = RScore + 1;
```

The formula begins by stating the correct order (Rorder), then creates the variable RScore. It then looks in turn at each digit within the subjects' estimate of Rorder and compares it with the digit

shown at that position in the correct order (Rorder). If the digit is the same as that in Rorder, then 1 is added to RScore. Hence the order 1235476890 would result in an RScore of 6, as only the first 3 and last 3 digits are in the correct positions. Note, however, that the order 2345678901 would produce an RScore of 0, as all the photographs are incorrectly placed. In this sense, the scoring can be seen as particularly unforgiving, as in the aforementioned example one could argue that it is only the first photograph that is out of place. However, real world navigating is equally unforgiving: in following a route one can make 9 correct turns out of 10, but if the first turn made is wrong one will end up in a very different location to that intended. Moreover, as with real world wayfinding the scoring mechanism is more forgiving the nearer one gets to the destination: if the first 9 of 10 route instructions made were correct one would probably be very close to the intended destination.

Appendix XIII shows the positions of the photographs used in the sequencing and distancing tasks, plotted on the Ordnance survey map of the study area.

Table 7.4: Mean task scores for each order of presentation

(standard deviations in brackets)

ORDER of presentation	1	2	3	4	5	6
n=	23	22	32	21	22	22
TASKS:						
Rscore (max=10)	6.00 (2.66)	6.04 (2.59)	7.13 (1.97)	6.71 (2.57)	7.00 (2.29)	6.22 (2.87)
BScore	7.65 (2.70)	7.27 (2.43)	8.10 (2.25)	7.62 (2.13)	7.91 (2.62)	7.54 (2.59)
GScore	7.13 (3.17)	6.82 (3.45)	7.98 (2.96)	7.00 (2.92)	7.77 (3.03)	7.09 (3.02)
Red route pointing task	49.79 (21.33)	53.98 (30.90)	55.73 (31.93)	46.75 (24.62)	48.16 (27.99)	49.71 (33.09)
Blue route pointing task	58.87 (28.66)	55.85 (26.31)	55.71 (30.14)	49.78 (26.67)	51.09 (29.20)	48.58 (31.79)
Green route pointing task	59.34 (32.07)	62.45 (32.22)	65.92 (31.51)	73.97 (29.53)	63.14 (36.58)	61.79 (29.83)
Times (secs)						
RRT	459 (183)	382 (143)	455 (264)	489 (197)	454 (215)	464 (456)
BRT	378 (215)	313 (99)	357 (167)	393 (160)	380 (208)	372 (397)
GRT	436 (269)	364 (129)	385 (168)	465 (186)	407 (207)	422 (394)
Distances (metres)						
RRD	1577 (1410)	1075 (565)	1339 (981)	1470 (832)	1735 (1640)	1293 (1089)
BRD	1295 (1084)	837 (437)	1170 (821)	1202 (724)	1440 (1754)	1245 (1418)
GRD	1243 (839)	923 (522)	1336 (1150)	1595 (1245)	1689 (1942)	1333 (1416)
Cross route tasks						
XRT Mean (degrees)	64.43 (28.82)	61.53 (28.85)	52.93 (24.85)	61.85 (25.18)	58.54 (26.52)	54.32 (24.64)
Correct landmarks	11.15 (9.41)	9.10 (7.15)	14.99 (9.45)	9.56 (6.59)	13.11 (11.53)	10.11 (7.66)

Red route sequencing task: descriptive statistics

The mean RScore for the sample of 133 subjects as a whole was 6.35. Twenty-four subjects correctly sequenced the photographs from the red route. Of these, seventeen were male, seven were female. Nine were aged 21 and under (Hence, 25% of this age group correctly sequenced the route), fourteen were in the age group 22-54 (21% of this age group), and only one was aged over 55. Sixteen were drivers, eight were non-drivers. Information group had a slightly more pronounced effect, but did not reach significance. The figures for correct sequences in the four information groups were: group I - 7; group II - 8; group III - 5; group IV - 4.

In addition to correct sequences, the various incorrect combinations proposed by subjects were also studied. This analysis showed that the ten photographs were arranged in a total of 57 different sequences. The different sequences suggested by subjects for the 3 route sequencing tasks are listed in Appendix XIII. Forty subjects placed the photographs into a sequence unique to them. An analysis of the 56 incorrect sequences showed that photograph number 6 caused subjects most problems. 106 subjects (79.7%) correctly sequenced the first 5 photographs but made an error thereafter. Eleven subjects (8.3%) arranged the photographs in the sequence 1234506789, a further eleven arranged them in the sequence 1234578960.

Blue route sequencing task: descriptive statistics

The mean score for the group of 133 subjects as a whole was 7.57. This was the highest score for the 3 routes as would be expected for the shortest and least complex route. Fifty eight subjects correctly sequenced the blue route photographs. Of these, 28 were male and 30 were female. 25 were in the age group 21 and under (69.4% of this age group), 26 were aged 22-54 (39.4% of this age group) and seven were aged 55 or over (22.6%). 32 were drivers and 26 were non-drivers. Order of presentation seemed to have some (non-significant) effect upon ability to correctly sequence this route: of the group who saw this route second (orders RBG and GBR) 25 subjects placed the photos in the correct sequence, by contrast 18 subjects who saw the blue route first and only 15 who saw it last were able to correctly sequence the photographs. Information condition also seemed to have a slight effect upon sequencing ability: 33 of those subjects who correctly sequenced the blue route (57%) were in groups I or III, and thus did not hear route guidance.

The photographs from the blue route were arranged in a total of 39 different sequences, and of these, 31 were each unique to one subject. Apart from the correct sequence, the most frequent sequence was 1253467890, recorded for 25 subjects (18.8%). Forty eight subjects (36.09%) placed the photographs in a sequence with photograph number 5 ahead of photographs 3 and 4.

Green route sequencing task: descriptive statistics

The mean GScore for the sample of 133 subjects as a whole was 6.977. 59 subjects correctly sequenced the photographs from the green route. Of these, 34 were male and 25 were female. Twenty five subjects were aged 21 and under (69.44% of this age group), twenty-one were aged 22 to 54 (43.94% of this age group) and five were aged over 55 (16.13% of the age group). There were 35 drivers, and 24 non-drivers. Order of presentation again showed a slight (but non-significant) effect, of those who saw the green route first 20 subjects correctly sequenced the photographs, as opposed to 16 who saw it second and 23 who saw the green route last. There was little difference between the four information groups in the numbers of correct sequences: fourteen in group I; thirteen in group II; seventeen in group III and fifteen in group IV.

In contrast to the red and blue routes, there was no one incorrect sequence into which a large number of subjects placed the green route photographs. The photographs were arranged in a total of 59 different sequences, with most of the errors arising on photographs 2 through to 5.

7.2.3 Analysis of variance for the sequencing task - description of the GLM Procedure

To analyse the effect of the independent variables upon subjects' ability to carry out the various tasks analysis of variance was carried out. Normally, the ANOVA procedure would be preferable for analysing variance, as it is more efficient than GLM. However, for unbalanced designs, i.e. models where there are unequal numbers of observations for the different combinations of CLASS variables specified in the MODEL statement, the General Linear Models Procedure should be used.

The GLM Procedure uses the method of least squares to fit general linear models. It allows the specification of any degree of interaction (crossed effects) and nested effects. Through the concept of estimability, GLM can provide tests of hypotheses for the effects of a linear model regardless of the number of missing cells or the extent of confounding. GLM prints the Sum of

Squares (SS) associated with each hypothesis tested and, upon request, the form of the estimable functions employed in the test. GLM carries out initial analysis of the hypotheses using Type I Sum of Squares. Then, if there are no missing cells, the Type III Sum of Squares is used to test these same hypotheses (SAS, 1988).

Table 7.5: Sequencing task: analysis of group differences

	Groups	n	OScore Max=30	RScore Max=10 (S.D.)	BScore Max=10 (S.D.)	GScore Max=10 (S.D.)
Mean Score	All	133	20.90	6.35	7.57	6.98
% of subjects scoring max.	All	133	13.30	18.00	43.60	44.40
Mean by age	18-21	35	24.75 (4.24)	7.19 (2.00)	8.97 (1.63)	8.58 (2.36)
	22-54	67	21.48 (5.60)	6.79 (2.23)	7.57 (2.35)	7.12 (3.03)
	55+	31	15.19 (6.68)	4.45 (2.84)	5.93 (2.84)	4.81 (2.90)
Mean by sex	M	65	22.05 (6.39)	6.74 (2.81)	7.83 (2.27)	7.48 (3.04)
	F	68	19.81 (6.43)	5.98 (2.21)	7.32 (2.75)	6.50 (3.14)
Mean by driver	Driver	69	21.56 (6.66)	6.77 (2.53)	7.64 (2.59)	7.16 (3.13)
	Non~	64	20.18 (6.27)	5.91 (2.50)	7.50 (2.49)	6.78 (3.11)
Mean By information group	Video	31	21.64 (6.28)	6.42 (2.59)	8.09 (2.27)	7.13 (3.04)
	Guidance	36	20.42 (6.24)	6.39 (2.66)	7.28 (2.68)	6.75 (2.89)
	Radio	36	22.03 (5.24)	6.64 (2.20)	7.92 (2.34)	7.47 (2.78)
	Radio+ Guidance	30	19.37 (8.10)	5.90 (2.78)	6.97 (2.77)	6.50 (3.84)
Results of GLM						
Age			p<0.001	p<0.001	p<0.001	p<0.001
Sex			p<0.01	p<0.05	n.s.	p<0.05
Driver			p<0.01	p<0.05	n.s.	p<0.05
Group			n.s.	n.s.	n.s.	n.s.
Age*Driver			p<0.05	n.s.	n.s.	p<0.05.

Table 7.5 shows the sequencing task scores for the three routes, and the overall score (OScore) by age, sex and driving ability of the participants, as well as the results of the GLM procedure performed on the data. Standard deviations are shown in brackets.

Analysis of variance of Red route sequencing task data

Analysis of variance using the GLM procedure was performed on the data to analyse group differences in ability to place the 10 photographs into the correct sequence. The model produced for RScore was found to be significant ($F(7,125)=6.19$, $p<0.001$, $r^2=0.257$) and showed the following main variables to have a significant effect upon performance:

- Age group $F(2,131)=16.13, p<0.001$;
- Sex $F(1,132)=4.21, p<0.05$;
- Driving ability $F(1,132)=7.35, p<0.05$.

As there are three levels to the variable "Age group", post hoc analysis was run using the Tukey procedure, to determine differences between particular means. Table 7.6 below is a table of means for this variable.

Table 7.6: Table of differences between means for RScore for the variable "Age group"

Comparison between Age groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$) indicated by ***
1 - 2	-0.6620	0.4525	1.5669	
1 - 3	1.4590	2.7770	4.0949	***
2 - 1	-1.5669	-0.4525	0.6620	
2 - 3	1.1638	2.3245	3.4852	***
3 - 1	-4.0949	-2.7770	-1.4590	***
3 - 2	-3.4852	-2.3245	-1.1638	***

A number of interactions were included in a subsequent analysis but none of these was found to be significant. The results in Table 7.5 suggest that ability to sequence the photographs deteriorates with age, with subjects in the 55 and over age group performing significantly worse than those in the other age groups. It should also be noted that the variation between individuals (as indicated by the standard deviation) increases with age. Table 7.5 also shows small but significant differences between male and female subjects and between drivers and non-drivers in red route sequencing task performance. However, the differences shown between male and

female are probably less reliable than the table would suggest, in that no distinction is made between drivers and non-drivers. The results of the post hoc analysis in table 7.6 show that there is a significant difference between the performance of the youngest subjects and that of the old, and between the middle-age and oldest subjects, but the performances of youngest and middle were not significantly different.

Analysis of variance of Blue route sequencing task data

Analysis of variance (using GLM) performed on the blue route sequencing task data produced a model which was significant ($F(7,125)=5.44$, $p<0.001$. $r^2 = 0.2335$) and which showed only one main variable to have a significant effect upon performance:

- Age group $F(2,131)=21.03$, $p<0.001$

Again, it can be seen that there is a significant age-related decline in ability to correctly sequence the photographs. However, in this instance, the post hoc analysis using the Tukey procedure indicated that all three age groups are significantly different from one another. In addition, the variation between individuals within the same group increases across the age range. The mean BScore values in Table 7.5 also show how much easier than the other two routes subjects found the blue route. None of the interactions were found to be significant.

Table 7.7: Table of differences between means for BScore for the variable "Age group"

Comparison between Age groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$) indicated by ***
1 - 2	0.3330	1.4614	2.5898	***
1 - 3	1.7586	3.0931	4.4276	***
2 - 1	-2.5898	-1.4614	-0.3330	***
2 - 3	0.4564	1.6317	2.8070	***
3 - 1	-4.4276	-3.0931	-1.7586	***
3 - 2	-2.8070	-1.6317	-0.4564	***

Analysis of variance of Green route sequencing task data

Analysis of variance performed on the green route sequencing task data again produced a significant model ($F(9,123)=5.17$, $p<0.001$. $r^2= 0.2746$) which showed the following main variables to have a significant effect upon performance:

- Age group $F(2,131)= 17.15$, $p<0.001$

- Sex F(1,132)= 4.82, $p<0.05$
- Driver F(1,132)=4.64, $p<0.05$
- Age*Driver F(2,131)=3.49, $p<0.05$

For the 55 and over age group, the mean sequencing score for this route was the lowest of the three routes. The high standard deviation evident for the green route shows that there is large variation between subjects within each gender group. Table 7.8 shows the post hoc analysis for the variable age group on the green route. This shows that the performance of all three age groups can be considered to be significantly different from one another.

Table 7.8: Table of differences between means for GScore for the variable "Age group"

Comparison between Age groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$) indicated by ***
1 - 2	0.0155	1.3787	2.7418	***
1 - 3	2.1244	3.7364	5.3484	***
2 - 1	-2.7418	-1.3787	-0.0155	***
2 - 3	0.9380	2.3577	3.7775	***
3 - 1	-5.3484	-3.7364	-2.1244	***
3 - 2	-3.7775	-2.3577	-0.9380	***

Unlike the red and blue routes, the GLM showed that there was a significant interaction between the variables age and driver. Table 7.9 below shows mean scores at the green route sequencing task by age and driving ability.

Table 7.9: Table of Means for GScore for the interaction between the variables Age_X and Driver

Level of Age_X	Level of driver	N	Mean	SD
18-21	Driver	16	9.31	1.88
18-21	Non-driver	19	7.89	2.60
22-54	Driver	35	6.88	3.21
22-54	Non-driver	32	7.47	2.84
55 and over	Driver	18	5.78	3.00
55 and over	Non-driver	13	3.46	2.22

Table 7.9 emphasises the importance of age as a predictor of performance. Although ability to drive is also a significant variable, the mean score for non-drivers in the youngest age group was better than that of all older subjects, regardless of their driving experience. Comparing the means of drivers and non-drivers in the youngest and oldest age groups suggests that for these groups ability to drive has some effect upon performance. (It should be noted that the sample sizes of these age groups are smaller than the middle age group and that this might explain the significant results (and absence of significance in the middle age group).

Sequencing task: all routes

Combining the scores from the three individual routes gives an overall score (maximum 30) for the sequencing task (variable OScore). The mean OScore for the full sample of 133 subjects was 20.90. To check whether any of the main variables have an effect upon ability to perform the sequencing task, analysis of variance using GLM was carried out on the OScore data. The GLM model, incorporating the main variables age, sex, group and driver[2], was found to be significant: $F(9,123)=9.78$, $p<0.001$, $r^2=0.4172$). The following main variables were significant:

- Age group $F(2,131)= 33.22$, $p<0.001$
- Sex $F(1,132)= 7.47$, $p<0.01$
- Driver $F(1,132)= 10.73$, $p<0.01$

Table 7.10: Table of differences between means for OScore for the variable "Age group"

Comparison between Age groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$) indicated by ***
1 - 2	0.7530	3.2925	5.8321	***
1 - 3	6.6032	9.6065	12.6097	***
2 - 1	-5.8321	-3.2925	-0.7530	***
2 - 3	3.6689	6.3139	8.9589	***
3 - 1	-12.6097	-9.6065	-6.6032	***
3 - 2	-8.9589	-6.3139	-3.6689	***

[2] A range of models incorporating the various combinations of main variables were tested to see whether there were any significant interactions between them. Where interactions are reported they are part of the model described for that route.

Post hoc analysis using the Tukey procedure (Table 7.10) showed that the performance of the three age groups can be considered to be significantly different from each other. In addition, the interaction between age group and driving ability was also significant:

- Age group*Driver $F(2,131)= 5.35, p<0.01$

Table 7.11: Table of Means for OScore for the interaction between the variables Age_X and Driver

Level of Age_X	Level of driver	N	Mean	SD
18-21	Driver	16	26.81	3.31
18-21	Non-driver	19	23.10	4.29
22-54	Driver	35	21.14	6.45
22-54	Non-driver	32	21.91	4.45
55 and over	Driver	18	17.72	6.55
55 and over	Non-driver	13	11.69	5.28

As with the comparable table for the green route (table 7.9) table 7.11 shows clear differences between the three age groups in their performance of the sequencing tasks, however, the table also emphasises the fact that it is only in the youngest and oldest age groups that driving ability appears to have an influence upon task performance. For both age groups the performance of drivers is significantly better than that of non-drivers. This is particularly apparent for the 55 and over age group where the performance of non-drivers is comparatively very poor.

Sequencing task: comparison of routes

Of 133 subjects who took part in phase I, only 10 subjects correctly sequenced all three routes and thus had an OScore of 30. Of these ten, 6 were male and 4 were female, 8 were drivers and only 2 were non-drivers, and only one was aged over 23. This group was compared with the ten lowest scorers on the sequencing task, who all scored less than 11 on the OScore. Of these ten subjects, 7 were female and 3 male, 5 were drivers and 5 non-drivers. One was aged 29, one was aged 37, two were aged 60 or over and the remaining six were all aged over 70. Table 7.4 showed there to be an increase in standard deviation across the three age groups in their OScore scores, suggesting that, not only is there a decline in spatial ability as measured by this task, but

also that the variation between people increases with age, and hence not all people experience the same decline in spatial ability. A relatively small, but significant difference between males and females in their performance of the sequencing task as a whole is evident from the results. It should be noted, however, that the standard deviation is very high when we compare only on the basis of gross distinctions such as gender. A small but significant difference between drivers and non-drivers is also evident. This difference is actually less than might be expected (particularly in light of other results discussed later in the chapter).

Comparing the three routes, subjects appear to have found the blue and green routes easier to sequence than the red route, with over 40% of subjects placing the photographs for these routes into the correct order (only 18% of subjects were able to correctly sequence the red route). The blue route was easier than the green (shorter distance, less turns, shorter duration) and this was shown by the fact that the mean score for the blue route for all 133 subjects was 7.57 as opposed to only 6.98 for the green route. Although the red route is the longest in both distance and journey time, the green route is a little more complex when measured in terms of turn density, so it is surprising that performance on the blue and green routes was so similar. The only variable that was significant on all three routes was age. Gender and ability to drive were both significant on the red and green routes, but on the easier blue route, on which most subjects performed well, neither variable was found to be significant. All possible interactions between the four main variables were tested in GLM models (which also included the individual variable effects), but only the interaction between age and driver was found to be significant, and this was only significant on the green route and for the variable OScore.

Age was expected to be a good predictor of performance, as the research reviewed in chapters 3 and 4 pointed to an age-related decline in working memory and spatial ability generally. However, there is no immediate explanation for the superior performance of drivers over non-drivers at the sequencing task. Comparing the performance of the 18-21 and 55-and-over age groups it is clear that drivers in both groups perform better than non-drivers on all but the blue route. It is tempting to suggest that driving gives the individual experience of the kind of skills necessary to perform well at spatial tasks such as the sequencing task. However, before we can draw any firm conclusions it is necessary to consider the performance of these two groups at the other tasks.

7.2.4 Distancing tasks

The distancing tasks are carried out in conjunction with the sequencing task. The main function of the distancing task (described in detail in the previous chapter) is to encourage subjects to think about the route they have just seen and how the various photographs used for the sequencing task are related both to each other and to the route itself. In this way the distancing task helps subjects to organise the route information they have acquired from watching the films. As such the results of this task are of less importance than some of the other tasks. The task produces an error score for each route (d_err_R, d_err_B and d_err_G). D_err_R, for example, represents the total deviation from their correct positions of each of the ten photographs on the red route. Subjects who have incorrectly sequenced the route are excluded from analysis of the distancing task, as their distance estimates clearly refer to the wrong photographs. Consequently, data was produced for 24 subjects for the red route, 58 for the blue route and 59 for the green route. Analysis of variance using GLM showed that none of the main variables reached significance for any of the three routes. A second GLM was also carried out on the sample as a whole, which again showed none of the variables to be significant.

The distancing task data does give some useful information about the accuracy of individuals' estimates of inter-landmark distances. By subtracting each estimate from the actual distance, squaring this result to remove any negative sign and then taking the square root of the product, we get a measure of the accuracy of each estimate:

$$d_R_dis_1 = \sqrt{((R_dis_1 - reddist1)*(R_dis_1 - reddist1))} \qquad [1]$$

where R-dis_1 = subject's estimate of the position of photograph 1 on the red route;
and reddist1 = correct position of photograph 1 on the red route.

The total error for the red route (d_err_R) is then calculated by summing the error figures for each of the ten photographs:

$$D_err_R = (d_R_dis1 + d_R_dis2 + d_R_dis3.....+ d_R_dis9 = d_R_dis10) \quad [2]$$

Table 7.12 gives the mean error figures for subjects' performance of the distancing task for each of the three routes. Columns 3 and 4 give the mean ratio-scaled error and actual error for subjects who correctly sequenced the routes, while columns 6 and 7 give the same information, but for subjects who incorrectly sequenced the routes. The task is carried out by placing the photographs along a strip of paper one metre in length and so to obtain the actual error in metres a calculation has to be performed on the raw scores. The total error for each route is calculated by taking the square root of the mean distancing error and multiplying this by the actual route length. The table shows that subjects who correctly sequenced the 10 scenes were slightly more accurate in their ability to judge distances between these scenes than subjects who were unable to place the scenes into the correct sequence. Although for each of the routes those who correctly sequenced the photographs were more accurate in estimating distance between the photographs, the difference between the mean distancing error figures is perhaps smaller than might be expected. It is also noticeable that the distancing error for the red route is much larger than for the other two routes, regardless of whether subjects were correct or incorrect in their sequencing of the route photographs. This larger error is explained by the fact that the figure for mean distancing error is multiplied by the total route length (the red route, being the longest is therefore likely to produce the largest error figure). Overall, the results of the distancing task indicate that it is not a particularly accurate measure of acquired spatial knowledge.

Table 7.12: Distancing task error scores for each route

Route	n Correct Sequences Only	Mean distancing error	Actual Total error (Metres)	n Incorrect sequences only	Mean distancing error	Actual Total error (Metres)
Red	24	0.09519	246.82	109	0.10076	253.94
Blue	58	0.06902	157.63	75	0.08615	176.11
Green	59	0.05689	155.03	74	0.08097	184.96

7.2.5 Single route pointing tasks

The single route pointing task measures subjects' ability to estimate directions between points on the same route. As such the task is a measure of route and landmark knowledge. Success at

the task depends upon subjects' ability to mentally visualise the route and its constituent elements, in order that they can imagine themselves standing at one landmark and can visualise the direction to a second landmark. This is the most difficult of the single route tasks and hence larger group differences should be apparent. For each route subjects are required to make 6 direction estimates. The mean error of these estimates (the difference between actual directions and subjects' estimates) measured in degrees, is the subject's mean error score for the route. Hence, if a subject's pointing score is 35.6 for the red route this means that this subject's direction estimates for the red route are an average of 35.6 degrees from actual.

Table 7.13: Single route pointing tasks: summary of group means for each route

	Groups	n	Red route SRT (S.D.)	Blue route SRT (S.D.)	Green route SRT (S.D.)
Mean Score	All	133	51.44	53.37	64.55
Mean by age	18-21	35	36.48 (18.77)	41.69 (23.77)	46.52 (30.47)
	22-54	67	54.97 (31.02)	50.43 (26.43)	65.22 (32.19)
	55+	31	60.70 (28.13)	72.89 (29.04)	83.47 (20.04)
Mean by sex	M	65	46.85 (28.00)	47.60 (30.64)	58.90 (33.96)
	F	68	55.82 (29.35)	58.88 (25.47)	69.95 (29.08)
Mean by driving ability	Drivers	69	49.09 (28.14)	50.20 (28.32)	61.83 (32.01)
	Non-drivers	64	53.97 (29.79)	56.78 (28.67)	67.49 (31.81)
Mean by information group	Video	31	53.45 (33.29)	50.67 (29.99)	61.16 (31.09)
	Guidance	36	54.61 (27.85)	52.48 (26.61)	71.07 (32.22)
	Radio	36	46.29 (25.48)	54.35 (28.87)	63.58 (29.21)
	Radio+ Guidance	30	51.73 (29.92)	56.03 (30.12)	61.41 (35.76)
Results of GLM					
Age			$p<0.001$	$p<0.0001$	$p<0.0001$
Sex			$p<0.05$	$p<0.05$	$p<0.05$
Driver			n.s.	$p<0.05$	n.s.
Group			n.s.	n.s.	n.s.

Red route

Subjects mean error scores for the red route pointing task ranged from 8.0 degrees (a 21-year-old female driver) to 144.6 degrees (a 37-year-old male non-driver). For the group of 133 subjects the mean error score was 51.44 degrees. Table 7.13 shows that the direction estimates of the youngest group of subjects were significantly more accurate than those of the other groups. Table 7.13 also shows the mean error scores for the routes by sex of the participant. The table shows that, when the sample was considered as a whole, males were slightly more accurate in estimating directions on the red route than females. However, no distinction is made between age groups and driver groups.

The GLM produced for the red route single route pointing task was significant ($F(7,125)=3.34$, $p<0.01$), although weak ($r^2 = 0.178$) and showed the following main variables to be significant:

- Age group $F(2,131)=8.26$, $p<0.001$
- Sex $F(1,132)=4.35$, $p<0.05$

Table 7.14: Table of differences between means for the variable Age (Red route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	-8.23	5.73	19.68	
3 – 1	8.36	24.21	40.05	***
2 – 3	-19.68	-5.73	8.23	
2 – 1	5.08	18.48	31.88	***
1 – 3	-40.05	-24.21	-8.36	***
1 – 2	-31.88	-18.48	-5.08	***

Post hoc analysis of the variable age was carried out using the Tukey procedure. The resulting data is shown in table 7.14 above. The actual means for each level of age can be found in table 7.13. The analysis showed that the performances of the youngest and oldest groups were significantly different from each other, and that of the youngest group was significantly different from that of the middle group. However, there was no significant difference between the performance of those in the middle and oldest age groups.

Although none of the interactions between variables were significant, table 7.15 is included to enable a comparison of the performances of drivers and non-drivers of both sexes and of

varying ages at the red route pointing task. The purpose of this comparison is to try to account for the finding that sex is a significant variable. Table 7.15 shows that at each of the three levels of age, the performances of male and female drivers and of male non-drivers are comparable. The direction estimating ability of female non-drivers, however, is much poorer than the other groups. This pattern is repeated across all three age groups. Hence it is possible that the poor performance of female non-drivers skews the results of the group of female respondents as a whole.

Table 7.15: Comparison of group performances at the Red route pointing task.

Level of Age_X	Level of Gender	Level of Driving ability	N	Mean pointing error in degrees	S.D.
1	Male	Driver	8	35.44	17.97
1	Male	Non-driver	8	33.37	23.77
1	Female	Driver	9	33.39	15.21
1	*Female*	*Non-driver*	*10*	*42.60*	*19.33*
2	Male	Driver	17	51.30	29.65
2	Male	Non-driver	18	50.12	27.47
2	Female	Driver	16	46.55	32.30
2	*Female*	*Non-driver*	*16*	*72.74*	*30.69*
3	Male	Driver	8	55.43	32.09
3	Male	Non-driver	10	61.90	29.82
3	Female	Driver	7	57.26	28.14
3	*Female*	*Non-driver*	*6*	*69.72*	*24.33*

Blue route

Mean pointing error scores for the blue route ranged from 10.2 degrees (a 21-year-old female driver) to 130 degrees (a 69-year-old male non-driver). The mean error score for the sample of 133 subjects was 53.37 degrees. Analysis of variance by the GLM procedure was again run on this data. The GLM produced for the blue route single route pointing task was significant ($F(7,125)=4.42$, $p<0.0001$), but again was quite weak ($r^2 = 0.244$). The results showed the following main variables to be significant:

- Age group $F(2,131)=14.60$, $p<0.0001$
- Sex $F(1,132)=6.78$, $p<0.05$

- Driver F(1,132)=5.55, p<0.05

Note from table 7.13 that there is a larger standard deviation between male subjects than between females. Again, post hoc analysis of the variable age was carried out using the Tukey procedure, and this data is shown in table 7.16 below.

Table 7.16: Table of differences between means for the variable Age (Blue route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance (p<0.05) indicated by ***
3 – 2	9.18	22.46	35.74	***
3 – 1	16.13	31.21	46.28	***
2 – 3	-35.74	-22.46	-9.18	***
2 – 1	-4.00	8.75	21.50	
1 – 3	-46.28	-31.21	-16.13	***
1 – 2	-21.50	-8.75	4.00	

In this instance, the mean error of the young and middle age groups can be considered significantly different from that of the oldest group of subjects, but not significantly different from each other. Again, the actual means for each age group can be found in table 7.13.

Green route

Mean pointing error scores for the green route ranged from 8.67 degrees (male driver aged 20) to 126 degrees (a female driver aged 47). The mean pointing error score for the sample of 133 subjects was 64.55 degrees. Analysis of variance by GLM of the green route single route pointing task was significant (F(7,125)=5.22, p<0.0001), but again was weak (r^2 = 0.226). The following main variables were found to be significant:

- Age group F(2,131)=13.79, p<0.0001
- Sex F(1,132)=5.05, p<0.05

The figures for the green route in Table 7.13 show that younger subjects again performed significantly better at this task than other groups. However, the standard deviation for this group is high, suggesting a wide variation in the performance of young subjects. By contrast, the standard deviation for the oldest group is low considering the high mean score, suggesting that

most older subjects performed poorly at this task. Post-hoc analysis using the Tukey procedure produced the following table of differences between means.

Table 7.17: Table of differences between means for the variable Age (Green route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	3.38	18.25	33.12	***
3 – 1	20.07	36.95	53.83	***
2 – 3	-33.12	-18.25	-3.38	***
2 – 1	4.43	18.70	32.98	***
1 – 3	-53.83	-36.95	-20.07	***
1 – 2	-32.98	-18.70	-4.43	***

Table 7.16 shows that in the case of the green route, the performance of all three age groups can be considered significantly different from one another. This is made clear if we compare the group means for the three age groups (table 7.13) which show that on this route the difference between the groups is more pronounced than was the case on either the red or blue routes.

Single route pointing tasks: summary and overall comparison

The results of the three single route pointing tasks indicate that only age and sex were significant variables across all three routes. Driving experience was a significant variable for the blue route but information condition was not significant for any of the routes. With regard to the age variable, differences between the age groups were most pronounced on the green route – this could be attributed to the fact that the green route is most complex in terms of turn density. Post-hoc analysis of the age group data for this route showed that the performance of the three age groups can be considered to be significantly different. With regard to gender, although this was a significant variable for all three routes, it is possible that the situation is more complex than it would at first appear. Table 7.15 showed that female non-drivers performed particularly poorly at all three levels of age, but that the performance of female drivers was comparable with that of male drivers across the age groups. Similar tables were composed for both the blue and green routes and these are summarised in table 7.18 below:

Table 7.18: Comparison of group performances at the Blue and Green route pointing tasks.

Level of Age	Level of Gender	Level of Driving ability	N	Mean pointing error in degrees **BLUE**	S.D.	Mean pointing error in degrees **GREEN**	S.D.
1	Male	Driver	8	33.04	18.68	32.48	22.87
1	Male	Non-driver	8	37.35	25.81	49.85	37.17
1	Female	Driver	9	37.96	26.72	40.41	27.34
1	Female	Non-driver	10	55.48	20.15	59.63	29.67
2	Male	Driver	17	39.11	24.46	59.62	35.29
2	Male	Non-driver	18	43.93	39.62	56.53	36.50
2	Female	Driver	16	58.92	27.64	66.88	29.57
2	Female	Non-driver	16	59.43	18.14	78.00	24.78
3	Male	Driver	8	68.23	32.51	77.93	23.88
3	Male	Non-driver	10	82.85	31.64	82.69	17.81
3	Female	Driver	7	62.47	25.88	84.22	20.59
3	Female	Non-driver	6	84.86	24.68	90.53	18.88

Table 7.18 shows the pointing task error scores for driving and non-driving male and female subjects across the three age groups. Taking the blue route first, the table shows that at each level of age there is a different pattern. The performances of male and female subjects in the youngest age group were all comparable with the exception of female non-drivers, whose performance was much poorer than their peers. Pointing task error scores for the middle age group suggest a gender effect is operating within this age group: males perform better than females, regardless of driving ability. In the oldest age group still another pattern is apparent: within this group there seems to be a clear driving effect: the performance of male and female drivers is comparable, while the performances of male and female non-drivers are again comparable but show much higher pointing error. For the green route no clear patterns emerge: at the youngest age level drivers perform better than their non-driving counterparts, whereas at the middle age level males perform better than females (although female drivers were much more accurate than female non-drivers. At the oldest age level male drivers perform better than male non-drivers and female drivers, whose performances are comparable. At this level female non-drivers are less accurate than the other groups. It should be pointed out that table 7.18 is

only included for explanation purposes – the results of the analysis of variance showed that there were no significant interactions between these variables, but the table is included because it gives a more detailed picture of the performances of male and female drivers and non-drivers at the three age levels.

7.3 Results of tasks measuring subsidiary route information

7.3.1 Distance estimates

Immediately before completing each single route pointing task subjects estimated the distance travelled and time taken to travel that route. The estimates varied considerably across subjects and across information conditions. Figures 7.1, 7.2 and 7.3 show the distribution of scores for the sample of 133 subjects for the red, blue and green routes respectively. These results can be interpreted by reference to two indicators of spatial ability. The first of these indicators is accuracy. The overall accuracy of estimates made by subjects can be compared to see whether any independent variables have an influence upon ability to accurately judge journey distances and durations. However, accuracy is not the only measure of spatial ability. Estimating distances from watching filmed footage of journeys is a difficult exercise: video footage tends to make roads look longer than they really are. In reality, movement through the environment provides our senses with a wide range of information from which travel distance can be inferred. However, in this experiment subjects do not move through the environment, the motion is all on film: subjects' distance estimates are therefore likely to be inaccurate.

A more valid measure is subjects' ability to assign values to the various distance and time estimates which, whilst lacking in accuracy, preserve the hierarchical order of the three routes (i.e. the red route estimated as longest, both in time and distance, followed by green and finally, blue). Whilst it might be difficult for subjects to estimate distances and times with accuracy, it might be possible for them to discern differences between three routes such that their distance and time estimates reflect these differences.

For these reasons our concern is not with the accuracy of each estimate, but more with the set of 3 estimates that each subject gives. Are subjects able to determine that the red route is longest, followed by the green and the blue, which are of similar length? Table 7.19 shows the actual distances, mean distance estimates for the sample as a whole and the range of estimates. Note

that only 132 subjects were included in this analysis, one of the 55 and over group made estimates of between 10 and 20 miles for each of the three routes. These estimates seriously skewed the overall data and so were removed.

Table 7.19 highlights the enormous range of people's distance estimates. Of course, the minimum and maximum figures are at the extremes, but the mean estimates and the standard deviations for the group as a whole suggest that the majority of subjects were, as expected, very inaccurate in their estimates of distance. Despite this, note that the mean estimates for the 3 routes preserve the route hierarchy, although the red and green routes are clearly judged to be more similar in length than they really are. To gain a better understanding the General Linear Models Procedure was performed on the data.

Table 7.19: Actual distance information and group mean estimates for each route

Route	n	Actual distance (metres)	Mean estimated distance (Metres)	Standard deviation (Metres)	Minimum (Metres)	Maximum (Metres)
Red	132	800	1468	1245	200	6440
Blue	132	600	1237	1200	150	7040
Green	132	650	1405	1410	150	8000

Distance estimates: analysis of variance

GLM analysis performed on the distance estimate data for each of the three routes showed that, in each case, only age was significant. The models were weak (as shown by the r^2 figures) although slightly higher r^2 figures were obtained when interactions were included. However, none of these interactions were significant and so are not included.

Models:

- Red $F(7,125)=3.36, p<0.005, r^2= 0.16;$
- Blue $F(7,125)=2.38, p<0.05, r^2= 0.16;$
- Green $F(7,125)=2.58, p<0.005, r^2= 0.13$

Age was the only significant variable for each route:

- Red $F(2,130)=10.38, p<0.001$,
- Blue $F(2,130)=8.07, p<0.001$,
- Green $F(2,130)=6.75, p<0.05$.

The mean distance estimates of the three age groups for each route are presented in one table (Table 7.20 below). None of the other main variables reached significance. Information group, although not significant, did seem to have some effect upon distance estimates however, with those in group I (no information) estimating all three routes as much longer than other groups, and those in the route guidance group making the lowest estimates on all three routes.

Table 7.20: Distance estimates by age group

Age group	n	Red Route	Standard deviation	Blue route	Standard deviation	Green route	Standard deviation
Actual		800m		600m		650m	
18-21	35	1131	700	906	585	983	587
22-54	67	1291	1001	1109	940	1316	1362
55 +	30	2262	1818	1916	1859	2107	1912

In addition, Table 7.20 shows that, while most subjects tended to overestimate the route distances, younger subjects are much more accurate at this task. It is apparent that the majority of the error in the mean for the sample as a whole is located in the scores of the oldest subjects. It is also evident that inter-subject variation increases greatly across the lifecycle, with the standard deviation present in older subjects' distance estimates being much greater than that for younger subjects. Less predictable was the difference in accuracy between those aged 18 to 21 and those aged between 22 and 54. The latter group was mainly comprised of subjects aged 23 to 40, there were few subjects in their 40's or 50's in the sample. However, despite the small age difference the youngest subjects were far more accurate than those aged just a few years older. Figure 7.4 depicts these distance estimates in the form of a bar chart.

Post-hoc analysis was performed on the data to check which levels of age were significantly different from each other. Tables 7.21, 7.22 and 7.23 show these effects. As can be seen from

the three tables, the same pattern is evident for each route. The mean distance estimates of the youngest and middle age groups are both statistically significant from those of the oldest age group, but not statistically significant from each other.

Table 7.21: Table of differences between mean distance estimates by Age (Red route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	326.4	938.2	1549.9	***
3 – 1	506.4	1199.2	1892.0	***
2 – 3	-1549.9	-938.2	-326.4	***
2 – 1	-319.7	261.0	841.8	
1 – 3	-1892.0	-1199.2	-506.4	***
1 – 2	-841.8	-261.0	319.7	

Table 7.22: Table of differences between mean distance estimates by Age (Blue route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	190.5	786.7	1383.0	***
3 – 1	380.3	1055.6	1730.9	***
2 – 3	-1383.0	-786.7	-190.5	***
2 – 1	-297.2	268.9	835.0	
1 – 3	-1730.9	-1055.6	-380.3	***
1 – 2	-835.0	-268.9	297.2	

Table 7.23: Table of differences between mean distance estimates by Age (Green route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	60.5	766.2	1471.8	***
3 – 1	382.6	1181.8	1981.0	***
2 – 3	-1471.8	-766.2	-60.5	***
2 – 1	-254.3	415.6	1085.6	
1 – 3	-1981.0	-1181.8	-382.6	***
1 – 2	-1085.6	-415.6	254.3	

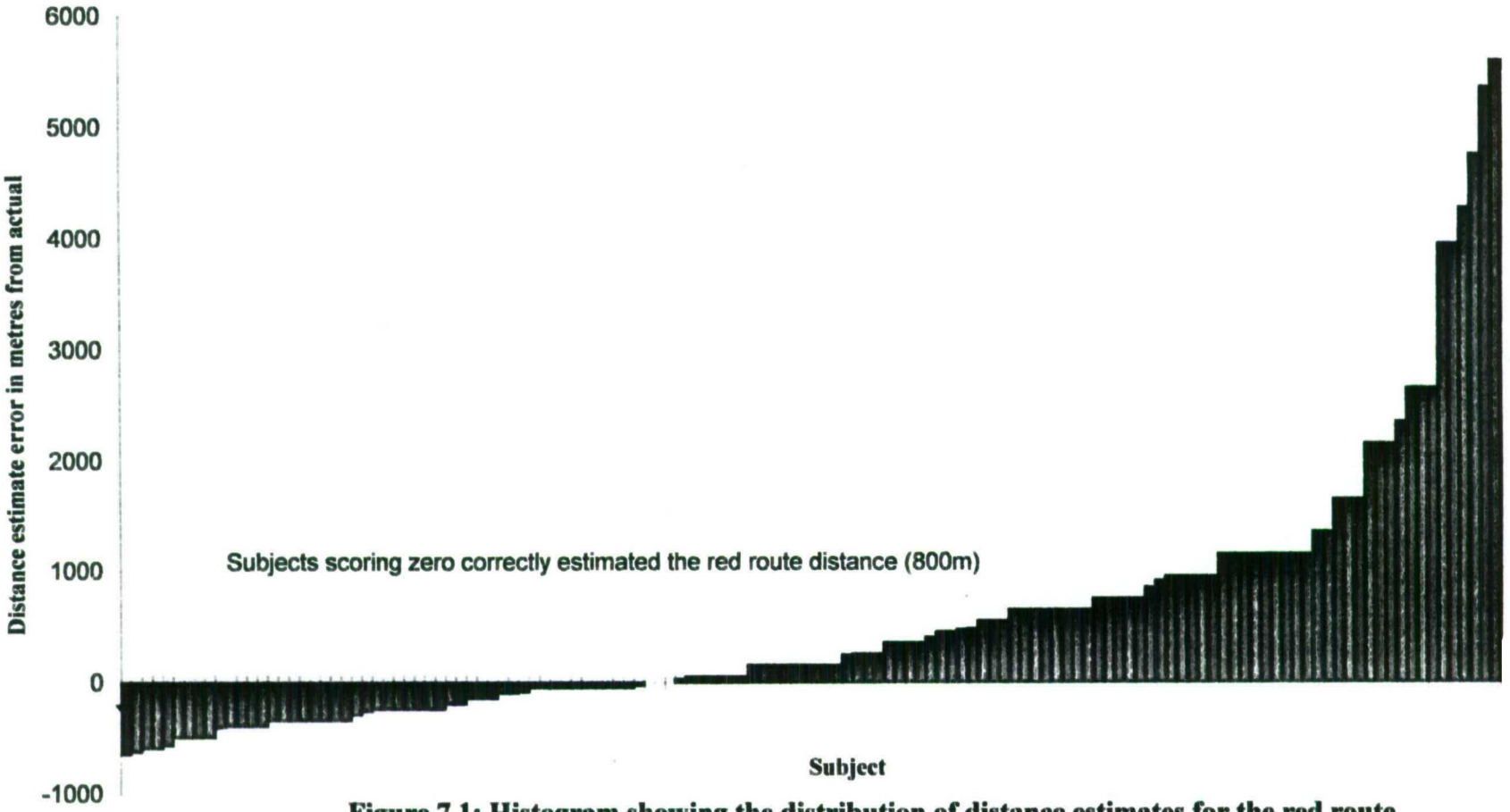


Figure 7.1: Histogram showing the distribution of distance estimates for the red route

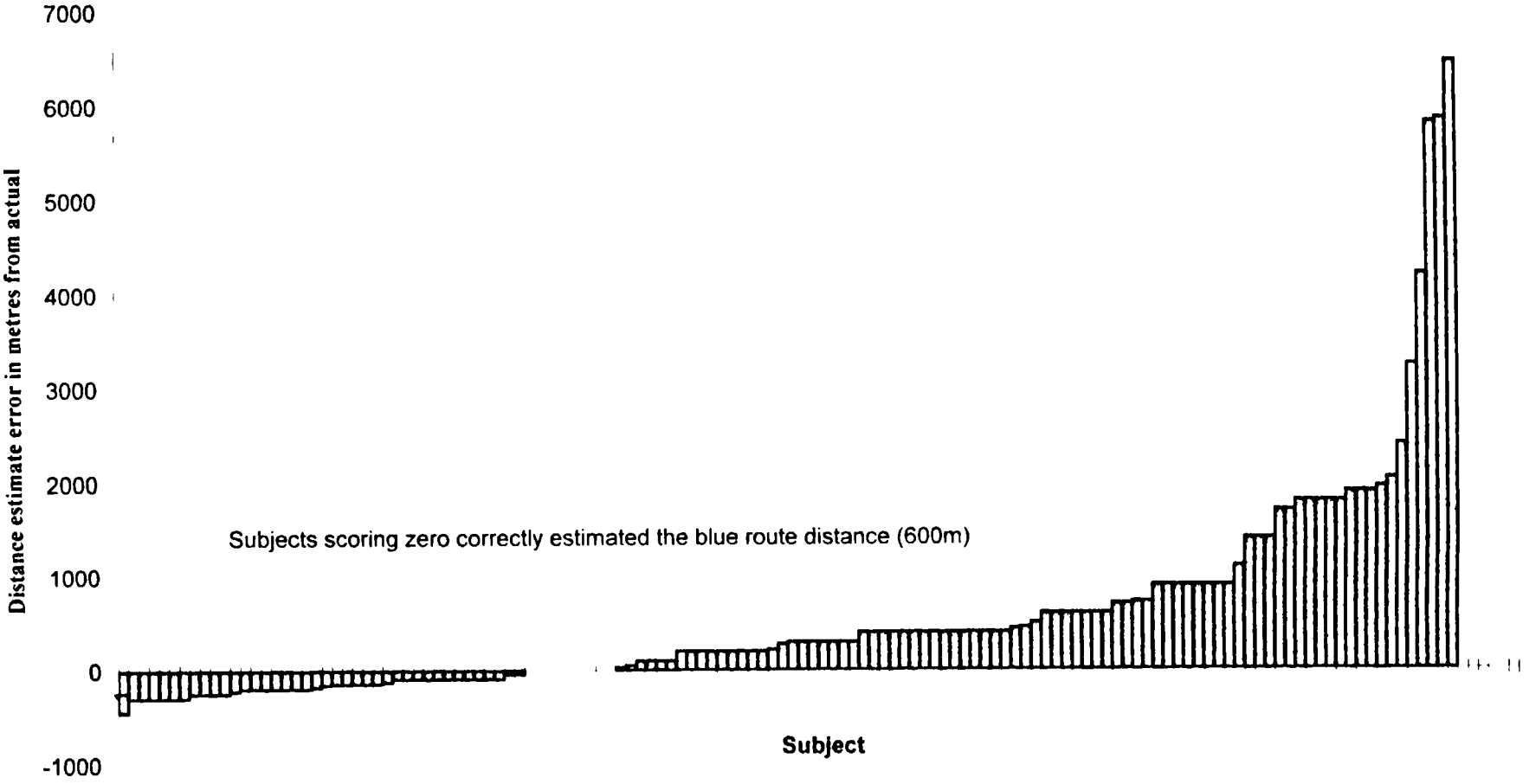


Figure 7.2: Histogram showing the distribution of distance estimates for the blue route

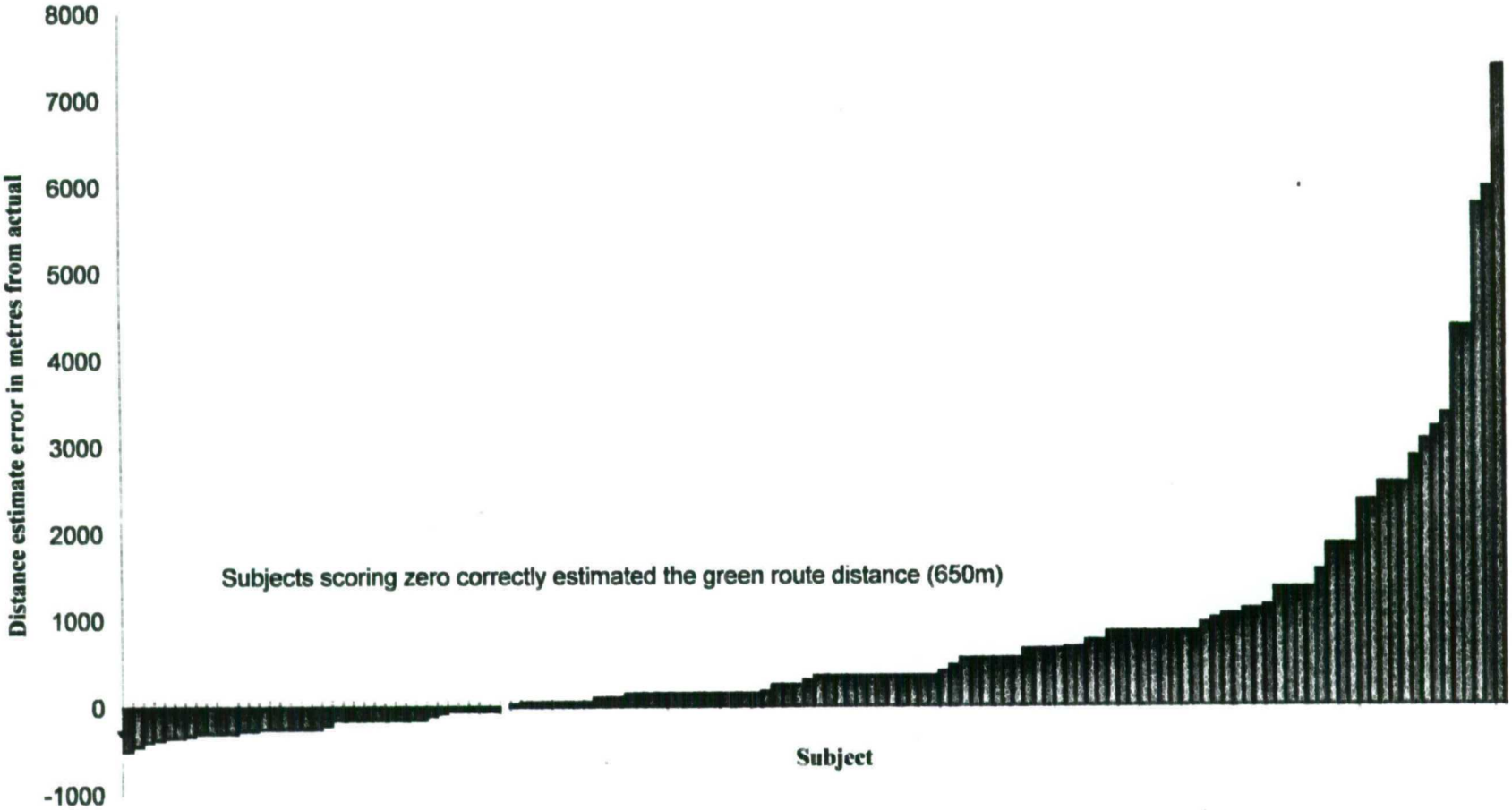
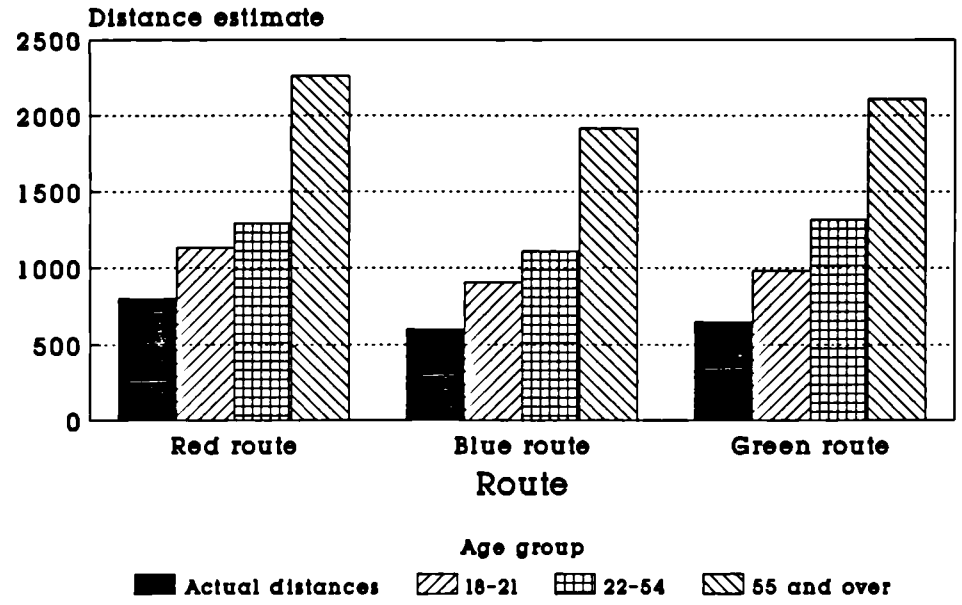


Figure 7.3: Histogram showing the distribution of distance estimates for the green route

Figure 7.4: Distance estimates for each route by age group



All distance estimates are in metres

The introduction to this section highlighted that the main concern with the distance estimates related to participants' ability to determine that the red route was longer than the green route, which in turn was longer than the blue route. Two tests were carried out to provide this information. First, a new variable, dist_seq, was created. This variable records the hierarchical order of an individual's distance estimates: i.e. which route was estimated as longest, followed by the route estimated as second longest etc. Table 7.24 shows the results of this analysis. The correct sequence of estimates should be R>G>B (the red route being the longest, followed by the green, then the blue route). Table 7.24 shows that 38 (almost 29% of subjects) detected this sequence. However, 47 subjects (35%) estimated at least two of the routes to be of equal length. Of these subjects, 24 (18%) estimated the blue and the green routes to be the same length.

This analysis tells us little about the within-subjects relationships between distance estimates. For this, correlation coefficients were computed for each subject.

Table 7.24: Frequency of each possible order of distance estimates

Order of distance estimates	No. of subjects placing routes in this order	Percentage	Cumulative Frequency	Cumulative Percent
R>G>B	38	28.6	38	28.6
R>B>G	18	13.5	56	42.1
G>R>B	10	7.5	66	49.6
G>B>R	6	4.5	72	54.1
B>R>G	9	6.8	81	60.9
B>G>R	5	3.8	86	64.7
R=B	7	5.3	93	69.9
R=G	16	12.0	109	82.0
B=G	24	18.0	133	100.0

7.3.2 Correlation coefficient analysis: tests used

Correlation measures the strength of the linear relationship between two continuous variables. A positive relationship does not imply causality, as other underlying causal relationships may exist. The standard test used to measure this relationship is Pearson's product-moment correlation. There are also a number of other statistics which have been proposed to measure the association between two continuous variables. These include:

- "Spearman's rank-order correlation coefficient - a nonparametric measure calculated as the correlation of the ranks of the data;
- Kendall's tau-b - a measure calculated from concordances and discordances. Concordance is measured by determining whether values of paired observations vary together (in concord) or differently (in discord).
- Hoeffding's measure of dependence, D - approximates a weighted sum over observations of chi-square statistics for two-by-two classification tables using each set of x,y values as the cut points for the classification. This statistic detects more general departures from independence than the correlations do."

SAS (1988), p.212

These coefficients were computed for subjects' distance estimates of each route correlated with their estimates for the other two routes. The purpose of this exercise was to test whether a subjects' distance estimate of one route influenced distance estimates for the other two routes. All four measures produced highly significant results, with all probabilities being less than 0.0001. For brevity only Spearman's rank order correlation coefficients are reported in Table 7.25 below. Under the null hypothesis, if there was no relationship between the two values the coefficient value would be zero, a perfect positive linear relationship would produce a coefficient of 1.

Table 7.25: Spearman's rank-order correlation coefficients for distance estimates for each route (probabilities in brackets).

	n	Red	Blue	Green
Red	132		0.83769 (p<0.0001)	0.90543 (p<0.0001)
Blue	132	0.83769 (p<0.0001)		0.90396 (p<0.0001)
Green	132	0.90543 (p<0.0001)	0.90396 (p<0.0001)	

The results in Table 7.25 show that distance estimates on each route were highly correlated.

7.3.3 Time estimates

In addition to estimating journey distances, subjects are asked to estimate the journey times. Two versions of the routes are seen, the first with the camera fixed directly ahead, the second with the camera panning left and right to show the various landmarks. For each route, the second version always takes slightly longer than the first. Subjects' estimates of the journey times again varied greatly. Figures 7.5, 7.6 and 7.7 show the distribution of time estimates for the red, blue and green routes respectively. Table 7.26 shows the sample means and range of subjects' estimates for each route.

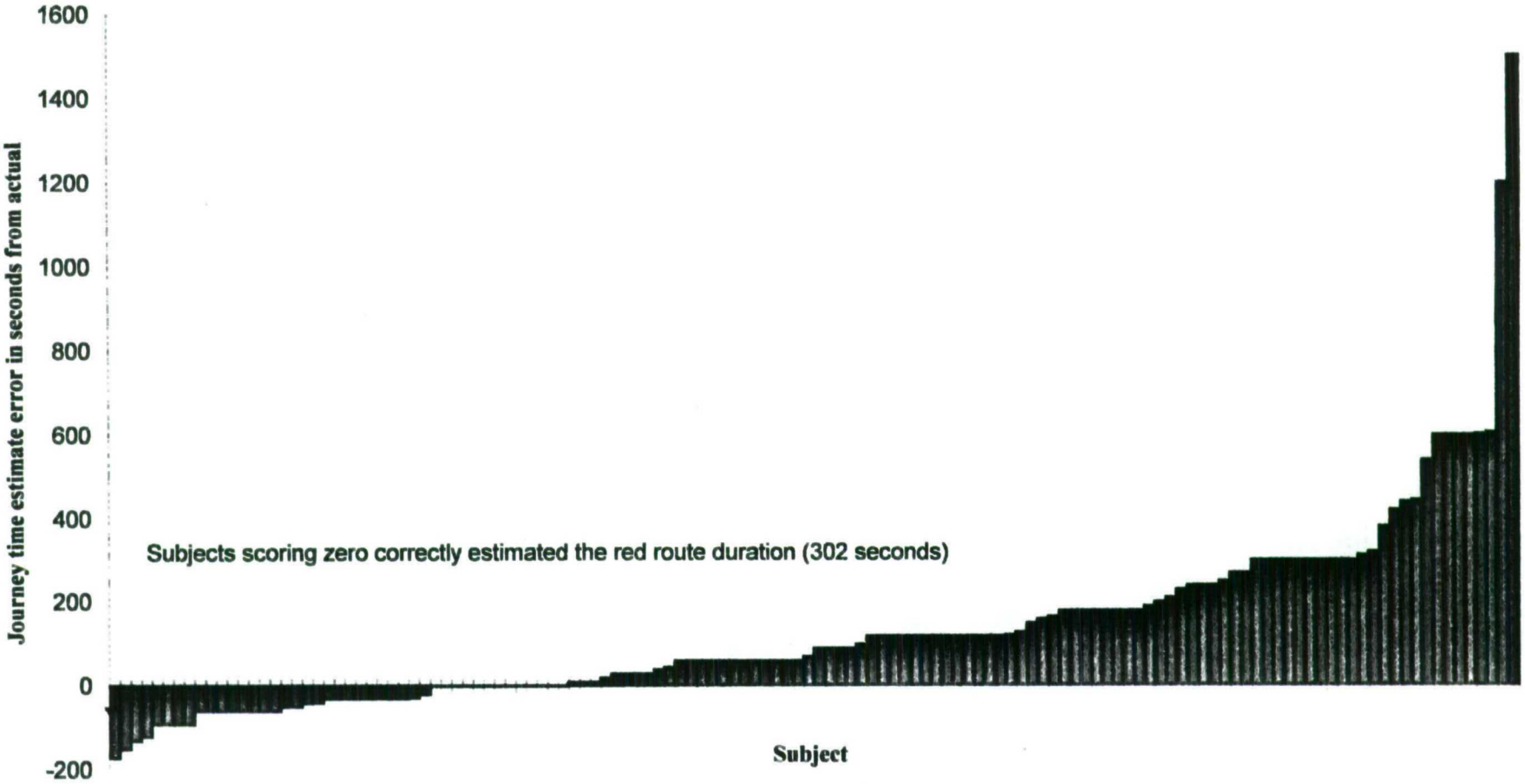


Figure 7.5: Journey time estimate error distribution for the red route

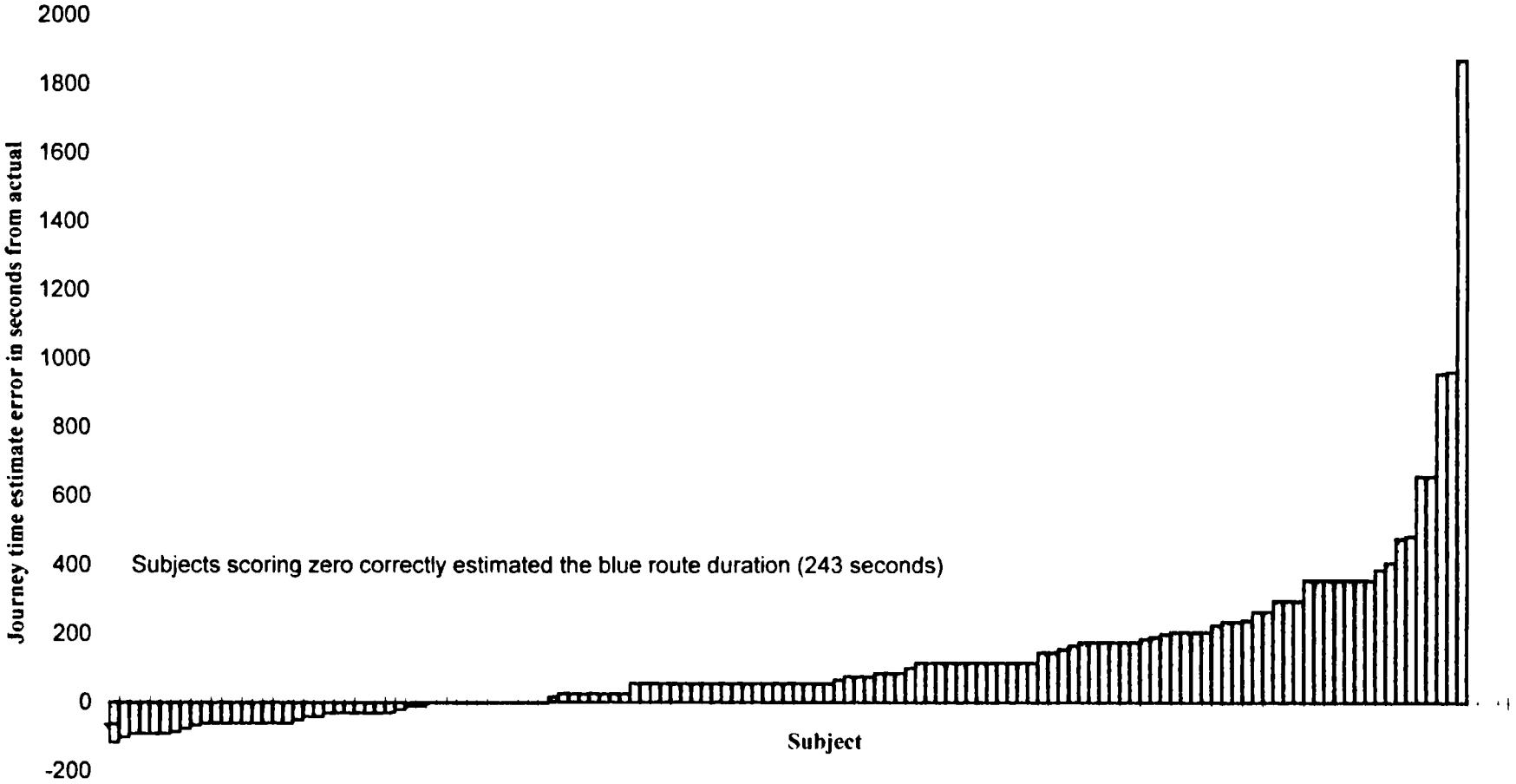


Figure 7.6: Journey time estimate error distribution for the blue route

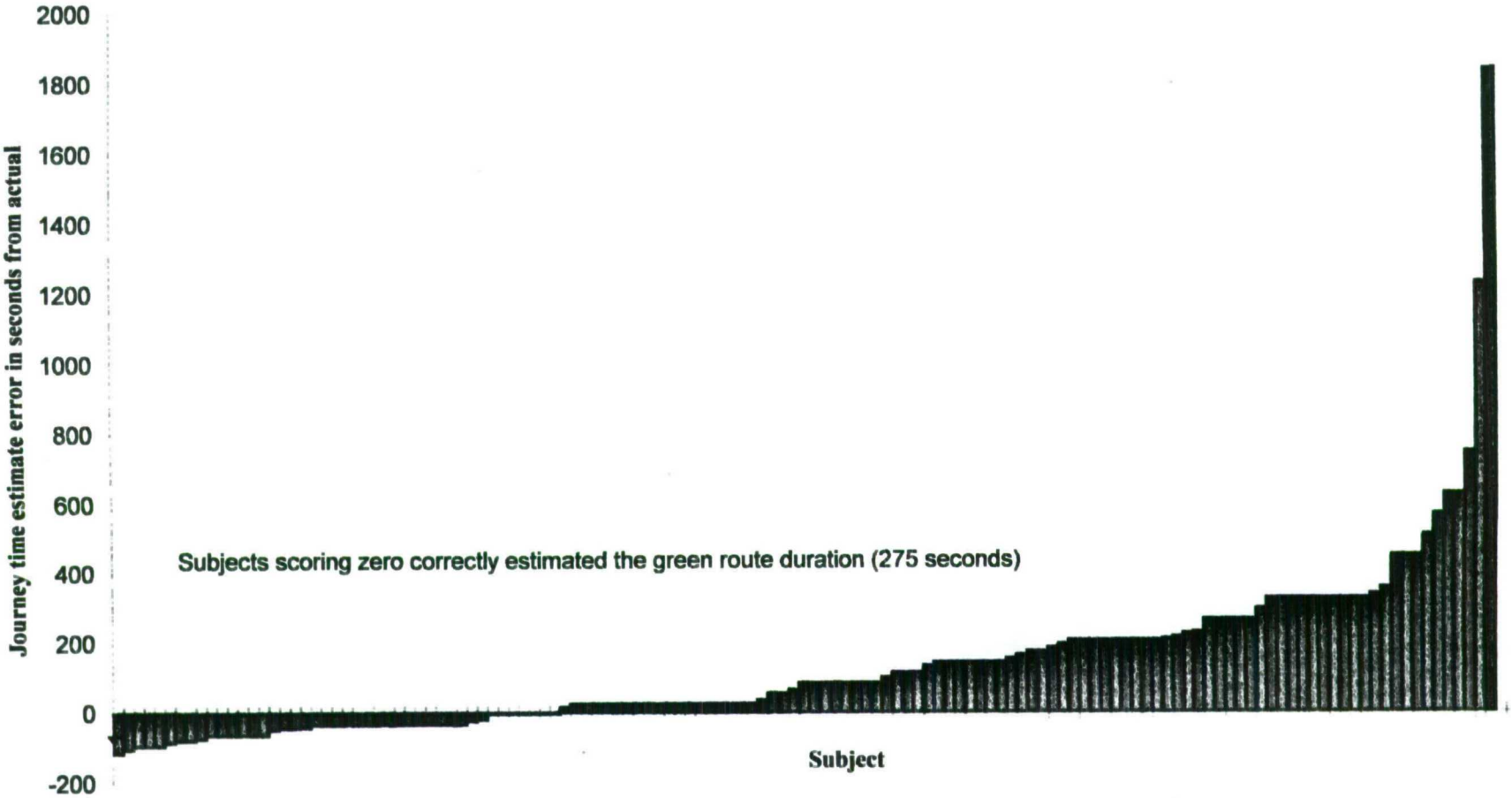


Figure 7.7: Journey time estimate error distribution for the green route

Table 7.26: Actual times, mean time estimates and range for each version of each route

Route (version)	n	Actual time (seconds)	Mean estimate	Standard deviation	Minimum	Maximum
Red (Route)	133	302	454.37	286.11	130	2410
Red (Landmark)	133	406	507.67	244.76	180	1813
Blue (Route)	133	243	366.55	237.46	125	2110
Blue (Landmark)	133	313	416.50	220.28	120	1515
Green (Route)	133	275	409.92	244.22	160	2110
Green (Landmark)	133	376	469.73	238.67	160	1682

As with the distance estimates, table 7.26 shows that the sample as a whole overestimated each of the journey times. However, the range of estimates indicates that this might hide the true picture. With regard to time estimation, the study aims to assess:

a) whether group differences exist with regard to time estimating accuracy (e.g. age, gender, driving ability);
b) the impact of route guidance information upon these estimates;
c) subjects' ability to determine which route is the longest in duration; and
d) subjects' ability to determine which of the two versions of each route is the longest in duration.

In order to address these questions analysis of variance (GLM) was performed on the time estimation data.

Time estimates: analysis of variance

The General Linear Models (GLM) procedure was used to analyse the time estimation data. This procedure showed that, of the main variables, age and driving ability had a significant effect upon time estimates. The effect of age was consistent across all three routes and across

both versions of each route. The results for each route version were very similar, and therefore for brevity only the significant results for the route versions are reported. In each case the model reported included all main variables (age, sex, driver, and information group). Order was included initially but was found to be non-significant and so was removed from the model. Separate models containing one of the possible two-way interactions between these variables were also constructed, however, none of these interactions were found to be significant. Consequently the models referred to below are composed solely from the single variables.

Red route:

The model for the red route time estimates was significant, but as with the distance estimates the model was weak, having a low R-square value.

- Model: $F(12,120)=2.80$, $p<0.005$, $r^2=0.22$
- Age group $F(2,131)=9.70$, $p<0.0001$
- Driver $F(1,132)=8.31$, $p<0.005$

The group means for drivers and non-drivers are shown in table 7.31 along with the comparable figures for the green route. Post-hoc analysis using the Tukey procedure was performed on the data to determine which of the levels of age were significantly different. This produced the following table of differences between means.

Table 7.27: Table of differences between mean time estimates for Age (Red route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	78.40	215.10	351.81	***
3 – 1	78.32	233.54	388.75	***
2 – 3	-351.81	-215.10	-78.40	***
2 – 1	-112.82	18.43	149.69	
1 – 3	-388.75	-233.54	-78.32	***
1 – 2	-149.69	-18.43	112.82	

Table 7.27 shows that the time estimates of both young and middle age groups are significantly different from the older age group but are not significantly different from each other. This result echoes the performances of these groups at the distance estimation tasks.

Blue route:

The model for the blue route was significant but very weak, with age the only significant variable:

- Model: $F(12,120)=2.26$, $p<0.05$, $r^2=0.18$
- Age group $F(2,131)=9.75$, $p<0.0001$

Table 7.28: Table of differences between mean time estimates for Age (Blue route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	61.35	177.30	293.24	***
3 – 1	85.35	217.00	348.64	***
2 – 3	-293.24	-177.30	-61.35	***
2 – 1	-71.62	39.70	151.02	
1 – 3	-348.64	-217.00	-85.35	***
1 – 2	-151.02	-39.70	71.62	

As with the red route time estimates, post hoc analysis (table 7.28) shows that the mean estimates of blue route duration of both young and middle age group subjects can be considered to be significantly different from those of older age group subjects, but are not sufficiently different from each other to be considered to have come from different samples.

Green route:

The model for the green route was significant but weak, with age and driving ability significant:

- Model: $F(12,120)=2.01$, $p<0.05$, $r^2=0.17$
- Age group $F(2,131)=8.47$, $p<0.001$
- Driver $F(1,132)=4.48$, $p<0.05$

Post-hoc analysis was carried out on the data to determine differences between the levels of age. Table 7.29 shows again that the mean time estimates of the young and middle age groups are not different enough to be considered to have come from different groups, but that both groups' time estimates are significantly different from those of the older age group.

Table 7.29: Table of differences between mean time estimates for Age (Green route)

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	62.24	182.72	303.20	***
3 – 1	63.36	200.16	336.96	***
2 – 3	-303.20	-182.72	-62.24	***
2 – 1	-98.24	17.44	133.12	
1 – 3	-336.96	-200.16	-63.36	***
1 – 2	-133.12	-17.44	98.24	

The mean time estimates for each age group for the three routes are presented in Table 7.30, while table 7.31 summarises the time estimates for drivers and non-drivers.

Table 7.30: Group mean estimates of route duration by age group (Route films)

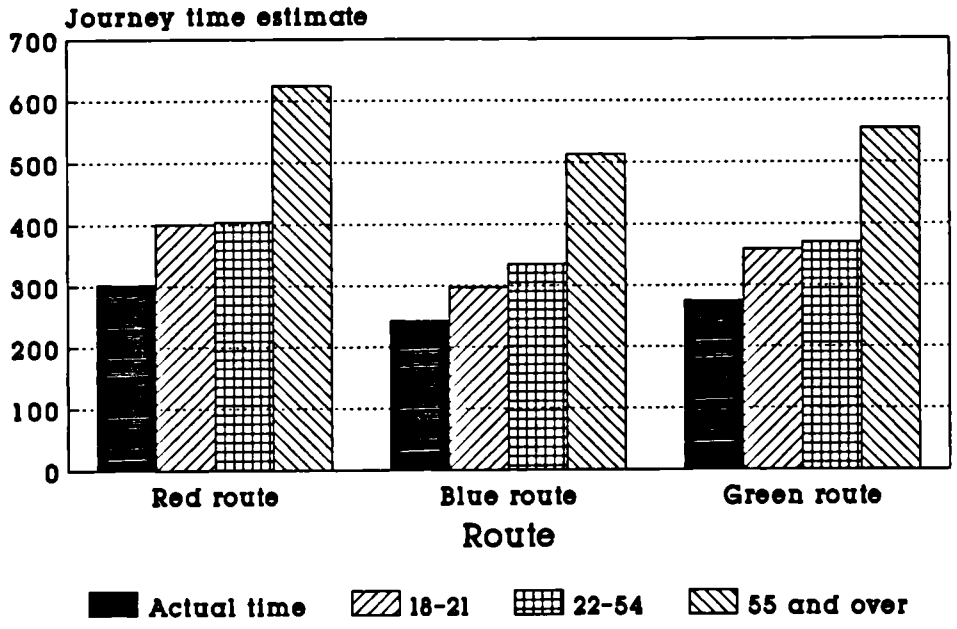
Age group	N	Red route mean	Red route standard deviation	Blue route mean	Blue route standard deviation	Green route mean	Green route standard deviation
Actual		302secs		243secs		275secs	
18-21	35	400.64	132.08	297.75	92.98	358.80	132.86
22-54	67	403.92	204.46	335.30	184.79	369.83	169.64
55+	31	624.19	458.67	512.97	366.13	554.64	388.79

Table 7.30 shows that, as with distance estimates, all age groups overestimate the time taken to travel the route, but elderly subjects overestimate these times by a considerable amount. This is graphically represented in Figure 7.8. In conjunction with this finding, the table also shows that the variation between older subjects is much greater than that between subjects of other age groups.

Summarising the time and distance data, two points can be made. First, both tasks produce mean estimates for all groups which are higher than the actual distances and times experienced. There is no immediate reason why this might be, although from an attentional allocation perspective (see chapter 4, section 4.4.2) an overestimating effect might be expected due to

subjects attending to visual information whilst carrying out the estimating task. Age is clearly the most reliable predictor of estimating ability, with the estimates of the older subjects tending to be much higher. The similarity of the estimates of the two younger age groups could perhaps be due to the similarity of the two groups, in that both are primarily comprised of students and staff of Imperial College. This similarity is emphasised when the mean ages of the two groups (19.71 and 30.42) are compared. These means are more similar than might be expected

Figure 7.8: Journey time estimates for each route by age group



considering the differences between the two age ranges (18-21 and 22-54).

Table 7.31 shows that drivers are much more accurate in their estimates of journey time than non-drivers. This effect was only apparent on the more difficult red and green routes.

Table 7.31: Group mean estimates of red and green route duration by driving group

Driver status	n	Red route mean (Seconds)	Red route standard deviation	Green route mean (Seconds)	Green route standard deviation
Driver	69	398.45	167.95	375.65	215.60
Non-driver	64	514.67	365.98	446.87	268.55

Table 7.32: Frequency of each possible order of time estimates

Sequence of Time estimates	Frequency	Percent	Cumulative frequency	Cumulative percent
R>G>B	35	26.3	35	26.3
R>B>G	19	14.3	54	40.6
G>R>B	17	12.8	71	53.4
G>B>R	6	4.5	77	57.9
B>R>G	5	3.8	82	61.7
B>G>R	2	1.5	84	63.2
R=B	5	3.8	89	66.9
R=G	19	14.3	108	81.2
G=B	25	18.8	133	100.00

In order to determine subjects' ability to rank the three routes in terms of duration a similar analysis to that described for Table 7.24 above was performed on the data. Table 7.32 shows the results of this analysis for the route film (comparable results were found for the landmark film). The table shows that only 26% of subjects were able to determine the correct sequence of journey times. A larger proportion considered two of the routes to be of equal duration.

7.3.4 Correlation coefficients for time and distance estimates

To test whether any correlation exists between the estimates participants made of journey distance and journey time, correlation coefficients were again calculated. The same measures were used as before, which again produced similar results. For consistency only Spearman's rank-order correlation coefficients are reported. The results of this analysis are shown in Table 7.33.

Table 7.33: Correlation coefficients for journey times and distances.

	n	Red route distance estimate	Blue route distance estimate	Green route distance estimate
Red route time estimate	132	0.198 ($p<0.05$)	0.087 n.s.	0.140 n.s.
Blue route time estimate	132	0.075 n.s.	0.143 n.s.	0.098 n.s.
Green route time estimate	132	0.137 n.s.	0.109 n.s.	0.208 ($p<0.05$)

Table 7.33 shows that distance estimates for the red and green routes are correlated with journey time estimates for the same routes. The correlation coefficients above show that the relationship between these estimates is not strong. However, it is possible that the experience of estimating times and distances in this experiment are quite similar. In particular, the fact that the two estimates are made one after the other (the distance estimate followed by estimates of route duration) suggest that the two estimates are likely to be closely related and based on similar information. Correlation coefficients were also computed for the correlations between time estimates and pointing task error. None of these approached significance.

7.4 Results of tasks measuring configurational knowledge

7.4.1 Cross-route pointing tasks

The next measure considered is the cross-route pointing task. This task requires subjects to integrate the knowledge acquired from the three routes so as to create new, previously untravelled routes. As such it requires respondents to invoke the most complex mental operations: holding one piece of acquired information in working memory whilst simultaneously attending to a second piece of information The cross-route pointing task enables us to produce a mean accuracy score for each subject, the lower these mean scores the more accurate the subjects' direction estimates. This variable is known as the XRT score. XRT scores ranged from 12.92 degrees (a 37-year-old male non-driver) to 115.17 degrees (a 34-year-old female non-driver). The mean for the sample of 133 subjects as a whole was 62.39 degrees.

Analysis of variance was again performed on the data using the GLM procedure. A range of models were run. All models tested included the four main variables (age, sex, driver and group) and all possible interactions between these variables were added to this basic model in turn to see which gave the most satisfactory results. The model described below was chosen as the best fit, combining a reasonable R-squared value with significance on a number of the variables.

Model $F(17,115)=5.97, p<0.001, r2=0.4687$

- Age group $F(2,131)=19.80, p<0.001$
- Sex $F(1,132)=14.74, p<0.001$
- Driver $F(1,132)=20.30, p<0.001$
- Age*sex*driver*group $F(6,124)=3.16, p<0.01$

Tables 7.34 - 7.36 show mean error scores for the single variable effects. Post-hoc analysis using the Tukey procedure was also run to investigate which of the three levels of the age variable were significantly different. Table 7.37 shows the differences between mean cross route error scores. Finally, table 7.38 gives the means for each of the 16 groups formed from the interaction between the four variables.

Table 7.34: Mean error scores for the cross route pointing task by age group

Age group	n	Mean error (degrees)	Standard deviation
18-21	35	46.56	25.33
22-54	67	64.06	26.02
55 +	31	76.69	20.25

Table 7.34 shows that, as with the single route pointing tasks, younger subjects are more accurate than older subjects in their ability to estimate cross route directions and that the difference between the young and middle groups is much greater than was the case with the single route pointing tasks.

Table 7.35: Mean error scores for the cross route pointing task by sex

Sex	n	Mean error (Degrees)	Standard deviation
Male	65	55.86	25.88
Female	68	68.65	26.15

As was the case with the single route pointing tasks, sex of participant was found to be significant (table 7.35). Again, this is for all subjects of all ages and driving abilities. Table 7.36 shows that, for the cross route pointing task, ability to drive has a significant effect, with drivers' direction estimates being significantly more accurate than those of non-drivers.

Table 7.36: Mean error scores for the cross route pointing task by driver status

Driver status	n	Mean error (Degrees)	Standard deviation
Driver	69	55.35	24.90
Non-driver	64	69.99	26.68

Table 7.37: Table of differences between mean cross route pointing scores for Age

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
3 – 2	1.87	12.63	23.39	***
3 – 1	17.91	30.13	42.34	***
2 – 3	-23.39	-12.63	-1.87	***
2 – 1	7.17	17.50	27.82	***
1 – 3	-42.34	-30.13	-17.91	***
1 – 2	-27.82	-17.50	-7.17	***

Table 7.37 shows that the mean error scores of the three age groups are all significantly different from one another. This contrasts with the single route pointing task where the difference between the young and middle age groups was not significant. The cross route pointing task is more difficult than the single route pointing task, however, requiring additional processing power beyond remembering the route taken. This increased difficulty makes the test a more discriminating one.

Table 7.38: Mean cross route pointing error scores for groups made up by age, driver status, sex and information group

Age	SEX	DRIVER	GROUP	N	Mean	SD
18-21	Male	Driver	4	8	30.28	10.33
18-21	Male	Non-driver	2	9	51.32	26.23
18-21	Female	Driver	1	8	35.87	21.31
18-21	Female	Non-driver	3	10	63.85	26.17
22-54	Male	Driver	1	8	43.28	24.87
22-54	Male	Driver	2	9	68.26	23.07
22-54	Male	Non-driver	3	8	53.48	27.34
22-54	Male	Non-driver	4	8	60.95	26.87
22-54	Female	Driver	3	10	49.58	17.52
22-54	Female	Driver	4	8	65.24	18.77
22-54	Female	Non-driver	1	8	99.72	8.54
22-54	Female	Non-driver	2	8	75.05	17.99
55 and over	Male	Driver	3	8	70.55	25.38
55 and over	Male	Non-driver	1	7	69.51	17.78
55 and over	Female	Driver	2	10	74.76	16.54
55 and over	Female	Non-driver	4	6	96.46	8.81

Table 7.38 shows the mean error scores for the 16 groups that make up the experiment. The first four rows comprise subjects in the 18-21 age group, male drivers and non-drivers, followed by female drivers and non-drivers. The next 8 rows comprise subjects in the 22-54 age group. The final four rows comprise subjects in the 55 and over age group. These three age groups will each be considered in turn.

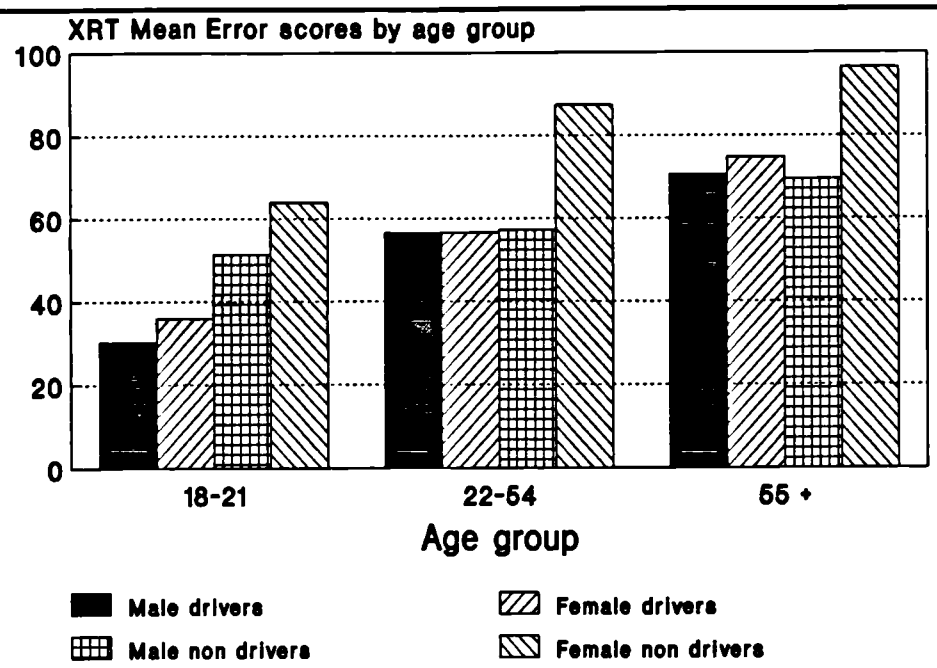
For subjects in the 18-21 age group the table shows that male and female drivers performed significantly better than their non-driving counterparts, and that the performance of female drivers is also significantly better than male non-drivers. Also note the low standard deviation of the male drivers group, showing that subjects in this group all performed to the same high standard.

For subjects in the 22-54 age group the table shows that males and females again follow similar patterns depending upon whether or not they are drivers or non-drivers. This age group contains sub-groups who either heard salient information in the form of route guidance, or heard non-salient information (nothing or radio). Male drivers who heard nothing performed best of all, and their performance is comparable with female drivers who heard radio. However, both these groups performed significantly better than similar groups who heard salient information (43.28 and 49.58 for male and female drivers hearing nothing or non-salient information, against 68.26 and 65.24 for male and female drivers hearing salient information). Given the fact that group was not a significant variable in any of the tasks to date, it is a little surprising to find such a large difference between groups depending upon the information they heard. Male non-drivers display the same pattern across the two types of information: male non-drivers who heard radio performed better than a similar group who heard radio and route guidance. The only group not showing a deterioration in performance across the two information conditions is female non-drivers. However, the performance of this group was very poor under both conditions. It should also be noted that, despite the very high mean error score the standard deviation in this group is the lowest of all the groups at only 8.54 degrees. This low standard deviation suggests that all subjects within this sub-group performed very poorly at the cross route pointing task. Possible reasons for this result will be discussed in the conclusions and discussion section, which relates the findings back to the research hypotheses.

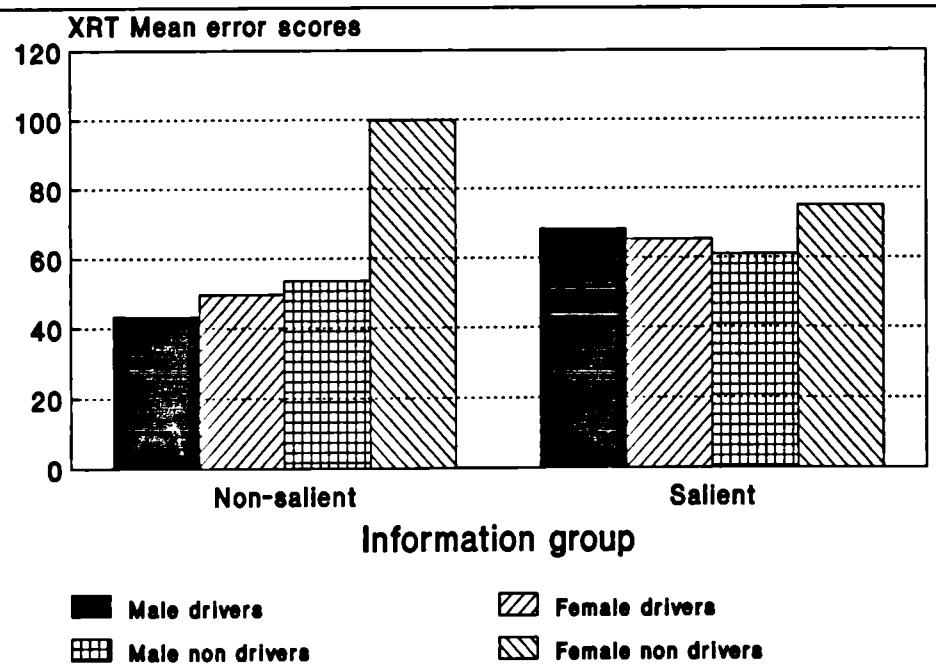
For subjects in the 55 and over age group the table shows that all groups except female non-drivers performed comparably. Again, the low standard deviation of the group mean for female non-drivers suggests that all subjects within this group performed comparably badly.

Taken together the results offer further support for the view that age is the most significant indicator of spatial ability, followed by driving experience, sex and the 4-way interaction between these variables and information condition. As Table 7.38 shows, age has a significant impact upon ability to acquire configurational knowledge of an unfamiliar area. Results of previous tasks suggested that gender was a significant variable in determining performance. However, these results show that, when driving experience is taken into account, male and female performance is comparable. Driving experience clearly had an effect upon performance. This was most evident in the 18-21 and 22-54 age groups, in which drivers performed significantly better than non-drivers. The 22-54 age group also allowed a comparison of similar groups under different information conditions. This showed that both male and female drivers performed significantly better when they did not listen to route guidance instructions. Moreover, comparing the performance of the group of male drivers who heard nothing with a comparable group of female drivers who listened to radio showed no significant differences between the two groups. However, both groups performed significantly better than similar non-driving groups.

Figures 7.9 and 7.10 overleaf show the effects of age and information condition respectively upon ability to acquire a configurational representation of the study area. It is clear from Figure 7.9 that age has a debilitating effect upon spatial knowledge acquisition ability. However, the graph shows that drivers in all age groups are more accurate in the pointing task than their non-driving counterparts. Figure 7.10 shows that additional guidance information has a negative impact upon performance of this task. A comparison of similar subjects across the two information conditions shows that the performances of all but female non-drivers are impaired by the presence of additional salient information.



XRT Mean scores are degrees from actual



XRT Mean scores are degrees from actual

Top: Figure 7.9 Effects of age upon performance of cross route pointing task

Bottom: Figure 7.10 Effects of information group upon cross route pointing task

7.4.2 Correlation coefficients for the single and cross route tasks.

Correlation coefficients were computed to investigate whether any relationship exists between an individual's performance at the single route tasks and their subsequent performance at the cross route pointing task. The reason for carrying out this analysis is to test one of the hypotheses regarding the performance of elderly subjects. It was hypothesised that elderly subjects performance at the cross route pointing tasks would be poor regardless of how they had performed at the single route pointing task, whereas for other subjects performance on the single route tasks would predict subsequent performance at the cross route pointing task. In other words, there would be no correlation between the elderly subjects' performance of tasks measuring single route knowledge and those measuring cross route (configurational) knowledge. It was hypothesised that this would be the case because there is an age-related decline in working memory, the cognitive resource which enables us to perform cognitive transformations upon (spatial) information.

Correlation coefficients were computed for each age group for the three single route pointing tasks and the cross route pointing task. The results of this analysis are shown in Table 7.39 below. Although four correlation coefficients were used, for brevity Table 7.39 simply gives details of the results of the Spearman's rank-order correlation coefficient analysis. (The results of the computations using the other measures were all comparable with the results of the Spearman's analysis.)

Table 7.39: Spearman's rank-order correlation coefficient analysis of the single and cross route pointing tasks by age group.

	Red Mean	Blue Mean	Green Mean
XRT_Mean			
Subjects aged 18-21	0.539	0.793	0.812
	$p<0.001$	$p<0.001$	$p<0.001$
Subjects aged 22-54	0.657	0.524	0.556
	$p<0.001$	$p<0.001$	$p<0.001$
Subjects aged 55 +	0.313	0.493	0.271
	n.s.	$p<0.01$	n.s.

Table 7.39 shows that for young and middle age group subjects performance at the single route pointing tasks is highly predictive of performance at the cross route pointing task. The strength of these relationships is shown in figures 7.11, 7.12 and 7.13, which show strong positive correlations between performance of the single and cross route pointing tasks. However, the performance of subjects in the 55 and over age group was not related to their performance at the cross route pointing task. Only on the blue route was their performance significantly correlated with subsequent cross route pointing task scores.

Further correlation analysis was carried out to see whether performance at the other tests of single route knowledge (the sequencing tasks) correlated with cross route pointing task performance. The results of this analysis are shown in table 7.40. Note that high scores on the sequencing task indicate good acquired knowledge, whereas on the cross route pointing task they indicate poor performance, hence the negative correlations.

Table 7.40: Spearman's rank-order correlation coefficient analysis of the sequencing task scores and cross route pointing tasks by age group.

	RScore	BScore	GScore
XRT_Mean			
Subjects aged 18-21	-0.372	-0.348	-0.544
	$p<0.05$	$p<0.05$	$p<0.01$
Subjects aged 22-54	-0.288	-0.260	-0.497
	$p<0.05$	$p<0.05$	$p<0.001$
Subjects aged 55 +	-0.294	-0.060	-0.224
	$p<0.05$	n.s.	n.s.

Although the results are less conclusive than for the relationship between pointing tasks it is clear that for subjects in the two younger age groups performance at the sequencing task correlates with subsequent performance at the cross route pointing task. Overall, these results support the hypothesis that older subjects' performance at the tasks measuring single route knowledge would not predict subsequent performance at the cross route pointing task.

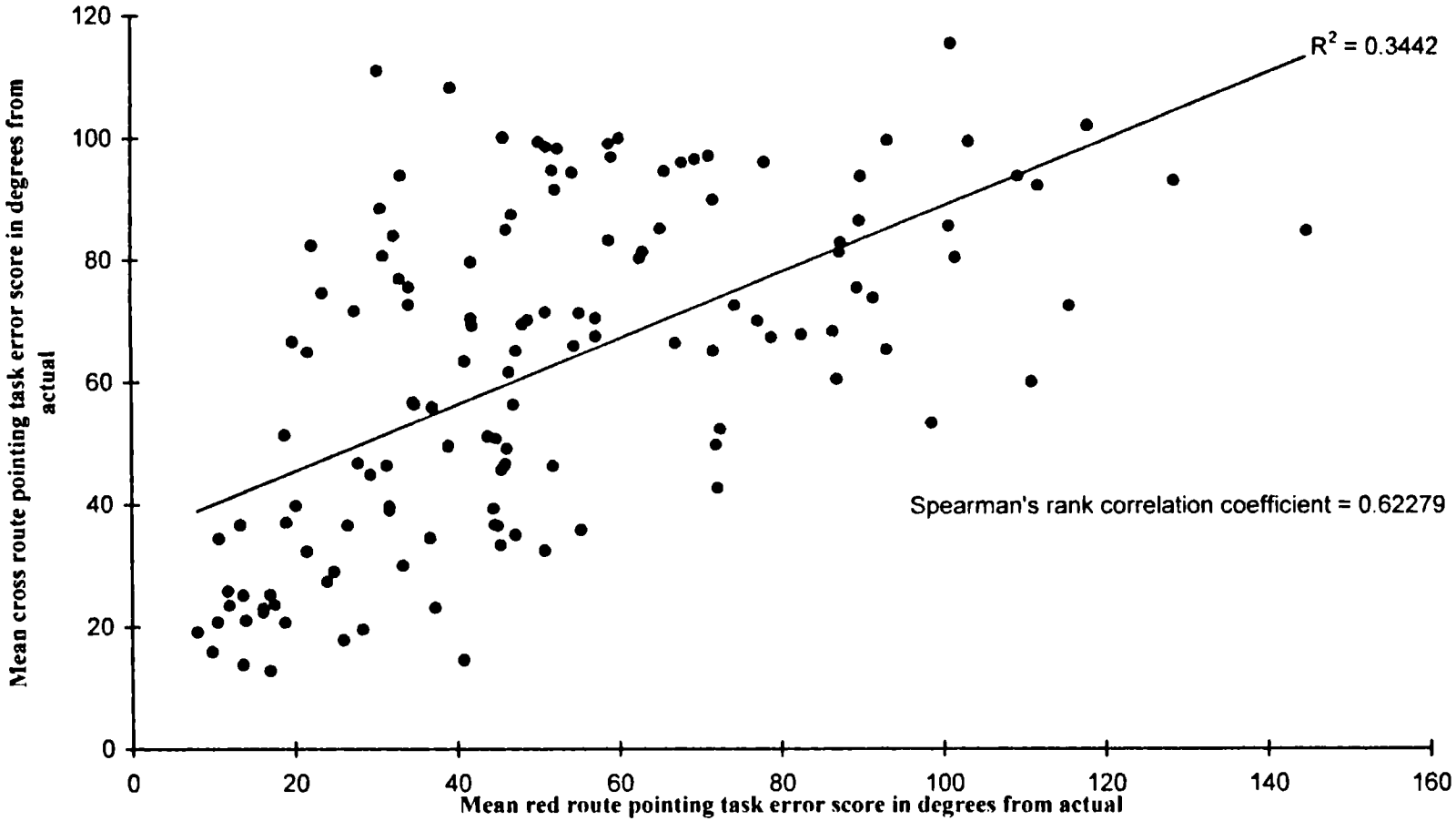


Figure 7.11: Plot showing the correlation between red route pointing task error and cross route pointing task error scores.

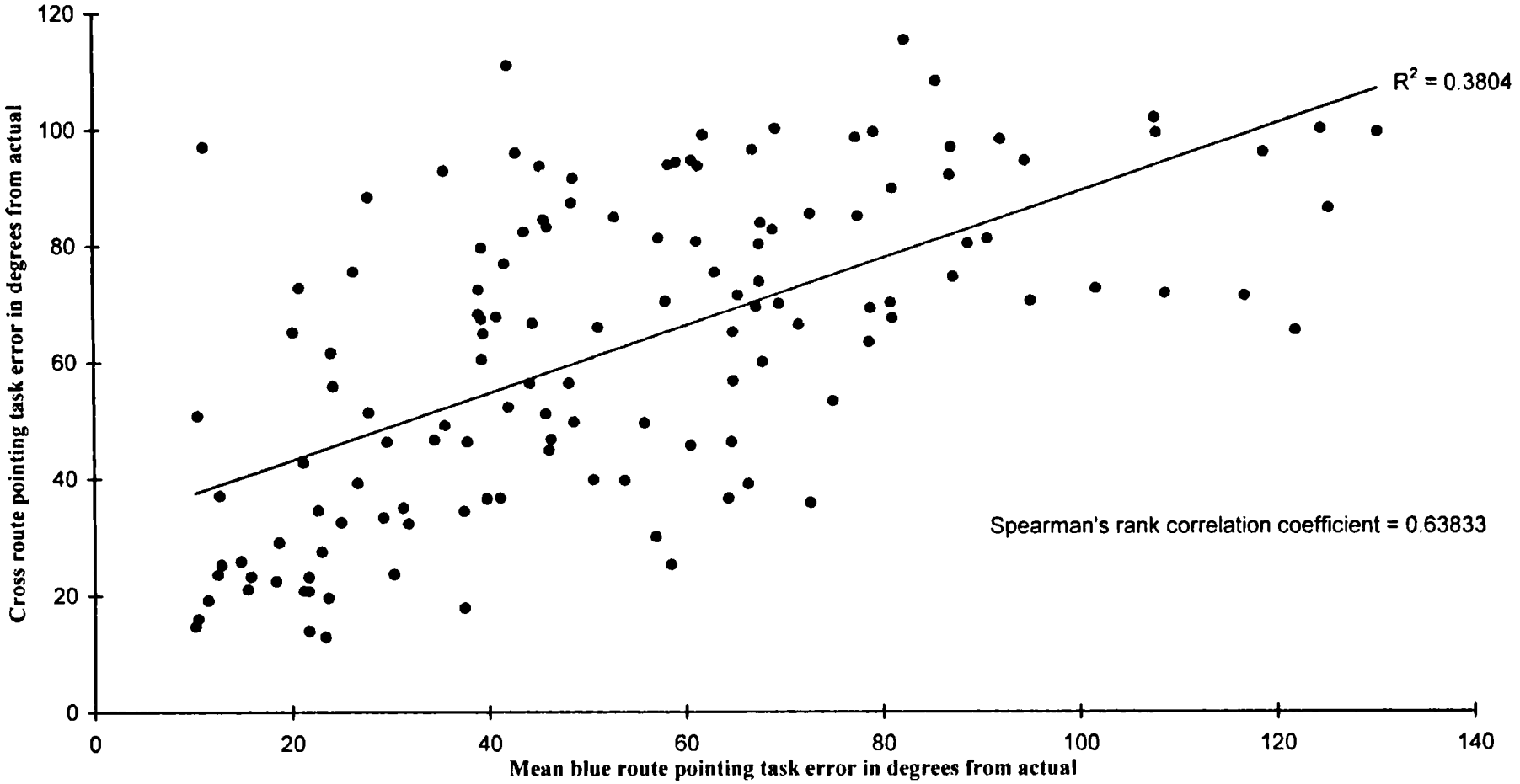


Figure 7.12: Plot showing the correlation between blue route pointing task error and cross route pointing task error scores

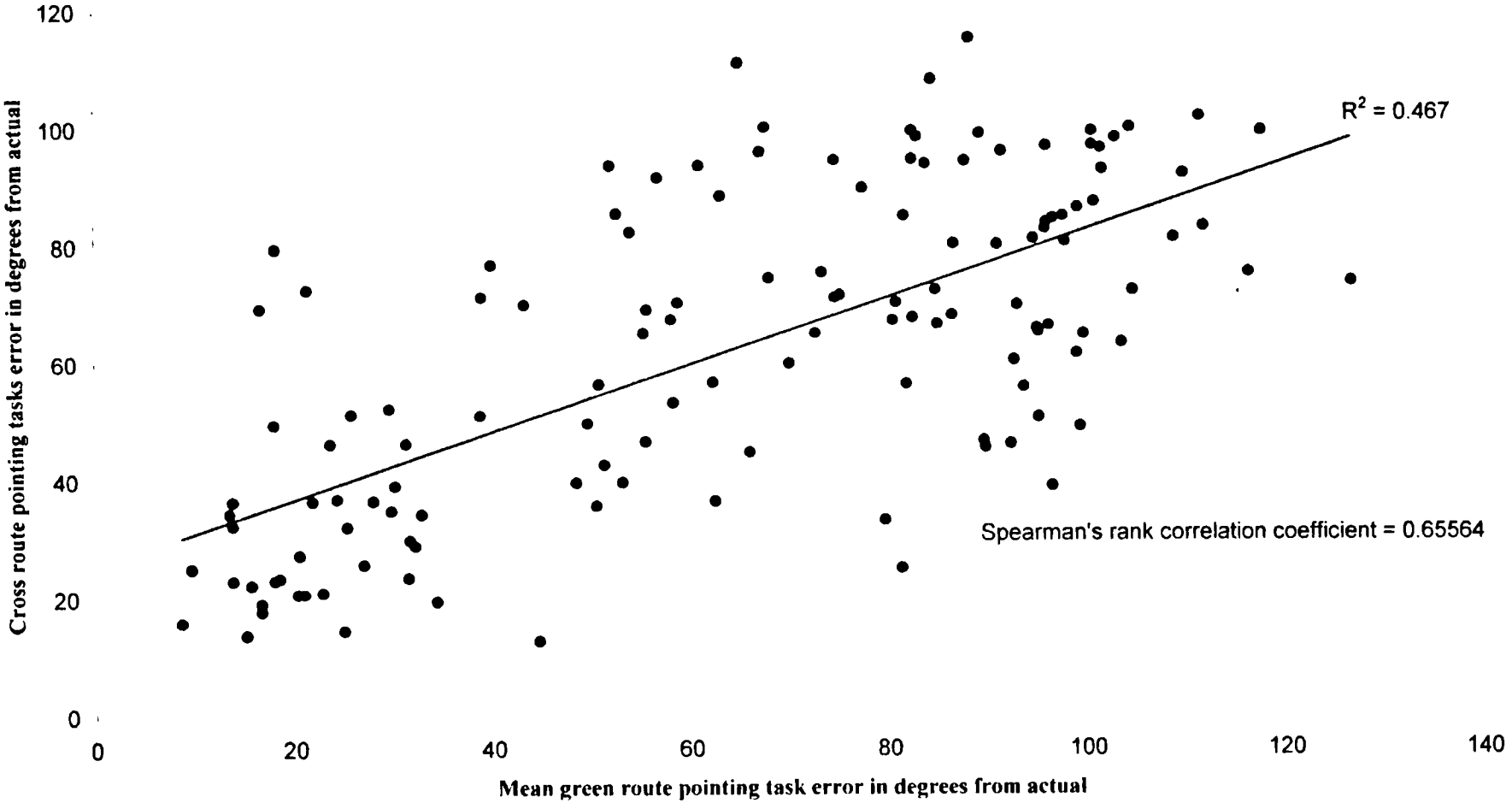


Figure 7.13: Plot showing the correlation between green route pointing task error and cross route pointing task error scores

7.4.3 Sketch map task

The cross route pointing task is one means of measuring subjects' ability to integrate the information acquired from the 3 separate routes into configurational knowledge of the area. An alternative approach - map drawing - was used in conjunction with the cross route pointing task. The use of different tasks to measure the same ability enabled an assessment of the validity of the two tasks as measures of configurational knowledge acquisition. Many subjects expressed the view that the pointing tasks were more mentally taxing than sketching a map of the area, although both tasks require configurational knowledge. All subjects were invited to draw a map of the area, but only 103 subjects were able to draw some form of map. Subjects in the 55 and over age group experienced most problems with this task. Table 7.41 is a break down of the sub-groups showing how many from each were able to draw a sketch map. Examples of some of the maps drawn by subjects in both phases of the experiment are shown in Appendix XIV.

Table 7.41: Map data by demographic group (based on age, driver status & sex)

Age	Sex	Driver status	N (all subjects)	N (able to draw a map)	%	Age Group %
18-21	Male	Driver	8	7	88	
18-21	Male	Non~	9	8	89	
18-21	Female	Driver	8	8	100	
18-21	Female	Non~	10	9	90	*91%*
22-54	Male	Driver	17	16	94	
22-54	Male	Non~	16	10	62	
22-54	Female	Driver	18	16	89	
22-54	Female	Non~	16	16	100	*87%*
55 +	Male	Driver	8	5	62	
55 +	Male	Non~	7	2	29	
55 +	Female	Driver	10	2	20	
55 +	Female	Non~	6	4	67	*42%*
Totals			**133**	**103**		*77%*

Table 7.41 shows that most subjects under age 55 were able to draw some form of map. Of those aged under 55 who were unable to draw a map 9 were male and 3 were female, 4 were drivers and 8 were non-drivers. Most of the subjects who were unable to produce any form of

map were from the 55 and over age group. Of these, 8 were male and 10 were female, 11 were drivers and 7 were non-drivers. It should be noted, however, that although 4 of the 6 female non-drivers in this age group produced a form of map, analysis of these sketches showed that they contained such sparse detail and poor quality as to be of little use in wayfinding (mean number of correctly placed landmarks=0.25).

Table 7.42: Maps produced by each information condition

Group	Information condition	N (group)	N(able to produce a map)	%
1	Video only	31	26	84
2	Route guidance	36	26	72
3	Radio	36	30	83
4	Radio plus guidance	30	21	70

Table 7.42 shows that there was little difference between the four information conditions in terms of the number of members of that group able to produce a map. Although subjects in the two route guidance conditions produced fewer maps, the differences are not significant. Further analysis is required to establish which of the main variables has an effect upon performance of the sketch map task.

Scoring the maps

Chapter 4 emphasised the problematic nature of sketch maps. To overcome some of these objections, the present study used a more quantitative approach to rate the map data, rather than making subjective judgements to establish the best and worst maps. Hence, the maps were scored on the following dimensions:

- Variable "Landmarks" - number of environmental features included on the sketch map, regardless of whether or not they were correctly placed;
- Variable "Correct" - number of environmental features correctly located (in terms of geographical position) on the subject's sketch map;
- Variable "Roads" - number of road names mentioned and correctly located on the sketch map;
- Variable "Segments" - number of road segments correctly placed on the sketch map;

- Variable "Total" - an overall map score which was created by adding the number of correctly located landmarks to the number of correctly positioned road segments. This was the variable used as an objective measure of map quality.

By focusing on specific elements within the maps rather than rating the quality of the overall map it was hoped that subjective bias resulting from stylistic or artistic differences between subjects' sketch maps would be reduced. Clearly the scoring of these variables is not truly quantitative in that it involves some subjective assessment of location accuracy. The main independent variable to be studied for this part of the analysis is the variable "Correct", as this shows not only that subjects recalled features within the study area, but also that they were able to correctly position these features within this space as represented in their sketch maps. The scoring of the maps was carried out by a group of 5 residents (henceforth known as the markers) who had lived in the study area for a minimum of 5 years. The variables described above were explained to the markers and three maps were selected as examples. These were scored by the experimenter in front of the markers. The 3 maps were scored on each variable and the reasons for these scores explained in detail. Each marker (3 male, 2 female, aged 27-36) was then provided with a copy of the Ordnance Survey map of the area and a random selection of 20 of the subjects' sketch maps. Scores were marked on a separate sheet so that they would not influence the other markers. Once each marker had completed marking their set of 20 maps they passed these on to the next person. Once each marker had marked all 100 maps the scores were collected and compared. For the majority of the maps and for the majority of variables the 5 markers marked the maps very similarly. The variables "Landmarks", "Roads" and "Segments" caused very few problems (apart from a few errors in adding up) as there was little margin for error. It had been anticipated that getting the group to agree that a feature was correctly positioned would cause problems, but even on this aspect there was very little disagreement. The criteria used for assessing location accuracy were intentionally kept broad: as long as the landmark was positioned in the correct segment of the correct road, this was enough to score a point. This means that only "global accuracy" was assessed, i.e. that the position of each landmark was accurate in the map as a whole: accuracy with respect to immediately local features was considered to be of less importance as this would be difficult to determine on a hand-drawn map of such a small scale. Moreover, there was the possibility that drawing style might cause differences in interpretation.

Of most interest was the variable "Correct". Of the 100 maps scored by the markers 8 were marked differently (at least + or – 5) by one marker on this variable. These 8 maps were re-considered and discussed by the group. As a result of discussions the scores for these 8 maps were reconsidered and scores for 4 maps adjusted slightly: 2 were increased by 2 and 3 landmarks respectively, while 2 were decreased by 2 landmarks. Clearly this scoring mechanism is open to criticism, in that the scoring of the maps was less qualitative than had been originally intended. However, the consensus achieved between the group of 5 markers could be considered to have added some validity to the final scores.

Map data: descriptive statistics

A total of 103 subjects were able to draw some form of sketch map. Analysis of these maps produced the data shown in Table 7.43.

Table 7.43: Map data

Variable	Mean	Standard deviation	Minimum	Maximum	Maximum possible
Landmarks	12.48	7.82	0	35	63
Correct	10.61	8.45	0	35	63
Roads	1.572	1.99	0	10	10
Segments	16.92[3]	6.95	0	31	31
Total	28.02	14.15	0	64	94

The maximum possible number of landmarks that could have been recorded by subjects is open to debate: strictly speaking any feature present in the study area and recorded on a subjects' map could be considered a landmark. To some extent this was the approach adopted and markers were advised to accept any feature which was present in the films or photographs (they were shown these beforehand, and asked to check with the experimenter if they were unsure). This makes it technically possible to achieve a much higher score than 63, if every building, tree, vehicle and visible feature in the area is included in the analysis. The maximum figure was reached by summing every feature that was included on at least one map: a total of 63 different

[3] Due to missing values the means for "Segments" and "Total" are based on 98 subjects whereas the means for the other variables are based on a sample of 103. This explains why the mean for "Total" is not the sum of the means for "Correct" and "Segments".

landmarks were recorded. Again, this system of scoring is far from ideal and perhaps other systems of scoring could have been employed. However, the scores considered as a whole give a reasonably accurate picture of the performance of the sample and it is fair to say that the scoring, whilst open to criticism, is consistent across all subjects in both experiments.

The range of values for each of these variables gives some indication of the variable quality of the maps produced. As was evident in the other tasks, particularly the more complex or taxing ones, the majority of the variance is due to older subjects, as shown in the following tables.

Map data: analysis of variance

Anova using the GLM procedure was used to determine the source of the variance between individuals. This procedure was carried out on all of the above mentioned dependent variables. The GLM showed the following variables to be significant:

For the variable Landmarks

The variable landmarks is a simple measure of the number of landmarks recalled. This measure made no distinction between correctly and incorrectly placed landmarks, but simply recorded the total number of landmarks evident on the sketch map. The model for this analysis was found to be significant, $F(7,94)=6.83$, $p<0.001$, $r^2=0.335$. The following main variables were significant:

- Age group $F(2,100)=13.43, p<0.001$
- Sex $F(1,101)=7.79, p<0.01$
- Group $F(3,99)=4.58, p<0.01$

Group means for these variables are shown in the following tables. Tables 7.44 and 7.45 give group means and post-hoc analysis for the variable Age. Table 7.46 shows means for both levels of the variable Sex. Tables 7.47 and 7.48 show group means and post-hoc analysis for Group.

Table 7.44: Mean number of landmarks recalled by age group

Age group	n	Mean number of landmarks recalled	Standard deviation
18-21	32	17.06	6.98
22-54	58	11.24	7.63
55 and over	13	6.77	4.38

Table 7.45: Table of differences between means for variable Landmark by Age

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
1 – 2	2.35	5.82	9.29	***
1 – 3	5.11	10.29	15.47	***
2 – 1	-9.29	-5.82	-2.35	***
2 – 3	-0.36	4.47	9.31	
3 – 1	-15.47	-10.29	-5.11	***
3 – 2	-9.31	-4.47	0.36	

Post-hoc analysis showed that the mean scores of the youngest and middle age groups were significantly different and that the performance of the youngest age group was also significantly different from the oldest age group. However, the means for the middle and older age groups were not significantly different. The difference in sample sizes of these two groups might account for the lack of significance.

Table 7.46: Mean number of landmarks recalled by sex of participant

Sex	N	Mean number of landmarks recalled	Standard deviation
Male	48	14.12	8.51
Female	55	11.05	6.94

Table 7.46 shows that a small but significant difference was again evident between male and female subjects, with males including more landmarks on their maps.

Table 7.47: Mean number of landmarks recalled by information group

Group	n	Mean number of landmarks recalled	Standard deviation
Video only	26	16.58	9.20
Route guidance	26	10.96	5.69
Radio	30	10.97	5.89
Route guidance + radio	31	11.48	9.31

Table 7.47 shows that subjects who watched the videos without accompanying soundtrack recalled significantly more landmarks than other groups. Interestingly, the performance of those subjects who heard non-salient information (radio) was comparable with those who heard salient information. Post-hoc analysis was carried out on the data to check which of the four levels of group were significant.

Table 7.48: Table of differences between means for variable Landmark by Group

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
1 – 4	0.02	5.10	10.18	***
1 – 3	0.97	5.61	10.25	***
1 – 2	0.82	5.61	10.41	***
4 – 1	-10.18	-5.10	-0.02	***
4 – 3	-4.41	0.51	5.43	
4 – 2	-4.56	0.51	5.59	
3 – 1	-10.25	-5.61	-0.97	***
3 – 4	-5.43	-0.51	4.41	
3 – 2	-4.63	0.005	4.64	
2 – 1	-10.41	-5.61	-0.82	***
2 – 4	-5.59	-0.51	4.56	
2 – 3	-4.64	-0.005	4.63	

Table 7.48 shows that the control group was significantly different from all other groups. This result suggests that, for this variable, listening to any type of additional information, salient or otherwise, has a negative impact upon task performance.

For the variable Correct

This variable is the same as Landmarks except that incorrectly positioned landmarks were excluded. Hence, this is the most accurate measure of the quality of subjects' sketch maps. The model was significant: $F(7,94) = 5.90$, $p<0.001$, $r^2=0.303$. The following variables reached significance:

- Age group $F(2,100)=14.08, p<0.001$
- Sex $F(1,101)=7.28, p<0.05$

Tables 7.49 and 7.50 show the means and differences between means for the variable age.

Table 7.49: Mean number of correctly placed landmarks by age group

Age group	N	Mean number of correct landmarks	Standard deviation
18-21	32	15.78	7.71
22-54	58	9.12	8.06
55 and over	13	4.54	4.89

Table 7.49 shows that, as with the other tasks, younger subjects performed significantly better than older subjects. To determine which levels of age were significantly different post-hoc analysis using Tukey was again carried out. The results of this analysis are shown in table 7.50.

Table 7.50: Table of differences between means for variable Correct by Age group

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
1 – 2	2.82	6.67	10.50	***
1 – 3	5.11	11.24	16.97	***
2 – 1	-10.50	-6.67	2.82	***
2 – 3	-0.76	4.58	9.93	
3 – 1	-16.97	-11.24	-5.51	***
3 – 2	-9.93	-4.58	0.76	

Table 7.50 shows that the performance of the younger age groups can be considered to be significantly different from each other, and that the mean performance of the younger group is significantly different from that of the oldest age group. However, the mean performances of the two older age groups were not significantly different.

Table 7.51 shows a significant gender effect. As with other tasks, when the performances of all males and females are compared and no distinction is made between age groups or between drivers and non-drivers, the mean performance of males is significantly better than females. As before, however, it is likely that the poor performance of female non-drivers, particularly older subjects has a disproportionate effect upon this result.

Table 7.51: Mean number of correctly placed landmarks by sex of participant

Sex	n	Mean number of correctly located landmarks	Standard deviation
Male	48	12.46	9.45
Female	55	9.00	7.20

For the variable Roads

The variable Roads, which is a measure of the number of road names recalled, is slightly different from the other variables, in that the groups who heard route guidance instructions have a clear advantage. Although some of the road names were visible on the video films of each route, only the route guidance groups actually heard the names of each road. The fact that information group was the only significant variable is therefore not surprising. This result shows that subjects were listening to the information provided to them by the recorded spoken instructions. The model was significant but weak: $F(7,95)=3.42$, $p<0.05$, $r^2=0.201$.

- Group $F(3,99)=6.15$, $p<0.001$

This effect is shown in Table 7.52. The table shows that, regardless of information condition, the majority of subjects did not recall more than one or two road names.

Table 7.52: Mean number of roads recalled by Information Group

Information group	n	Mean number of roads recalled	Standard deviation
Video only	26	1.07	1.81
Route guidance	26	2.57	2.30
Radio	30	0.60	0.96
Route guidance + Radio	21	2.33	2.12

In order to establish which comparisons cause the effect post-hoc analysis was carried out using the Tukey procedure. The results of this analysis are shown in table 7.53

Table 7.53: Table of differences between means for variable Roads by Group

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
2 – 4	-1.17	0.24	1.66	
2 – 1	0.16	1.50	2.84	***
2 – 3	0.68	1.98	3.27	***
4 – 2	-1.66	-0.24	1.17	
4 – 1	-0.16	1.26	2.67	
4 – 3	0.36	1.73	3.10	***
1 – 2	-2.84	-1.50	-0.16	***
1 – 4	-2.67	-1.26	0.16	
1 – 3	-0.82	0.48	1.77	
3 – 2	-3.27	-1.98	-0.68	***
3 – 4	-3.10	-1.73	-0.36	***
3 – 1	-1.77	-0.48	0.82	

Table 7.53 shows that the mean score for group 2 is significantly different from groups 1 and 3, but not significantly different from group 4, and that group 4 is significantly different from group 3 (but not group 1). This result is not unexpected given the distinct advantage that these two groups (2 and 4) have over the others. In fact one could argue that the result is not as conclusive as one might expect: even those who heard road names only recalled - or chose to include on their maps - an average of between 2 and 3 names out of a possible 10.

For the variable Segments

The variable Segments is a similar measure to Roads but is less affected by information condition than roads, as it does not rely on the road name. This variable measures each road in terms of the constituent segments of which it is comprised. A segment is defined as a stretch of road between two road junctions. One long road could be comprised of many segments in this way. Hence, the variable is an indicator of the individuals' knowledge of the overall structure of the study area. Only 98 of the 103 subjects who drew a map included roads on their maps, hence the data is based on these 98 subjects. The model was significant but only explained approximately 17% of the variance and so was very weak: $F(7, 90)=2.58, p<0.05, r^2=0.167$. Only one variable was significant:

- Age groupF(2,101)=6.93, p<0.002

This effect is shown in Table 7.54.

Table 7.54: Mean number of road segments recalled by age group

Age group	n	Mean number of road segments recalled	Standard deviation
18-21	32	19.81	6.52
22-54	53	16.43	6.50
55 and over	13	11.85	6.80

Post-hoc analysis revealed the following differences between means.

Table 7.55: Table of differences between means for variable "Segments" by Age group

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance (p<0.05) indicated by ***
1 – 2	-0.14	3.38	6.89	
1 – 3	2.80	7.97	13.13	***
2 – 1	-6.89	-3.38	0.14	
2 – 3	-0.27	4.59	9.45	
3 – 1	-13.13	-7.97	-2.80	***
3 – 2	-9.45	-4.59	0.27	

Table 7.55 shows that only the mean scores for the youngest and oldest groups are significantly different from one another.

For variable Total

This variable is the sum of landmarks and road segments included in a subjects' map. The model for this variable was significant: F(7,90)=5.03, p<0.001, r2=0.281. Only one variable was found to be significant:

- Age groupF(2,95)=13.39, p<0.001

This effect is shown in Table 7.56.

Table 7.56: Mean total score on map task by age group

Age group	n	Mean total score	Standard deviation
18-21	32	35.87	12.62
22-54	53	26.13	13.31
55 and over	13	16.38	10.66

Post-hoc analysis performed on this data produced the following data:

Table 7.57: Table of differences between means for variable "Total" by Age group

Groups being compared	Simultaneous lower confidence limit	Difference between means	Simultaneous upper confidence limit	Significance ($p<0.05$) indicated by ***
1 – 2	3.09	9.74	16.39	***
1 – 3	9.72	19.49	29.26	***
2 – 1	-16.39	-9.74	-3.09	***
2 – 3	0.55	9.75	18.94	***
3 – 1	-29.26	-19.49	-9.72	***
3 – 2	-18.94	-9.75	-0.55	***

Table 7.57 shows that when the two variables "Correct" and "Segments" are summed to produce the variable "Total" the performance of all three age groups can be considered to be significantly different from each another.

To summarise the results of the map task, some consistency is evident across the various measures used to analyse the data. On four of the five measures (Landmarks, Correct, Segments and Total) age of subject was a significant variable. Clearly this result is fairly robust. Sex of subject was significant for the variables "Landmark" and "Correct", while Information condition was significant for the variables "Landmark" and "Roads". The problems of reliability of the variable "Sex" have already been discussed – when driving ability and/or age are taken into consideration there are no gender differences. Information condition was expected to be significant for the variable "Roads" but not for the variable "Landmark". This result was important in that the performance of all groups who heard some form of information, salient or otherwise, was significantly different (inferior) to that of the control group, who heard nothing.

7.4.4 Comparison of performance of demographic groups across tasks.

The sketch maps give a second indication of subjects' configurational knowledge, in addition to the cross route pointing task. The sketch map task has the advantage that most people are familiar with the idea of giving directions via pictorial representations. A correlation analysis was run comparing performance on the cross route pointing task (variable "XRT_Mean") with performance on the map task (variable "Correct"). Pearson's product-moment, Kendall's Tau b and Spearman's rank-order correlation coefficients were run, with all producing highly significant results ($p<0.0001$.) Spearman's correlation coefficient for this relationship was -0.63318. The negative value is due to the fact that high scores indicate good performance on the map task, but poor performance on the cross route pointing task. The probability of performance on the two measures not being related is 0.0001. Figure 7.14 plots this relationship.

Table 7.58 shows the sample separated into the demographic groups which made up the four information conditions. The table shows that the best group performances at both measures of configurational knowledge were by young male drivers and young female drivers. The next best group performances were by male drivers aged 22-54 and by female drivers in the same age group. With the exception of the young male drivers group, all these best performances came from subjects who saw the videos accompanied by non-salient information (i.e. either nothing or radio). The table also emphasises that performance of the cross route pointing task and the sketch map task are correlated: of the 10 groups who performed best at the cross route pointing task, 8 are also in the top 10 sketch map performances. The table emphasises the poor performance of similar groups across the information conditions: this is particularly evident if one compares the performances of the two groups of male drivers in the 22-54 age group. At both tasks those who were in information condition I (no information) scored very highly – their mean scores were the third best at both tasks. However, a group of male drivers in the same age group who saw the videos under the route guidance information condition performed poorly: the mean scores for the group were 10^{th} and 13^{th} best out of 16.

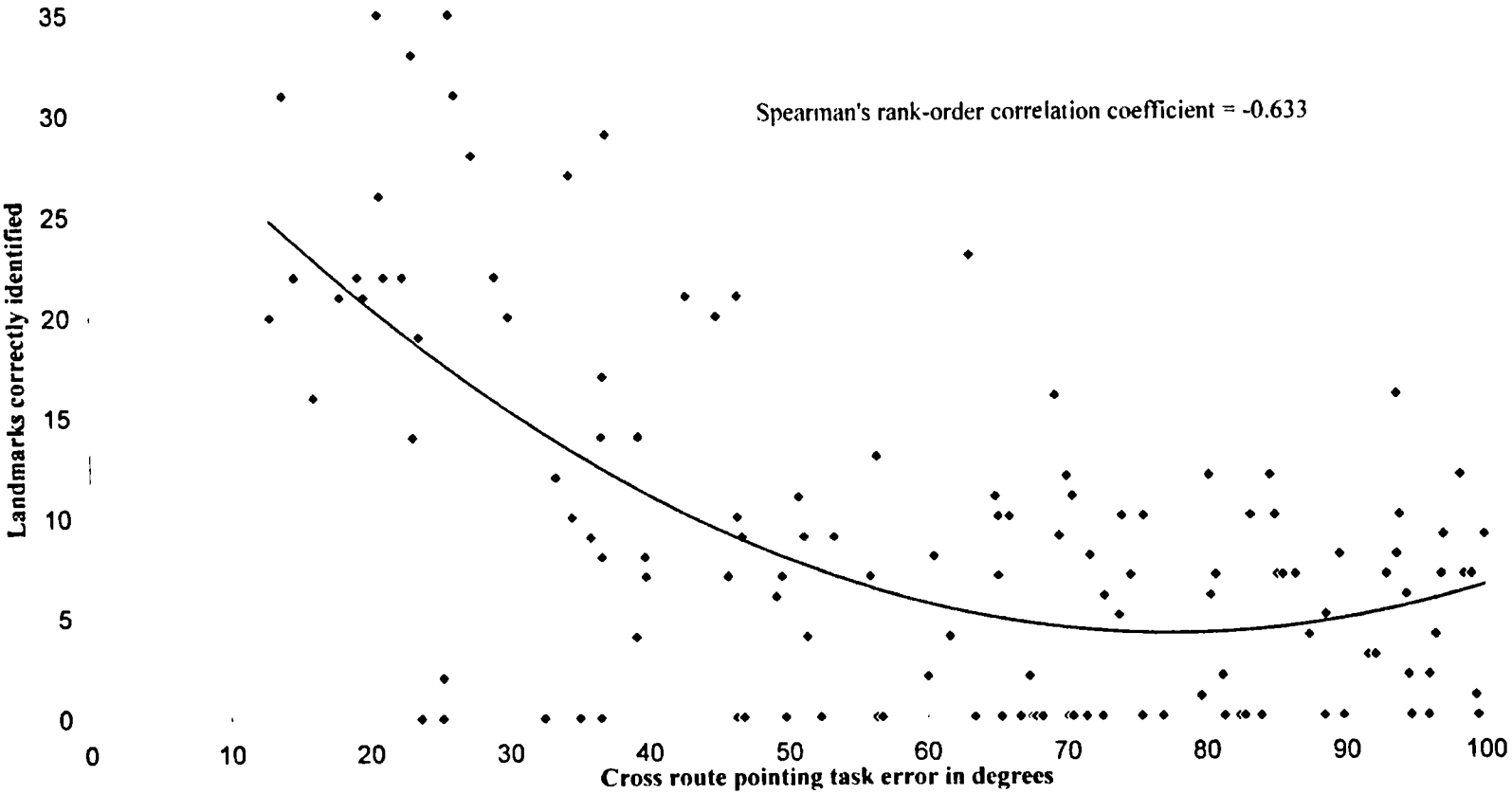


Figure 7.14: Scatterplot showing the relationship between XRT scores and performance at the map sketching task

Table 7.58: Comparison of the performance of demographic groups at cross route pointing and sketch map tasks

Group	n	Mean XRT_Mean Score	SD	Mean No. of correct landmarks	SD
Male drivers 18-21	8	30.28	10.33	18.28	9.12
Male non-drivers 18-21	9	51.32	26.23	14.00	5.75
Female drivers 18-21	8	35.87	21.31	18.75	10.29
Female non-drivers 18-21	10	63.85	26.17	12.78	4.29
Male drivers 22-54 (I)	8	43.28	24.86	17.00	14.52
Male drivers 22-54 (II)	9	68.29	23.06	6.25	5.95
Male non-drivers 22-54 (I)	8	53.48	27.34	11.17	7.81
Male non-drivers 22-54 (II)	8	60.95	26.87	13.75	10.44
Female drivers 22-54 (I)	10	49.58	17.52	6.90	5.80
Female drivers 22-54 (II)	8	65.24	18.77	6.33	2.06
Female non-drivers 22-54 (I)	8	99.72	8.54	6.50	4.37
Female non-drivers 22-54 (II)	8	75.05	17.99	7.75	2.76
Male drivers 55+	8	70.55	25.38	8.20	5.07
Male non-drivers 55+	7	69.51	17.78	4.50	6.36
Female drivers 55+	10	74.76	16.54	4.00	1.41
Female non-drivers 55+	6	96.46	8.80	0.25	0.50

7.4.5 Correlation coefficient analysis of tasks used in phase I.

Over the course of the experiment three tasks in particular highlight subjects with above average cognitive mapping ability. These "indicator tasks" are the sequencing task, the cross route pointing task and the sketch map task. Correlation analysis was performed on the data from the

sequencing tasks, to see whether performance at these tasks correlated with subsequent performances at the pointing tasks. Table 7.59 shows the results of this analysis.

Table 7.59: Correlation coefficients for pointing and sequencing tasks

	n	RScore	BScore	GScore	OScore
Red_Mean	133	-0.36258 (p<0.0001)	-0.29735 (p<0.0005)	-0.40744 (p<0.0001)	-0.48002 (p<0.0001)
Blu_Mean	133	-0.32545 (p<0.0001)	-0.38948 (p<0.0001)	-0.51091 (p<0.0001)	-0.55064 (p<0.0001)
Grn_Mean	133	-0.34274 (p<0.0001)	-0.34171 (p<0.0001)	-0.44960 (p<0.0001)	-0.51021 (p<0.0001)
XRT_Mean	133	-0.38918 (p<0.0001)	-0.38446 (p<0.0001)	-0.51986 (p<0.0001)	-0.58206 (p<0.0001)

(All coefficients are Spearman's rank-order correlation coefficients)

Table 7.59 shows that performance at the sequencing and pointing tasks is correlated. This suggests that good performance on one predicts good performance at the others. To test this hypothesis, the top performers in all tasks were treated as distinct groups and the mean score for each group on the other two tasks was calculated. These figures are shown in Table 7.60. The table shows that subjects who performed best at one of the three tasks also performed exceptionally well at the other two tasks. The average ages of the top performing groups at each of the three indicator tasks ranged from 23.09 to 24.33 years, as opposed to a sample average of over 35 years.

Subjects whose mean pointing error was 20 degrees or less for the cross route pointing task recalled and correctly positioned an average of nearly 24 landmarks and had an overall score of 27.67 for the sequencing task, these figures compare very favourably with those for the sample as a whole. Furthermore, the groups' estimates of journey distance and duration were much more accurate than for the sample as a whole. Subjects who recalled and correctly positioned 23 landmarks or more had a mean XRT_mean score of 23.85 degrees, an OScore of 28.38 and again showed much more accuracy in estimating distance and duration. Finally, those who scored a maximum 30 on the sequencing task had a mean pointing error score of 22.7 degrees

and recalled and correctly located nearly 25 landmarks and demonstrated good accuracy in estimating distance and durations. These results suggest that configurational knowledge is composed of a wide range of subsidiary and subordinate information which is combined to create a configurational representation of the area: subjects who performed best in one of the three indicator tasks also produced particularly accurate estimates of route distances and times.

Table 7.60: Comparison of groups composed of subjects recording the top performances in the three indicator tasks

Groups Variables	Mean for all subjects (n=133)	Subjects whose XRT_Mean was less than 21 degrees (n=9)	Subjects who recalled more than 23 landmarks (n=13)	Subjects with an OScore=30 (n=11)
Mean Age	35.5	24.33	23.76	23.09
XRT_Mean	60.89	17.32	23.85	22.74
Correct	10.61	23.77	27.23	24.60
OScore (Max=30)	20.90	27.67	28.38	30.00
RRD (Actual=800)	1462	827	833	843
BRD (Actual=600)	1237	763	703	754
GRD (Actual=650)	1405	802	806	666
RRRT (Actual=302)	454	335	406	312
BRRT (Actual=243)	366	251	281	276
GRRT (Actual=275)	409	314	301	299

This analysis of the three groups of top performers suggests that good performance at one of the tasks is correlated with good performance in the other two. This could have been anticipated for the cross route and sketch map tasks, in that both are designed to measure configurational knowledge. Nevertheless it is reassuring to find that performance on one task predicts performance on the other. The sequencing task, however, only measures route knowledge and so good performance at this task would not necessarily predict good performance on the other tasks. Indeed, one could argue that success at tasks measuring single route knowledge is no guarantee of success at tasks measuring configurational knowledge, in that there is no requirement to integrate the information acquired from the separate routes into a configurational representation of the area as a whole. However, Table 7.60 shows that those who had an OScore of 30 also performed very well on the other tasks, reinforcing the idea that good route knowledge is the foundation of good configurational knowledge.

This concludes the results for experiment 1. The following section summarises the findings for each task and relates these findings back to the research hypotheses.

7.5 Summary

This section summarises the results and is organised around the first two research questions proposed in chapter 1:

i) What impact will IVRGIS supplying audible guidance instructions have on the underlying cognitive processes that govern spatial behaviour;
ii) Are all groups equally capable of using audible route guidance information?

For each of these questions a number of hypotheses were proposed, based on the literature reviews in chapters 2, 3 and 4. For each question the relevant results are first summarised and then each hypothesis is considered in turn.

7.5.1 The effects of information upon underlying cognitive processes

The research has focused upon the cognitive mapping process as being representative of underlying cognitive processes involved in spatial behaviours such as wayfinding and navigation. With regard to the effects of information condition upon these processes, only three

results were significant:

For the cross route pointing task:

- Age*sex*driver*group $F(6.124)=3.16$, $p<0.01$.

For the sketch map task variable "Landmarks":

- Information group $F(3,99)=4.58$, $p<0.01$, *Group 1 different from all other groups*

and for the sketch map task variable "Roads":

- Information group $F(3,99)=6.15$, $p<0.001$, *Group 2 different from all except group 4*

Five hypotheses relate specifically to the effects of information: these are hypotheses 1, 2(a and b), 3, 5 and 8. To some extent the hypotheses are closely related, and share a common null hypothesis. However, they have been proposed as a result of different research and so each will be evaluated individually.

Hypothesis 1: (from chapter 2: transportation research)

H_1: The spatial knowledge acquired by subjects hearing audible route guidance information will be superior to that of subjects who do not hear route guidance information.

On tasks measuring single route knowledge and subsidiary information (time and distance estimates) there were no significant differences between groups in task performance. On tasks measuring configurational knowledge, however, there were three results for which group was a significant variable. For the cross route pointing tasks the interaction between the variables age, sex, driver and group was significant, and on the sketch map task the variables "Landmarks" and "Roads" were both significant.

However, when the group means are examined and post-hoc analysis carried out on these data it is clear that the performance of those who heard route guidance information is certainly not better than that of those who heard either radio or nothing. Table 7.38 (p.201) shows the breakdown of the cross route pointing task scores by age, sex, driver and information group. If we focus on the groups in the 22-54 age range and compare the performance of similar subjects it is evident that all groups with the exception of female non-drivers performed far worse when they listened to route guidance information. This effect was most apparent when comparing male drivers who

heard route guidance with those who heard nothing – the latter group had a group mean pointing error of 43 degrees, whereas a similar group who heard route guidance had a group mean pointing error of 68 degrees. Similarly, female drivers had a mean pointing error of 49 degrees in the radio condition, but 65 degrees in the route guidance plus radio condition.

With regard to the sketch map data, tables 7.47 and 7.48 showed that on the variable "Landmarks" there were significant differences between the performance of subjects dependent upon information condition. However, post-hoc analysis of the results showed that the performance of those who saw the films without any information was significantly better than all other groups, again leading to a rejection of the hypothesis. For the variable "Roads" those in the full route guidance condition performed significantly better than all other groups, whereas those who heard full guidance plus radio only performed better than those who heard radio. While these differences are clearly attributable to the fact that those who heard route guidance information had the advantage of hearing the names of the roads in the study area, they also show that certain audible information can be acquired

In summary, information condition was significant on 3 variables, but the results do not support the hypothesis and so we accept the null hypothesis – that there are no differences between subjects based on information condition.

Hypothesis 2a: (from chapter 3: resources and workload research)

H_1 : The primary task performance of subjects listening to audible route guidance will be superior to that of subjects who hear nothing, or listen to radio (non-relevant information), regardless of task complexity, as the two tasks utilise different resources.

Hypothesis 2a is similar to the aforementioned hypothesis and the same conclusion can be drawn – we reject this hypothesis and accept the null hypothesis – there are no significant differences between the information conditions.

Hypothesis 2b: From a central resource theory perspective -

H_1: The primary task performance of subjects listening to audible route guidance information will be inferior to that of subjects who hear nothing, as resources are demanded from the same central pool.

This hypothesis is more difficult to reject as we have evidence that on at least one task the performance of groups who heard audible guidance *was* inferior to that of groups who heard nothing. On one of the measures of the sketch map task ("Landmarks") those who heard nothing (the control) clearly performed significantly better than all other groups, (mean number of landmarks included by the control = 16.58, as opposed to between 10.96 and 11.48 for the three other groups) which would suggest that the hypothesis should be accepted. However, this variable is not the best indicator of spatial knowledge as it is simply a sum of the landmarks included on the sketch map – regardless of accuracy. On the more reliable measures of acquired spatial knowledge: the cross route pointing task and the sketch map variable "Correct", although the mean score of the group who heard nothing was higher than that of other groups, these differences were not significant.

Perhaps the most revealing finding is that on the cross route pointing task the interaction between the four main independent variables was significant (see table 7.38 for group means). This result is important because it suggests that information condition has a differential effect across the various combinations of age, gender and driving ability. For example, in the youngest age group information condition appears to have little effect and driving ability is more important. Similarly, in the 55 and over age group, information condition has a minimal impact by comparison with the debilitating effects of age. In the middle age group, however, where the experimental design allows a comparison of similar subjects across salient and non-salient information conditions, male and female drivers and male non-drivers all performed significantly better when they heard either radio or nothing.

In summary, although there is some evidence to support the hypothesis, the results are far from conclusive and not consistent across all tasks. Consequently the evidence is insufficient to enable us to reject the null hypothesis.

Hypothesis 3: (from chapter 3: resource and workload research)

H_1: The primary task performance of subjects listening to radio will be superior to that of subjects listening to salient information.

Hypothesis 5: (from chapter 3 – car phone research)

H_1: Subjects' performance of the primary task will be adversely affected by attending to salient information, but not by attending to non-salient information (e.g. radio).

Although originating from different areas of research, these hypotheses both suggest that listening to salient information will have an adverse effect upon performance of the various tasks, whereas listening to radio, which is non-salient information, will have less impact. Analysis of the descriptive statistics for the single route tasks and distance and time estimates shows little consistency across the tasks. In the sequencing tasks the mean scores for the radio and control groups was slightly higher than the other groups. On the single route pointing tasks again there is little consistency. On the red route the radio group has the lowest mean, but on the blue and green routes it is the second highest. None of the group results for these tasks were statistically significant.

A straight comparison of the performances of the four information conditions at the cross route pointing and map sketching tasks again shows little difference between scores at the group level, although the mean for the radio group was the lowest. In summary, there is little evidence to support the hypothesis and again we accept the null hypothesis - that there were no significant differences between the information conditions.

Hypothesis 8: (from chapter 4 – time estimation research)

H_1: Subjects required to listen to full route guidance instructions will make less accurate estimates of journey time than those who hear nothing or non-salient information.

A straightforward analysis of the time estimation results by information group shows little consistency across the three routes. For the red and blue routes the radio group had the lowest mean estimate of duration, but for the green route the group mean estimate was higher than that for the route guidance condition. The only consistent finding, and most interesting aspect of the time estimate results is that the control group, who heard nothing, had the highest group mean estimate of duration on all three routes. This directly contradicts hypothesis 8. In summary, the control group performed consistently poorer than the other three groups, while the radio group – who it was hypothesised would have most in common with the control – actually produced mean time estimates which did not differ significantly from those of the salient information groups. As such, there is no consistency and little evidence to support the hypothesis.

Overall, results which focus upon differences between information group show that, for this sample and for these tasks, there were no significant differences due to the information heard.

These are disappointing results, but it is possible that the composition of the groups was such that other effects would be far more significant: particularly differences due to the age of the respondents.

7.5.2 Are all groups equally capable of using audible route guidance information?

This research question specifically relates to potential differences between groups in their ability to acquire and use information provided by route guidance and information systems. Hypotheses were proposed relating to two particular variables: ability to drive and age of subject. With regard to driving ability, a total of 10 results were statistically significant, these were:

For the sequencing tasks:

- RScore: Driving ability: $F(1,132)=7.35$, $p<0.05$
- GScore: Driving ability: $F(1,132)=4.64$, $p<0.05$
  Age*Driving ability: $F(2,131)=3.49$, $p<0.01$
- OScore Driving ability: $F(1,132)=10.73$, $p<0.01$
  Age*Driving ability: $F(2,131)=5.35$, $p<0.01$

For the single route pointing tasks:

- Blue route: Driving ability: $F(1,132)=5.55$, $p<0.05$

Time and distance estimates

Driving ability was not significant for any of the distance estimates, but for time estimation the following results were significant:

- Red route time estimate: Driving ability $F(1,132)=8.31$, $p<0.005$
- Green route time estimate: Driving ability $F(1,132)=4.48$, $p<0.05$

Measures of configurational knowledge

For the tasks measuring configurational knowledge, driving ability was not significant for any of the sketch map task variables, but for the cross route pointing task:

- Driving ability: $F(1,132)=20.30$, $p<0.001$
- Age*sex*driver*group: $F(8,124)=3.16$, $p<0.01$

The hypotheses relating to driving ability will now be evaluated in light of these results.

Hypothesis 4: (from chapter 3 – development of skills)

H_1: Performance of tasks measuring spatial knowledge will be significantly correlated with ability to drive.

Ability to drive was a significant variable for two of the three sequencing tasks, the overall score for the sequencing task, two of the time estimates, and for the cross route pointing task. Driving ability was not significant for the sketch map tasks. For all tasks on which driving ability was a significant variable the group mean for drivers was at least slightly better than that for non-drivers. For the sequencing tasks drivers as a group performed slightly better than non-drivers on all routes, and on the more complex red and green routes and on the overall score (OScore) these differences were significant. Drivers scores at the single route pointing tasks were better than those of non-drivers and for the blue route this difference was significant (table 7.13). Drivers' time and distance estimates, although not statistically significant, were closer to actual than non-drivers (Red: 1341 v 1607 metres; Blue: 1165 v 1315; Green: 1297 v 1524) time estimates were also more accurate than non-drivers for the red and green routes (table 7.31) and these results were significant ($p<0.05$). Finally, on the cross route pointing task drivers were significantly more accurate in estimating directions than non-drivers (55 degrees pointing error as opposed to 70 degrees, see table 7.36). This consistency of results across the various measures of performance suggests that there is good evidence to support the hypothesis. However, when we compare drivers and non-drivers of different ages there are differences within the three levels of age (table 7.9). For example, on the green route sequencing task the 18-21 and 55+ age groups drivers performed better than non-drivers, but in the middle age group non-drivers performed slightly better. Similarly, table 7.38 showed that in the 18-21 age group male drivers performed significantly better than male non-drivers (30 v 51 degrees error) and female drivers performed significantly better than female non-drivers (36 v 64 degrees error). In the 22-54 age group there are two groups each of male and female drivers and non-drivers (8 groups in all). While the two groups of female drivers in this level of age both perform significantly better than the two groups of female non-drivers, only one of the groups of male drivers performed better than the two male non-driving groups. In the 55 + level of age the mean error scores for male drivers and non-drivers are very similar (70.5 v 69.5), whereas female drivers at this age level perform significantly better

than female non-drivers.

Considering these results together it is clear that ability to drive has some effect upon ability to perform the various tasks used to measure spatial knowledge acquisition. This driving effect was present in a range of the tasks, and was consistent in direction (i.e. wherever there was an effect due to driving, drivers always performed better than non-drivers). However, analysis of the interaction effects (see particularly tables 7.15 and 7.38) suggest that the effect was not straightforward, and there appears to be a differential effect across age groups. The results offer good evidence to support the hypothesis, and given that ability to drive was a significant variable on the most important measure of spatial knowledge acquisition (cross route pointing task) it appears reasonable to accept the hypothesis as it stands: performance of tasks measuring spatial knowledge is related to ability to drive. There is clearly a difference between drivers and non-drivers in their performance of the various tasks, but the differences between age groups suggest that there are differences between drivers dependent upon other factors (particularly age and length of driving experience) As such we accept the hypothesis but subsequent experiments will be run which will explore these age and experience differences in more detail. These results will be discussed in conjunction with the age group results.

The final two hypotheses for this experiment relate to the effects of age. Of all the main variables age showed the most consistent effect across the full range of tasks. The following list summarises the age effect for the various tasks. In each case, the post-hoc analysis is also given - the figures 1, 2 and 3 refer to the levels of age, whereby 1 = 18-21, 2 = 22-54, and 3 = 55 and over.

Sequencing tasks:

RScore Age $F(2,131)=16.13$, $p<0.001$ *1 different from 3, 2 different from 3*

BScore Age $F(2,131)=21.03$, $p<0.001$ *All groups different*

GScore Age $F(2,131)=17.15$, $p<0.001$ *All groups different*

Age*Driver $F(2,131)=3.49$, $p<0.05$

OScore Age $F(2,131)=33.22$, $p<0.001$ *All groups different*

Age*Driver $F(2,131)=5.35$, $p<0.01$

Single route pointing tasks:

Red route: Age $F(2,131)=8.26$, $p<0.001$ *1 different from 2, 1 different from 3*

Blue route: Age $F(2,131)=14.60$, $p<0.001$ *1 different from 3, 2 different from 3*

Green route Age $F(2,131)=13.79$,$p<0.001$ *All groups different*

Distance estimation:

Red route: Age $F(2,130)=10.38$, $p<0.001$ *1 different from 3, 2 different from 3*

Blue route: Age $F(2,130)=8.07$, $p<0.001$ *1 different from 3, 2 different from 3*

Green route: Age $F(2,130)=6.75$, $p<0.05$ *1 different from 3, 2 different from 3*

Time estimation:

Red route: Age $F(2,130)=9.70$, $p<0.001$ *1 different from 3, 2 different from 3*

Blue route: Age $F(2,130)=9.75$, $p<0.001$ *1 different from 3, 2 different from 3*

Green route: Age $F(2,130)=8.47$, $p<0.001$ *1 different from 3, 2 different from 3*

Cross route pointing task:

Age $F(2,130)=19.80$, $p<0.001$ *All groups different*

Age*sex*driver*group $F(8,124)=3.16$, $p<0.01$

Sketch map tasks:

Landmarks: Age $F(2,100)=13.43$, $p<0.001$ *1 different from 2, 1 different from 3*

Correct: Age $F(2,100)=14.08$, $p<0.001$ *1 different from 2, 1 different from 3*

Segments: Age $F(2,100)=6.93$, $p<0.01$ *1 different from 3*

Total: Age $F(2,95)=13.39$, $p<0.001$ *All groups different*

The two hypotheses relating to age will now be considered in light of these findings.

Hypothesis 6: (from chapter 3 - effects of age upon working memory)

H_1: The quality of subjects' performance of tasks measuring spatial knowledge will be negatively correlated with age.

The first hypothesis suggests that, as age of subject increases, quality of performance at the various tasks measuring spatial knowledge acquired will decline. Comparing the means for each level of age and considering the highly significant effect of age at the various tasks would suggest that this is the case. However, to determine which of the three levels were significantly different post-hoc analysis was run on the data (results in italics above). For the hypothesis to be accepted as it stands it would be necessary to show that there was a significant decline in performance across the three age groups, and not simply that the youngest age group performed significantly better than the oldest. If we look at the tasks in turn we can see that for two of the three

sequencing tasks (blue and green routes) all groups are significantly different from one another, and performance deteriorates with age. Considering the single route pointing tasks, only on the green route did the age effect show differences between all three levels. For the measures of subsidiary information an identical pattern was evident across all 6 estimation tasks (3 estimates of route distance and 3 of route duration): in all cases the 18-21 year old and the 22-54 year old groups were both found to be significantly different from the 55 and over group, but not significantly different from each other. For the cross route pointing task, and for the variable "Total" on the sketch map task, all groups were significantly different from each other. For the sketch map task variables "Landmarks" and "Correct" the youngest group was significantly different from both other groups, but the middle age group was not significantly different from the oldest group. Finally, for the variable "Segments" only the youngest and oldest groups were significantly different from one another.

In summary, clear age differences were found on the majority of tasks, with the youngest group performing better than the middle age group, who in turn performed better than the oldest age group. This pattern of results was consistent across all the tasks. Post-hoc analysis showed that on some tasks differences between the three levels were not all significant, (e.g. on the distance and time estimation tasks). However, the most important measure of spatial knowledge used in these experiments is the cross route pointing task because this is a measure of how well the information acquired from the other tasks has been integrated. On this task it is clear that performance deteriorates across the three age groups and the three groups are significantly different from each other. In conclusion, the results provide significant evidence in support of the hypothesis and consequently the null hypothesis can be rejected.

Hypothesis 9: (from chapter 4 - effects of age upon configurational knowledge acquisition)

H_1: Elderly subjects will perform poorly on tasks measuring configurational knowledge, regardless of their performance on tasks measuring lower order spatial knowledge.

H_0 Elderly subjects' performance of tasks measuring configurational knowledge will be correlated with their performance of lower order tasks.

The results above show that age has a significant effect upon ability to perform the various tasks used in this experiment. However, to find out whether there is a correlation between performance at the single route tasks and performance at the cross route pointing task correlation analysis was run. This data is shown in table 7.39. The table shows that for subjects aged 18-21 and 22-54

performance at all three single route pointing tasks was significantly correlated with subsequent performance at the cross route pointing task. For the 18-21 age group the correlations were 0.54 for the red route, 0.79 for the blue route and 0.81 for the green route, showing how clearly the two tasks are correlated. This is the pattern of responses one would expect, as the cross route pointing task measures ability to integrate the information acquired from the three individual routes into a configurational representation of the study area as a whole. However, the table also shows that for subjects aged 55 and over cross route task performance was only correlated with the blue route task performance, the easiest of the three routes. By contrast with the correlation scores for the other two age groups this correlation was poor (0.49). On the other routes task performance was not correlated. Similarly, young and middle age group subjects' performances on the sequencing tasks were all significantly correlated with cross route pointing task performance. For older subjects only the red route pointing task was correlated with the cross route pointing task. In summary, the results show that whereas younger subjects' single route task performance was a good indicator of subsequent configurational task performance, older subjects not only performed poorly on the tasks measuring configurational knowledge, but their previous performance on the single route tasks had little impact upon performance of these tasks. Consequently, we can reject the null hypothesis, and the evidence is sufficient to enable us to accept the hypothesis.

7.6 Discussion

7.6.1 The effects of listening to route guidance information upon cognitive mapping ability.

The main aim of phase I of the research project was to study the impact of receiving and attending to route guidance instructions upon the underlying cognitive processes involved in spatial ability – i.e. to acquire a cognitive map of an unfamiliar area.

The hypotheses relating to the effects of information can be divided into two: hypotheses 1 and 2a both consider the possibility that listening to additional route guidance information will have a beneficial effect upon wayfinding performance, whereas hypotheses 2b, 3, 5 and 8 consider the potential distraction that might be caused by the introduction of audible guidance.

Taking hypotheses 1 and 2a first, chapter 2 discussed the benefits transportation researchers have predicted will arise from widespread use of route guidance and information systems. The

summary of results suggests that predicted improvements to cognitive maps (Schofer *et al.*, 1993) may have been overstated. Experiment 1 showed that there were no significant differences between the information groups in their performance of the tasks measuring constituent elements of spatial knowledge, or in tasks measuring ability to integrate this information into a cognitive map of the area – and the information they heard had little impact upon the quality of the cognitive representation they acquired. Consequently we cannot conclude that listening to route guidance information had any beneficial effect upon cognitive map acquisition or development.

The other hypotheses in this section all related to the possibility that attending to additional information might have a detrimental effect upon performance of a primary task, and in particular upon the underlying cognitive processes involved in wayfinding and navigation. The summary of results showed that there was only limited evidence to support these hypotheses, and where there was evidence it was insufficient or inconclusive. Consequently, whilst we cannot conclude that there are any benefits to be derived from attending to audible route guidance, neither do the results support the hypothesis that doing so will have a detrimental effect.

The experiment was designed to enable a comparison of the performance of similar groups with and without route guidance instructions. The middle age group was composed of 8 sub-groups made up by gender, driving ability and information condition (see table 7.38). Comparing the performance of these 8 groups across the information conditions it is clear that both male and female drivers performed significantly better when they heard either nothing, or non-salient information. This result suggests that attending to additional information which relates specifically to visual information does have a detrimental effect upon performance. However, the results of other tasks were less conclusive. It is possible that it is only on tasks measuring configurational knowledge that significant differences are apparent. Alternatively, given that the interaction between the four main variables was the only occasion when group was a significant variable, perhaps different groups respond differently to the information, and it is only at this level of analysis that these subtle differences emerge.

i) The subject sample in experiment 1 comprised adults aged 18-86, drivers and non-drivers were used. A number of potential problems could be cited with this design. First, the three age groups are not equal in terms of the age range within each level. This was recognised as a potential problem at the outset of the experiment, and could have been remedied by focusing specifically upon groups of younger subjects in equal age bands. However, previous research (see chapters 3 and 4) into the effects of age suggested that older adults are likely to have most problems with information provided by IVRGIS, consequently it was considered essential that this group were included. However, the distribution of these subjects across the four information conditions may have been uneven. Specifically, the experimental design assigned two groups of drivers and two groups of non-drivers to each condition, but each of these groups also differed in terms of age and gender. It is possible that the sub-groups created by this procedure were uneven in terms of their spatial ability: e.g. female non-drivers aged 18-21 are likely to perform significantly better than female non-drivers aged 55 and over (or female drivers aged 55+). The experimental design employed a standard method of assigning subjects to each of the four information conditions, but perhaps the three age groups were so different that the effects of age obscured or diluted the effects of other variables. Of course, all of these possible explanations are easy to suggest with hindsight, but before the experiment was run there was no way of knowing that drivers and non-drivers, for example, would be so different in terms of their ability at the tasks. Indeed, it is quite possible that the performance of certain of the sub-groups was so poor that it skewed the data for that group as a whole. This is particularly apparent if we simply compare male and female subjects without taking into account driving experience. The poor performance of female non-drivers at all age levels certainly skewed the data for females as a group (see table 7.38 for group means). In response to these potential flaws, the second experiment (see chapter 8) only employed subjects within the age range 18-35, all of whom were drivers. In this way, it was hoped that differences between subjects would be minimised, placing the emphasis upon the information conditions. It should be noted, however, that it is as a result of having run experiment I that we are in a position to make an informed decision about focusing upon drivers and young subjects.

ii) Another possible explanation relates to the guidance information used in the experiment. The guidance used was based upon the route guidance instructions used in existing IVRGIS and it is possible that this was simply not particularly useful in the present experiment. It is possible that some subjects were simply ignoring the information and concentrating solely upon acquiring information from the visual source. Measures were taken to prevent this - subjects had to list the instructions as they heard them, and although efforts were made to reduce the potential distraction caused by this instruction listing, these may not have been totally successful. Prior to running the experiment there was a concern that this device might either add to the cognitive demands of the experiment or act as a visual distraction. However, the lack of significant differences between the control and radio groups and the route guidance groups suggests that the device was having a minimal distraction effect. The method employed for recording instructions attempted to minimise the potential for visual distraction – and subjects did not appear to have any difficulties in recording the initial letter of each piece of guidance without looking away from the films. It is possible that efforts to reduce the distraction effect were too successful - subjects were able to list the instructions but ignore what they were listing, with the consequence that the various forms of information had little impact. However, the weight of previous human factors research (see chapter 3) which contradicts this view suggests that this is unlikely. The possibility that the route guidance instructions used in experiment I were not best suited to the wayfinding task will be explored in experiment II, which will use guidance information based more directly upon the research reviewed in chapters 3 and 4, and which makes particular reference to visible features of the environment (i.e. landmarks).

iii) Alternatively, one could criticise the presentation method employed. However, whilst the method might be criticised for being too difficult for some subjects, or for being unrealistic, or for not successfully approximating the real-world experience of wayfinding and navigation, it is difficult to see how presentation mode would influence the impact of route guidance instructions. The videos provided all the information necessary to enable subjects to perform the tasks, and it is possible that as a consequence there was little incentive to attend to the additional information provided by the guidance, but this is more a flaw of the information or of the testing procedures than of the presentation mode. All subjects saw the same films, and only differed in

terms of what they heard. As a possible explanation for the lack of significant differences between the four information conditions this is not a particularly persuasive argument.

iv) A potentially more plausible explanation for the lack of significant differences between information conditions is that the testing methods were poorly suited to measuring the effects of different types of information. Perhaps it would have been possible to design tasks which specifically measured the knowledge subjects acquired from the audible information, although it is unclear how one test could have achieved this given that the four groups heard different types of information. The primary task was clearly to acquire spatial knowledge of the area, but the primary aim of the experiment was to consider the positive and negative impacts of audible information upon this process. The tasks employed certainly measured spatial knowledge acquired, but perhaps were less successful at measuring the impact of audible instructions. Indeed, the effects of information were inferred from performance of the tasks. It is also possible that the dependent variables were more suited to detecting negative impacts than positive. In an ideal situation the same individual would have been tested with and without audible guidance. This would have enabled a direct comparison of performance under both conditions. However, this was not possible in this experiment –as it would have required more than one study area, which in turn would have caused problems of comparison between performance on each area. In addition, there would have been a significant learning effect between trials.

In summary, possible explanations for the lack of significant differences between information conditions are:

- the dominant effect of age was such that it masked the effects of other variables;
- alternatively, the combinations of age, gender and driving ability that make up the subject sample may have been unequally distributed across the four information conditions resulting in a dilution of the effects of information;
- or the results can be accepted at face value with the conclusion that the audible guidance used in this experiment simply didn't have an effect upon wayfinding performance or the cognitive processes that underpin this process.

These issues will be addressed in experiment 2 by concentrating upon subjects within a smaller age range, all of whom will be drivers, and by using amended information that research discussed in chapters 3 and 4 suggests might have a more beneficial impact upon wayfinding performance.

7.6.2 Distance and time estimation

A subsidiary research issue relating to the effects of information was the potential impact that listening to guidance might have upon distance and time estimation. Although no hypothesis was proposed with regard to distance estimates, previous research into distance estimation accuracy has shown that journey distances are overestimated in the presence of additional physical barriers such as rivers, major roads or railway lines. However, there has been little research into the effect of additional auditory information upon distance estimates. In the field of time estimation, however, the dominant model of the perception and estimation of time (the attentional allocation model, discussed in chapter 3) posits that we have a finite amount of attention which has to be shared between tasks. Consequently, when carrying out a primary task which requires a lot of attention, less attention is available for the secondary task of time estimation and so estimates are likely to be less accurate.

From this theoretical position one might hypothesise that the presence of additional information would lead to inaccurate distance estimates. This was clearly not the case in this experiment, the presence of additional information did not impair distance estimating ability. A possible explanation for this finding is that the absence of an auditory stimulus enabled subjects in this group to focus all their attentional resources upon the primary task of acquiring spatial knowledge. Consequently, this group gave less attention to the estimation of journey distance. However, knowledge of route distance had been expected to be encoded as part of the information acquired about the route – this result suggests that either distance information is not encoded, or more plausibly, that in the early stages of acquiring route knowledge this aspect is very inaccurate. It is reasonable to assume that distance estimation would have become more accurate with increased familiarity, although this was not something that could be investigated within the confines of the present experiment.

Differences between the three groups were less pronounced on the time and distance estimates, for which the lower age groups were not significantly different from each other, although both

groups were significantly different from the older group. The R-Squared values for the models derived for these tasks were all particularly low, and performance on these tasks was poor generally (i.e. across the age groups). It is also possible that ability to estimate time and distance are skills that decline with less rapidity than other aspects of spatial ability: this might explain the lack of differences between the two younger groups. Alternatively, it has been argued that distance information is not stored as part of peoples' mental representations of the environment, but is instead deduced from information stored in the mental representation they have acquired of the environment (Downs and Stea, 1977). The results of the distance and time estimation tasks in the present research support this theory – subjects estimates of distance were largely inaccurate, regardless of age, driving ability or gender.

Ability to drive was a significant variable for time estimates on two of the three routes. In considering possible reasons for this finding one needs to consider the nature of driving and what skills might develop with driving experience. Driving possibly gives the individual more experience of situations where they are required to estimate journey times. In urban driving, where traffic jams are a frequent occurrence, it is more relevant and thus more usual to conceptualise a journey in terms of journey time rather than journey distance. Consequently, drivers would have more experience of estimating journey times. An alternative explanation is that driving requires drivers to be able to switch attention between various sources. This experience might result in an enhanced ability to concentrate and switch attention between separate events, as is required of subjects in the present experiment. Certainly, it is common for drivers to hold conversations with a passenger whilst simultaneously attending to driving, and perhaps this ability is enhanced with experience. Experiment I made the gross distinction between drivers and non-drivers. The possibility that driving experience enhances spatial ability generally is an issue that will be explored further in experiment II, which will focus solely upon a group of drivers. If driving ability enhances ability to acquire spatial knowledge, one would expect performance to be correlated with number of years' driving experience: experienced drivers should therefore perform better than newly qualified drivers.

7.6.3 Group differences

Summary

The results of experiment I showed that age was the most reliable predictor of performance at the various tasks. The main indicator of acquired spatial knowledge is performance of the cross

route pointing task, as this requires subjects to integrate the information acquired from the three separate routes into a configurational representation of the study area as a whole. Similarly, the map sketching task measures configurational spatial knowledge, but produces 5 variables, whereas the cross route pointing task results in a single variable, XRT_Mean, which can be compared across all subjects. Analysis of these tasks produced strong support for the hypothesis regarding the debilitating effects of age. Moreover, on the cross route pointing task the three age groups were found to be significantly different from one another, showing that there was a decline across the three age levels and the differences were not just between youngest and oldest subjects.

Effects of ageing upon landmark knowledge.

Section 4.4.3 reviewed research into ageing and its effects upon the various aspects of spatial knowledge. Landmark knowledge was characterised as recognition-in-context memory (Kirasic, 1991) which showed little decline across the lifespan, although studies (e.g. Perlmutter *et al.*, 1981) have shown that context and task complexity may have an impact upon performance and that ageing affects the encoding of certain information previously considered to be acquired automatically. The results of experiment I showed that performance of subjects at tasks measuring landmark knowledge (sequencing and single route pointing tasks) declined with age, which would appear to contradict previous research. However, it is possible that the tasks were more complex than those employed in previous work – particularly as much of this previous research (particularly Kirasic, 1991) has tended to focus on subjects familiar with a particular area. The present experiment required subjects to learn unfamiliar routes after only two exposures, and landmark knowledge was investigated in conjunction with route knowledge, which may have made this a more demanding test of landmark knowledge than simply asking subjects whether or not a landmark was present in the study area.

Effects of ageing upon route knowledge

The work of Ohta (1983) (chapter 4 section 4.3) suggested that route learning in a novel environment would pose more problems for older than younger adults because older subjects take longer to learn the relationships between landmarks and locations. The present results again support this view, with an age-related decline in performance at the sequencing and pointing tasks evident. However, whereas researchers such as Ohta and Kirasic investigated the effects of old age, the present research considered differences in the performance of subjects from 18 to

86. The results of experiment I suggest that performance of certain tasks declines from a much earlier age. Results for the sequencing task (blue, green and overall scores) showed that the three age groups were significantly different from each other, and not simply that the oldest age group were significantly different from the youngest. For the single route pointing tasks, a different pattern of significance was evident across each of the three routes (see page 234 for details of the group differences) and it is possible that differences between the three routes (e.g. route distance, complexity, quality of landmarks) account for this. Overall, results of the tasks measuring route and landmark knowledge suggest a decline in performance between each level of age.

Effects of ageing upon acquisition of configurational knowledge

Previous research (e.g., Herman and Coyne, 1980) has shown that older adults have difficulty acquiring and manipulating multiple perspectives of large-scale environments. It was hypothesised that the complex nature of the operations required to produce configurational knowledge would result in a greater age-related deficit for this aspect of spatial knowledge than either landmark or route knowledge. The present results support previous research.

Considering the results of both the single and cross route tasks together offers good support for the hypothesis that an age-related decline in working memory is responsible for the pattern of older subjects' performances. Correlation analysis run on the single and cross route tasks showed that the single route scores of this group were poorly correlated with their subsequent performance on the cross route tasks. Although older subjects generally performed comparatively poorly at all tasks, the strength of the effect on tasks measuring configurational knowledge suggests that it is the ability to combine different pieces of information acquired from separately experienced sources which caused this group most problems. This is a result which could have implications for the long term success of IVRGIS, as one of the primary target groups in the non-commercial market is elderly, affluent drivers. This result and its implications will be discussed in detail in chapter 9.

The debilitating effects of age appeared to some extent to be ameliorated by ability to drive. There also appeared to be a more pronounced beneficial effect of driving for women than for men. For the cross route pointing task, for example, the performances of male and female drivers in the 18-21 age group were significantly better than those of non-drivers. Female

drivers in the other age groups performed significantly better than their non-driving peers, but the performance of male drivers in these two age groups was comparable with male non-drivers. Although gender differences were found when the sample was considered as a whole, a consistent finding throughout experiment 1 was that, when driving ability is taken into consideration, gender-related differences are minimal and non-significant. Indeed, young female drivers performed as well as their male counterparts and better than all other groups. Chapter 4 discussed research into gender differences and suggested that gender differences have reduced over the last 30 years, partly due to changes in society's view of women, but also as a result of changes in society itself . Children of 30 years ago were raised according to a much stronger model of what constitutes typical behaviour for each gender. Nowadays, the boundaries are more blurred. In addition, changes in society have produced a climate in which parents are ever more concerned about child safety and consequently are less willing to allow their male offspring to roam and play with the same freedom that they themselves had. From this perspective it is possible to explain why young male and female drivers were comparable in their performance of tasks, whereas in older age groups they differed. If one considers driving to enhance spatial ability, and females spatial ability at certain tasks to be inferior to that of males, then driving experience might well improve the spatial ability of females more than that of males, with the consequence that female drivers' performance would be expected to be significantly better than that of female non-drivers.

In summary, age clearly has a major impact upon cognitive mapping ability, with both accuracy and quantity of spatial knowledge acquired declining with age. Whilst this effect had been predicted by reviews of previous research, the scale of the decline in cognitive mapping ability from the 18-21 year old subjects to those only a few years older was not anticipated. Drivers performed significantly better than non-drivers in all age groups, although the effect of driving ability was less apparent in the youngest and oldest age groups, where effects of age were more significant. Although analysis of variance of the main effect variables using GLM showed gender differences in cognitive mapping ability, when driving ability was taken into account, no gender differences were found.

7.7 Conclusions

i) A review of the route guidance literature suggested that subjects' cognitive mapping should be enhanced by the presence of route guidance instructions. Generally, however, the results failed to support this hypothesis, no significant differences were found between the information groups, although the interaction between the four main variables (which included information condition) was significant. A comparison of the performance of similar subjects with and without information (see table 7.38) showed that those who heard salient information performed far worse than those hearing non-salient information at the cross route pointing tasks, the main measure of cognitive mapping ability. The problem appeared to lie not in the quantity of information being provided, but in the type of information. Previous research had recommended that guidance instructions should be kept to the minimum required to enable wayfinding, so as not to distract the driver. The route guidance instructions used in phase I were directly in keeping with these findings. Clearly, these instructions did not enhance the cognitive maps of those who heard them: if anything, for some they seemed to have the opposite effect. A second phase of research was planned which would attempt to improve on the effectiveness of route guidance instructions.

ii) In order to be certain that subjects were listening to the guidance instructions, subjects in groups II and IV were asked to list the initial letters of the instructions they heard. This simple device was felt to be essential to ensure that subjects were not simply ignoring the information. The results suggest that subjects experienced few problems in coping with this additional task. The task did not require subjects to look away from the screen and so the possibility of visual distraction was minimised. However, there is the possibility that whilst not actually distracting from the primary task, the act of recording the instructions was adding to the cognitive demands of the task or interfering with subjects' concentration and attentional processes. Again, the results of experiment I appear to contradict this view, as no significant differences due to information group were apparent, but in order to be sure experiment II will include a group hearing full guidance, but with no requirement for them to respond to this information.

iii) The results of experiment I showed that there is wide variation in the cognitive mapping performance of different age and driving ability groups. However, it also showed that it

would be difficult to draw any firm conclusions regarding the quality and usability of guidance instructions with such a diverse subject sample. In particular, the results showed that the cognitive mapping performance of older adults was poor regardless of information condition, suggesting that this group experienced problems with the experiment which may have overshadowed any problems they had with different types of information. In order to enable any firm conclusions to be made regarding the effects of information, the second phase of research will need to present the various types of guidance to a far more homogenous group of subjects, in order that any differences in performance could be attributed to differences in the information rather than individual differences.

iv) It was apparent from an analysis of the data that some subjects had acquired good route knowledge but confused some of the scenes in the sequencing task test photographs. The analysis of sequencing task data showed that some subjects found difficulty in distinguishing between the last 4 photographs in the sequence, as these showed quite similar scenes. Unfortunately, this was unavoidable as the route travelled around a square. Whilst the four sides of the route around the square are actually quite distinct, many subjects found at least one of the photographs difficult to correctly sequence. On the blue route, two photographs were causing the majority of problems. Photographs 3 and 5 were along the same stretch of road and thus, it was at first thought that subjects had simply remembered the order incorrectly. However, on closer examination, there was a potential similarity between photograph number 5 and the area around photograph number 3. Photograph 5 showed a crossroads with a street sign saying "St Peter's Road". Similarly, the corner at which photograph number 3 was taken also had a street sign saying "St Peter's Road", although the scenes in each were distinctly different. Thus, it is possible that subjects who placed the photographs in this order were correct in their memory of the route, but had mistakenly believed photograph number 5 to be a view of the area at photograph 3. With regard to the green route photographs, it was surprising to find that most of the errors on this route arose from photographs 2 through to 5 which were all taken along the same road. This should have made sequencing these photographs easier in that landmarks common to the four photographs are visible in each and should give clues to the correct sequence. Clearly, some subjects were able to use this information while others were oblivious to it. It is possible that good wayfinders develop a deeper field of

vision enabling them to link upcoming features with those in the immediate visual field. Despite the problems that some subjects had with the test photographs it was decided that the second phase of the research should use the same sets so as to enable comparison of subjects' performances in both phases.

v) No significant differences were found between groups in ability to arrange the photographs the correct distance apart (distancing task). More surprising was the finding that there were no differences in performance of this task between those who had correctly sequenced the route and those who had not. This would suggest that this is not an effective measure of route knowledge acquisition. However, as stated at the beginning of this chapter, the main purpose of this task is to help subjects organise the route knowledge they have acquired. Consequently, whilst problematic, it was decided to retain this task for the second phase of the project.

8 EXPERIMENT II: USING LANDMARKS TO IMPROVE ROUTE GUIDANCE INSTRUCTIONS

8.1 Introduction

Experiment II was designed to address the third of the research questions, relating to the type of instructions used in route guidance systems. Research by Alm (1990) Alm and Berlin (1991) and Burnett *et al.*, (1994), discussed in chapter 4, highlighted the importance of landmarks to effective route guidance instructions. However, to date there has been little attempt to incorporate such findings into commercial IVRGIS which rely on instructions of the type used in experiment I. Experiment I showed there were no significant differences between the wayfinding performance (as measured by a series of tasks) of groups regardless of the route guidance instructions they listened to. The aim of experiment II is to explore the effect on cognitive maps of using route guidance instructions which incorporate specific references to landmarks visible at choice points such as turns. Based on the findings of experiment I and the previous landmark research reviewed in chapter 4 it is predicted that groups who listen to instructions making clear reference to landmarks will perform significantly better than other groups at tasks measuring configurational knowledge. This is because the reference to landmarks should strengthen memory for spatial arrangements such as the location of turns and the direction that the routes take at these turns. Formally stated:

Hypothesis 7: effects of instructions making reference to landmarks (from chapter 4)

H_1: Subjects who hear instructions containing references to visible landmarks should acquire superior spatial knowledge to those who hear information that makes no reference to landmarks.

The cross route pointing task is the most accurate and reliable measure of spatial knowledge, particularly for a sample of young subjects, as it requires subjects to integrate the information they have acquired from each individual route into a representation of the area as a whole. "Superior spatial knowledge" will therefore be measured in terms of lower mean error scores at the cross route pointing task.

In addition to investigating the potential benefit of instructions linked to visible salient landmarks, a number of problems were identified with experiment I which are addressed by experiment II. The first section of this chapter describes the amendments made to the experimental design in an attempt to address these problems (8.1.1). The experimental procedure employed for experiment II was the same as for experiment I except for the guidance

instructions heard. However, because of the change in sample composition a number of new variables were introduced, these are described in section 8.1.2. Section 8.1.3 then sets out predictions that can be made as a result of the findings of experiment I regarding the effects of information and likely group differences that might be observed in this second experiment. The final section before the results are described (section 8.1.4) gives details about the sample composition.

8.1.1 Amendments made to the experimental design for experiment II

Experiment I highlighted the significant effects of the variables age and driving ability. However, as a result of experiment I it was concluded that the strength of the effect due to these variables and the wide range of subjects' ages and driving experience may have masked the effect of information condition. Having identified that age and ability to drive were significant factors in determining participants' ability to acquire a cognitive map of the study area, experiment II focused exclusively upon drivers aged 35 and under. The groups were kept as homogeneous as possible in order that the main difference between groups would be the information they heard whilst watching the videos. Hence, experiment II involved 80 participants, aged from 18 to 35, in four groups of 20 (10 male and 10 female). All were students at Imperial College and all held a full driving licence. The recruitment procedures described in section 7.1.3 were again employed for the second experiment.

The differential performance of similar subjects across the information conditions, and the reduced accuracy evidenced by those subjects who watched the videos in the salient information conditions, led to a reappraisal of the route guidance instructions presented to subjects. It was apparent that the route guidance instructions used in experiment I, recommended by ergonomists and route guidance systems designers and discussed in chapter 3, were not in fact assisting in the development of cognitive maps. Consequently, experiment II was designed with the aim of improving the route guidance instructions used in experiment I by incorporating direct references to landmarks as suggested by research reviewed in chapter 4 section 1.

The four groups saw the same videos watched by the original four groups in experiment I. In experiment I the 6 possible orders of route presentation were tested. As no significant differences between the various possible orders were found, experiment II only used one order: Red, Blue, Green. Subjects differed only in what they heard in addition to the video footage. The four groups in experiment II were assigned to one of the following information conditions:

- I Watched the videos in silence;
- II Heard complete route guidance instructions;
- III Heard landmark information followed by directions (e.g. "At the garage, turn left");
- IV Heard directions followed by landmark information (e.g. "Turn left at the garage").

Groups III and IV therefore heard instructions linking turn information to landmarks occurring at that turn. Previous research (Alm, 1990; Alm and Berlin, 1991; Burnett, May and Ross, 1994) has pointed to the importance of landmarks in wayfinding and cognitive mapping of unfamiliar areas. Hence, these two conditions were created to test whether it is possible to strengthen the cognitive map acquired simply by making mention of the landmarks which occur in the vicinity of choice points. By linking the direction of a turn to a landmark an association is made which might otherwise have been overlooked. To check whether order of information has any effect group IV presents the same information but in the opposite order to group III. The full texts of each of these sets of instructions are listed in Appendix III.

Apart from linking directions to visible landmarks, these amended guidance instructions differed from the original instructions in two other ways. First, at the end of the red route the last two instructions are 'doubled up', i.e. they are presented in one message ("At the T-junction, turn left, then left again"). In experiment I these two instructions were presented as 2 separate messages, but it was felt that in reality they would be better presented in this doubled up form, given the proximity of the two turns. Second, since making the first videotapes, the author had taken part in some demonstration runs in a vehicle equipped with the Bosch TravelPilot route guidance system. In keeping with the instructions used by this system, a new instruction was included when the car maintained a straight-ahead course on the same stretch of road. Hence, those hearing amended instructions heard instructions such as "Continue past St. Peter's school".

8.1.2 Explanation of new variables used in the analysis of experiment II data

With the second experiment controlling for the most significant factors, between-subjects differences were not expected to be as dramatic as those in experiment I. In addition, a new variable, based on the participant's country of primary residence (i.e. where they had lived for the majority of their lives) was introduced to test the theory that previous experience of similar spatial layouts might affect one's ability to acquire spatial knowledge of a novel environment. This theory follows from Kaplan's (1973) ideas of functional adaptation (see chapter 4 section 2 for

more details) and is termed 'generic spatial knowledge'. It is possible that the three groups constructed could differ in terms of factors other than primary residence, for example, fluency in English, or cultural differences in the use of spatial language. However, the variable will be referred to as 'Nation', if differences between the groups do emerge then these possible explanations will need to be explored.

Further variables were created which were determined by subjects' performance at specific tasks. For example, a new variable 'performance' was created. This was formed from the three single route pointing tasks scores for each subject. Thus, if a subject had least error on the red route, and most error on the green route they would be assigned to performance group RBG. In this way it is possible to determine whether a subject's performance on the single route pointing tasks has any bearing on their performance on the cross route pointing task, as well as on the other measures. Note that a subject who shows the pattern GBR, whereby they scored best (i.e. had the lowest error) on the green route, followed by the blue and the red routes, could be argued to have best demonstrated learning, having improved their performance at each successive level of the experiment. In contrast, a subject whose performances are in the order RBG might be interpreted as having shown least learning, or alternatively, an inability to cope with the additional information provided on the second and third routes.

Experiment I made the gross distinction between drivers and non-drivers, whereas experiment II concentrates specifically upon drivers. Consequently, for experiment II the variable 'years' was created, based upon the number of years that each individual had held a driving licence. Three categories of driving experience were created: one year or less; between 2 and 5 years; and more than 5 years. This enabled checking of whether length of driving experience has an influence upon task performance. With regard to this variable, however, it should be noted that: a) holding a driving licence may not necessarily mean having driving experience (this was double checked by a series of questions in the questionnaire completed by participants at the end of the experiment); and b) driving experience is not the same as, and is no indicator of, driving ability.

Experiment I distinguished between three levels of age group. With this factor being controlled for in experiment II, a new age-based variable was created (age2). This variable was not used to assign subjects to groups, but was used *post-hoc* to check whether performance differences were evident in a smaller age range. Experiment I also considered the 6 different orders of presentation possible, but found no significant effect due to order of presentation. Consequently, experiment II used just one order of presentation (Red-Blue-Green) to further increase the homogeneity between

subjects. Apart from these changes the experimental design and procedure were exactly the same as that used for experiment I.

8.1.3 Hypotheses to be tested in experiment II

The results of experiment I enable the following predictions to be made regarding the expected outcomes of experiment II:

a) The effects of landmark information

The importance of landmarks to the cognitive mapping process was highlighted in chapter 4. Subjects who hear instructions which make specific reference to landmarks occurring at choice points such as junctions should acquire a more accurate representation of the route. Moreover, because a mental association has been formed between a turn and the landmark this representation should be encoded and stored more efficiently. Consequently, when the subject has to integrate the information acquired from each separate route into a configurational representation of the area as a whole (cross route pointing task) the three separate routes will be better encoded and will thus be easier to integrate. This hypothesis can be summarised thus:

Hypothesis 7: The effects of landmark information

H_1: Subjects hearing route guidance which makes reference to salient landmarks visible in the immediate vicinity of turns will perform significantly better than the control group at the cross route pointing task

b) Group differences

Age was the most significant variable in experiment I. In experiment II the age range is much lower. But the results of experiment I suggested that there were differences not just between the youngest and oldest subjects - on certain tasks, notably the pointing and sketch map tasks, the youngest group were also significantly different from the middle age group. Consequently, experiment II using a sample with a smaller age range, it is predicted that there will still be an effect due to age, with younger subjects performing significantly better at the cross route pointing task and sketch map task than older subjects. Stated formally:

Hypothesis 10: The effects of ageing

H_1: Subjects in the 18-21 age group will perform significantly better than subjects in the 22 and over age group at the tasks measuring configurational knowledge: the cross route

pointing task and the sketch map task.

Driving ability was also significant in many of the tasks in experiment I. However, experiment I only distinguished between drivers and non-drivers. Experiment II aims to extend these findings by investigating possible differences between drivers of varying levels of experience. Chapter 3 discussed Anderson's theory of the development of skill, and concluded that skills such as driving become more automated with experience. In the first year after passing the driving test it is suggested that drivers are still learning and acquiring driving skills, and as a result have little attention available to focus on developing skills such as wayfinding and navigation. Consequently, it is predicted that there will be an effect due to number of years' driving experience, with performance at the various tasks improving with driving experience. The results of experiment I showed that drivers performed better at a range of tasks. However, the main measure of spatial knowledge acquisition is the cross route pointing task, and so the following hypothesis is proposed:

Hypothesis 11: The effects of increased driving experience

H_1: Subjects who have been driving for 1 year or less will perform significantly worse at the cross route pointing task than those with more driving experience.

Finally, chapter 4 (p.81-82) discussed Kaplan's theory of generic spatial knowledge and similar work on frames, scripts and schema (Bartlett, 1932; Kaplan, 1973; Minsky, 1975; Rumelhart, 1975, Schank, 1975). The review of this research led to the hypothesis that subjects who have lived in the UK for the majority of their lives will have acquired significant experience of similar spatial layouts to that employed in these experiments and the probable features that would be expected on a typical British high street. Consequently this group will have an advantage over non-UK residents in that they will be better able to predict the likely spatial layout of the environment. This generic spatial knowledge will be reflected in their sketch maps, which should include a greater number of landmarks. However, generic knowledge will not provide subjects with information about the correct location of these landmarks and so there will be no differences between groups in the number of correctly located landmarks included in their sketch maps. The following hypothesis is proposed and will be tested in experiment II:

Hypothesis 12: The effects of primary residence location

H_1: Subjects whose primary residence has been the UK will record significantly more landmarks in their sketch maps than subjects whose primary residence is outside the

UK.

8.1.4 Sample details

Eighty subjects took part in experiment II (40 female, 40 male). All subjects were students of Imperial College. The age range of subjects was 18 to 35 (mean age = 23.25). The mean ages for the two age groups were 20 years for the 18-21 age group and 26.19 for the 22-and-over age group. The mean ages for each information group were:

- Group I 22.75 years;
- Group II 24.15 years;
- Group III 22.75 years;
- Group IV 24.4 years.

Subjects came from 22 different nations (listed in Appendix XII). Forty one (51%) subjects' primary residence was in the UK, 23 (29%) had lived most of their lives in another country in Europe and 16 (20%) had lived primarily outside Europe. Driving experience ranged from 6 months to 17 years (mean driving experience = 4.71 years).

As with experiment I the General Linear Models Procedure was used for all analysis and the Tukey procedure used for all post-hoc analysis. The following results sections are presented in the same sequence as that for experiment I: section 8.2 reports on tasks measuring single route knowledge, section 8.3 presents the results of the tasks measuring subsidiary route information (distance and time estimates) while section 8.4 reports on tasks measuring configurational spatial knowledge. Section 8.5 summarises the results and considers the original hypotheses and how they are addressed by these results. Section 8.6 discusses these results and section 8.7 presents conclusions from experiment II.

8.2 Results of tasks measuring single route knowledge

8.2.1 Sequencing task

As with experiment I, the sequencing task results in a score for each route (RScore, BScore and GScore) for each subject. Arranging the 10 photographs into their correct order gives a maximum score of 10 for each route and thus a maximum sequencing task score (OScore) of 30.

Red route sequencing task: descriptive statistics

The red route, being the most complex of the three routes, and being the first to be viewed, proved the most difficult for subjects to sequence correctly. The 80 subjects arranged the 10 photographs in a total of 23 different sequences. Of these, 23 subjects (28.75%) correctly sequenced the route (1234567890). A further 10 (12.5%) placed them in the sequence 1234578960, 9 (11.3%) placed them in the sequence 1234507869 and 8 (10%) placed them in the sequence 1234507896. The mean score for the sample as a whole was 7.56. All but 3 subjects placed the first 5 photographs in the correct sequence and it is clear from the figures that, as in experiment I, the 6th and tenth photographs were the cause of most problems. Of the 23 subjects who arranged the photographs correctly, eleven were male and 12 were female. Six were from group I, 8 from group II, 4 from group III and 5 from group IV. Thirteen were from the UK (56.5%), 10 were from Europe (43.5%). None of the 16 subjects whose primary residence was outside Europe were able to sequence the red route correctly. Given that 51% of the sample was from the UK and only 29% were from Europe this would appear to suggest a much higher rate of success for the European subjects.

Red route sequencing task: analysis of group differences

The GLM analysis of variance procedure was performed on the data to analyse group differences in ability to sequence the photographs. The model was relatively weak, but significant ($F(15,64)=2.29$, $p<0.05$ R-Square=0.350). The analysis showed that the only significant variable was country of primary residence:

- Nation $F(2,77)=3.70$, $p<0.05$
- Group*Nation $F(6,73)=4.06$, $p<0.01$

Although the interaction between information group and nation of primary residence was significant small group sizes make this finding unreliable[1]. Table 8.1 shows mean RScores for the variable 'Nation'. As can be seen from the table of means, it was surprising that this variable was significant, as the three scores are similar. Concerns over this result were confirmed when the post-hoc analysis using Tukey showed that none of the three levels of nation were significantly different from each other.

[1] The interaction between group and nation results in 12 levels with between 3 and 12 subjects in each. Clearly a sample of 3 subjects is not a reliable group from which to draw conclusions.

Table 8.1: Red route sequencing task performance by Nation

	Nation	n	Mean RScore (Max=10)	SD
1	UK	41	7.66	1.93
2	Europe	23	7.96	2.03
3	Outside Europe	16	6.75	1.06
All subjects		80		

The post-hoc analysis presented in table 8.2 shows that although the difference between the means for groups 2 and 3 approaches significance, there are no significant differences between the three groups. At first this was confusing - how could the F-test in the ANOVA produce a significance level less than the critical alpha (.05) but follow-up tests comparing levels of the factor fail to do so? Communication with the SPSS Support desk (see http://www.spss.com/newsltrs/kw/current/stat66.htm for a complete discussion of why the results of pre- and post-hoc tests don't always agree) indicated that this is a known problem associated with the F-test, and is almost certainly attributable to sampling error:

> "...the results of significance tests using sample data frequently produce logical contradictions.....the reason such contradictory results can occur is that when we make inferences about population parameters (such as population means) using sample data, our estimates are subject to sampling error. If we dealt with the entireties of finite populations, we could compute the mean or other parameter(s) of interest in each population and then compare results. There would be no sampling error and no need for measures of precision of estimation (such as standard errors)."
>
> SPSS (1998), p.2

The author goes on to conclude:

> "We cannot generally avoid the problem since we cannot identify finite populations of interest and measure all members of populations. We can understand the true nature of the problem and accept its implications. One implication is the problem will always be with us in standard situations. Another implication is that we can minimise the problem by using larger sample sizes for more precision and reduced confusion."
>
> SPSS (1998), p.3

From this it is clear that the only real remedy for the problem caused by logical inconsistencies is to expand the sample size. For this reason all results which display this inconsistency between the ANOVA and post-hoc analysis will be assumed to be non-significant to minimise the possibility of making Type II errors, but it is felt that given the relatively small sample sizes

it is better to err on the side of caution, than to make inferences about the general population, that cannot be substantiated.

The post-hoc analysis presented in table 8.2 shows that although the difference between the means for groups 2 and 3 approaches significance, there are no significant differences between the three groups.

Table 8.2: Post hoc analysis of differences between t scores (RScore) for variable Nation

Comparison Between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance (p<0.05 indicated by ***)
1 - 2	-1.337	-0.298	0.741	0.771
1 - 3	-0.267	0.908	2.084	0.160
2 - 1	-0.741	0.298	1.337	0.771
2 - 3	-0.914	1.206	2.504	0.074
3 - 1	-2.084	-0.908	0.267	0.160
3 - 2	-2.504	-1.206	0.914	0.074

Blue route sequencing task: descriptive statistics

The blue route is the least complex of the three routes and subjects arranged the 10 photographs in only 14 different sequences. Forty four subjects (55%) correctly sequenced the blue route. A further 15 subjects (19%) placed the photographs in the sequence 1253467890. The mean score for the sample as a whole was 8.45. Of those who correctly sequenced the photographs, 26 (59%) were female and 18 (41%) male, 25 were from the UK (57%), 11 (25%) were from Europe and 8 (10%) were from the rest of the world. In terms of information group the group distribution was 13 from group I, 10 from group II, 13 from group III and 8 from group IV.

Blue route sequencing task: analysis of group differences

The analysis of variance model created to analyse the blue route sequencing task data was similar to that for the red route ($F(15,64)=2.26$, $p<0.05$. R-Square=0.347). The GLM showed that the following variable was the only one to have a significant effect upon performance of the blue route sequencing task:

- Years $F(2,77)=4.96$, $p<0.05$,

Table 8.3 shows that the mean score for the group of subjects with more than 1 years' driving experience was higher on the blue route sequencing task than the equivalent group mean for the other two groups.

Table 8.3: Blue route sequencing task performance by years of driving experience

Driving experience group	N	Actual BScore (Max =10)	S.D.
1 year or less	13	7.62	1.85
More than 1yr less than 5 yrs	42	9.14	1.49
More than 5 years	25	7.72	2.19

Post-hoc analysis using the Tukey procedure was again run to establish which of the driving experience groups were significantly different. The results of this analysis are shown in table 8.4.

Table 8.4: Post-hoc analysis of variable Years showing differences between means (BScore)

Comparison Between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance (p<0.05indicated by ***)
1 - 2	-2.837	-1.527	-0.217	***
1 - 3	-1.516	-0.105	1.307	
2 - 1	0.217	1.527	2.837	***
2 - 3	0.380	1.423	2.465	***
3 - 1	-1.307	0.105	1.516	
3 - 2	-2.465	-1.423	-0.380	***

Table 8.4 shows that the mean performance at the blue route sequencing task of subjects with between 1 and 5 years' driving experience was significantly different from that of those with less or more driving experience. This result suggests that driving experience improves sequencing task ability up to a certain point, after which age of subject also has an effect, and outweighs the benefit derived from driving. However, these are only tentative suggestions at this stage. This was the only significant variable for the blue route sequencing task.

Green route sequencing task: descriptive statistics

The green route, being the final route to be seen, is in some ways the best indicator of subjects' ability to acquire route knowledge from the videos, in that subjects are now fully familiar with the task requirements. However, by this stage they have also experienced two other routes and so are having to retain a large amount of information. Subjects placed the ten photographs in a total of 17 sequences. None of the sequences other than the correct one was recorded by more than 2 subjects. 63 subjects (79%) correctly sequenced the green route. Of these, 32 were male, 31 were female. The mean for the sample as a whole was 8.725. Of the three routes this was the highest mean sequencing task score. Distribution across the information groups was 14 from group I, 16 from group II, 17 from group III and 16 from group IV. Thirty one (49%) were from the UK, 20 (32%) were from Europe and 12 (19%) were from the rest of the world.

Green route sequencing task: analysis of group differences

The GLM showed no significant differences for any of the main independent variables (age, sex, information group or country of primary residence). The model derived for this route was particularly weak and non-significant ($F(15,64)=0.65$, $p<0.822$. R-Square=0.133) and is partially due to the fact that 79% of the sample correctly sequenced the route. It is possible that this high success rate is due to the low age of the subjects, unlike the sample in experiment I none of this group are limited in their ability by age-related reductions in working memory capacity. Consequently, the group may have been able to use knowledge they had acquired from the first two routes to help organise the information being acquired from this route. It is also apparent that information condition was not significant on any of the three routes, which again could be due to the high scores across the three tasks.

All routes: analysis of group differences

The three individual sequencing scores are summed to create a fourth variable - OScore. The GLM analysis showed that none of the main variables were significant. The model for OScore was weak and non-significant ($F(15,64)=1.69$, $p<0.08$, R-Square=0.284). The interaction between group and nation was significant ($F(6,73)=3.24$, $p<0.01$). The table of means produced by GLM showed that sub-group means ranged from 22.00 to 28.00. However, the number of subjects within each group ranged from 3 to 12 and so these figures are not reliable. Consequently, details of the group means are not reported.

Overall, the scores for the sequencing tasks were particularly high, even taking into account the younger age of subjects and the fact that they were all drivers. Although there were few significant differences between the various groups the mean scores for the sample as a whole show a definite improvement from route to route (Red 7.56 Blue 8.45 Green 8.725). This improvement was not evident in experiment I, partly because of the sample composition, but also because subjects were exposed to one of 6 different orders of presentation instead of the one order used in experiment II.

8.2.2 Distancing task

As in experiment I, the distancing task produces an error score for each route (d_err_R, d_err_B and d_err_G) which represents the total deviation from the correct positions of each of the ten photographs on the route. Subjects who arranged the ten photographs into an incorrect sequence were excluded from this analysis as their estimates of inter-scene distance referred to the wrong

photographs. This produced data sets of 23 subjects for the red route, 44 subjects for the blue route and 63 for the green route. No significant effects were found for any of the main independent variables for either the red or the blue routes (perhaps due to the small sample sizes). However, the model for the green route was significant ($F(19,43)=2.17$, $p<0.01$, R-Square=0.489) A significant effect was found for the variable 'group' ($F(3,62)=3.56$, $p<0.05$).

Table 8.5 shows the mean total error for each group performing the distancing task on the green route. The figures in columns 3 and 4 of Table 8.5 therefore represent the total squared error where the ratio scaled route length is 1.000. The figures in columns 5 and 6 suggest that those subjects who saw the video accompanied by full route guidance instructions (Group II) were less accurate than the other groups in their positioning of the scenes along the route. However, post hoc analysis was run on the data to check which of the four information conditions were significantly different. This analysis is shown in table 8.6.

Table 8.5: Distancing error scores (Green route) by group

Group	N	Mean Distancing Error (Total for green route)	Standard deviation	Actual error (Metres)	Standard Deviation (Metres)
I	14	0.05062	0.06258	146.24	162.61
II	16	0.11214	0.11874	217.67	223.98
III	17	0.04398	0.03668	136.32	124.50
IV	16	0.07885	0.05504	182.52	152.49

This table shows that mean distancing scores for only two groups were significantly different from one another, these were the full route guidance condition and the "Landmarks followed by directions" amended guidance condition. It is interesting that these two groups should be significantly different. The full guidance condition makes clear reference to distances to turns and contains the most detailed information. As such we might have expected this group to be significantly different from the control group, who heard nothing. However, the fact that this was not the case suggests that the difference is not related to quantity of information, but rather type of information.

Table 8.6: Post-hoc analysis of distancing task data for "Information Group"

Group comparison	Lower simultaneous confidence limit	Difference between means	Upper simultaneous confidence limit	Significance ($p<0.05$ indicated by ***)
2 – 4	-0.030	0.033	0.096	
2 – 1	-0.003	0.061	0.127	
2 – 3	0.006	0.068	0.130	***
4 – 2	-0.096	-0.033	0.030	
4 – 1	-0.037	0.028	0.093	
4 – 3	-0.027	0.035	0.097	
1 – 2	-0.127	-0.061	0.003	
1 – 4	-0.093	-0.028	0.037	
1 – 3	-0.058	0.007	0.071	
3 – 2	-0.130	-0.068	-0.006	***
3 – 4	-0.097	-0.035	0.027	
3 – 1	-0.071	-0.007	0.058	

8.2.3 Single route pointing tasks

Red route

The single route pointing task for the red route produced the following results. Subjects' mean error scores ranged from 8 degrees (female aged 21 with 3.5 years' driving experience, whose primary residence was in the UK) to 104 degrees (female aged 22 with 3 years' driving experience and whose primary residence was outside Europe). The mean error for all 80 subjects was 42.38 degrees. The model produced using GLM showed that none of the 5 main independent variables (age, sex, group, nation and years) were significant.

Blue route

The single route pointing task for the blue route produced mean error scores ranging from 7.5 degrees (male aged 30 with 12 years' driving experience, whose primary residence was in Europe) to 116.2 degrees (male aged 19 with 1.5 years' driving experience, whose primary residence was in the UK). The mean error score was 39.17 degrees for all subjects. The model produced using GLM was weak and not significant ($F(15,64)=1.53$, $p<0.13$, R-Square=0.263). Of the 5 independent variables, only years was significant: $F(2,77)=3.53$, $p<0.05$.

Table 8.7: Mean error scores by variable Years for the blue route pointing task

Level of Years	N	Blue route mean error	Standard deviation
1 (1 year or less)	13	48.11	34.41
2 (2 to 5 years)	42	39.29	18.85
3 (6 years+)	25	34.31	16.11

As can be seen from Table 8.7, with relatively small increases in driving experience subjects' mean error scores for the blue route decrease significantly. The standard deviation also drops dramatically, showing an increase in homogeneity in the group. Post-hoc analysis using Tukey was carried out on the data to determine which of the three levels of 'years' were significantly different from one another. The results of this analysis are shown in table 8.8.

Table 8.8 shows that only the blue route sequencing task scores of the least and most experienced groups can be considered to be significantly different from each other.

Table 8.8: Post hoc analysis of variable Years for the blue route pointing task

Comparison between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance (p<0.05 indicated by ***)
1 - 2	-6.280	8.825	23.930	
1 - 3	-2.472	13.802	30.076	***
2 - 1	-23.930	-8.825	6.280	
2 - 3	-7.045	4.977	16.999	
3 - 1	-30.076	-13.802	2.472	***
3 - 2	-16.999	-4.977	7.045	

Green route

Error scores for the green route ranged from 10.5 degrees (male aged 21 with 3 years' driving experience, whose primary residence was the UK) to 100 degrees (male aged 29 with 3 years' driving experience, whose primary residence was outside Europe). The mean score for the 80 subjects was 42.22 degrees. The model produced using the GLM procedure was significant but weak ($F(15,64)=2.21$, $p<0.05$, R-Square=0.341) Three of the five main independent variables were found to be significant:

- Age2 $F(1,78) = 5.33, p<0.05$
- Group $F(3,76) = 3.27, p<0.05$
- Years $F(2,77) = 3.97, p<0.05$

The following tables show these effects.

Table 8.9: Mean error scores for the green route pointing task by age group

Age2	N	Green mean error	Standard deviation
18-21	38	41.08	27.74
22 or older	42	43.25	27.55

Table 8.9 shows a slight difference between the two age groups, with younger subjects being marginally more accurate than older subjects. However, post-hoc analysis failed to show any significant difference between the two groups, which is more likely given the small difference between the means. Table 8.10 shows large differences in means between the four information conditions in their effect upon performance of the green route pointing task. What is most unusual about this data is the difference between groups III and IV. Although group III receive the same information as group IV, only reversed, the mean error for group III is almost twice that of group IV. Post-hoc analysis using the Tukey procedure was run on this data to determine which of the four levels were significantly different.

Table 8.10: Mean error scores for the green route pointing task by information group

	Level of Group	N	Green route mean error	Standard deviation
I	Video only	20	46.03	29.10
II	Route guidance	20	40.21	28.11
III	Landmarks/directions	20	54.88	30.14
IV	Directions/Landmarks	20	27.78	13.72

This analysis is presented in table 8.11 which shows that only groups 3 and 4 can be considered to be significantly different from each other, and that neither can be considered significantly different from the control group.

Table 8.11: Post-hoc analysis of green route pointing task data for "Information Group"

Group comparison	Lower simultaneous confidence limit	Difference between means	Upper simultaneous confidence limit	Significance ($p<0.05$)
1 – 2	-14.85	5.82	26.51	0.879
1 – 3	-29.53	-8.85	11.83	0.673
1 – 4	-2.43	18.25	38.94	0.102
2 – 1	-26.51	-5.82	14.85	0.879
2 – 3	-35.35	-14.67	6.00	0.250
2 – 4	-8.25	12.43	33.11	0.394
3 – 1	-11.83	8.85	29.53	0.673
3 – 2	-6.00	14.67	35.35	0.250
3 – 4	6.42	27.10	47.78	***
4 – 1	-38.94	-18.25	2.42	0.102
4 – 2	-33.11	-12.43	8.25	0.394
4 – 3	47.78	-27.10	-6.42	***

Table 8.12 shows the mean scores for each of the three levels of driving experience and shows that those subjects who had been driving for more than 5 years were more accurate at this pointing

task than those whose driving experience was limited to 5 years or less. Post-hoc analysis using the Tukey procedure (table 8.13) shows that only the two more experienced driving groups can be considered to be significantly different from one another.

Table 8.12: Mean pointing error scores for the green route by years

Level of years (Since passing driving test)	N	Green route mean error score	Standard deviation
1 (1 year or less)	13	40.06	26.57
2 (2-5 years)	42	48.50	30.03
3 (6 years +)	25	32.79	20.72

It is interesting that the majority of group differences only emerge on the final route. The sample of 80 subjects were purposefully kept as homogeneous as possible. Consequently, it is possible that differences in cognitive mapping ability might only appear when subjects have been exposed to a large amount of information: when working memory is required to hold all the information from the previous routes, whilst acquiring new information from the final route.

Table 8.13: Post-hoc analysis of 'Years' (Green route pointing task)

Comparison between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$ indicated by ***)
1 - 2	-26.212	-8.444	9.324	
1 - 3	-11.874	7.268	26.411	
2 - 1	-9.324	8.444	26.212	
2 - 3	1.571	15.712	29.853	***
3 - 1	-26.411	-7.268	11.874	
3 - 2	-29.853	-15.712	-1.571	***

8.3 Results of tasks measuring subsidiary route information

8.3.1 Distance estimation

The increased homogeneity of the sample of subjects who took part in experiment II would lead one to assume that distance estimates would not vary to the extent they had in experiment I. Whilst this was the case, the range was still surprising. Between-subject variation was quite dramatic, but there was little within-subjects variation apparent. Subjects giving a low estimate for the red route distance gave comparably lower estimates for the other two routes. Those who gave very high estimates for the red route, gave similarly high estimates for each of the other two routes. Consequently, less emphasis was placed upon accuracy than with recognition of the order

of distances: that the red route was longer than the green route which in turn was longer than the blue route. The distribution of distance estimates for the red, blue and green routes for the experiment II sample as a whole are shown in figures 8.1, 8.2 and 8.3 respectively.

Red route distance estimation

The actual distance of the red route was 800 metres. Subjects' estimates for the red route distance ranged from 200 metres to 3500 metres. The mean distance estimate for all subjects was 1217 metres. The GLM model produced was non-significant ($F21,58)=1.27$, $p<0.25$, R-Square=0.315). None of the independent variables used in the analysis of variance approached statistical significance.

Blue route distance estimation

The actual distance of the blue route was 600 metres. Subjects' estimates for the blue route ranged from 180 metres to 2500 metres. The mean distance estimate for all subjects was 1060 metres. Of the independent variables used in the analysis of variance only one was statistically significant:

- Information Group $F(3,76)=2.79$, $p<0.05$.

Means for each group are shown in Table 8.14.

Table 8.14: Mean distance estimates for the blue route by information group.

Group	Information Condition	Mean distance estimate Blue route(Metres)	Standard deviation (Metres)
I	No information	950.00	483.09
II	Full guidance	879.50	449.04
III	Landmarks-Directions	1314.75	609.45
IV	Directions-Landmarks	1097.50	599.86

To determine which of the four groups are significantly different, post-hoc analysis was carried out. The results of this analysis are shown in table 8.15 below, which shows that although the difference between the group means for groups 2 and 3 is very close to reaching significance ($p=0.06$) the groups cannot be considered to be significantly different from each other. The table also confirms that none of the groups can be considered to be significantly different from the control group.

Table 8.15: Post-hoc analysis of blue route distance estimates for "Information Group"

Group comparison	Lower simultaneous confidence limit	Difference between means	Upper simultaneous confidence limit	Significance ($p<0.05$)
1 – 2	-379.49	70.50	520.49	0.976
1 – 3	-814.74	-364.75	85.24	0.152
1 – 4	-597.49	-147.50	302.49	0.822
2 – 1	-520.49	-70.50	379.49	0.976
2 – 3	-885.24	-435.25	14.74	0.061
2 – 4	-667.99	-218.00	231.99	0.578
3 – 1	-85.24	364.75	814.74	0.152
3 – 2	-14.74	435.25	885.24	0.061
3 – 4	-232.74	217.25	667.24	0.581
4 – 1	-302.49	147.50	597.49	0.822
4 – 2	-231.99	218.00	667.99	0.578
4 – 3	-667.24	217.25	232.74	0.581

Although the results are not significant, it is worthwhile to briefly explain what might have accounted for the results. The full guidance condition contains information about the distance to turns, e.g. "50 metres to left turn" which may have assisted subjects in estimating distances. Post-experiment group discussions regarding the strategies used to tackle the various tasks revealed that some subjects had tried to remember and count up the number of times they heard distance information, from which they estimated the total journey length. This may have helped some subjects, although it also lead others to make overestimates. However, in addition to the relatively accurate estimates of group II, table 8.14 also shows that subjects in group III were far more inaccurate in their distance estimates than subjects in the other groups. It should also be noted that the standard deviations for these groups are all high, showing that there was quite a wide range in the estimates.

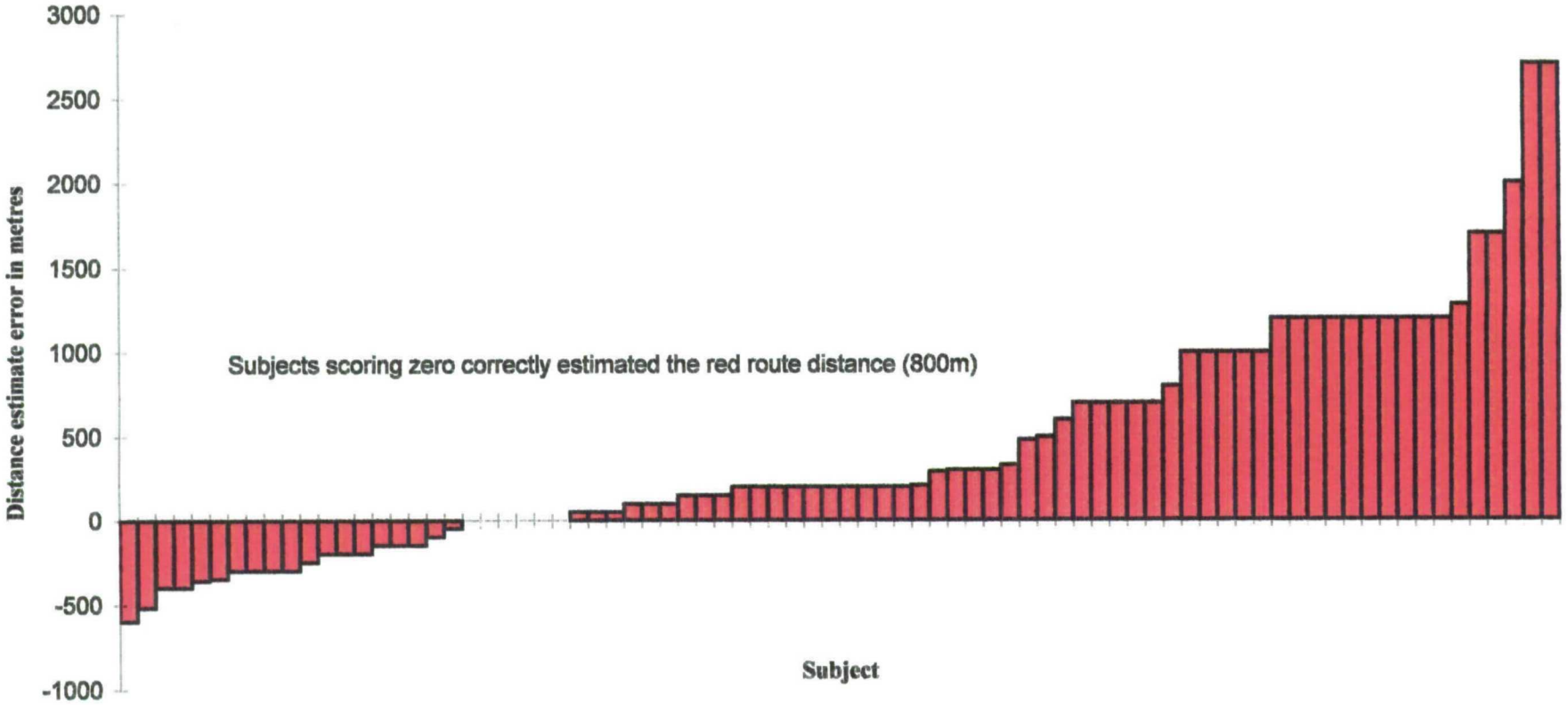


Figure 8.1: Distance estimate error distribution for the red route

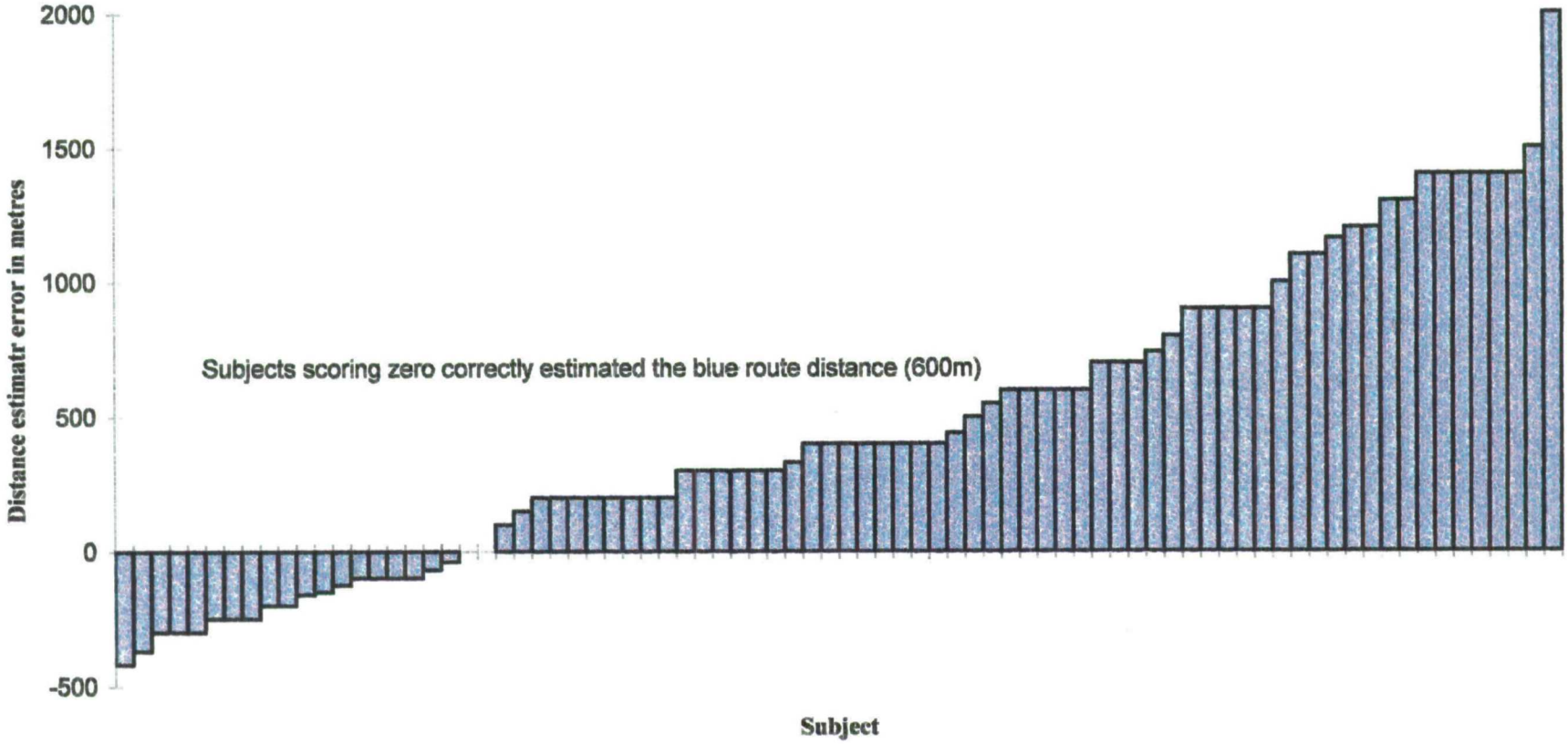


Figure 8.2: Distance estimate error distribution for the blue route

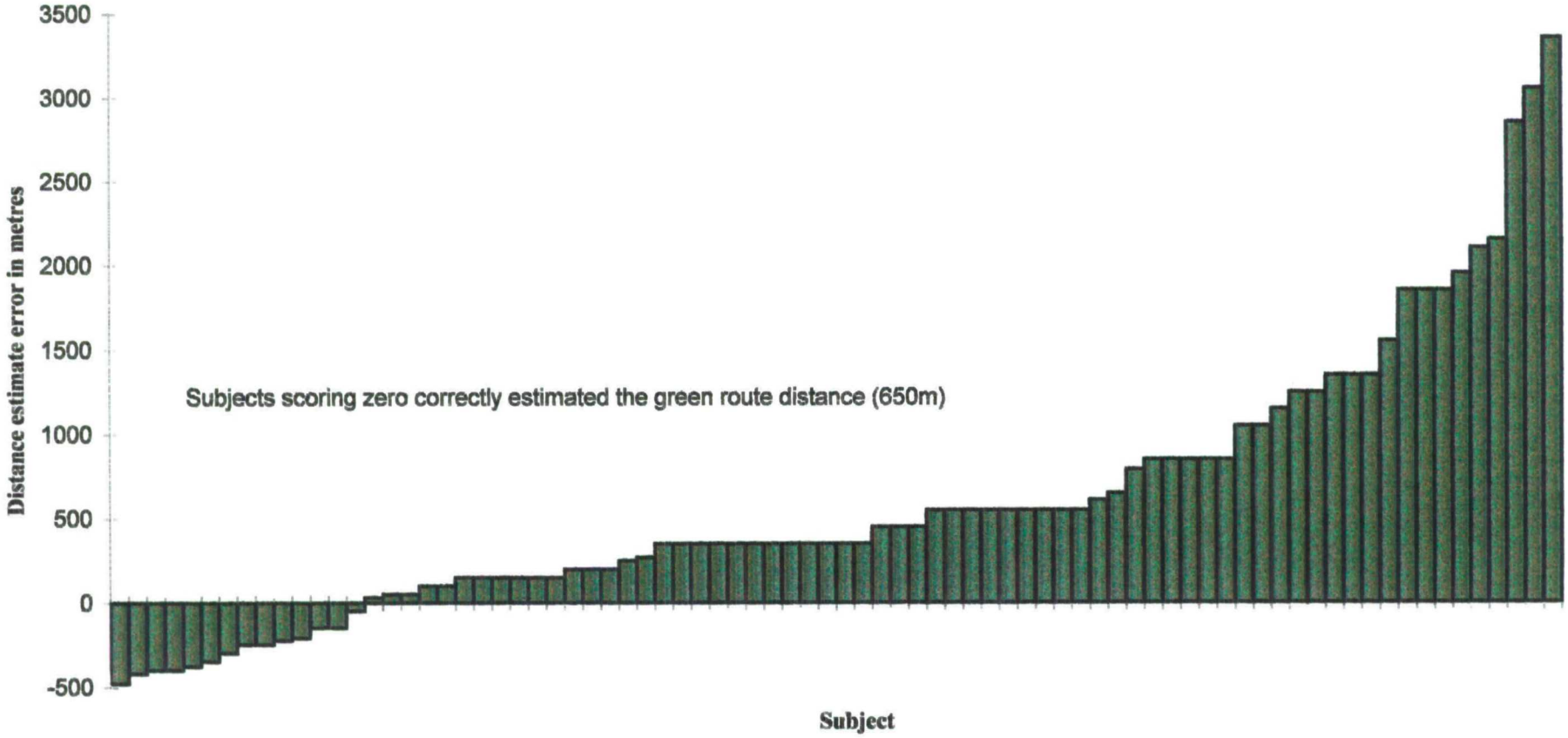


Figure 8.3: Distance estimate error distribution for the green route

Green route distance estimation

The actual distance of the green route was 650 metres. Subjects' estimates for the green route ranged from 170 metres to 4000 metres. The mean distance estimate for all subjects was 1226 metres. None of the independent variables used in the analysis of variance approached statistical significance.

Determining the sequence of distances

As in experiment I, a new variable, 'dist-seq', was created to analyse subjects' ability to determine the order of distances: that the red route was the longest followed by the green route and the blue route. Analysis of this variable showed that only 14 subjects (17.5%) were able to determine this sequence. Twenty-six subjects (32.5%) estimated two of the routes to be equal in length. Table 8.16 shows the figures for each possible sequence order. The table also shows that only 32.5% of the sample determined the red route to be the longest. These figures are actually lower than those for experiment I, in which nearly 29% of all subjects determined the correct sequence and 42% estimated the red route as longest.

Table 8.16: Frequency of each possible order of distance estimates

Order of distance estimates	Number of subjects placing routes in this order	Percentage	Cumulative frequency	Cumulative percent
R>G>B	14	17.5	14	17.5
R>B>G	12	15.0	26	32.5
G>R>B	14	17.5	40	50.0
G>B>R	4	5.0	44	55.0
B>R>G	6	7.5	50	62.5
B>G>R	4	5.0	54	67.5
R=B	4	5.0	58	72.5
R=G	12	15.0	70	87.5
B=G	10	12.5	80	100.0

In order to check whether an individuals' distance estimates for one route correlated with those for the other two routes, correlation coefficients were calculated for each route. The same 4 types of coefficient were calculated as in experiment I. All correlations were positive and highly significant ($p<0.001$), confirming the findings of experiment I, that participants' estimates of journey distance for one route are correlated with the estimates they gave for the other two routes.

Correlation coefficients were also calculated for accuracy of distance estimates against (single and cross route) pointing task accuracy. The results of this analysis showed that none of the correlations were significant at or below the 5% level. This is in sharp contrast to the first experiment in which the two measures were highly correlated. The difference in the composition of the two samples (in particular the removal of older subjects and non-drivers) probably accounts for this.

8.3.2 Estimates of Journey time

Journey time estimates were made for both versions of each route. Consequently, six time estimates are recorded for each subject. As with the distance estimates, the most striking aspect of these results is the wide variation between subjects in their estimates. Given the increased homogeneity of the groups it is surprising that subjects asked to estimate an actual time of just over 5 minutes made estimates ranging from 3 minutes to 20 minutes. For all three routes subjects tended towards overestimation. Figures 8.4, 8.5 and 8.6 show the distribution of time estimates for the red, blue and green routes respectively. The following sections consider each route individually to test if any of the independent variables has an effect upon journey time estimates.

Red route journey time estimates

Actual travel times for the red route are 302 seconds for the route film and 406 seconds for the landmark film. Subjects' estimates of these times ranged from 180 seconds to 1200 seconds for the route film and from 170 seconds to 2100 seconds for the landmark film. The mean estimates (all subjects) for the two versions were 417 and 515 seconds respectively. Analysis of variance (GLM procedure) showed that none of the independent variables approached significance for the route film. The model produced for the red route landmark film was significant ($F(21,58)=3.735$ $p<0.005$, R-Square=0.638) and the variables information group and nation were both significant.

- Group $F(3,76)=8.080$, $p<0.001$
- Nation $F(2,77)=4.331$, $p<0.05$

Table 8.17 shows the group means for the four Information groups, while table 8.18 shows the post-hoc analysis for the variable using the Tukey procedure.

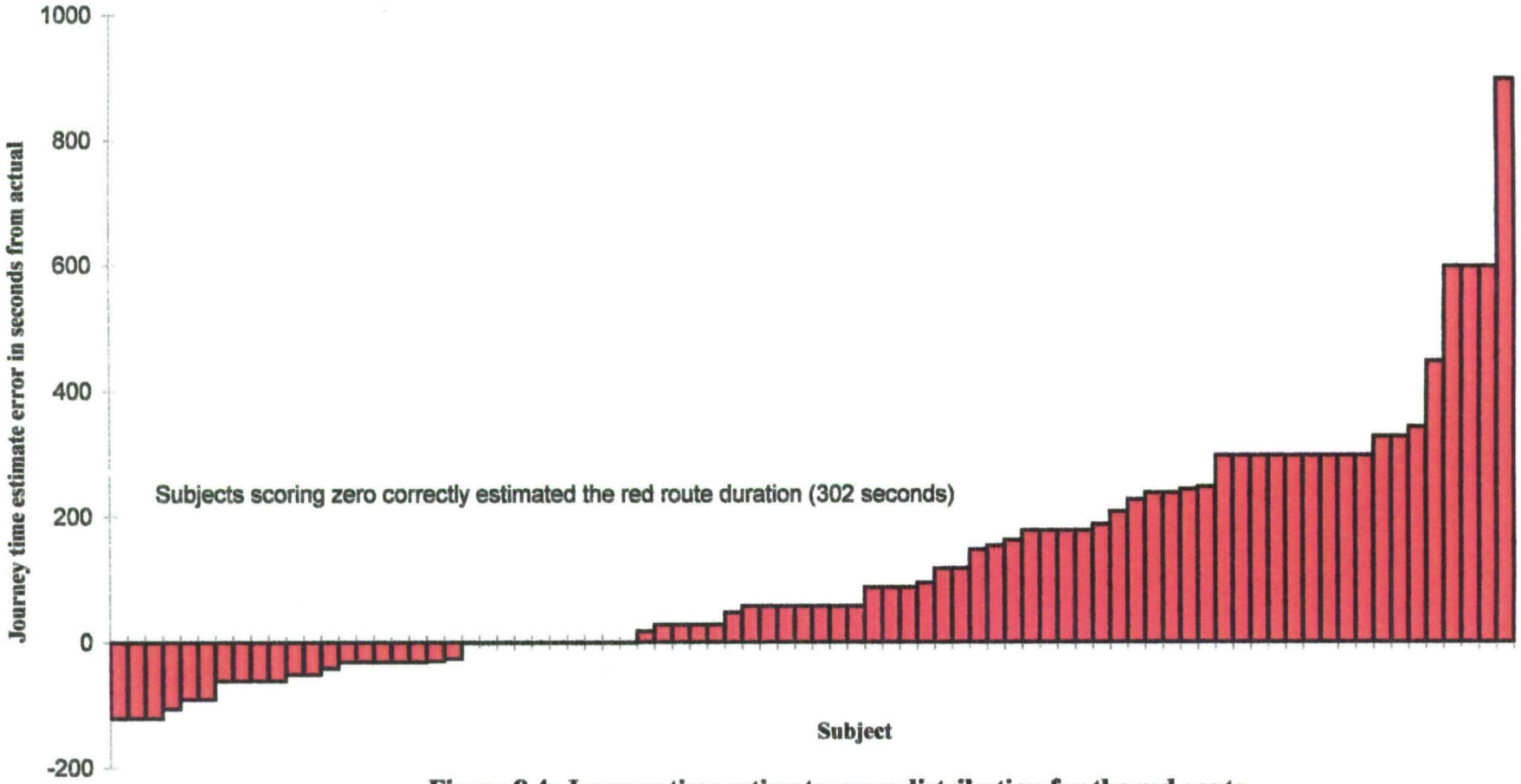


Figure 8.4: Journey time estimate error distribution for the red route

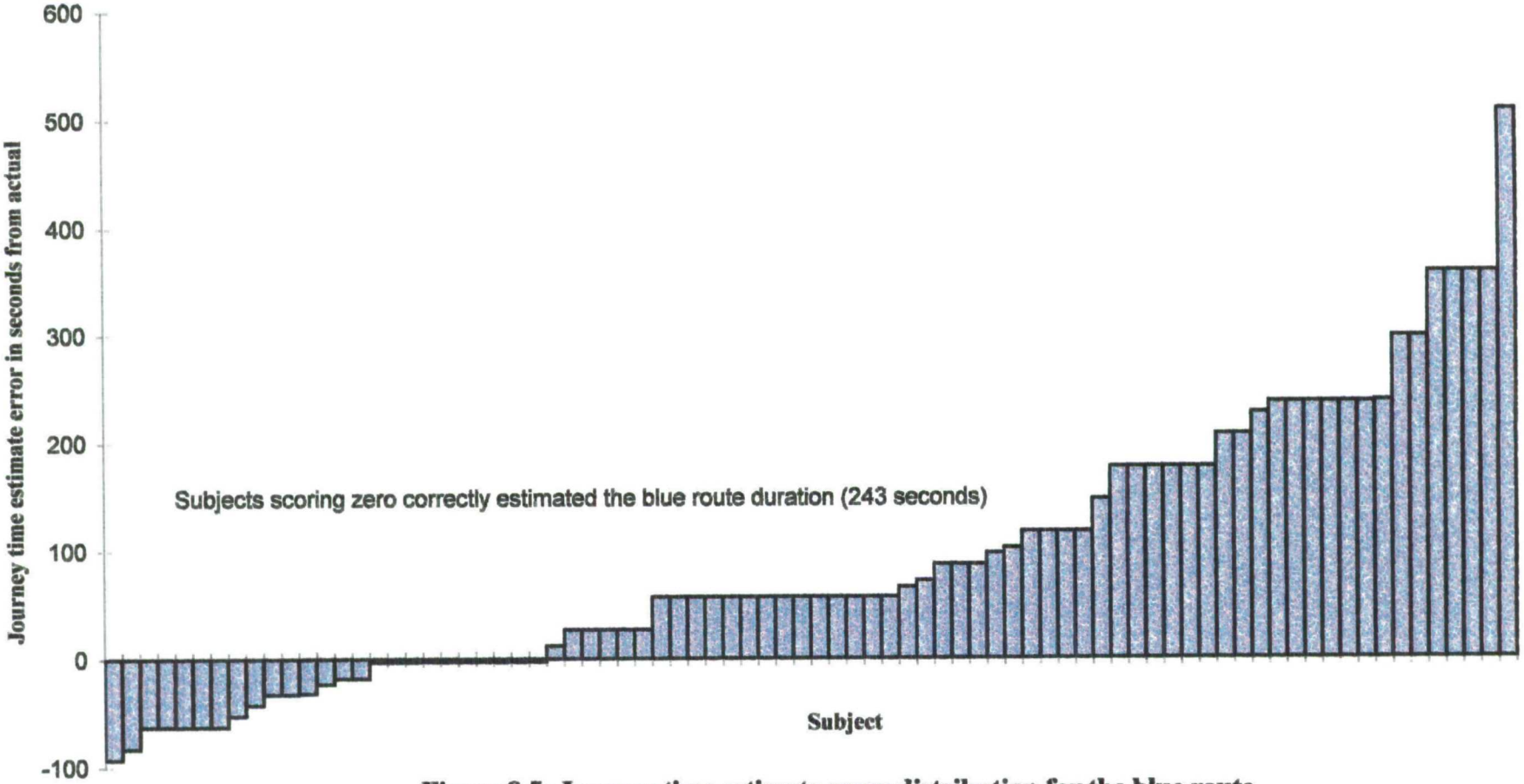


Figure 8.5: Journey time estimate error distribution for the blue route

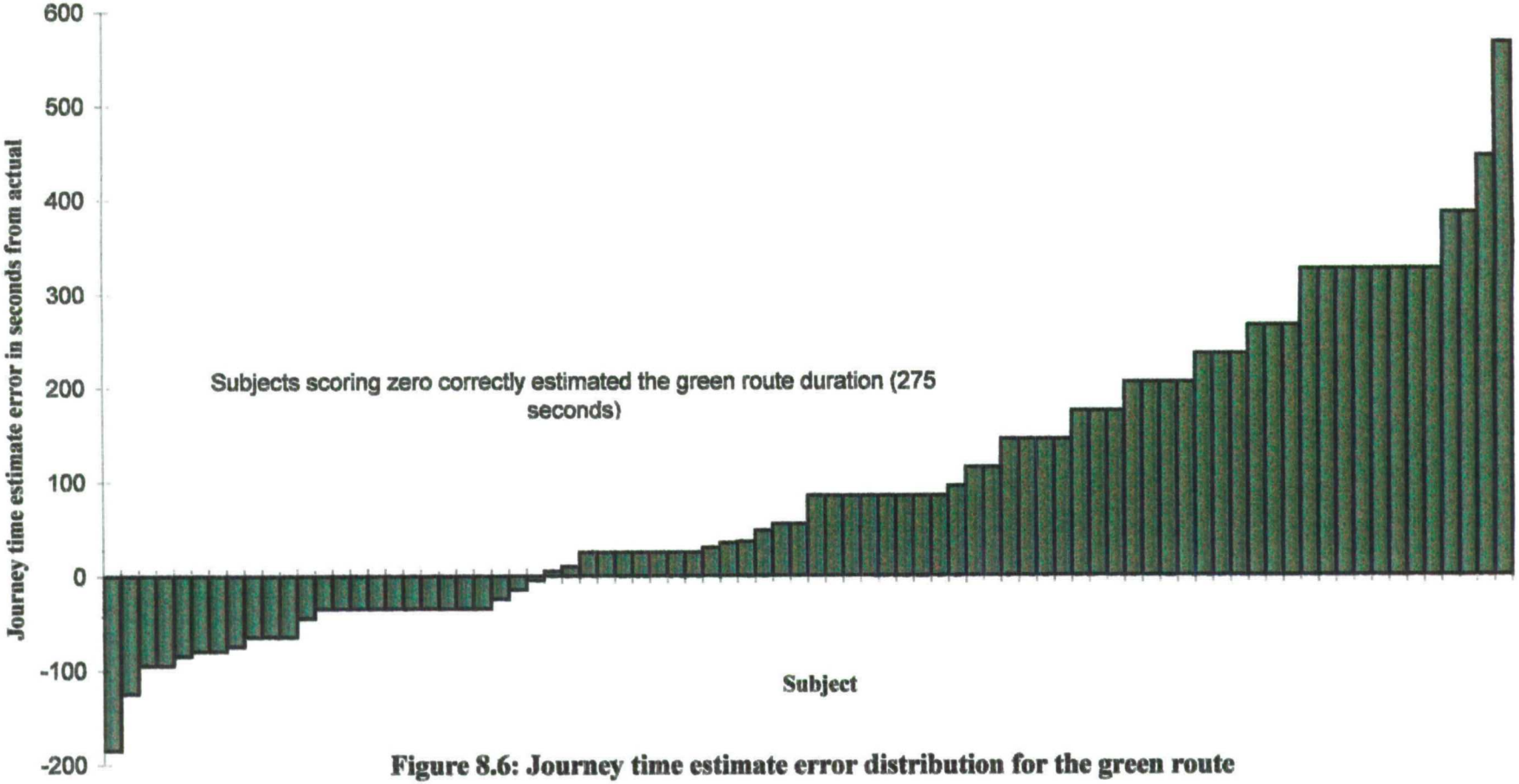


Figure 8.6: Journey time estimate error distribution for the green route

Table 8.17: Mean journey time estimates (Information group) for red route landmark film

Group	Information condition	N	Mean (Secs.)	Standard deviation
I	No information (Control)	20	417.18	161.89
II	Full guidance	20	660.00	433.70
III	Landmarks-directions	20	473.80	190.75
IV	Directions-landmarks	20	490.87	187.18

Table 8.18: Post-hoc analysis of time estimates (Information) for red route landmark film

Group comparison	Lower simultaneous confidence limit	Difference between means	Upper simultaneous confidence limit	Significance ($p<0.05$ indicated by ***)
1 – 2	-345.86	-204.15	-62.44	***
1 – 3	-193.71	-52.00	89.71	.750
1 – 4	-206.21	-64.50	77.21	.606
2 – 1	62.44	204.15	345.86	***
2 – 3	10.44	152.15	293.86	***
2 – 4	-2.065	139.65	281.36	.055
3 – 1	-89.71	52.00	193.71	.750
3 – 2	-293.86	-152.15	-10.43	***
3 – 4	-154.21	-12.50	129.21	. 995
4 – 1	-77.21	64.50	206.21	.606
4 – 2	-281.36	-139.65	2.065	.055
4 – 3	-129.21	12.50	154.21	.995

Table 8.18 shows that the red route time estimates (landmark film) for subjects who heard full route guidance instructions can be considered to be significantly different from the control group and from the group who heard landmarks followed by directions. This is an interesting result because this group had the lowest (and most accurate) group mean distance estimates for the blue route (and it was suggested that this was due to the presence of information about distances, but for time estimates the group mean is significantly higher than the other groups. It is possible that the same distance information had a detrimental effect upon time estimates.

Table 8.19 shows the group means for the red route landmark film for the variable nation, while table 8.20 shows the post-hoc analysis for this result, which this time uses the Tukey procedure.

Table 8.19: Mean journey time estimates by Nation for red route landmark film

	Group	N	Mean (Metres)	Standard deviation (Metres)
1	UK	41	423.55	177.52
2	Europe	23	532.97	372.59
3	Rest of world	16	625.85	254.17

Table 8.20: Post-hoc analysis of time estimates by Nation for red route landmark film

Comparison Between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance (p<0.05 indicated by ***)
1 - 2	-269.98	-108.03	53.92	
1 - 3	-405.33	-222.09	-38.85	***
2 - 1	-53.92	108.03	269.98	
2 - 3	-316.43	-114.06	88.31	
3 - 1	38.85	222.09	405.33	***
3 - 2	-88.31	114.06	316.43	

Table 8.20 shows that the time estimates for UK residents and those whose primary residence was outside Europe can be considered to be significantly different from one another, but neither are significantly different from the Europe group. In other words, there were no differences between British and European subjects in their time estimating ability, but British subjects were more accurate than those whose primary residence was outside Europe.

Blue route journey time estimates

The actual times taken to travel the blue route are 243 seconds for the route film and 313 seconds for the landmark film. Subjects' estimates of these times ranged from 150 seconds to 750 seconds for the route film and from 190 seconds to 920 seconds for the landmark film. The mean estimates for the two versions were 335 and 408 seconds respectively. There were no significant differences for the route film, but the model produced for the landmark film by GLM was significant ($F(21,58)=1.98$, $p<0.05$, R-Square=0.417) and showed that the following variables reached significance:

- Information Group $F(3,76)=3.17$, $p<0.05$
- Primary residence $F(2,77)=3.40$, $p<0.05$.

Table 8.21 shows the group means for the variable Information group. Table 8.22 shows the post-hoc analysis for this variable.

Table 8.21: Journey time estimates for the blue route by Information group

Group	n	Blue route mean Journey Time estimate (Landmark film)	Standard deviation
I	20	332.30	128.53
II	20	486.67	200.49
III	20	408.51	147.85
IV	20	427.00	158.86

Table 8.22: Post-hoc analysis of time estimates (Information) for blue route landmark film

Group comparison	Lower simultaneous confidence limit	Difference between means	Upper simultaneous confidence limit	Significance ($p<0.05$ indicated by ***)
1 – 2	-250.94	-138.70	-26.46	***
1 – 3	-194.24	-82.00	30.24	.214
1 – 4	-202.49	-90.25	21.99	.149
2 – 1	26.46	138.70	250.94	***
2 – 3	-55.54	56.70	168.94	.522
2 – 4	-63.79	48.45	160.69	.645
3 – 1	-30.24	82.00	194.24	.214
3 – 2	-168.94	-56.0	55.54	.522
3 – 4	-120.49	-8.25	103.99	.997
4 – 1	-21.99	90.25	202.49	.149
4 – 2	-160.69	-48.45	63.79	.645
4 – 3	-103.99	8.25	120.49	.997

Table 8.22 shows that the mean time estimate for the group who heard full route guidance is significantly different from that for the control group. However, there were no significant differences between this and any other group.

Table 8.23 shows journey time estimates for the blue route landmark film by Nation while the post-hoc analysis for this variable (using the Tukey procedure) is shown in table 8.24.

Table 8.23: Journey time estimates for the blue route landmark film by Nation

Primary residence	n	Blue route mean journey time estimate (Landmark film)	Standard deviation
Britain	41	361.73	142.70
Europe	23	418.69	177.75
Other	16	511.37	163.33

Table 8.24: Post-hoc analysis of time estimates by Nation for blue route landmark film

Comparison Between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$) indicated by ***
1 - 2	-149.51	-56.96	35.58	
1 - 3	-254.35	-149.64	-44.93	***
2 - 1	-35.58	56.96	149.51	
2 - 3	-208.32	-92.68	22.96	
3 - 1	44.93	149.64	254.35	***
3 - 2	-22.96	92.68	208.32	

Tables 8.23 and 8.24 show that the estimates of blue route journey time made by UK residents are

significantly different from those of subjects whose primary residence is outside Europe, whereas neither of these group means is significantly different from that for European subjects.

Green route journey time estimates

The actual times taken to travel the green route are 275 seconds for the route film and 376 seconds for the landmark film. Subjects' estimates of these times ranged from 90 seconds to 840 seconds for the route film and from 150 seconds to 1200 seconds for the landmark film. The mean estimates for the sample as a whole for the two versions were 371 and 458 seconds respectively. The model produced by GLM for the route film was not significant ($F(21,58)= 1.26$, $p<0.25$, R-Square=0.31, but showed that sex was significant:

- Sex $F(1,78)=6.58$, $p<0.05$

Table 8.25 shows the means for male and female subjects and shows that both groups were quite accurate in estimating the duration of the route film, but males tended to overestimate while females tended to underestimate slightly.

Table 8.25: Journey time estimates for the green route (Route film) by sex of subject

Sex	N	Mean Time estimate in seconds for green route (Route film)	Standard deviation
Male	40	405.62	154.32
Female	40	337.97	150.39

The GLM model for the green route landmark film was not significant ($F(21,58)=1.48$, $p<0.15$, R-Square=0.349) but showed Nation to be significant:

- Nation $F(2,77)=4.24$, $p<0.05$.

Table 8.26 shows the group means for the 3 levels of the variable Nation. Table 8.27 presents the post-hoc analysis for this variable. Table 8.26 shows that the time estimates of subjects whose primary residence was outside Europe were much higher than the other two groups.

Table 8.26: Journey time estimates for the green route by country of residence

Country of residence	N	Time estimates for the green route landmark film	Standard deviation
Britain	41	414.44	187.23
Europe	23	442.39	182.65
Rest of world	16	593.12	214.85

The post-hoc analysis using Tukey (table 8.27) confirms that this groups' time estimates can be, considered to be significantly different from those of both the other groups and their estimates can be considered to be significantly less accurate than the other two groups.

Table 8.27: Post-hoc analysis of time estimates by Nation for green route landmark film

Comparison Between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance (p<0.05 indicated by ***)
1 - 2	-146.82	-27.95	90.91	
1 - 3	-313.18	-178.69	-44.19	***
2 - 1	-90.91	27.95	146.82	
2 - 3	-299.27	-150.73	-2.20	***
3 - 1	44.19	178.69	313.18	***
3 - 2	2.20	150.73	299.27	***

Determining the sequence of journey times

An analysis of the estimates of journey times showed that only 15 subjects (18.8%) determined the correct sequence. In experiment I this figure was 26.3%. Similarly, in this second experiment 28 (35%) of all subjects estimated the red route as the longest in duration. In experiment I this figure was 41%. Table 8.28 shows the figures for each possible sequence. Correlation coefficients were also calculated for the relationships between the three routes. These showed that, as with the distance estimates, an individual's estimates of journey time for one route are highly positively correlated with their estimates for the other two routes.

Table 8.28: Frequency of each possible order of time estimates

Sequence of time estimates	Frequency	Percent	Cumulative frequency	Cumulative percent
R>G>B	15	18.8	15	18.8
R>B>G	13	16.3	28	35.0
G>R>B	14	17.5	42	52.5
G>B>R	12	15.0	54	67.5
B>R>G	3	3.8	57	71.3
B>G>R	2	2.5	59	73.8
R=B	3	3.8	62	77.5
R=G	5	6.3	67	83.8
G=B	13	16.3	80	100.0

Further correlation analysis was performed to see whether there was a link between distance and

time estimates. Again, the four correlation coefficients were computed for the correlation between time estimates for the three route films and distance estimates for the routes. This analysis showed that only the green route distance and time estimates were correlated at the 5% significance level (Spearman's rank-order correlation coefficient = 0.26063 ($p<0.05$). This is in keeping with findings for the other tasks, which showed that effects tend to appear most strongly on the final of the three routes.

8.4 Results of tasks measuring configurational spatial knowledge

8.4.1 Cross route pointing task

As in experiment I, the cross route pointing task produces a single score - XRT - measured in degrees, which gives a measure of subjects' configurational knowledge of the area. This is the average error (average deviation from actual) of a subjects' direction estimates. Scores for the cross route pointing task ranged from 13.92 degrees error (male aged 23 with 5.5 years' driving experience, whose primary residence was the UK) to 89.58 degrees error (female aged 20 with just over a year's driving experience, whose primary residence was outside Europe). The mean XRT score for all 80 subjects was 46.53 degrees. The comparable score for experiment I was 61.16 degrees, the difference being attributable to the removal of older subjects and non-drivers. Figure 8.7 shows the spread of scores for the full sample of subjects who took part in the second experiment. The cross route means are plotted against age.

Analysis of variance (GLM) was performed on the data to establish the main variables responsible for the group differences. A number of models were tested before that in Table 8.29 was selected as being the most reliable (having an R-square value = 0.69) to explain the variance. The figures show that the main variables age2, group and performance were all significant at the 5% level or below. Tables 8.29-8.33 show the mean pointing error scores for the cross route pointing task for each of these variables.

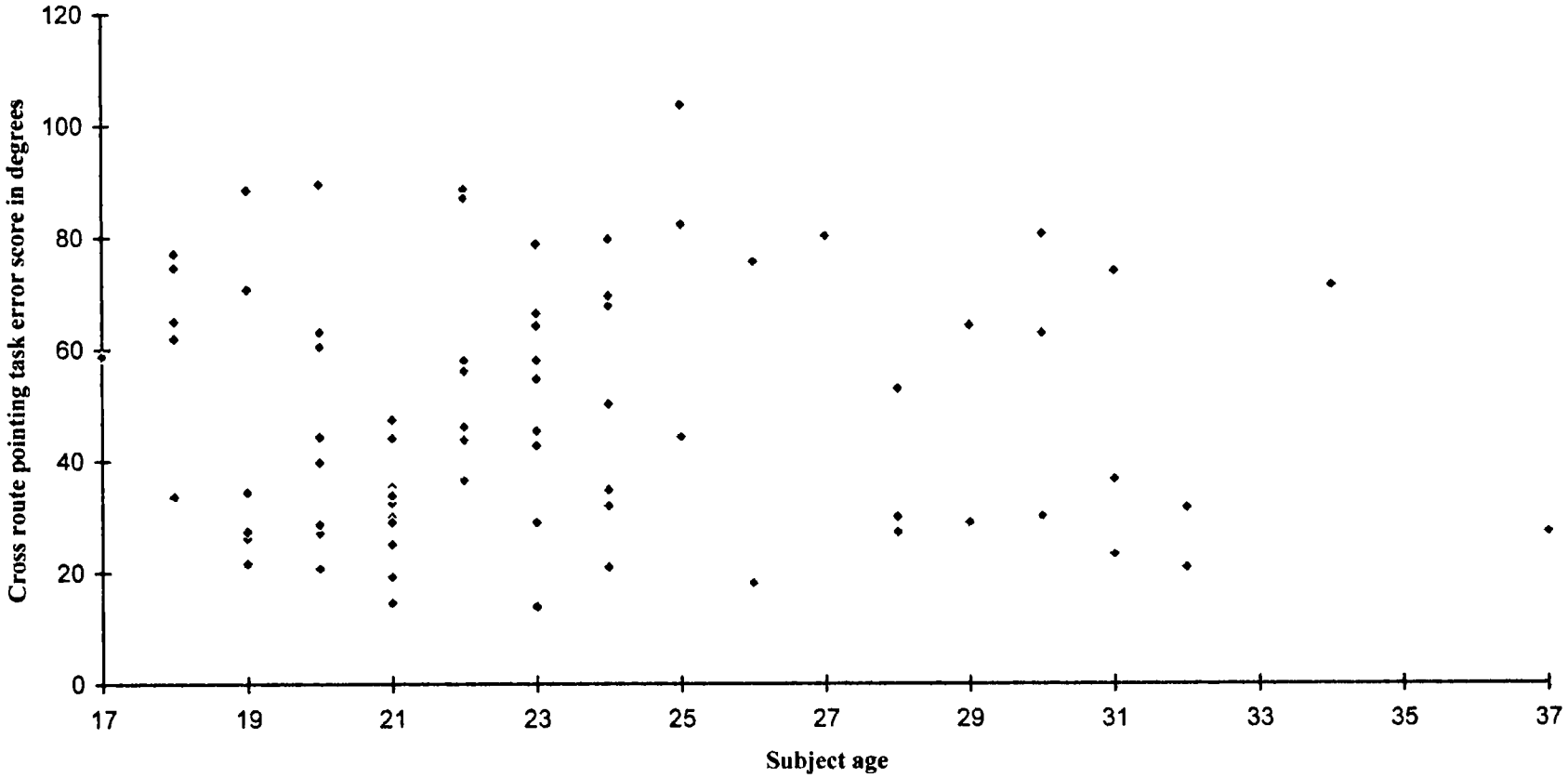


Figure 8.7: Cross route pointing task mean scores for the sample plotted against age of subject

Table 8.29: Analysis of Variance General Linear Models Procedure

Dependent Variable: XRT_Mean

Source	DF	Sum of squares	Mean Square	F Value	Prob > F
Model	33	24981.951	757.029	3.29	0.0001
Error	46	10594.115	230.307		
Corr. Total	79	35576.066			

R-Square	C.V.	Root MSE	XRT_MEAN Mean
0.702	33.097	15.3993	46.5279

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sex	1	21.777	21.777	0.095	0.760
Age	1	1533.422	1533.422	6.658	0.013
Group	3	1699.300	566.433	2.819	0.045
Nation	2	1230.354	615.177	2.671	0.080
Years	2	891.529	445.764	1.936	0.156
Performance	5	3258.337	651.667	2.830	0.026
Age*Nation	2	1214.060	607.030	2.636	0.082
Group*Nation	6	5281.645	880.274	3.822	0.004
Group*Years	6	5105.064	850.844	3.694	0.004
Performance*Sex	5	3958.278	791.656	3.437	0.010

Table 8.30: Mean error scores for the cross route pointing task by Age

Level of Age	N	Mean	S.D.
1 (18-21)	38	44.98	21.71
2 (22-and-over)	42	47.93	20.93

Table 8.30 shows the difference between the two age groups to be small, but significant. When one considers that the mean ages of the two groups are much closer together than was the case in experiment I this finding serves to reinforce the age-related results of experiment I.

Table 8.31: Mean error scores for the cross route pointing task by information group

Group	Information condition	N	XRT Mean	S.D.
I	Video only	20	47.443	26.27
II	Route guidance	20	45.243	16.52
III	Landmarks/directions	20	52.337	21.79
IV	Directions/landmarks	20	41.087	19.09

Table 8.31 shows XRT means for the four information groups. Subjects in groups III and IV might have been expected to show similar performances given that the information provided to both is the same, just presented in the reverse order. The figures in table 8.31 suggest that those in the Directions-Landmark condition performed better than the group who heard this information reversed. Post-hoc analysis was run on the data to check which of the four groups were significantly different. Table 8.32 shows the results of this analysis which employed the Tukey procedure. This table shows that despite the variable being significant none of the mean scores can be considered to be significantly different from one another.

Table 8.32: Post-hoc analysis of XRT scores for variable Information group

Group comparison	Lower simultaneous confidence limit	Difference between means	Upper simultaneous confidence limit	Significance ($p<0.05$ indicated by ***)
1 – 2	-10.59	2.20	14.99	.968
1 – 3	-17.68	-4.89	7.89	.739
1 – 4	-6.44	6.35	19.15	.552
2 – 1	-14.99	-2.20	10.59	.968
2 – 3	-19.88	-7.09	5.70	.458
2 – 4	-8.64	4.15	16.95	.822
3 – 1	-7.89	4.89	17.68	.739
3 – 2	-5.69	7.09	19.88	.458
3 – 4	-1.54	11.25	24.04	.103
4 – 1	-19.14	-6.35	6.43	.552
4 – 2	-16.95	-4.15	8.64	.822
4 – 3	-24.04	-11.25	1.54	.103

If performance was related to the amount of additional information coped with, subjects in group 2 would have been expected to perform worst of all, this being the group who have to cope with most information. Similarly, from this perspective those in group I would have been expected to

perform best of all. This was clearly not the case and these results suggest that the effect of additional information is more complex than simply being related to amount of information. The order in which this information was presented may also have had an impact upon performance.

For each subject the pointing error scores for the 3 individual routes are placed into rank order, hence there are 6 possible combinations (RBG,RGB,BRG,BGR,GRB,GBR, where RBG means that a subject's performance was best on the red route, followed by the blue route and worst on the green route etc). Table 8.33 shows that the majority of subjects (73%) performed best on either the red route or the green route. Subjects whose performance on the blue route was best, followed by the red route (BRG) showed the best performance at the cross route pointing task. The worst cross route mean score was for those subjects who performed best at the green route followed by the blue and then the red routes (GBR). Subjects exhibiting this response pattern might have acquired good spatial knowledge of one route, but appeared unable to integrate the information acquired from the other two routes.

Table 8.33: Mean error scores for the cross route pointing task by performance

Level of Performance	N	XRT Mean	S.D.
1 R>B>G	19	41.71	17.33
2 R>G>B	11	49.48	21.63
3 B>R>G	10	34.73	13.04
4 B>G>R	12	44.49	19.83
5 G>R>B	9	43.99	29.61
6 G>B>R	19	58.34	21.00

In addition to the main variable effects, a number of interaction effects were apparent. Whilst these were, in some cases, highly significant, the differences in cell sizes make analysis of these results problematic. However, the final pairwise interaction considered (gender*performance) offers an insight into the differences between male and female subjects in their performance of the three individual routes. Table 8.34 shows the distribution of male and female subjects across the 6 possible performance orders, and the mean cross route pointing task scores for each group.

Table 8.34 shows a difference between the sexes in their preference for how they acquired knowledge of the three routes. The largest single group of males performed best on the red route, followed by the blue then the green: in the order that the routes were presented. Conversely, the

largest single group of females performed best on the green route, followed by the blue and worst, on the red route: the opposite to presentation order. However, for both sexes there is no apparent relationship between performance order and actual cross route pointing scores.

Table 8.34: Cross route pointing scores by gender and performance

Sex	Level of performance	N	XRT Mean	S.D.
Male	RBG	11	42.92	19.79
Male	RGB	5	59.00	23.06
Male	BRG	5	36.50	12.20
Male	BGR	8	35.68	13.05
Male	GRB	4	33.64	31.40
Male	GBR	7	73.71	11.16
Female	RBG	8	40.03	14.40
Female	RGB	6	41.54	18.55
Female	BRG	5	32.97	15.03
Female	BGR	4	62.10	20.58
Female	GRB	5	52.27	28.64
Female	GBR	12	49.37	20.39

8.4.2 Correlation coefficients for the single and cross route pointing tasks

Experiment I showed that performance of the single route pointing tasks predicted performance of the cross route pointing tasks. Experiment II employed a more homogeneous subject sample, which might have affected this finding. Consequently, correlation analysis was performed on the single route and cross route pointing task data. Four coefficients were calculated, but as before, only Spearman's rank-order correlation coefficients are presented in table 8.35 below.

Table 8.35: Correlation coefficients for the single and cross route pointing tasks

	n	Red_Mean	Blu_Mean	Grn_Mean
XRT_Mean	80	0.31478 ($p<0.0045$)	0.57250 ($p<0.0001$)	0.52741 ($p<0.0001$)

Table 8.35 (and table 8.41 later) show that, as in experiment I, there is some degree of correlation between performance at the single route pointing tasks and subsequent performance at the cross route pointing task. Despite the differences between the two samples, the correlations in each

experiment are quite similar.

8.4.3 Sketch map data

All 80 subjects managed to draw some form of sketch map. Analysis of these sketch maps proceeded as for experiment I, with the same variables being created. Experiment I had shown that some subjects who had limited knowledge of the area still tended to include a large number of road segments in their maps, which could have distorted the results if included in the overall map score, hence the variable 'correct' is used as the main indicator of sketch map quality. The following results refer specifically to this variable.

The number of landmarks correctly placed on subjects' maps ranged from 1 to 51. The average for the sample as a whole was 16.375. A number of different models were tested before one was found which managed to explain even a modest amount of the variance. This model was not significant ($F(27,52)=1.22, p<0.30$, R-Square=0.390). Analysis of variance (GLM Procedure) showed that the main variables age, country of primary residence and years were significant:

- Age $F(1,78)=6.39; p<0.05$
- Nation $F(2,77)=3.62; p<0.05$
- Years $F(2,77)=3.61; p<0.05$

Table 8.36 shows the mean number of landmarks correctly located on subjects' sketch maps for each of the two age groups. As expected, there is only a small difference between the two groups, although enough to be significant.

Table 8.36: Correctly located landmarks by age group

Level of Age	N	Mean	S.D.
1 (18-21)	38	15.868	8.75
2 (22-and-over)	42	16.833	11.00

Table 8.37 shows the mean number of correctly placed landmarks for each of the primary residence groups, from which it is apparent that those whose primary residence was outside Europe recalled fewer landmarks than either of the other groups. Post-hoc analysis was carried out on this data and this is shown in table 8.38 below.

Table 8.37: Correctly located landmarks by nation (country of primary residence)

Country of primary residence	N	Mean	S.D.
1 (UK)	41	16.24	9.24
2 (Europe)	23	18.95	11.91
3 (Rest of world)	16	13.00	7.95

Table 8.38: Post-hoc analysis for the sketch map task by variable Nation

Comparison Between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$ indicated by ***)
1 - 2	-8.67	-2.71	3.24	.519
1 - 3	-3.50	3.24	9.98	.481
2 - 1	-3.24	2.71	8.67	.519
2 - 3	-1.49	5.95	13.40	***
3 - 1	-9.98	-3.24	3.49	.481
3 - 2	-13.40	-5.95	1.49	***

Table 8.38 shows that the mean performance of group 2 - those whose primary residence was in Europe - can be considered to be significantly different from that of the Rest of the world group, but not significantly different from the UK group.

Table 8.39: Correctly located landmarks by number of years' driving experience

Level of years	N	Mean	S.D.
1 (1 or less)	13	13.54	6.53
2 (2-5 years)	42	15.57	9.54
3 (more than 5)	25	19.20	11.63

Table 8.39 shows the mean number of correctly located landmarks by number of years' driving experience. Post-hoc analysis was also carried out on this data and the results of this analysis are shown in table 8.40 below. Table 8.40 shows that groups 2 and 3 can be considered to be significantly different from each other but the other comparisons are not significantly different. There would appear to be some evidence to suggest that increased driving experience enhances ability to carry out the wayfinding and navigation tasks required of them in this experiment, but both the strength of this relationship and the results of the post-hoc analysis were not conclusive. Consequently, it is safer to reject this result as being unreliable. Moreover, the findings of

experiment I suggest that if there are any benefits to be derived from driving, these are quickly, offset by the debilitating effects of ageing.

Table 8.40: Post-hoc analysis for the sketch map task by Years' driving experience.

Comparison between groups	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	Significance ($p<0.05$ indicated by ***)
1 - 2	-9.29	-2.03	5.22	.778
1 - 3	-13.48	-5.66	2.16	***
2 - 1	-5.22	2.03	9.29	.778
2 - 3	-9.40	-3.63	2.15	.292
3 - 1	-2.16	5.66	13.48	***
3 - 2	-2.15	3.63	9.40	.292

Road names

The number of road names correctly mentioned by subjects ranged from 0 to 10. The mean number mentioned on maps for the group as a whole was 1.96. Clearly, if subjects were actually listening to the instructions they were being given then those who heard complete route guidance instructions would have an advantage, in that they heard the name of each road travelled. This was indeed found to be the case, the mean number of road names for the other three groups ranged from 0.65 to 1.25, but for the full guidance group the mean was 5.20 road names.

8.4.4 Comparison of performances across tasks

Table 8.41 shows correlation coefficients for the sequencing task, single and cross route pointing tasks and the sketch map task. This analysis was performed to test for correlations between performance at one task and performance at others. This summary table shows that performance across the various tasks is correlated. Certainly, one would expect there to be a correlation between the single and cross route pointing scores, as the cross route pointing task requires good route knowledge to be performed well. For the same reason the correlations between performance of the sequencing tasks and the cross route pointing task were to some extent expected. The correlations between sequencing tasks and the single route pointing tasks were not expected. However, it should be noted that only performance on the red and green route sequencing tasks correlated with pointing task scores. Figure 8.8 plots the relationship between number of landmarks correctly identified in the map task (Correct) and the cross route pointing task score.

Table 8.41: Correlation coefficients for the various tasks performed during experiment II

	N	XRT_Mean	Red_Mean	Blu_Mean	Grn_Mean
RScore	80	-0.44373 (p<0.001)	-0.23211 (p<0.05)	-0.43115 (p<0.001)	-0.39635 (p<0.001)
BScore	80	-0.18789 (n.s.)	0.01081 (n.s.)	0.04844 (n.s.)	-0.08802 (n.s.)
GScore	80	-0.47802 (p<0.001)	-0.23710 (p<0.05)	-0.31438 (p<0.01)	-0.28875 (p<0.01)
OScore	80	-0.54241 (p<0.001)	-0.19687 (n.s.)	-0.35313 (p<0.01)	-0.36905 (p<0.001)
XRT_Mean	80	-	0.31478 (p<0.01)	0.57250 (p<0.001)	0.52741 (p<0.001)
Correct	80	-0.65414 (p<0.001)	-0.32968 (p0.01)	-0.48040 (p<0.001)	-0.41404 (p<0.001)

Table 8.42 shows average scores for the sequencing task and the other main indicators of performance. Two groups are considered: those who scored a maximum of 30 for OScore and the 15 participants with the lowest scores (20 or below). Averages for the sample as a whole are also given as a comparison. It can be seen that those subjects who performed best in the sequencing task had an average age significantly less than the average age of the sample as a whole. Those subjects who scored lowest at the sequencing task had an average age significantly higher than the group average age.

Table 8.42: Comparison of subjects scoring highest and lowest at the Sequencing tasks

Group	Mean age	Mean XRT Score	Mean Correct Score (Maps)	Mean Total Score (Maps)
Best performers (maximum of 30)	21.93	29.175	25.2	48.47
Worst performers (less than 20)	24.27	65.856	7.8	23.53
All subjects	23.25	46.528	16.375	34.76

Table 8.42 also shows that the three measures (OScore, XRT Score and Correct (Landmarks correctly located on map)) are correlated: those who scored a maximum of 30 at the sequencing task scored significantly better at the other two tests. This result suggests that the three tests are measuring similar cognitive processes.

8.4.5 Evidence of learning

In experiment II all subjects undertook the pointing tasks in the same order. This makes it possible to track individuals, or groups, across the experiment and to monitor their progress. We would expect performance to improve from the red to the blue routes, partly as a result of subjects' increased familiarity with the task requirements, and partly because the blue route is less complex than the red. Performance on the blue route should also be better than that on the green route: the green route is longer in distance, takes longer to watch and is more complex, having more turns. Furthermore, because it is the last of the three routes to be seen there is a potential for subjects to become fatigued, or to simply lose interest in the experiment. Even those who do retain a keen interest and are not mentally fatigued could suffer from an overload of information. This would be reflected in a lower than expected cross-route pointing task score.

However, if pointing accuracy improves from the red to the blue route, and again from the blue route to the green route, one could argue that this is evidence of learning. The cross route pointing task enables us to test this theory. If lower error scores on successive routes is indicative of learning we would expect groups demonstrating this pattern to also score well on the cross route pointing task. Configurational knowledge depends upon the integration of knowledge acquired from the three individual routes and consequently, good configurational knowledge is dependent upon good route knowledge.

Figure 8.9 shows mean error scores of the four information groups for the single route and cross route pointing tasks. The graph shows that the mean error scores of group IV (who heard directions followed by landmarks) improved across the three single route tasks. None of the other groups demonstrated this pattern of responses. Indeed, the mean error scores of groups I and III appear to deteriorate across the three single route tasks. However, this improvement across routes was not significant. The graph also shows that the mean cross route pointing task error score for group IV was lower than that of the other three information groups, supporting a link between good route knowledge and good configurational knowledge. Either those who demonstrated progressively better route knowledge were more able to integrate this knowledge into a configurational representation of the area, or the information they had acquired was of a better quality and thus resulted in better configurational knowledge.

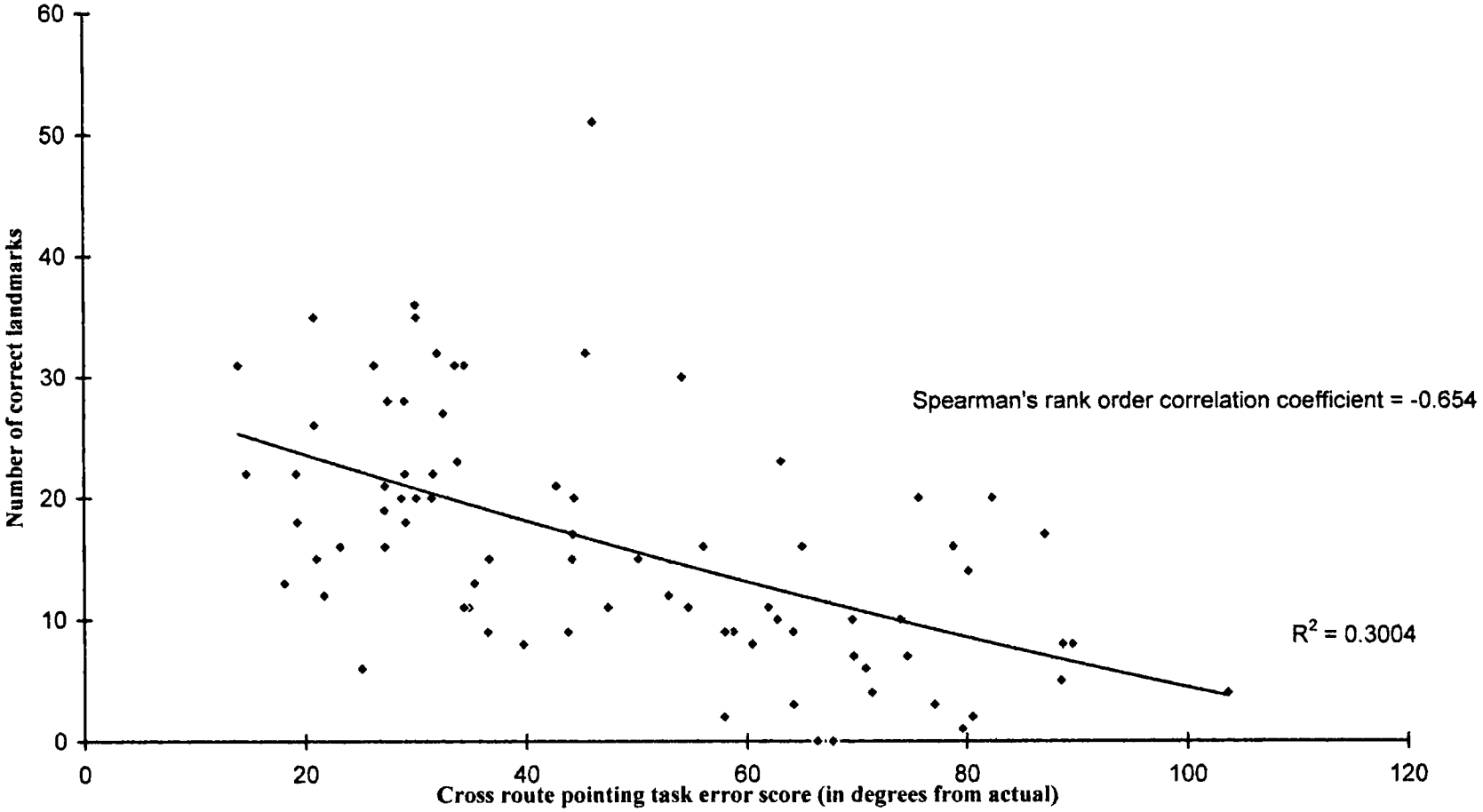
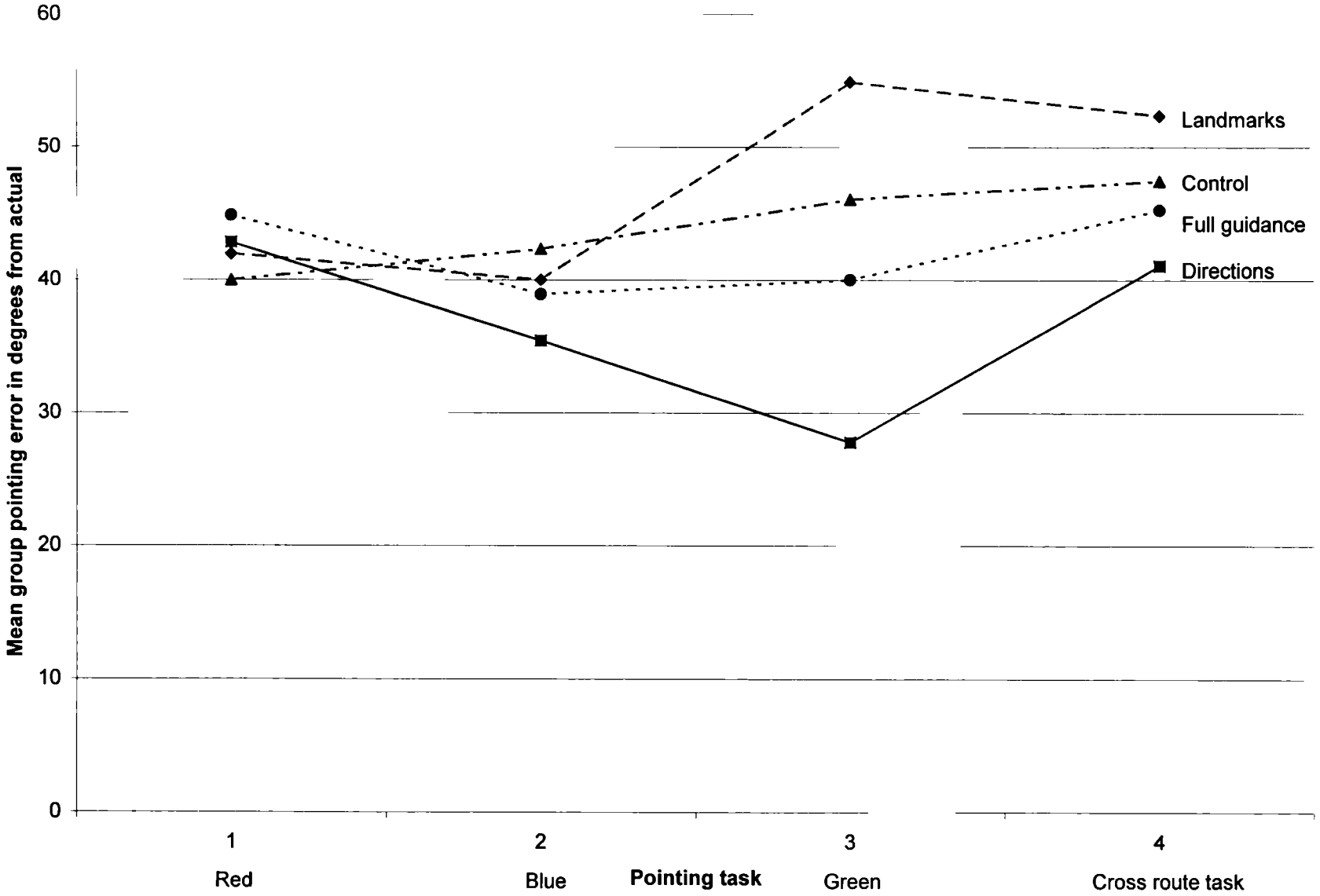


Figure 8.8: Cross route pointing task scores plotted against number of landmarks correctly positioned and identified on sketch map


60
50
40
30
20
10
0
Mean group pointing error in degrees from actual
Landmarks
Control
Full guidance
Directions
1
Red
2
Blue
Pointing task
3
Green
4
Cross route task

8.5 Summary of results of experiment II

This section summarises the results of experiment II which addressed the third research question proposed in chapter 1:

"Are the detailed instructions currently in use in route guidance systems the most effective?"

Experiment I had shown that there were no significant differences between the various information groups in their ability to perform the majority of tasks. The route guidance instructions used in experiment I were based upon recommendations of IVRGIS designers and ergonomists working in the field of vehicle navigation. However, previous research reviewed in chapter 4 (e.g. Alm, 1990; Alm and Berlin, 1991; Burnett, May and Ross, 1994) had shown landmarks to be of fundamental importance to the cognitive mapping process. Consequently, experiment II examined the use of alternative instructions which placed more emphasis upon environmental landmarks, in an attempt to strengthen subjects' representations of the study area.

In addition, the findings of experiment I led to the development of an experiment which focused upon 80 individuals, all drivers, and all in the age range 18-35. This was to enable a comparison of the performance of drivers of different levels of experience, to test whether driving enhances cognitive mapping performance. A subsidiary aim of the research was to test the theory of generic spatial knowledge, by comparing the performance of drivers whose country of primary residence was Britain, with that of drivers whose primary residence was elsewhere in Europe and those whose primary residence was outside Europe. Section 8.5.1 summarises results relevant to hypothesis 7, while section 8.5.2 summarises results which add to the findings of experiment I and which address hypotheses 10 and 11. Finally, section 8.5.3 summarises results which relate to the new variable, Nation and which address hypothesis 12.

8.5.1 Effects of instructions making reference to landmarks

The following results showed a significant effect due to information condition. Post-hoc analysis of the data is shown in italics.

Sequencing task.

No significant effects due to information condition were found on the sequencing tasks

Distancing task:

There were no significant differences for the red and blue routes, but for the green route:

- Group $F(3,62)=3.56, p<0.05$) *2 different from 3*

The group mean for subjects who heard full route guidance instructions was significantly different from that of subjects who heard landmarks followed by directions, the former overestimating and the latter being closest to actual. However, neither were significantly different from the control.

Single route pointing tasks

Information condition was not significant for the red or blue routes but for the green route:

- Group $F(3,76) = 3.27, p<0.05$ *3 different from 4*

The group mean for subjects who heard landmarks followed by directions was the most inaccurate and was significantly different from the best group mean, which was by subjects who heard the reverse information – directions followed by landmarks. Again, none of the experimental conditions was significantly different from the control group.

Distance estimates

There were no significant differences on either the red or green route distance estimates, but for the blue route:

- Group $F(3,76)=2.79, p<0.05$. *1 different from 3, 2 different from 3*

The group mean for the landmarks-directions group was significantly different from either the control or those who heard full route guidance instructions. The group mean for those who heard landmarks-directions was least accurate. Consequently it is possible to conclude that this group performed worse as a result of hearing landmark-direction information than if they had heard nothing.

Time estimates

For the Red route:

- Group $F(3,76)=3.35, p<0.05$ *2 different from all other groups*

Those who heard full route guidance instructions were significantly different from all other groups and their time estimates were the most inaccurate. It is possible to conclude, therefore, that those who heard full guidance performed significantly worse than if they had heard no instructions or the other types of information.

For the blue route:

- Group $F(3,76)=3.17, p<0.05$ *1 different from 2*

The control group made the most accurate estimates of green route journey time and were significantly more accurate than those in the full route guidance condition who were least accurate. It is therefore possible to conclude that the time estimates of those who heard full

guidance were significantly worse than if they had heard no information at all.

There were no significant differences due to information condition on the green route.

Cross route pointing task

- Group $F(3,76)=2.83, p<0.05$ *1 different from 4*

For the cross route pointing task the control group performed worst of all and were significantly different from the group who heard directions-landmarks, who were the most accurate in estimating direction between landmarks on different routes. Consequently, it is possible to conclude that the group who heard directions followed by landmarks performed significantly better than if they had heard no information.

Sketch map task

No significant effects due to information condition were found for the sketch map task.

The hypothesis which relates to using landmarks in route guidance instructions will now be evaluated in light of these results.

Hypothesis 7: effects of instructions making reference to landmarks (from chapter 4)

H_1: Subjects who hear instructions containing references to visible landmarks should acquire superior spatial knowledge to those who hear information that makes no reference to landmarks.

Of the 5 tasks on which information condition was a significant variable, 2 measure route knowledge, 2 measure subsidiary information and one measures configurational knowledge. This latter task is the main measure of acquired spatial knowledge. However, in summarising the results of the effects of information it is possible to identify three particular effects:

i) The effect of full route guidance on distance estimates;

ii) The effect of full route guidance on time estimates;

iii) The effect of amended instructions on spatial knowledge.

i) The effect of full route guidance on distance estimates.

It was apparent that some subjects in the full guidance condition were using the distance element of the instructions (e.g. 50 metres to left turn) to inform their estimates of route distance for both the distancing and distance estimation tasks. This is reflected in the accuracy of the distance

estimates of this group. However, as a consequence this group had a significant advantage over the other groups who did not hear any information about distances. The full guidance group heard information which could have given them a much better idea of total route distance as at key points they were told that the distance to a turn was 50 metres. Moreover, some subjects admitted that they had counted up the number of times the instruction was given and had used this to calculate the total distance travelled. Despite these advantages it was only on the blue route that information condition was significant, and although the group mean of those who heard full guidance was closest to the actual distance this group were not significantly different from the control group. Consequently, this result cannot be considered significant, even though some subjects were able to use the information to their advantage. The performance of those who heard landmarks followed by directions, however, was significantly different from that of the control group. For this group we can conclude that their distance estimate for the blue route was significantly worse than if they had heard nothing.

ii) The effect of full route guidance on time estimates

It is also apparent that this same information may have resulted in subjects making overestimates of the time taken to travel each journey. Certainly, for both the red and blue routes the group mean of those who heard full route guidance information was the least accurate. Moreover, post-hoc analysis showed that on both routes the group mean for the group who heard full guidance was significantly different from all other groups. This suggests that the presence of full information did impair time estimates for this group.

Chapter 4 section 4.2 discussed the attentional allocation model of time estimation, and noted that the presence of additional visual information leads to inaccurate time estimation -

> "The output of the timer becomes less reliable as the visual information processor captures more attention. Thus, as the amount of information to be perceived increases this requires more processing and so less attention is available to focus on the temporal information. As a consequence, ability to estimate time will be impaired."

It is possible that there is also an audible information processor working alongside the visual information processor, and these results suggest that a similar effect might be apparent with regard to audible information – the presence of full route guidance leads the audible information processor to demand more attention, thus leading to inaccurate estimates of time. Whilst not one of the original hypotheses, this was quite a conclusive result, as the post-hoc analysis showed that all groups were significantly different to the group who heard full guidance. As such it is possible

to conclude that the presence of full route guidance may indeed lead to impaired time estimates, but that simpler route guidance instructions which do not make reference to distance do not have this effect.

iii) The effect of amended instructions on spatial knowledge

Information condition was significant on the green route pointing task. Post-hoc analysis of this result showed that the group mean for subjects who heard directions followed by landmarks was only significantly different from that of subjects who heard landmarks followed by directions, and so it is not possible to reject the null hypothesis. However, the main measure of acquired spatial knowledge is the cross route pointing task, on which information condition was significant. Post-hoc analysis of the cross route pointing task showed that the performance of subjects hearing directions followed by landmarks was significantly different from that of subjects hearing nothing - subjects who heard instructions of the form "Turn left at the garage" performing significantly better than the control. Consequently, the null hypothesis can be rejected for this group – and it is possible to conclude that the performance of this group was positively affected by listening to guidance.

In summary, the results show a variety of effects relating to information condition, depending upon the task requirements. Full route guidance instructions had a detrimental effect upon time estimation. There was little evidence from the single route tasks in support of the hypothesis – there were no significant effects due to information condition for the sequencing task, and although there was a significant group effect on the distancing task the results did not support the hypothesis.

However, the hypothesis predicted an effect on configurational knowledge acquisition, not on route knowledge, which is what the sequencing tasks measure. The main measures of configurational spatial knowledge acquisition are the sketch map and cross route pointing tasks – and on this latter task the group mean of subjects who heard directions followed by landmarks was indeed more accurate than other groups, and significantly different from the control group. Furthermore, it should be noted that it was only on the green route and cross route pointing tasks that an effect due to information condition became apparent. This could be attributed to the fact that the sample was composed of young drivers, who experienced little difficulty in acquiring a reasonable representation of individual routes. It is possible that by the third route they were having to hold three route representations in working memory, with the result that errors and individual differences started to have an effect. If this explanation is correct then

errors would have been even more apparent on the cross route pointing task where subjects were required to integrate this information into a configurational representation of the area as a whole. The results of the cross route pointing task showed that this was the case. Section 8.1.3 predicted that subjects hearing instructions incorporating landmarks would perform better at the cross route pointing task than those who heard nothing. The results showed that this was the case - the group mean for group 4 was significantly different from that of the control group, and so we can conclude that there was a positive effect due to the information condition.

8.5.2 Results which add to the findings of experiment I

Experiment I showed age to be the main predictor of performance and that ability to drive also had an effect upon performance of the tasks. Experiment II tried to refine these results by using a sample composed entirely of younger (18-35) drivers. Consequently, a new variable "Years" was constructed to determine whether *increased* driving experience improves the ability to acquire the spatial information that underpins wayfinding and navigation. The group with only 1 years' driving experience are therefore considered to be the control group and the performance of the other groups is compared against this group. The following results showed a significant effect due to number of years' driving experience. Post-hoc analysis of the data is shown in italics.

Sequencing tasks:

For the blue route:

- Years $F(2,77)=4.96, p<0.05$ *1 different from 2, 3 different from 2*

The performance of those with 2-5 years' driving experience was significantly different from that of the groups with 1 year or more than 5 years' driving experience. This group had the highest group mean score for the blue route sequencing task and we can conclude that those with 2-5 years' driving experience performed significantly better than new drivers because of their increased driving experience.

Pointing tasks:

For the blue route:

- Years $F(2,77)=3.53, p<0.05$ *1 different from 3*

The mean pointing error score for the group who had 1 years' driving experience was significantly different from that of the group who had 5 or more years' driving experience. The latter group had the most accurate group mean pointing error score for the blue route. We can therefore conclude that those with 5 or more years' driving experience performed significantly

better than those who had been driving for 1 year or less.

For the green route:

- Years $F(2,77)=2.79, p<0.05$ *2 different from 3*

The mean pointing error score for the group who had 5 or more years' driving experience was significantly different from the group with 2-5 years' driving experience. The 5+ years group had the most accurate group mean pointing error score for the green route. However, neither group was significantly different from the control group and so the null hypothesis (there will be no differences between groups, regardless of driving experience) cannot be rejected.

There were no significant differences due to driving experience at the cross route pointing task.

Sketch map task:

For the variable "Correct"

- Years $F(2,77)=3.61, p<0.05$ *2 different from 3*

The group mean number of correctly placed landmarks for the 5+ years group was significantly different from that of the 2-5 years group. The 5+ years group recorded the highest group mean number of correctly placed landmarks. Again, the mean for this group was not significantly different from the control and so the null hypothesis cannot be rejected. Hypothesis 11 will now be evaluated in light of these results.

Hypothesis 11: The effects of increased driving experience

H_1: Subjects who have been driving for 1 year or less will perform significantly worse at the cross route pointing task than those with more driving experience.

An effect due to number of years' driving experience was predicted, with performance at the various tasks improving with driving experience. For this hypothesis to be accepted it would have to be demonstrated that those who had been driving for more than 1 year performed significantly better than the control group, the subjects who had been driving for 1 year or less. Only four tasks showed a significant effect due to driving experience, three of which measured acquired route knowledge, while the remaining test (sketch map) measured configurational knowledge. On none of the tasks was one group significantly different from both the other groups. On the blue route sequencing task the group with 2-5 years' driving experience were

significantly different from the control, while for the blue route pointing task the group with more than 5 years' driving experience were significantly different from the control group. For both tasks a group of experienced drivers performed significantly better than the control group, but did not perform significantly differently from the other experienced driving group. If the hypothesis had stated that there should be a difference between each of the three levels then these results would not be significant. It is hypothesised that driving enhances wayfinding skills, but these skills do not develop until the driver has mastered the driving task. Consequently, the only group of drivers who would show a noticeable difference from other drivers was that group who had only been driving for a very limited period of time. Hence, the hypothesis was simply that the control group would perform differently from more experienced drivers. For results on which one of the experienced groups performed significantly better than the control group it is possible to accept the hypothesis for this group. However, the results offer only limited evidence in support of the hypothesis, and it is concluded that, overall, the null hypothesis should be accepted.

Given the age range of the subject sample, and the significant effect that age had in experiment I, it is possible that age was conflicting with driving experience to produce somewhat unclear effects. The results of these tasks should be considered in conjunction with others which showed an age-related effect. Hypothesis 10 predicted that in experiment II there would also be an effect due to age, with younger subjects performing significantly better at the cross route pointing task than older. The following results relate to this hypothesis:

Single route pointing tasks:

Green route:

- Age $F(1,78)=5.33$, $p<0.05$

Cross route pointing task:

- Age $F(1,78)=8.06$, $p<0.01$

Sketch map task:

- Age $F(1,78)=6.39$, $p<0.05$

These results offer strong evidence to support the prediction of an age-related effect. On all the above tasks younger subjects performed better than older subjects. More importantly, these

tasks are the most difficult: the green route is the most complex single route pointing task in terms of turn density (see section 7.1.4); and in that it is the final route to be seen, and there is therefore the chance that subjects are experiencing fatigue, boredom, and/or information overload, while the cross route pointing and sketch map tasks measure ability to integrate the information acquired from the various other tasks. Consequently, it could be argued that it is on these routes that group differences are most likely to appear. In particular, the debilitating effects of age make the tests of configurational knowledge more difficult for older subjects. The age range of this sample was comparatively small and so the fact that there was still a strong age-related effect serves to reinforce the central conclusion of experiment I. The results offer strong evidence to support the hypothesis and consequently the null hypothesis can be rejected.

From these results it would appear that the age-related decline in spatial ability begins much earlier than has previously been thought to be the case. The results also help to clarify the results on which driving experience was a significant variable. There is clearly a relationship between increased age and increased driving experience. It is also clear that age was the most reliable predictor of performance in both experiments. It is therefore possible that age and driving experience were having a contradictory effect: as age increases task performance declines, but conversely, as driving experience increases task performance improves. It is possible that this conflict had the overall effect of weakening any effects due to driving experience.

8.5.3 Effects of nationality

It was predicted that subjects who had lived in the UK for the majority of their lives would have acquired experience of similar spatial layouts to that employed in these experiments and would consequently be better able to predict the likely spatial layout of the environment. This beneficial effect due to past experience was termed 'generic spatial knowledge' and it was predicted that it would be reflected in subjects' sketch maps, which should include a greater number of landmarks. But because generic spatial knowledge would not provide subjects with information about the *correct* location of these landmarks no differences between groups were expected in number of correctly located landmarks included in their sketch maps. GLM analysis was performed on the sketch map data. This showed that none of the main variables were significant for the variable Landmarks. Consequently, the above predictions regarding the effects of nationality cannot be sustained. However, a number of other tasks did show an effect due to nationality. The following results showed a significant effect due to nationality. In all

cases, the UK group are considered to be the control group.

Sequencing tasks:

Red route:

- Nation F(2,77)=3.70, p<0.05 *2 different from 3*

The sequencing task scores of subjects whose primary residence was on mainland Europe were significantly different from those of subjects whose primary residence was outside Europe. Those from Europe had the highest sequencing scores while those from the rest of the world had the lowest. However, neither were significantly different from the control group of UK residents.

Time estimates:

Red route:

- Nation F(2,77)=3.72, p<0.05 *1 different from 3*

Green route:

- Nation F(2,77)=4.24, p<0.05 *1 different from 3, 2 different from 3*

On both the red and green routes the group mean time estimates of subjects whose primary residence was in the UK were significantly different from those of subjects whose primary residence was outside Europe. On the green route the time estimates of European subjects were also significantly different from those of subjects whose primary residence was outside Europe. In both cases the group mean time estimates of subjects from the rest of the world were highest. Consequently, it can be concluded that the time estimates of those from outside Europe were significantly poorer than the control group and for this result we can accept the hypothesis.

Sketch map task:

- Nation F(2,77)=3.62, p<0.05, *1 different from 2, 2 different from 3*

For the sketch map task the group mean number of correctly placed landmarks included by subjects from Europe was significantly different from the number included by subjects from the UK or from the Rest of the World. However, the direction of the result was not as expected – European subjects performed significantly better than either of the other groups.

The significant results summarised above suggest that subjects whose primary residence was outside Europe did experience some problems at certain tasks. The poor time estimating ability of this group was particularly unexpected and there seems to be little rational explanation for

this result. Moreover, on the sketch map task subjects from Europe performed significantly better than either of the other groups. Again, this result was not expected. In summary, there is little evidence to support hypothesis 12 and, with the exception of results pertaining to time estimation, the null hypothesis must be accepted.

The next section will discuss the results of experiment II and propose possible explanations for them.

8.6 Discussion

8.6.1 The effects of incorporating landmarks into route guidance instructions

The discussion is organised around the main questions addressed by experiment II. The central issue that was considered by this experiment was the potential benefit to be derived from incorporating landmarks into verbal route guidance instructions. Experiment I had shown that there were no significant differences between groups regardless of the information they heard whilst watching the videos. Experiment II attempted to improve upon this by incorporating landmarks into the instructions given. The results suggest these efforts were at least partly successful.

Experiment II used a smaller sample, all of whom were drivers aged between 18-35, and so it was expected that if differences were shown between the information conditions these differences would be small. Of the 20 significant effects shown in experiment II 7 were due to information condition. Significant effects were shown on the sequencing task, distancing task, distance estimates, time estimates, single route and cross route pointing tasks. The fact that all these tasks showed an effect due to information condition would appear to suggest a strong effect and support for the hypothesis. The nature and direction of this effect, however, was not consistent across all tasks. On certain tasks effects were clearly due to the quantity of information present in the instructions. For example, on the time estimation task, the time estimates of the full guidance group were significantly different from the control on both the red and blue routes. This group heard more information than the other groups and so it is possible that quantity of information accounts for the results. This finding offers support for the attentional allocation model of time estimation (section 4.4.2) and is discussed in more detail in section 8.6.3 below.

However, on other tasks quantity of information was not the cause of differences. Blue route distance estimates for those who heard landmarks followed by directions were significantly different from those of the control group. Quantity of information could not explain this result, as the full guidance condition heard more information but performed comparably with those who heard nothing. What was it about these instructions that made distance estimation so inaccurate – and why was the effect only apparent on the blue route? While it is easy to see how the full guidance instructions might have assisted distance estimation, reasons for the poor performance of the landmark-direction group are less obvious.

Chapter 4 summarised research considering the effect that landmarks have upon cognitive mapping ability. From this it was concluded that making reference to landmarks at decision points such as junctions would strengthen the cognitive representation acquired of the relevant area. The results of experiment II offer partial support for this hypothesis – directions followed by landmarks had a positive effect, but landmarks followed by directions did not. The four information conditions cover three types and levels of information: no information; limited but situation-specific information (i.e. landmark information); and full information. The amended instructions used in experiment II reduced the quantity of salient information to be processed, as well as changing the type of information heard. The full route guidance instructions gave distance information but made no reference to visible features The amended instructions, by contrast, were much simpler and made clear reference to landmarks occurring at decision points such as junctions. Despite this, the results of the post hoc analysis failed to show any significant differences between the information groups. The lack of a significant difference between the performance of this group and the control suggests that the type of information presented did not have a positive effect upon ability to acquire spatial knowledge.

The importance of order of presentation of guidance information

However, the results for the pointing tasks also showed up an unexpected difference between the two versions of amended instructions. Both groups heard precisely the same information, simply presented in two different orders. Consequently, little difference had been anticipated in the performances of the two groups. However, while the group mean error score for the directions-landmarks group was significantly lower than the control group, the group mean error score for the landmarks-directions group was higher. Presentation order of information would thus appear to be of importance. At first this result seems confusing: why should people hearing instructions of the form "Turn left at the garage" perform so much better than those hearing instructions of the form "At the garage turn left"? An information processing approach to the problem offers one possible explanation by considering the cognitive requirements of dealing with each instruction.

In both scenarios two separate pieces of equally important information have to be processed: the direction that we have to turn in order to follow the correct route, and the junction (landmark) at which we have to carry out this action. Separately, the two pieces of information are useless: it is only when they are integrated that we are able to make use of them. In order for this integration process to take place, the first part of the instruction must be received, processed and stored in working memory while the second piece of information is similarly operated upon. Clearly, if the first piece of information is easy to process then cognitive resources are made available for the processing of the second piece of information. Conversely, if the first piece of information is ambiguous, or requires some degree of interpretation (and thus additional processing) before it can be stored in working memory, then the cognitive resources available to deal with the second piece of information will be reduced. Indeed, one could argue that, if there is ambiguity in the first piece of information the second piece of information may not be attended to and so could be missed.

From this perspective it is clear that those in the direction-landmark group have a distinct advantage. The first part of each instruction delivered consists of a two-word phrase: either 'turn left' or 'turn right'. This information is easily processed, and because it is short, is easily stored in working memory while the second part of the instruction is being attended to and processed. Integration of the two pieces of information can thus begin immediately the second piece of information is processed. In the reverse situation, the first piece of information to be processed is much longer, up to 7 words long as opposed to a maximum of two. The information is also more open to interpretation, and may require visual search to pinpoint the location of the landmark being referred to (although, by definition landmarks should be visually distinctive and easily

recognised). As this information is being processed the second piece of information is being delivered. While this is short and easy to process, cognitive resources may still be attending to and processing the initial part of the instruction, thus leaving less attention available to deal with the turn information. As a consequence, storage of the message is poor and retrieval of the information may suffer. In short, the link between the two vital pieces of information is weak, resulting in potential storage and retrieval problems. Given that making estimates of directions between landmarks on different routes depends upon the integration of separately acquired information into a configurational whole, this result supports the view that guidance instructions linking directions to landmarks can enhance the formation of cognitive maps.

8.6.2 Group differences

Driving experience

Experiment I identified group differences due to age and ability to drive. Experiment II therefore concentrated upon creating a homogeneous sample in order to reduce group differences and to enable the information conditions to be focused upon. The success of this effort is shown by the increased number of effects due to information condition. However, analysis of the experiment II results also revealed differences between driving groups. Analysis of variance showed that, for the blue route sequencing task, subjects who had been driving for 1 year or less performed significantly poorer than those who had been driving for between 2 and 5 years. For the blue route pointing task direction estimates of those who had been driving for a year or less were significantly less accurate than those with 5 years' driving experience. In addition, those with only a year's driving experience recalled and correctly located significantly fewer landmarks than more experienced groups. However, there were no differences between these groups in their performance of the cross route pointing task. In each of these results one of the experienced driving groups performed significantly better than the control group who had least driving experience. It could be argued that for the results to be significant both experienced driving groups would have to have performed significantly better than the control group. This would certainly be the case if it had been hypothesised that spatial ability simply increases with driving experience. However, the hypothesis was that newly qualified drivers have not yet automated the driving task, and so for them driving still makes demands upon the available attention resources. Consequently, this group have yet to show an improvement in wayfinding skills because their attention is still predominantly focused towards maintaining safe control of the vehicle. For this reason the fact that the results are not consistent (in terms of which of the more experienced groups performed best) is not so important.

An alternative but compatible perspective is offered by researchers in the Netherlands (Wierda and Aasman, 1992) who have posited a difference in the visual information processing capabilities of newly qualified and experienced drivers (see chapter 3). From this perspective, driving experience is considered to facilitate the development of multiple channels of processing, while inexperienced drivers have only a single processing channel with which to address information. If this is the case then it would help to explain the results of the present research – new drivers have not yet developed these multiple channels and so are less adept at acquiring salient route information which will enable them to remember the route. Moreover, the presence of audible information would require a second channel to be available for processing this additional information. Inexperienced drivers would be expected to experience more difficulties with this information than experienced drivers.

Even so, the results do not offer particularly strong evidence in support of the hypothesis. If driving experience enhanced cognitive mapping ability per se, then we would expect the biggest group differences to occur on the cross route pointing task, as this is the task which most conclusively tests configurational knowledge. Whilst differences were evident on the other measure of configurational knowledge (map sketching task) someone with accurate route knowledge could conceivably score reasonably well on this task by having very good knowledge of one route, without demonstrating the ability to integrate the knowledge acquired from the 3 routes. From these results one might conclude that increased driving experience enhances route knowledge but has no effect upon ability to integrate knowledge of several routes into configurational knowledge of the area as a whole. However, this explanation would not account for the lack of differences on single route tasks for the other routes. Consequently, although there is some evidence to suggest differential performance between drivers of different levels of experience, the evidence is not sufficient to enable any firm conclusions, but suggests that further research would be required.

Age

Age was a significant variable on the single route (green route) pointing task, on the cross route pointing task, and on the sketch map task. As with experiment I younger subjects performed better than older subjects. Given the age range of the sample it was a little surprising that there was still a strong age effect. However, it should be noted that actual group differences were quite small on each of these tasks, and it was only when post-hoc analysis using the LSMEANS and TDIFF procedures was undertaken that larger differences were revealed, suggesting that other factors

such as driving experience were being taken into account by the post-hoc analysis. Note also that, with the exception of the green route pointing task, age group differences were not evident on any of the single route tasks. Experiment I showed that older subjects experienced most difficulties at the tasks measuring configurational knowledge and it was concluded that age-related declines in working memory were responsible for this inability to integrate the information acquired from the three separate routes. The results of experiment II appear to suggest a similar effect, but in a sample with a much smaller age range. Previous research into the effects of ageing upon spatial ability (Kirasic, 1991) suggests that this age-related decline in working memory is not apparent until much later life, and so this seems an unlikely explanation for the difference in results.

It is possible that the two groups differed in other ways. In particular, the 18-21 year olds were all undergraduates, while the group of 22-35 year olds was composed of undergraduates, postgraduates studying for Masters degrees, doctoral students and post-doctoral researchers. It is clear that the University operates a different recruitment procedure for these two groups. Competition for undergraduate places is fierce, with the result that Imperial College undergraduates typically require 3 very high grades at A level (the exams taken in British senior schools at age 18) or equivalent. Whilst there is also competition for places on Masters and Doctoral programmes, this is much less intense, and other factors (such as availability of funding and previous work experience) might be taken into consideration in selecting candidates. There is no evidence to suggest that spatial ability is linked with educational ability, (or for that matter, IQ) but it is possible that the group aged 18-21, who have already demonstrated an aptitude and enthusiasm for passing exams, may also demonstrate similar qualities with regard to the problem solving tasks employed in these experiments. The very nature of the experimental tasks may have appealed to the problem solving skills of this group. That said, the two groups are still likely to be more similar to each other than they are to the wider population of the same age range. For this reason it would be unwise to extend the results of the research to other groups.

Gender

The evidence for gender differences in wayfinding skills is very mixed and appears, in part, to be dependent upon the nature of the tasks used to test participants. Previous research has produced conflicting results regarding gender differences in wayfinding tasks. Male superiority at spatial tasks involving mental rotation has been demonstrated (Hyde, 1990; Masters and Sanders, 1993; Voyer *et al.*, 1995), Lawton *et al.*, (1996) have recently shown that males are more accurate than women in direction estimation, while female superiority with regard to recall of landmarks has been shown (Galea and Kimura, 1993). The results of the present research offer support for some

of these findings, but the results also suggest that more attention should be paid to the effect of driving experience upon task performance.

Experiment I identified gender differences on both the single and cross route pointing tasks (males being more accurate) and on the sketch map task (males recalling more landmarks than females). However, when male and female drivers were compared, experiment I found no gender differences. Experiment II, concentrating specifically upon drivers, found no gender differences (except for the green route time estimation task, on which females were more accurate). The results suggest that driving enhances wayfinding performance and cognitive mapping ability generally. Consequently, older males would be expected to perform better than older females due to differences in driving experience: older males being more likely to have been drivers before older females. From this perspective, the fact that women nowadays are as likely as men to drive could account for the lack of group differences in younger subjects.

Alternative explanations could be proposed to account for the results, although these explanations seem less plausible. The tasks used in the experiment did not favour female subjects. If anything, past research (Linn and Petersen, 1985; Voyer *et al.*, 1995) suggests that males should have been better at the tasks measuring mental rotation ability (i.e. pointing tasks). This was certainly the case when driving ability was not taken into account. However, when male and female drivers were compared, there were no gender differences in performance of the pointing tasks. It is likely that the male and female groups in experiment II are not representative of the general population of males and females. Whilst this may be true, it alone would not account for the results above.

Alternatively, one could argue that the females in this study are more like males than other females, or *vice versa*. One would have to state clearly in what ways the two groups are so similar. Clearly, they all attend the same institution, and can be considered to be of similar intelligence levels. The fact that most were science students could also have contributed to the similarity: past research (e.g. Wilson and Canter, 1990) has shown that there are similarities in the way that individuals from the same occupation group conceptualise and solve problems.

In summary, it is true that the male and female subjects in this study are all from the same educational institution, and are thus likely to be selected from a narrower range of intellectual ability than is evident in the general population. It is true that all were scientists and as a consequence could be considered to be more similar than two randomly chosen groups of males and females. These factors all serve to minimise the differences between the groups, with one

exception: gender. If differences between the two groups had been found then one could argue quite strongly that the effect was due to the only significant difference between the two groups and so differences in performance of a task could be attributable to this independent variable. It is precisely because of the similarities between the two groups that the lack of gender differences is of importance. All things being equal, when like is compared with like, no differences between male and female subjects were found. Little reference has been made to driving ability in previous studies of gender differences in spatial ability. Further research could pursue this line of enquiry, to establish whether driving experience does indeed reduce gender differences in spatial abilities such as wayfinding.

8.6.3 Time estimation

The most important finding regarding estimation of journey time was that accuracy of time estimates was related to the quantity of information heard whilst watching the videos. Subjects who heard no information (control) were most accurate, those who heard directions accompanied by landmarks or *vice versa* were less accurate, and those who heard full guidance instructions were least accurate of all. For the red and blue routes the control group and full guidance group were significantly different from one another, suggesting that the latter group's time estimates were significantly affected by the information they heard.

The prevalent model of the perception and estimation of time, the attentional allocation model, discussed in section 4.4.2, suggested that time estimation accuracy is directly affected by quantity of information seen. The attentional allocation model of time estimation was proposed as a result of experiments involving subjects estimating very small durations, but it is reasonable to assume that a similar process might be involved when larger durations are estimated. The present study compared subjects' ability to estimate journey times whilst *hearing* different levels of information. The results show that accuracy of time estimation is affected not only by the quantity of visual information to be simultaneously attended to, but also by the quantity of audible information heard whilst attending to visual information. This is an important finding because the attentional allocation model refers specifically to visual information and distinguishes between two processors: a visual information processor and a temporal processor, or timer. The results of the present study suggest that additional information does not have to be in visual form to have an impact upon temporal estimation.

These results suggest that the distinction made by Thomas and Weaver (1975) between visual and

temporal information processors may be too narrow and limiting. Clearly, the visual information processor alone would be incapable of handling auditory information. Therefore, there must be a third processor in operation, or the 'visual' processor must be a general 'information' processor, which does not discriminate between various possible sources of information. The results of experiment II offer convincing evidence that the presence of complex, salient, audible information has an impact upon time estimation ability, whereas simpler audible information does not have this effect.

However, it is also important to consider possible alternative explanations for these results. The two types of information used in experiment II differ not just in terms of the complexity of the information presented to subjects, but also in terms of references made to distance information. The full guidance group heard information regarding the distance to the next turn (e.g. "Turn left in 50 metres"). Whilst some subjects in this group admitted to having used this information to estimate journey distance, it is evident that the same information may have caused them to overestimate journey durations. Section 4.4.2 reviewed research showing that distance estimates are affected by amount of spatial detail encountered along the route (e.g. Briggs, 1973; Canter and Tagg, 1975; Milgram, 1976; Canter, 1977; Byrne, 1979; Thorndyke, 1981) and it was suggested that a similar effect might be operating with regard to journey time estimations. Section 4.4.2 also suggested that journey time estimates are likely to utilise all information available to us, inferring journey times by using information about the distance and speed travelled. The distance estimation task immediately preceded the time estimation task, and so it is highly likely that time estimates were in part based on these distance estimates. The distance estimates of the full guidance group were comparatively accurate, which might lead one to conclude that time estimates for this group would be equally accurate. The results showed that this was not the case – red route time estimates for this group were significantly less accurate than all other groups and for the blue route they were significantly less accurate than the control group. It is possible that the presence of distance information in the full information condition prompted this group to focus attention on accurately estimating distance with the consequence that they gave less attention to the accuracy of their time estimates.

8.6.4 Generic spatial knowledge

The results offer little support for the view that previous experience of similar spatial layouts enhances ability to learn novel but similar environments. Effects due to primary residence were only apparent on the red route sequencing task, time estimation task (red and green routes) and the

sketch map task. The only tasks on which the hypothesis was supported were the red and green time estimation tasks. There seems little obvious reason why subjects whose primary residence was outside Europe would perform so poorly at this task, when their performance at the majority of the other tasks (including the major indicator of performance, the cross route pointing task) was not significantly different from the other groups. Possible differences in language ability would not be an issue in time estimation and so it is difficult to find plausible explanations for this result.

With regard to the sketch map task, the group mean number of correctly placed landmarks recorded by European residents was significantly different from the other two groups. Of the results for which nation was a significant variable this is the most important task, in that it involves the integration of knowledge. The results of this task did not support the hypothesis, European subjects performed significantly better than UK residents or those of the group from the Rest of the World. Clearly, if the theory of generic spatial knowledge were correct then European residents would perform significantly poorer than UK residents. The fact that their performance was actually significantly better suggests that either there is little validity in the hypothesis (the most likely explanation), or that this group of European residents were not representative of Europeans generally. If European and UK residents had performed comparably but both had performed significantly better than non-Europeans, then it could be argued that European towns (either in UK or on mainland Europe) are much more similar than had been predicted, but are significantly different from cities outside Europe. Alternatively it could have been argued that language problems could account for these differences or that individuals from outside Europe failed to include as many landmarks on their maps, not because their spatial knowledge was poor, but perhaps because of cultural differences, or differences in emphasis. The poor performance of UK residents, however, suggests that the hypothesis is flawed and the null hypothesis should be accepted.

Methodological issues

The experimental procedure used in these experiments is not without its problems. The use of video, whilst enabling many individuals to acquire a good degree of configurational knowledge of a previously unfamiliar area, also conveyed the impression that roads were much longer than reality. This was not a major problem: all participants were subject to the same conditions and no comparisons were made between these groups and the wider population. It was recognised that the experiment could only approximate the experience of wayfinding in the real world: the vast quantity of information present in the real environment could not be conveyed in its entirety on a

video film of the routes. Nor would this have been acceptable. The experiment required that all subjects saw the same routes and the same details on each route. This would have been impossible if each subject had travelled the real routes.

The extent to which the videos accurately simulate the wayfinding experience, and in particular the experience of receiving route guidance instructions whilst wayfinding, is a matter for debate. Efforts were made to approximate the real world experience. Participants were given instructions which encouraged them to treat the experience as a wayfinding exercise, and to seek out information which would help them remember the journeys they travelled and how these were connected. In addition, before watching each route, they were given a simplified map showing the start point and destination for the route they were about to see. This combination of pre-trip instructions and simplified map was provided in an attempt to give purpose to the exercise and was designed in response to criticism levelled at the original experimental design.

The combination of instructions and maps was quite successful as a means of adding purpose to the experiment. The pre-trip instructions made the exercise more like a real-world wayfinding exercise, while the simplified map enabled subjects to place the route within a wider frame of reference. Without it, participants would have had little understanding of why the route was taking a particular turning or travelling in a particular direction. It should be made clear, however, that the map was of little use on its own, showing only two points and no spatial detail such as roads or landmarks: this detail had to be acquired from watching the videos.

8.7 Conclusions

Experiment II was designed to test the hypothesis that incorporating landmarks into route guidance instructions would help subjects to acquire a cognitive map of the study area. The results offer some support for this hypothesis. The most important of the tasks performed in the experiment is the cross route pointing task, which requires subjects to integrate the information they have acquired from the three separate routes into a configurational representation of the study area. The results of this task suggest that instructions of the form "Turn [Direction]at the [Name of Landmark]" did not have a beneficial effect, with there being no significant differences between the group who heard these instructions and those who heard no information Furthermore, the results suggest that order of presentation of this information is of importance. Subjects who heard the same information but in the form "At the [Name of Landmark] turn [Direction]" did not

benefit from the instructions.

Evidence to support the hypothesis relating to the effects of driving was limited and not wholly satisfactory. The results suggest that increased driving experience does have some effect upon performance of tasks measuring route knowledge (sequencing and pointing tasks), but these results were not conclusive and it is clear that further work focussing specifically upon this issue would be necessary before any firm conclusions could be drawn. Similarly, there was only limited support for the hypothesis relating to generic spatial knowledge and again, further experimentation involving a larger, more equally distributed sample is required.

The results did provide support for the hypothesis relating to the effects of information upon time estimation. These results support the theory of attentional allocation (Thomas and Weaver, 1975) but suggest that the theory might be too limited in its proposal of the existence of two information processors: a visual information processor and a temporal processor. The present results confirm the hypothesis that information need not necessarily be in visual form for it to have an impact on time estimation ability – audible information was shown to have an impact upon this ability.

Experiment II succeeded in creating a sample of subjects who were more homogeneous than the sample used in experiment I. Whilst, as intended, this approach focused attention upon the effects of the guidance information, with hindsight this may not have been the best approach. Given that experiment I identified age-related problems in ability to perform the various tasks (particularly those measuring configurational knowledge), it might have been better to recruit a larger sample of older adults and to see whether the amended instructions improved their performance of the various tasks. The aim of the strategy adopted for experiment II was to limit individual differences with regard to spatial ability, and to thus focus upon the information conditions, but in doing so a group was selected who had relatively little difficulty in performing the various tasks. Consequently, the potential for improvement that could be associated with instruction condition was limited.

The final chapter of this thesis will provide an overview of both experiments and attempt to draw together conclusions from the various findings, offer guidelines for future development of the audible interface, and suggest possible lines of enquiry for further research.

9 SUMMARY, CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

The previous two chapters presented the results of this research, summarised these findings and reconsidered the research hypotheses in light of them. This final chapter summarises the research approach taken, links the present results to previous research, and sets out conclusions and recommendations that can be drawn from the results. The chapter is divided into five sections. Section 9.1 summarises the research approach taken in the project. Section 9.2 reconsiders the three central research questions, and offers conclusions in light of the research findings. Section 9.3 considers novel aspects and limitations of the study. Section 9.4 offers a set of recommendations regarding the effect of audible route guidance for future IVRGIS design and implementation. Finally section 9.5 discusses possibilities for future research.

9.1 Summary of research approach taken

This research project started from the broad viewpoint that, whilst transportation researchers had predicted that benefits will arise as a result of the introduction of audible route guidance into vehicles, very little research has considered the possible impact that audible route guidance might have on cognitive processes. The focus of the research was sharpened in the form of research questions identifying specific issues needing to be addressed. These were:

1. What impact will listening to audible guidance instructions have on the underlying cognitive processes that govern spatial behaviour?
2. Are all groups equally capable of using audible route guidance information?
3. Are the detailed instructions currently in use in route guidance systems the most effective?

These research questions led to the development of a methodology consisting of research objectives which would address these issues. These research objectives were:

- to carry out a literature review of research capable of informing the questions. Research in three areas (transportation, human factors and spatial cognition) was reviewed (chapters 2, 3 and 4 respectively);
- to identify gaps and weaknesses in existing knowledge and to use the knowledge gained from these reviews to develop hypotheses
- to design experiments suitable for investigating the possible effects of audible guidance on the processes which govern spatial behaviour.

9.1.1 Gaps and weaknesses in existing research

- The review of transportation research showed that while transportation researchers appear to have recognised the importance of cognitive maps to spatial behaviour, there is generally poor understanding of these underlying cognitive processes that shape spatial behaviour.
- The transportation review also identified a general lack of in-depth research analysing the impact of IVRGIS on these processes.
- The review of human factors research highlighted the prevalence of Multiple Resource Theory (Wickens, 1984) in the development of IVRGIS, but - with regard to audible route guidance instructions - noted that there has been little attempt to evaluate this theory.
- The review of human factors research suggested that certain groups - elderly drivers in particular – might experience problems coping with the information provided by route guidance systems, but again, with regard to audible information little research had explored these issues.
- The review of cognitive mapping literature noted a lack of research which has considered the impact of audible information on the cognitive mapping process.
- The review of cognitive mapping research also highlighted conflicting results with regard to group differences in wayfinding and navigation abilities. A degree of disagreement among researchers was noted as to the extent of the effect of ageing on the cognitive mapping process. There was also some disagreement regarding differences between men and women in this ability.

The literature reviews identified the process by which we acquire spatial knowledge (i.e. cognitive mapping) as the cognitive process which underpins spatial problem solving behaviours such as wayfinding and navigation (Arthur and Passini, 1992) and was considered to be a particularly suitable process on which to observe the effects of route guidance information because:

a. Both cognitive mapping and ability to drive are spatial abilities, requiring the continuous appraisal and integration of information from multiple sources to enable the individual to reach a specific goal. Wayfinding and navigation abilities are likely to be developed by increased driving experience.
b. Transportation researchers (e.g. Schofer *et al.*, 1993) have suggested that ITS might have a beneficial effect upon the acquisition of cognitive maps.

c. To date research has failed to consider the effects of audible information on the cognitive mapping process and so, aside from the relevance to ITS, a study of the impact of audible route guidance on this process fills a gap in existing cognitive mapping research.

At this point it should be emphasised that the research was not attempting to investigate the effects of information upon driving performance or safety, but upon the underlying cognitive processes which govern spatial behaviour in general. As a means of studying the effects of information on these underlying processes it was decided that a dual-task paradigm was appropriate (see section 3.2.1), whereby two tasks were given to subjects: the primary task was to acquire a cognitive map of an unfamiliar area, and the secondary task (performed simultaneously) was to listen to route guidance instructions. Consequently the research considered the impact that various forms of audible guidance will have upon the cognitive mapping process.

A further review (chapter 5) considered methods available to study the process, as a result of which experiments were designed to test the effects of audible guidance on the acquisition and development of cognitive maps. Experiment I tested hypotheses relating to research questions 1 and 2, while experiment II tested hypotheses relating to research question 3, as well as testing new hypotheses formulated as a result of the findings of experiment I. Thus, the experiments met the final research objective: to study the effects of different types of audible guidance instructions upon the cognitive mapping process.

9.2 Conclusions

The research questions will now be reconsidered in light of the results of the experiments and conclusions will be made regarding these results.

9.2.1 RQ1: The impact of audible guidance instructions on cognitive processes

The first research question related to the introduction of audible guidance instructions and considered the impact these instructions will have upon underlying cognitive processes. With regard to the effects of information five hypotheses were proposed. Results (particularly the sketch map variable "Roads") showed that subjects were listening to the information presented to them and did recall some of this information. Subjects in the full guidance condition had the advantage of having heard the names of the roads and this was reflected in the high number of

road names included on this groups' sketch maps. However, while results showed that subjects were listening to the information, they also showed that for 4 of the 5 hypotheses the null hypothesis could not be rejected. Information group was a significant variable on three tasks, but post-hoc analysis showed that those subjects who heard full route guidance did not perform significantly better than others. These results lead to the following conclusion.

- **Full guidance instructions as currently used in IVRGIS do not have a positive impact on the underlying cognitive processes involved in wayfinding and navigation.**

It should also be stressed, however, that a number of the hypotheses specifically predicted that listening to full guidance information would have a *negative* impact on the cognitive mapping process. The results may not have shown any positive impact on cognitive maps, but nor did they offer conclusive support for the view that attending to audible route guidance would place additional demands on attention resources resulting in impaired primary task performance. The control group certainly recalled significantly more landmarks than other groups in the sketch map task (or more correctly, included more landmarks on their sketch maps – other groups may have recalled more landmarks, but did not include them). This finding would appear to support hypothesis 2b, which argued that the primary task performance of subjects who heard full guidance would be inferior to that of subjects in the control group, who heard nothing. Further support for a possible negative effect caused by attending to audible guidance was provided by an analysis of the performance of *similar subjects* across information conditions. Table 7.38 showed that the cross route pointing task group means of separate groups of male and female drivers were more accurate (closer to actual) when they heard either nothing (male drivers) or radio (female drivers) than when they heard route guidance. Overall, however, there was insufficient evidence to reject the null hypothesis and so it must be concluded that there were no significant differences between groups regardless of information condition.

In looking for explanations for these results one possibility put forward was that other variables (particularly age and driving ability) were having a strong effect on task performance that masked any group differences due to information condition. As a consequence it was decided that a second experiment should be conducted which would focus directly on the effect of different types of guidance information. In order to achieve this the second experiment recruited a sample of subjects with less variety in age and driving ability: the age range was reduced to 18-34 and all subjects were qualified drivers.

9.2.2 RQ2: Are the instructions currently used in IVRGIS the most effective?

In designing the amended instructions to be used in experiment II, previous human factors and cognitive mapping research (e.g. Alm, 1990, Alm and Berlin, 1991; Burnett *et al.*, 1994) was considered. An analysis of this research led to the conclusion that, to be most effective, route guidance instructions should make specific reference to visible landmarks as a means of strengthening the cognitive map acquired by subjects. It was argued that people regularly refer to landmarks in giving instructions and so should find it easier to understand and make use of instructions that include landmark information than guidance which provides distance information and refers to road names. The results of experiment II were disappointing: although information condition was a significant variable on the distancing task, single route pointing task, distance and time estimating tasks and the cross route pointing task, on the most important of these – the cross route pointing task - post-hoc analysis failed to show a significant effect due to particular conditions. The fact that information condition was significant on so many of the tasks, coupled with the number of statistics which approached significance, suggests that information condition was having some sort of an effect, but that it was inconclusive. Shorter instructions require less information processing (there being less information to process) and, because the information they provide is based around features visible in the immediate environment, they do not require re-coding to be incorporated into the cognitive representation. Furthermore, explicit reference to landmarks creates a link between visual information and verbal instructions, which assists the individual when (s)he has to recall the information.

A second group of subjects in experiment II heard the same information but in the reverse order (e.g. "At the garage turn left"). This group did not benefit from the instructions they heard. As a result it was concluded that the order in which route guidance information is presented can influence the effectiveness of the information. These results were examined (section 8.6.1) from an information processing perspective and it was concluded that processing the landmark information first was causing problems. When direction information was presented first subjects were quickly able to process this information because there was no ambiguity (the instruction being limited to turn left or turn right), and thus cognitive resources were free to deal with the second element of the instruction. By contrast, in information processing terms the landmark instruction was more complex, being composed of more elements, and was more ambiguous in that it required the subject to visually search for, locate and identify the landmark being referred to.

In summary the following conclusions regarding the effects of information can be made:

- The detailed guidance instructions currently used in IVRGIS did not enrich, enhance or have any positive effect on the cognitive maps subjects acquired of an unfamiliar area. The results of experiment I showed that there were no significant differences between groups hearing either route guidance, radio, a combination of the two, or hearing nothing;
- The results of experiment II were inconclusive. Although effects due to information condition were identified by the GLM, post-hoc analysis using the Tukey procedure failed to show a significant effect that could be attributed to one of the information conditions. Although non-significant, the direction of the many effects revealed suggests that further research should be carried out to explore the possibility that instructions linking directions to landmarks visible at the turning point can improve the quality of the cognitive map of an unfamiliar area as measured by tasks designed to measure configurational spatial knowledge.
- The same information presented in the opposite order did not have the same positive effect.

9.2.3. Are all groups equally capable of using audible route guidance information?

This question considered group differences in ability to use route guidance instructions. The human factors literature review (chapter 3) highlighted the difficulties that older subjects have been found to experience with wayfinding and navigation (e.g. Burns and Galer-Flyte, 1997), information processing and with IVRGIS generally (van Wolffelaar *et al.*, 1990). Chapter 4 also considered the wayfinding difficulties of elderly people from a cognitive mapping perspective and concluded that these problems were due to information processing limitations caused by an age-related decline in working memory.

In critically reviewing previous human factors research into IVRGIS it was noted that models of the behavioural effects of IVRGIS have been based on multiple resource approaches - but with little empirical research to support the conclusions. Research offered in support has invariably employed expert subjects (e.g. Allport *et al.*, 1972; Parkes and Coleman, 1990). The present research aimed to redress the balance by considering the impact of audible guidance on subjects from a much wider age range and with different levels of driving experience. Consequently it was expected that in experiment I there would be a wide range of scores at the various tasks. This was certainly the case, and age was identified as the best predictor of

performance. The 55 and over age group performed relatively poorly at all tasks, and especially poorly at the cross route tasks. Furthermore, whereas the single route task scores of younger subjects were correlated with their subsequent performance at the cross route tasks, the older subjects' single route scores were poorly correlated with subsequent cross route task performance. The cross route tasks involve the integration of information acquired from separate sources, a skill which depends on working memory, a cognitive resource which has been shown to decline with age (Baddeley, 1986). Consequently, experiment I provided convincing evidence for the importance of working memory to tasks which require simultaneous storage and operation functions. Older adults performed poorly at the various tasks regardless of information condition and it is possible to conclude that, whilst this group were able to acquire information from the individual routes, they were unable to integrate this information as required by the tasks measuring configurational knowledge.

The generally poor performance of older subjects makes drawing conclusions regarding the impact of audible guidance on this age group problematic, as their poor performance could be attributed to the tasks employed rather than the information heard. The results do confirm, however, that older adults experience more problems than younger adults with regard to wayfinding and navigation and it would be tempting to conclude that this was exacerbated by the presence of IVRGIS information. One might also conclude that older adults would experience more problems when presented with audible route guidance in a driving environment. However, neither of these statements can be fully supported with evidence from the present research. The results *suggest* that elderly drivers might experience more problems than other groups with additional information, due to the aforementioned working memory limitations, but the results of experiment I do not establish this conclusion. Similarly, as elderly adults were shown to have difficulties integrating information acquired from separate sources it would be reasonable to expect these same difficulties to be manifested in a driving environment, but the results of the experiments cannot lead to this conclusion. It is possible to conclude, however, that older subjects did not derive any benefit from the route guidance instructions, despite being the group who stood to benefit most given their poor cognitive mapping ability.

The results for subjects in the 55 and over age group also need to be treated with caution for other reasons. First, the sample size for this age group was relatively small (n=31) and was spread across four conditions. Second, the experimental design meant that only one sub-group

from this age group experienced each information condition and consequently the four conditions were experienced by subjects with different characteristics: one group each of male drivers; female drivers; male non-drivers; and female non-drivers. This makes it difficult to compare performances as they could be attributed to driving ability or gender. Third, it is likely that the educational level of this group was lower than that of the rest of the sample. While there is no evidence to suggest that IQ or educational level affect cognitive mapping ability it is certainly possible that younger subjects would be more at home with the test-like nature of the tasks. In summary, the results of the over 55 age group should be treated cautiously, and while it is clear that, as a group, the over 55's experienced major problems in cognitive mapping performance, there is no evidence to show that they performed significantly worse when required to simultaneously attend to audible route guidance information.

Driving ability was shown to be a significant factor in experiment I, with drivers performing significantly better than non-drivers at all tasks including the cross route pointing task. From this it is concluded that ability to drive enhances cognitive mapping ability as measured by the tasks employed in this experiment. Experiment II attempted to extend this result by considering drivers of different levels of driving experience, and hypothesised that the performance of young newly qualified drivers at the various tasks would be inferior to that of groups with more than 1 year's driving experience. Number of years' driving experience was significant on a range of tasks, with the group mean performance of those who had been driving for only a year or less significantly poorer than at least one of the more experienced driving groups on the blue route sequencing and pointing tasks, and the sketch map task. Only on the green route pointing task was there any variation from this: on this route the group mean of subjects who had been driving for 2-5 years was significantly worse than both the other groups. Taking all the results together it is clear that there is a degree of consistency in the findings, but that overall it would be safer to attribute the effects to chance. The evidence was insufficient to enable any further conclusions to be drawn regarding this group.

Nationality was another variable introduced in experiment II. It was hypothesised that subjects who had lived in the UK for the majority of their lives would have acquired extensive experience of spatial layouts similar to the study area It was hypothesised that this "generic spatial knowledge" (see section 4.2) would lead to the UK group demonstrating better route knowledge. It was further suggested that, because additional processing was required to turn this route knowledge into configurational knowledge, there would be less of an effect on tasks

measuring configurational knowledge. Nation was significant on a number of tasks and in each case the group from outside Europe performed significantly worse than the other two groups. However, the results were not conclusive. On some tasks subjects whose primary residence was in mainland Europe performed better than UK or Rest of the World subjects.

In summary, the results lead to the following conclusions regarding group differences in ability to acquire a cognitive map (primary task) whilst attending to route guidance instructions:

- Cognitive mapping ability declines with age. Comparison of subjects' performance of the single and cross route pointing tasks suggest that this is due to older subjects experiencing problems at the integration stage: this group found it difficult to integrate the information they had acquired from separate sources into a configurational representation. This integration ability is dependent upon working memory and the results offer support for the view (Kirasic, 1991) that an age-related decline in working memory capacity causes problems at the integration stage;
- Ability to drive enhances cognitive mapping ability as measured by the tasks employed in these experiments;
- Older adults' cognitive mapping performance was not enhanced by listening to route guidance instructions;
- The hypothesis that newly qualified drivers would experience more difficulties than experienced drivers in attending to route guidance whilst simultaneously performing a primary task was rejected;
- There was insufficient evidence to support the hypothesis that subjects whose primary residence was outside the UK would perform significantly poorer than UK residents at the various tasks.

9.2.4 The effects of information on time estimation accuracy

It was hypothesised (hypothesis 8) that subjects required to listen to audible guidance would make less accurate estimates of journey time than those who did not hear route guidance instructions. The results of experiment I failed to support this hypothesis, but experiment II provided strong support. The hypothesis was based on the attentional allocation theory of time estimation (Thomas and Weaver, 1975 – see section 4.4.2) and experiment II showed that the journey time estimates of subjects who heard full guidance instructions were significantly less accurate than all other groups. This group estimated journey times to be much longer than other

subjects. This result offers convincing support for the attentional allocation theory. However, the results do not simply support the theory, in the view of the author they extend it. Thomas and Weaver (1975) proposed that time estimation accuracy decreases as the quantity of *visual* information to be processed increases. The present results are important because they suggest that the theory can also be applied to *audible* information: as the amount of audible information to be processed increases so time estimation accuracy deteriorates. Clearly further research would need to be undertaken to investigate this issue in more detail, but for the present it can be concluded that:

- Time estimation accuracy is negatively affected by simultaneously attending to detailed audible route guidance instructions, but not by simpler instructions or by non-salient information (radio).

9.3 Novel aspects and limitations of the research

9.3.1 Novel aspects of the research

a) The use of video

Whilst a number of studies have compared the spatial knowledge acquired from video with direct experience of an environment (e.g. Goldin and Thorndyke, 1982; Ohta, 1983), this was the first study of its kind to attempt to convey spatial knowledge of an unfamiliar area using videotaped footage of journeys through that area. It is clear from the results, particularly the sketch maps, that the method was largely successful. Although the use of slides does have advantages (see section 5.3), use of the video methodology was vindicated by the number of subjects who were able to draw a reasonable representation of the whole area after viewing each route only twice. These subjects had acquired configurational knowledge of a previously unfamiliar area simply by watching film of three routes through that area. This is an important development in the battery of methodologies available to cognitive mapping researchers.

There are a number of reasons for the success of the method. Filmed footage has the distinct advantage of presenting a moving view of the environment, rather than static snapshots of a route. The dynamic nature of the films presented a more realistic view of the environment, and closely simulated the experience of travel through the area. Furthermore, the technique has the very distinct advantage of being the same for all who saw it, giving excellent experimental control.

Consequently, it is concluded that it is possible for subjects who are unfamiliar with an area to acquire configurational spatial knowledge of that area by viewing video footage of journeys through the area.

b) The use of three routes

One of the other novel aspects of this study was the use of three routes. Previous studies (e.g. Moar and Carleton, 1982; Golledge *et al.*, 1993) have only attempted to convey spatial knowledge of an area through the presentation of two interconnected routes through the area. Chapter 5 discussed the limitations and problems associated with the use of two routes and predicted a range of benefits to be derived from using three routes. The results of the experiments show that spatial knowledge developed over the course of the experiment, as additional links were made between existing knowledge (i.e. that gained from a previous route) and the spatial information obtained from the route being viewed. By the time subjects had seen all three routes not only had they gained knowledge of the individual routes, but they had also acquired multiple perspectives of the routes, enabling a more detailed and spatially accurate representation of the area to be formed. Most important of all – this knowledge was acquired after a very short space of time and after only two exposures to each route. This compares very favourably with the number of viewings employed by both Moar and Carleton (1982) and by Golledge *et al.*, (1993) in their experiments.

It is important to remember that the three routes were not chosen arbitrarily, but were designed with the specific purpose of enabling multiple representations of the area to be acquired. To this end all three routes crossed at one intersection (the T-junction by the Cross Keys pub). This was the only part of the area which was visible on all three routes, and it served as a focal point. This is no different from conventional research of this type, where two routes converge at a point. However, the use of three routes enabled the area to be traversed by routes beginning and ending in different directions (the red route started facing north and ended facing south; the blue route started facing east and ended facing west, and the green route started facing west and ended facing north), giving a far greater coverage of the area. The use of multiple perspectives enabled subjects to acquire a configurational knowledge of the area which involved the integration of information from each of these perspectives. This multiple perspective knowledge is more akin to the way in which spatial knowledge develops in real world settings.

The maps produced by participants in this experiment (for examples see Appendix XIV) showed evidence of configurational knowledge which was spread over a reasonably wide area and was not confined to knowledge of two simple linear routes. This is an important development from

previous research using two routes (e.g. Moar and Carleton, 1982; Golledge *et al.*, 1993) which has shown that subjects are able to integrate the information acquired from each route. The external representations produced from exposure to two routes tend to have the appearance of two routes integrated, and are limited to a thin corridor of experience rather than configurational knowledge of a wide area. Consequently, although technically the knowledge acquired is configurational knowledge, it could be criticised for being unrealistic. The use of three routes enables subjects to acquire configurational knowledge of a wider area, more like natural neighbourhood knowledge which would normally develop over a considerable time.

One of the objections which could be raised against the use of three routes is the extra information processing required to deal with the third route. For older subjects particularly, this may have been problematic, given that age has a negative effect on working memory, the cognitive resource which plays a key role in the formation of configurational knowledge. Older subjects did certainly have more problems with the tasks than younger subjects, but age-related research considered in chapter 4 suggested that this would probably have been the case with any experiment measuring cognitive mapping performance in an unfamiliar environment. The testing methods (particularly the sequencing and distancing tasks), enabled subjects to organise the information they acquired from each separate route. In addition, because a trade-off had to be made between the number of routes that could be shown and the number of times each route could be seen, subjects were only permitted to see each route twice, and each viewing was of a different aspect of the route. This meant that the viewing part of the experiment remained a relatively fresh experience. Other experiments, which have involved multiple viewings of the same route, might cause fatigue in subjects more readily than this experiment with its emphasis upon novel experience. In summary, the use of three routes - designed to cover a wide area - has the potential to provide more information than 2 routes, while enabling the same information to be presented to subjects in fewer presentations. These two advantages together make the method an attractive one for research into the spatial knowledge acquisition process.

Overall, the use of three routes was a success. The quality of the maps produced shows that it is possible to integrate the information acquired from three separately experienced routes into a configurational representation of an unfamiliar area. However, careful planning is required to ensure that 3 routes which interconnect at key points are plotted through the area, and that each route features a range of environmental uses and prominent landmarks. The success of using three routes suggests that it would be worthwhile to conduct a follow up study comparing the spatial

knowledge acquired by subjects viewing 2 or 3 routes through the same area.

9.3.2 Limitations of the research

Sample problems

It is important to stress that the research and the conclusions that can be drawn from the results do have limitations and that the research is not without its flaws. Regarding the limitations of the research, the sample employed in the experiments is not representative of the wider population. The majority of younger subjects came from one of the leading academic institutions in the UK, and it is clear that the group are not representative of people in this age group generally. The educational level attained by subjects in the 55 and over age group was very different from the youngest group, and also slightly different from the 22-54 age group, but not unrepresentative of the general population in this age group. Clearly, the educational opportunities available to today's young people are very different from those available when today's over 55's were of school age. In defence of this research approach, finding a significant healthy sample of subjects aged over 55 who had never driven (and who were not barred from doing so on medical grounds) was difficult: and to find males in this category was extremely difficult. Consequently, while it is acknowledged that the groups are more different in terms of educational qualifications than is desirable, the need to recruit a sample of older non-drivers made it inevitable that such differences would arise.

Laboratory-based research

It is also the case that the findings of the present research are limited by the fact that they were all achieved within a laboratory setting. Consequently, questions could be raised regarding their applicability to the real world. This is an issue which was given considerable attention at the outset of the project. It was clear that a trade-off was required between realism and control (see chapter 6 for a more detailed discussion of this issue) and that some realism could be maintained through the use of video, whereas experimental control would be lost if the experiment took place in a real world setting. Of more concern is the potential criticism that subjects would behave differently in a real world setting. Subjects were directed to concentrate on the visual element, and were encouraged to treat the experiment as a wayfinding exercise. However, it is possible that some subjects did not behave as they would have done if they were in a real-world wayfinding situation.

Variations in cognitive mapping ability

Although the review of the cognitive mapping process (chapter 4) had identified a number of variables which could affect the quality of cognitive maps, it is fair to say that prior to carrying out the research the author was of the opinion that most of this variation was due to differences between individuals in their goals and purposes with respect to a neighbourhood or in their familiarity with respect to that neighbourhood. This was one of the primary reasons for choosing to use a study area which was unfamiliar to all subjects. It was expected that this would reduce the variation between individuals. Experiment I showed, however, that the process of spatial knowledge acquisition itself was a process that varied greatly between individuals, even when all started from the same base knowledge level and were given exactly the same environment to learn. Experiment II attempted to reduce this between subjects variation by concentrating on a more homogeneous sample, with only partial success. Certainly this variation was minimised, but the range of scores at most tasks showed that cognitive mapping ability is affected by factors other than age and driving ability. This may account for the poor results in experiment II, particularly those related to information condition, where despite a significant effect being apparent in the analysis of variance, post-hoc analysis failed to show significant effects that could be attributed to a particular information condition.

9.4 Recommendations

The findings of this research project suggest a number of recommendations regarding the provision of audible guidance instructions. The following recommendations are made with the goal of maximising the potential benefits of in-vehicle route guidance whilst minimising the possible disbenefits.

1. Instructions should be kept short and should not be overly complex.

The results of experiments I show that full and detailed guidance does not have a positive effect on the cognitive mapping process. Experiment II showed that, with careful attention to the content, short guidance instructions can have some beneficial effects. In-vehicle guidance should offer system users sufficient guidance to enable wayfinding, but not so much guidance that the user is passive and development of a cognitive map is impaired. In order to avoid overloading or distracting the driver, effective guidance should balance quantity of information provided with the need for active exploration on behalf of the user, to facilitate cognitive mapping,

2. Instructions should make limited use of distance information

It was clear from the distance estimation tasks that people have great difficulty accurately estimating distances. Consequently, there is little value in referring to distances when giving instructions. Instructions of the form "Turn left in 400 metres" are less useful than those which refer to a visible landmark, for example "Turn left after the petrol station".

3. Make explicit reference to landmarks in guidance instructions

Wherever possible guidance instructions should make use of landmarks present at decision points. Landmarks provide a visual link to the information being heard, thus enabling associations to be made between this guidance information and the cognitive representation being acquired. The most effective landmarks in these experiments were those which were most prominent in terms of size, colour and context. The church and the petrol station were referred to by nearly all subjects – even by subjects whose maps were very poor. Consequently it is recommended that IVRGIS designers should refer to landmarks which:

a) are distinctive for **all** individuals;

b) do not require, or depend upon local knowledge; and

c) are likely to remain permanent for some considerable time.

3. Order of presentation of instructions

Experiment II also showed that careful consideration needs to be paid to the order of presentation of guidance which incorporates landmarks. The results showed that, in issuing route guidance instructions, the direction instruction (e.g. Turn left) should be presented first, followed by the landmark at which the turn should be made.

4. Make varying *levels* of information available

Contrary to research (Wochinger and Boehm-Davis, 1995) which has suggested that all individuals can cope with the same guidance, the present research has shown that different groups have very different abilities regarding wayfinding and navigation with and without the additional benefit of route guidance instructions. The diversity evident in people's cognitive mapping abilities suggests that varying levels of information should be made available, to suit the particular cognitive mapping skills of the individual.

5. Allow drivers to modify and adapt guidance to suit personal and situational requirements

The diverse range of purposes that individuals have with respect to a specific environment, or route, and the range of reasons that one might have for making a particular journey suggest that IVRGIS should incorporate a facility whereby guidance is adaptable to suit the particular requirements of the driver. An individual's *environmental role* (see chapter 4) needs to be considered as this will determine the kind of information and the kind of guidance required. Business or commuter drivers, for example, are likely to have different guidance criteria to tourists.

9.5 Directions for future research

9.5.1 The use of the video methodology in other fields

The use of three videos of interconnected routes has shown itself to be a useful addition to the battery of techniques which may be employed to study cognitive mapping, and the effects of hearing route guidance information upon this process. Indeed, by comparison with other techniques which have been employed in previous research the video method has proved to be capable of depicting a more realistic version of the environment, while retaining excellent experimental control. The success of the method suggests that it could be worthwhile to develop the technique as a standard tool for measuring spatial ability. Because the videos present a realistic image, but allow the experimenter to maintain complete control, it is possible to compare the performance of a wide range of individuals under the same conditions. Of particular interest to developmental psychologists would be the opportunity to study the performance of younger people at the various tasks, in order to explore the development of spatial ability and cognitive mapping skills. The same videos could also be used to study in more detail the effects of ageing upon spatial ability and cognitive mapping. It would thus be possible to build a comprehensive dataset of cognitive mapping and spatial ability across the full lifecycle. This dataset could also be used as a control or comparison group in the assessment of individuals with neuropsychological problems involving topographical disorientation. The use of three routes of differing complexity would enable researchers to assess the extent of subjects' ability to acquire route knowledge. The existence of a database of control group subjects would enable researchers to quantify the extent of the problem, while the experimental procedure would highlight whether subjects were having problems at the route knowledge acquisition stage, or whether they were able to acquire route knowledge, but were unable to integrate this information into a configurational representation.

9.5.2 Effects of amended guidance on the cognitive mapping performance of older drivers

The success of instructions which linked the direction of turn to a visible landmark showed that route guidance could have a beneficial effect. Unfortunately, due to time and financial constraints it was not possible to test whether these amended instructions would have had more of a beneficial effect on the cognitive mapping performance of older subjects than the guidance instructions used in experiment I. A possible direction for future research, therefore, is to test the conclusions made above regarding the effectiveness of these instructions by considering the effects of amended instructions solely upon a group of elderly drivers. One of the advantages of the video method is that the environment is the same, and so participants' performances can be compared regardless of when the experiments are carried out.

From a basic and uninformed view this research has progressed by developing research questions and a set of research objectives which could address these questions. Research in other areas was reviewed which improved understanding of the processes underpinning navigation, wayfinding and other spatial behaviours. A set of testable hypotheses were devised and a novel experiment designed to investigate the effect that attending to audible guidance has on spatial cognition and the cognitive mapping process. Hence, transportation research has been advanced by improving our understanding of processes which are often referred to but rarely considered in any detail by the discipline. Human factors research has been advanced by experiments which considered the behavioural impact of audible guidance, while cognitive mapping research has been extended by a consideration of the impact of audible information upon the cognitive mapping process. In addition, the range of methodologies available to cognitive mapping researchers has been extended and improved through the design of experiments which use video footage to convey a more realistic representation of the environment and three routes to enable a more naturalistic representation to be acquired.

The results of the experiments carried out have answered some of our questions regarding the effects of attending to audible information upon the cognitive mapping process, whilst raising many more. It is hoped that this project has made some contribution to the existing body of knowledge and that the methodological developments made will enable future research to further unravel the complexities of the process of spatial knowledge acquisition, its development and decline.

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Appendices

The following pages contain the materials used in the various tasks of this experiment. For binding purposes some of the materials have been reduced in font size.

APPENDIX I: EXPERIMENT CHECKLIST SHOWING THE SEQUENCE OF VIDEO PRESENTATIONS AND TASKS

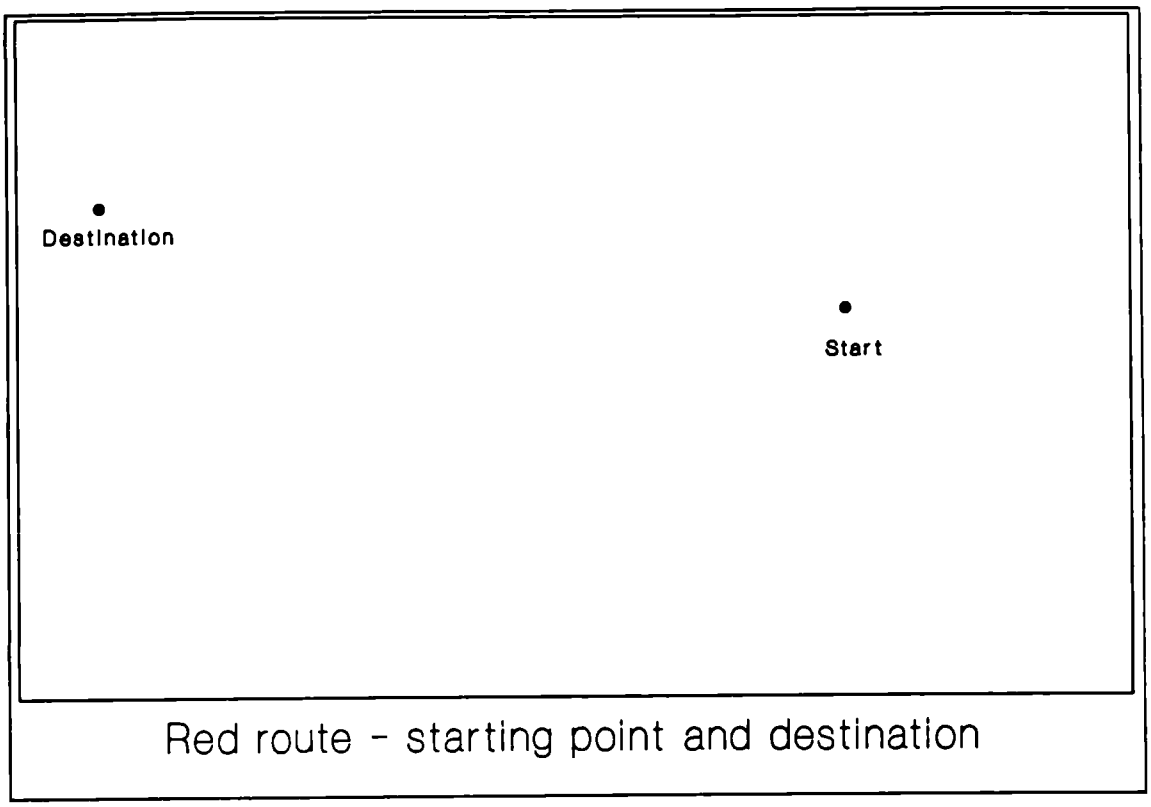
[ ]1 Give pre-trip instructions to subjects to read. Explain experiment.
Check if subjects are wearing a watch, if so ask them to hand in.
[ ]2 Show route map for first route.
If condition is RTI, give S's sheet for recording directions and instruct.
[ ]3 Show video for first route. Collect simplified map.
[ ]4 Give sequencing/distancing task instructions sheet.
[ ]5 Give subjects set of 10 photographs, a pen and a metre strip. Subjects do tasks.
[ ]6 Collect photographs in order they are set out.
[ ]7 Collect metre strips.
[ ]8 Give subjects single route pointing task instruction booklet.
[ ]9 Give subjects landmarks set for this route. Subjects do pointing task.
[ ]10 Collect photos and task book.
[ ]11 Remove cross route landmarks. This concludes the tasks for the first route.

[ ]12 Show subjects second route map.
If condition is RTI, give S's sheet for recording directions and instruct.
[ ]13 Show video for second route. Collect simplified map.
[ ]14 Give subjects set of 10 photographs and a metre strip.
[ ]15 Remind subjects to put name, start and end on the strip. Subjects do tasks.
[ ]16 Collect photographs in order they are set out.
[ ]17 Collect metre strips.
[ ]18 Give subjects single route pointing task instruction booklet.
[ ]19 Give subjects landmarks set for this route. Subjects do pointing task.
[ ]20 Collect photos and task book.
[ ]21 Remove cross route landmarks. This concludes the tasks for the second route.

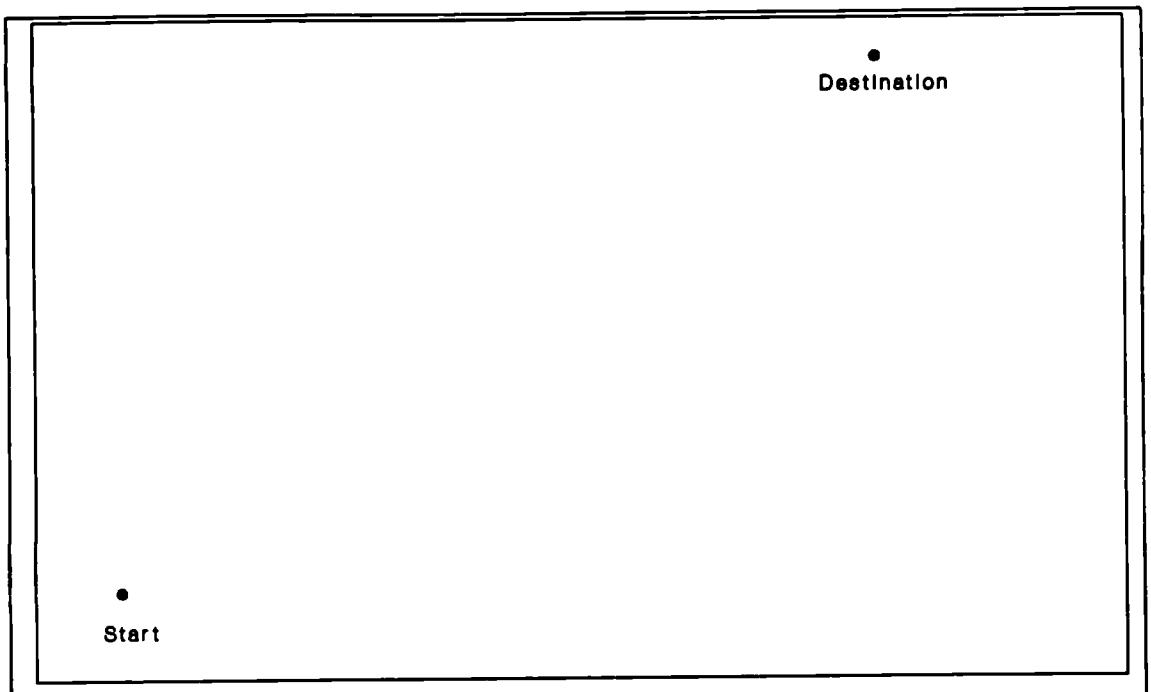
[ ]22 Show subjects third route map.
If condition is RTI, give S's sheet for recording directions and instruct.
[ ]23 Show video for third route. Collect simplified map.
[ ]24 Give subjects set of 10 photographs and a metre strip.
[ ]25 Remind subjects to put name, start and end on the strip. Subjects do tasks.
[ ]26 Collect photographs in order they are set out.
[ ]27 Collect metre strips.
[ ]28 Give subjects single route pointing task instruction booklet.
[ ]29 Give subjects landmarks set for this route. Subjects do pointing task.
[ ]30 Collect photos and task book.
[ ]31 Remove cross route landmarks. This concludes the single route tasks.

[ ]32 Give cross route pointing task sheet and cross route landmarks from each route.
[ ]33 Subjects do cross route pointing task.
[ ]34 Collect photos and task sheet.
[ ]35 Give questionnaire and sketch map sheet. Subjects complete questionnaire and sketch a map of the area.
[ ]36 Pay subjects and ask them to sign receipt form. Return watches.
[ ]37 Debrief subjects and show correct map. This concludes the experiment.

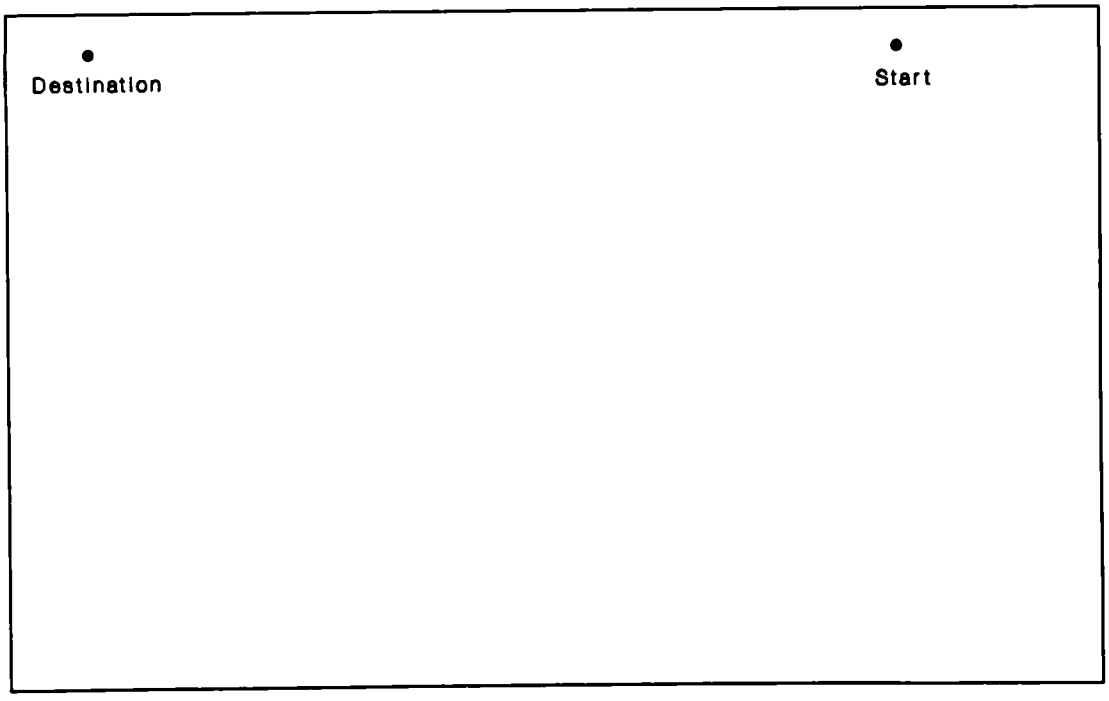
APPENDIX II: **EXAMPLES OF THE SIMPLIFIED MAPS USED IN BOTH PHASES OF THE EXPERIMENTS**



Red route - starting point and destination



Blue Route - starting point and destination



Green Route - starting point and destination

APPENDIX III: ROUTE SCRIPTS AS HEARD BY ADDITIONAL INFORMATION GROUPS

PHASE I: Full guidance instructions.

Script for Red Route

Current position: heading North on Standish Road
50 metres to T-Junction
At the end of the road turn left
Turn left into King Street
New position: heading West on King Street
50 metres to left turn
Turn left into Black Lion Lane
New position: heading South on Black Lion Lane
50 metres to junction
Continue straight ahead at junction
Follow road round to the right
New position: heading West on St Peter's Square
50 metres to right turn
Turn right into St Peter's Square
New position: heading North on St Peter's Square
50 metres to T-Junction
At the end of the road turn left
Turn left into St Peter's Square
New position: heading West on St Peter's Square
50 metres to T-Junction
At the end of the road turn left
Turn left into St Peter's Square
New position: heading South on St Peter's Square

Script for Blue Route

Current position: heading East on St Peter's Square
50 metres to left turn
Follow the road round to the left
New position: heading North on Black Lion Lane
50 metres to right turn
Turn right into St Peter's Road
New position: heading East on St Peter's Road
50 metres to crossroads
At the crossroads, continue straight ahead
50 metres to left turn
Follow the road round to the left
New position: heading North on Beavor Lane
50 metres to T-Junction
At the end of the road turn left
Turning left into King Street
New position: heading West on King Street

Script for Green Route

Current position: heading West on King Street
30 metres to left turn

Turn left into Standish Road
New position: Heading South on Standish Road
50 metres to Crossroads
At the Crossroads turn right
Turn right into St Peter's Road
New position: Heading West on St Peter's Road
50 metres to T-Junction
At the end of the road turn right
Turn right into Black Lion Lane
New position: Heading North on Black Lion Lane
50 metres to left turn
Turn left into St Peter's Villas
New position: heading West on St Peter's Villas
50 metres to T-Junction
At the end of the road turn right
Turn right into St Peter's Square
New position: heading North on St Peter's Square
50 metres to T-Junction

PHASE II: Amended instructions.

Script for red route: Landmarks followed by directions.

Current position, heading north.
At the garage, turn left.
At the red brick building, turn left.
Continue past the pub on the corner.
Heading south towards St. Peter's church.
Continue past the Cross-Keys pub.
Follow the road round to the right.
Take the first right.
At the T-junction, turn left, then left again.

Script for blue route: Landmarks followed by directions.

Current position, heading east towards St. Peter's church.
Follow the road round to the left.
Take the first right.
At the crossroads, continue straight ahead.
Continue past St. Peter's school.
Follow the road round to the left.
Continue past the building site on your left.
At the end of the road, turn left.

Script for green route: Landmarks followed by directions.

Current position, heading west.
At the garage, turn left.
At the crossroads, turn right.
At the Cross-Keys pub, turn left.
At the pub on the corner, turn left.
Continue ahead to the T-junction.
At the T-junction, turn right.

Script for red route: Directions followed by landmarks.

Current position, heading north.

Turn left at the garage.
Turn left at the red-brick building.
Continue past the pub on the corner.
Heading south, towards St. Peter's church.
Continue past the Cross-Keys pub.
Follow the road round to the right.
Take the first right.
Turn left at the T-junction, then left again.

Script for blue route: Directions followed by landmarks.

Current position, heading east towards St. Peter's church.
Follow the road round to the left.
Take the first right.
Continue ahead at the crossroads.
Continue past St.Peter's school.
Follow the road round to the left.
Continue past the building site on your left.
Turn left at the end of the road.

Script for green route: Directions followed by landmarks.

Current position, heading west.
Turn left at the garage.
Turn right at the crossroads.
Turn right at the Cross-Keys pub.
Turn left at the pub on the corner.
Continue ahead to the T-junction.
Turn right at the T-junction.

APPENDIX IV:

ACTUAL AND RATIO-SCALED DISTANCES BETWEEN PHOTOGRAPHS USED IN THE SEQUENCING AND DISTANCING TASKS.

RED ROUTE

Actual Distance from start	*Ratio-scaled Distance from start*
80	0.100
100	0.125
210	0.263
280	0.350
365	0.456
490	0.613
550	0.687
600	0.750
750	0.937
800	1.000

BLUE ROUTE

Actual Distance from start	*Ratio-scaled Distance from start*
0	0.000
90	0.150
200	0.333
235	0.392
280	0.466
315	0.525
380	0.633
450	0.750
500	0.833
600	1.000

GREEN ROUTE

Actual Distance from start	*Ratio-scaled Distance from start*
30	0.046
85	0.131
155	0.238
200	0.307
250	0.384
310	0.477
360	0.554
400	0.615
460	0.708
650	1.000

(All actual distance measurements are in metres)

APPENDIX V: INSTRUCTIONS AND TASK SHEETS USED IN THE POINTING TASKS

(After Tversky, 1981)

The following pages show the instructions sheets for the single route and cross route pointing tasks, followed by an example of the task sheet.

Instructions for the single route pointing task
Your name _____

Please answer the following questions and then read the instructions before turning the page.

This is the ..... route I have seen (enter either `first', `second' or `third').

Name of route: RED ROUTE BLUE ROUTE GREEN ROUTE
(circle one)

Please estimate the length in metres of this route .....metres / yards
(delete as applicable)

and estimate the time that the journey took: Route film took ....mins.....seconds
Landmark film took .....mins.....seconds

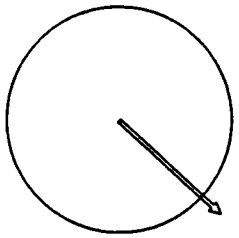
Each of the following pages has a circle with a dot at its centre and an arrow facing the top of the page. Each page also has a pair of letters at the top which refer to the photographs you have been given. Imagine that you are standing where the first photo was taken and that this position is at the centre of the circle. The direction of this photo is represented by the arrow. You are asked to `point' to the second landmark by drawing a straight line from the dot in the centre out in the direction that the target photograph is located. So, A->B means imagine you are standing at the scene in photo A, now point in the direction of the landmark in photograph B by drawing a straight line from the dot to the circle to represent this direction.

For instance if the landmarks were located:

A.

B.

You would draw...



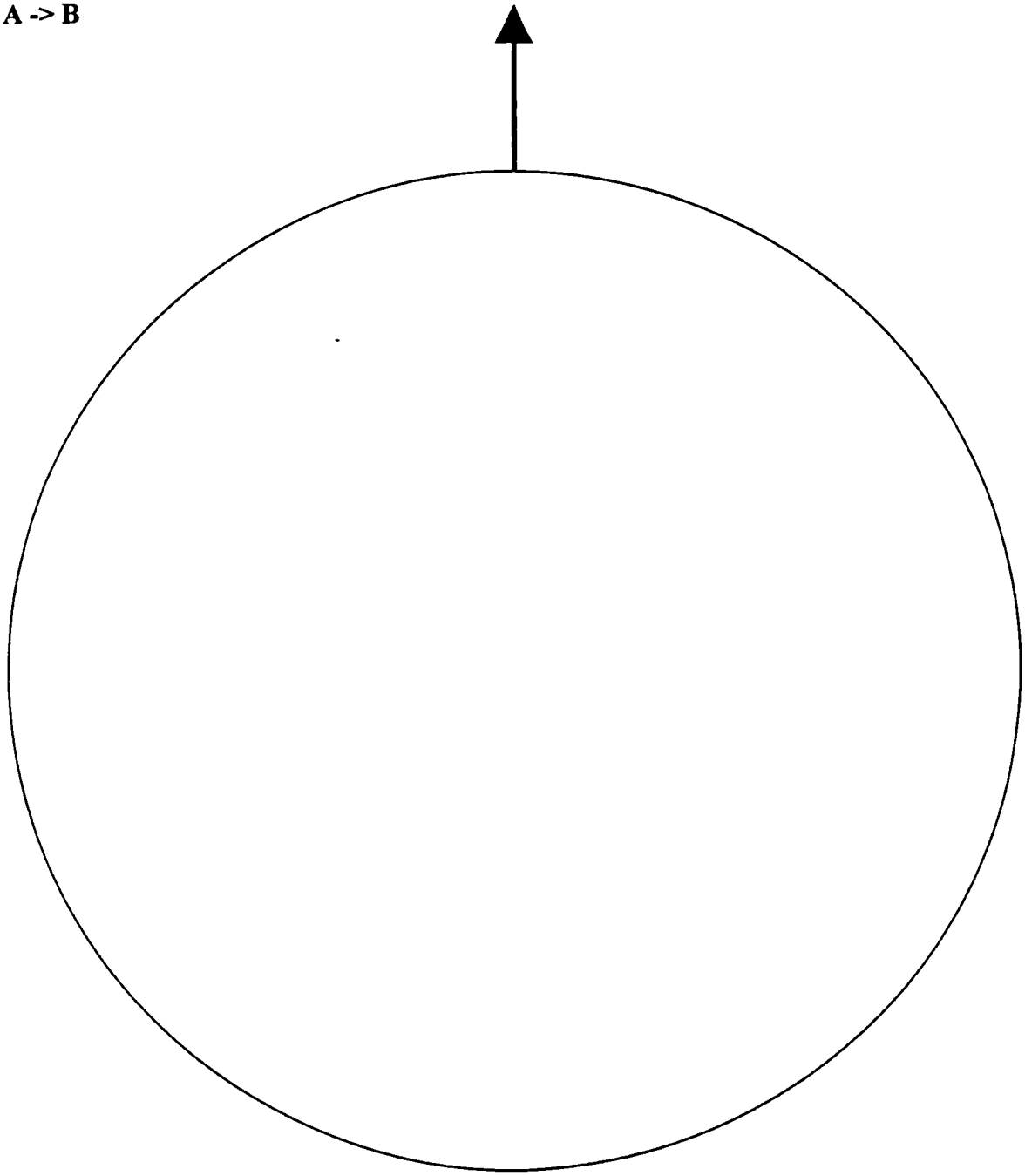
No_____

SPATIAL KNOWLEDGE STUDY: CROSS ROUTE POINTING TASK

You have now seen all three routes and have made distance and direction judgements between points on each route. We now want you to try and estimate the direction of a landmark on one route to landmarks on the other routes. This booklet contains 24 pages (one per judgement). As before you will be shown a photograph from one route (referent) and asked to imagine that you are pointing to landmarks represented in other photographs (targets). However, this time the targets will be on a different route to the referent photograph.

As in the single route pointing tasks the photographs are labelled and each page in this booklet is labelled with a pair of locations (e.g. RA - GB) The first letters refer to the referent photograph (where you are to imagine yourself standing) and the second pair of letters refers to the target location to which you are asked to point. As before you do this by drawing a straight line from the dot in the centre of the page in the direction that you think the target landmark is located.

A -> B



APPENDIX VI: POINTING TASKS

I) LANDMARK PHOTOGRAPHS USED.
II) ANGLES BETWEEN PHOTOGRAPHS

I) LANDMARK PHOTOGRAPHS USED

Red route

JETABOUT
AIB
Bank
AIB
Bank
No Vehicle
Access To
Gt. West Road
B477 WYY
B

C

Blue route

B

C

Green route

Barton Office Equipment Co. 325
Barton Office Equipment Co
OFFICES TO LET
MARSH & PARSONS
LBE 0336
A

FULLER'S
THE CROSS KEYS
B

Khan's
C

Single route pointing tasks:

RED ROUTE:

RA-RB 176
RA-RC 141
RB-RA 328
RB-RC 95
RC-RA 142
RC-RB 126

BLUE ROUTE:

BA-BB 78
BA-BC 82
BB-BA 340
BB-BC 175
BC-BA 290
BC-BB 310

GREEN ROUTE:

GA-GB 124
GA-GC 174
GB-GA 4
GB-GC 307
GC-GA 331
GC-GB 37

Cross route pointing task

RA-BA 121	RC-BA 284	BA-RA 39	BB-RA 59	GB-RA 352	GC-RA 313
RA-BB 59	RC-BB 197	BA-RC 18	BB-RC 14	GB-RC 290	GC-RC 162
RA-GB 80	RC-GB 201	BA-GB 71	BB-GB 5	GB-BA 244	GC-BA 120
RA-GC 129	RC-GC 163	BA-GC 35	BB-GC 24	GB-BB 96	GC-BB 29

(All angle measurements are in degrees with the heading depicted in the referent photograph read as 90 degrees).

APPENDIX VII: LIST OF VARIABLES AND SAS SETUP FILE

```
/* SAS program to setup COGMAP data...
17 March 1995
*/

libname COGMAP  '~/work/ptrc95/datasets';
filename csv_data '~/work/ptrc95/rawdata/new.csv';

data COGMAP.test;
infile csv_data delimiter=',' missover lrecl=1000;
                                        input  S
                                          Sex
                                          Age1
                                          Age2
                                          AgeA
                                          AgeB
                                          AgeC
                                          Driver
                                          Years
                                         Howoften
                                          Towork
                                         Howmuch
                                          Prof
                                          Group
                                          Order

                                          RARB
                                          RARC
                                          RBRA
                                          RBRC
                                          RCRA
                                          RCRB

                                          BABB
                                          BABC
                                          BBBA
                                          BBBC
                                          BCBA
                                          BCBB

                                          GAGB
                                          GAGC
                                          GBGA
                                          GBGC
                                          GCGA
                                          GCGB
                                          RABA
                                          RABB
                                          RAGB
                                          RAGC
                                          RCBA
                                          RCBB
                                          RCGB
                                          RCGC
                                          BARA
```

BARC
BAGB
BAGC
BBRA
BBRC
BBGB
BBGC
GBRA
GBRC
GBBA
GBBB
GCRA
GCRC
GCBA
GCBB
RRD
BRD
GRD
RRRT
RRLT
BRRT
BRLT
GRRT
GRLT
RORDER
BORDER
GORDER
REDDIST1
REDDIST2
REDDIST3
REDDIST4
REDDIST5
REDDIST6
REDDIST7
REDDIST8
REDDIST9
REDDIST0
BLUDIST1
BLUDIST2
BLUDIST3
BLUDIST4
BLUDIST5
BLUDIST6
BLUDIST7
BLUDIST8
BLUDIST9
BLUDIST0
GREDIST1
GREDIST2
GREDIST3
GREDIST4
GREDIST5
GREDIST6
GREDIST7
GREDIST8
GREDIST9
GREDIST0

XRT_Mean
Roads
Landmark
Correct
Segments
Total;

```
RARB_X = 172;  /* RARB */
RARC_X = 150;  /* RARC */
RBRA_X = 324;  /* RBRA */
RBRC_X = 112;  /* RBRC */
RCRA_X = 243;  /* RCRA */
RCRB_X = 233;  /* RCRB */
BABB_X =  78;  /* BABB */
BABC_X =  82;  /* BABC */
BBBA_X = 340;  /* BBBA */
BBBC_X = 175;  /* BBBC */
BCBA_X = 290;  /* BCBA */
BCBB_X = 310;  /* BCBB */
GAGB_X = 145;  /* GAGB */
GAGC_X = 215;  /* GAGC */
GBGA_X = 210;  /* GBGA */
GBGC_X = 139;  /* GBGC */
GCGA_X = 120;  /* GCGA */
GCGB_X = 172;  /* GCGB */
RABA_X = 121;  /* RABA */
RABB_X =  59;  /* RABB */
RAGB_X = 102;  /* RAGB */
RAGC_X = 168;  /* RAGC */
RCBA_X = 357;  /* RCBA */
RCBB_X = 287;  /* RCBB */
RCGB_X = 303;  /* RCGB */
RCGC_X = 159;  /* RCGC */
BARA_X =  39;  /* BARA */
BARC_X = 360;  /* BARC */
BAGB_X =  66;  /* BAGB */
BAGC_X = 356;  /* BAGC */
BBRA_X =  59;  /* BBRA */
BBRC_X =  15;  /* BBRC */
BBGB_X = 355;  /* BBGB */
BBGC_X =  24;  /* BBGC */
GBRA_X = 200;  /* GBRA */
GBRC_X = 139;  /* GBRC */
GBBA_X =  68;  /* GBBA */
GBBB_X = 273;  /* GBBB */
GCRA_X = 121;  /* RCGC */
GCRC_X = 202;  /* GCRC */
GCBA_X = 213;  /* GCBA */
GCBB_X = 157;  /* GCBB */

If ABS(RARB_X - RARB) < 180 then d_RARB=ABS(RARB_X - RARB);
else d_RARB=360-ABS(RARB_X - RARB);
If ABS(RARC_X - RARC) < 180 then d_RARC=ABS(RARC_X - RARC);
else d_RARC=360-ABS(RARC_X - RARC);
If ABS(RBRA_X - RBRA) < 180 then d_RBRA=ABS(RBRA_X - RBRA);
else d_RBRA=360-ABS(RBRA_X - RBRA);
If ABS(RBRC_X - RBRC) < 180 then d_RBRC=ABS(RBRC_X - RBRC);
else d_RBRC=360-ABS(RBRC_X - RBRC);
```

```
If ABS(RCRA_X - RCRA) < 180 then d_RCRA=ABS(RCRA_X - RCRA);
else d_RCRA=360-ABS(RCRA_X - RCRA);
If ABS(RCRB_X - RCRB) < 180 then d_RCRB=ABS(RCRB_X - RCRB);
else d_RCRB=360-ABS(RCRB_X - RCRB);
If ABS(BABB_X - BABB) < 180 then d_BABB=ABS(BABB_X - BABB);
else d_BABB=360-ABS(BABB_X - BABB);
If ABS(BABC_X - BABC) < 180 then d_BABC=ABS(BABC_X - BABC);
else d_BABC=360-ABS(BABC_X - BABC);
If ABS(BBBA_X - BBBA) < 180 then d_BBBA=ABS(BBBA_X - BBBA);
else d_BBBA=360-ABS(BBBA_X - BBBA);
If ABS(BBBC_X - BBBC) < 180 then d_BBBC=ABS(BBBC_X - BBBC);
else d_BBBC=360-ABS(BBBC_X - BBBC);
If ABS(BCBA_X - BCBA) < 180 then d_BCBA=ABS(BCBA_X - BCBA);
else d_BCBA=360-ABS(BCBA_X - BCBA);
If ABS(BCBB_X - BCBB) < 180 then d_BCBB=ABS(BCBB_X - BCBB);
else d_BCBB=360-ABS(BCBB_X - BCBB);
If ABS(GAGB_X - GAGB) < 180 then d_GAGB=ABS(GAGB_X - GAGB);
else d_GAGB=360-ABS(GAGB_X - GAGB);
If ABS(GAGC_X - GAGC) < 180 then d_GAGC=ABS(GAGC_X - GAGC);
else d_GAGC=360-ABS(GAGC_X - GAGC);
If ABS(GBGA_X - GBGA) < 180 then d_GBGA=ABS(GBGA_X - GBGA);
else d_GBGA=360-ABS(GBGA_X - GBGA);
If ABS(GBGC_X - GBGC) < 180 then d_GBGC=ABS(GBGC_X - GBGC);
else d_GBGC=360-ABS(GBGC_X - GBGC);
If ABS(GCGA_X - GCGA) < 180 then d_GCGA=ABS(GCGA_X - GCGA);
else d_GCGA=360-ABS(GCGA_X - GCGA);
If ABS(GCGB_X - GCGB) < 180 then d_GCGB=ABS(GCGB_X - GCGB);
else d_GCGB=360-ABS(GCGB_X - GCGB);
If ABS(RABA_X - RABA) < 180 then d_RABA=ABS(RABA_X - RABA);
else d_RABA=360-ABS(RABA_X - RABA);
If ABS(RABB_X - RABB) < 180 then d_RABB=ABS(RABB_X - RABB);
else d_RABB=360-ABS(RABB_X - RABB);
If ABS(RAGB_X - RAGB) < 180 then d_RAGB=ABS(RAGB_X - RAGB);
else d_RAGB=360-ABS(RAGB_X - RAGB);
If ABS(RAGC_X - RAGC) < 180 then d_RAGC=ABS(RAGC_X - RAGC);
else d_RAGC=360-ABS(RAGC_X - RAGC);
If ABS(RCBA_X - RCBA) < 180 then d_RCBA=ABS(RCBA_X - RCBA);
else d_RCBA=360-ABS(RCBA_X - RCBA);
If ABS(RCBB_X - RCBB) < 180 then d_RCBB=ABS(RCBB_X - RCBB);
else d_RCBB=360-ABS(RCBB_X - RCBB);
If ABS(RCGB_X - RCGB) < 180 then d_RCGB=ABS(RCGB_X - RCGB);
else d_RCGB=360-ABS(RCGB_X - RCGB);
If ABS(RCGC_X - RCGC) < 180 then d_RCGC=ABS(RCGC_X - RCGC);
else d_RCGC=360-ABS(RCGC_X - RCGC);

If ABS(BARA_X - BARA) < 180 then d_BARA=ABS(BARA_X - BARA);
else d_BARA=360-ABS(BARA_X - BARA);
If ABS(BARC_X - BARC) < 180 then d_BARC=ABS(BARC_X - BARC);
else d_BARC=360-ABS(BARC_X - BARC);
If ABS(BAGB_X - BAGB) < 180 then d_BAGB=ABS(BAGB_X - BAGB);
else d_BAGB=360-ABS(BAGB_X - BAGB);
If ABS(BAGC_X - BAGC) < 180 then d_BAGC=ABS(BAGC_X - BAGC);
else d_BAGC=360-ABS(BAGC_X - BAGC);
If ABS(BBRA_X - BBRA) < 180 then d_BBRA=ABS(BBRA_X - BBRA);
else d_BBRA=360-ABS(BBRA_X - BBRA);
If ABS(BBRC_X - BBRC) < 180 then d_BBRC=ABS(BBRC_X - BBRC);
else d_BBRC=360-ABS(BBRC_X - BBRC);
If ABS(BBGB_X - BBGB) < 180 then d_BBGB=ABS(BBGB_X - BBGB);
```

```
else d_BBGB=360-ABS(BBGB_X - BBGB);
 If ABS(BBGC_X - BBGC) < 180 then d_BBGC=ABS(BBGC_X - BBGC);
else d_BBGC=360-ABS(BBGC_X - BBGC);
 If ABS(GBRA_X - GBRA) < 180 then d_GBRA=ABS(GBRA_X - GBRA);
else d_GBRA=360-ABS(GBRA_X - GBRA);
 If ABS(GBRC_X - GBRC) < 180 then d_GBRC=ABS(GBRC_X - GBRC);
else d_GBRC=360-ABS(GBRC_X - GBRC);
 If ABS(GBBA_X - GBBA) < 180 then d_GBBA=ABS(GBBA_X - GBBA);
else d_GBBA=360-ABS(GBBA_X - GBBA);
If ABS(GBBB_X - GBBB) < 180 then d_GBBB=ABS(GBBB_X - GBBB);
else d_GBBB=360-ABS(GBBB_X - GBBB);
If ABS(GCRA_X - GCRA) < 180 then d_GCRA=ABS(GCRA_X - GCRA);
else d_GCRA=360-ABS(GCRA_X - GCRA);
 If ABS(GCRC_X - GCRC) < 180 then d_GCRC=ABS(GCRC_X - GCRC);
else d_GCRC=360-ABS(GCRC_X - GCRC);
 If ABS(GCBA_X - GCBA) < 180 then d_GCBA=ABS(GCBA_X - GCBA);
else d_GCBA=360-ABS(GCBA_X - GCBA);
 If ABS(GCBB_X - GCBB) < 180 then d_GCBB=ABS(GCBB_X - GCBB);
else d_GCBB=360-ABS(GCBB_X - GCBB);

Red_Mean = Mean (d_RARB,d_RARC,d_RBRA,d_RBRC,d_RCRA,d_RCRB);
 Blu_Mean = Mean  (d_BABB,d_BABC,d_BBBA,d_BBBC,d_BCBA,d_BCBB);
Grn_Mean = Mean (d_GAGB,d_GAGC,d_GBGA,d_GBGC,d_GCGA,d_GCGB);
XRt_Mean = Mean (d_RABA,d_RABB,d_RAGB,d_RAGC,d_RCBA,d_RCBB,
                 d_RCGB,d_RCGC,d_BARA,d_BARC,d_BAGB,d_BAGC,
                 d_BBRA,d_BBRC,d_BBGB,d_BBGC,d_GBRA,d_GBRC,
                d_GBBA,d_GBBB,d_GCRA,d_GCRC,d_GCBA,d_GCBB);

                    R_dist = 800;   /* RRD */
                    B_dist = 600;   /* BRD */
                    G_dist = 650;   /* GRD */

                R_time1 = 302;  /* RRRT  (route version) */
               R_time2 = 406;  /* RRLT  (landmark version) */
                    B_time1 = 243;  /* BRRT */
                    B_time2 = 313;  /* BRLT */
                    G_time1 = 275;  /* GRRT */
                    G_time2 = 376;  /* GRLT */

                     d_R_dist = -(R_dist - RRD);
                     d_B_dist = -(B_dist - BRD);
                     d_G_dist = -(G_dist - GRD);

                   d_R_tim1 = -(R_time1 - RRRT);
                   d_R_tim2 = -(R_time2 - RRLT);
                   d_B_tim1 = -(B_time1 - BRRT);
                   d_B_tim2 = -(B_time2 - BRLT);
                   d_G_tim1 = -(G_time1 - GRRT);
                   d_G_tim2 = -(G_time2 - GRLT);

                  R_SeqOK = (Rorder = 1234567890);
                  B_SeqOK = (Border = 1234567890);
                  G_SeqOK = (Gorder = 1234567890);

        RScore = 0;
        BScore = 0;
        GScore = 0;
        do i = 1 to 9;
```

```
if (int(Rorder/10**(10-i)) - int(Rorder/10**(11-i))*10) = i then
RScore = RScore+1;
if (int(Border/10**(10-i)) - int(Border/10**(11-i))*10) = i then
BScore = BScore+1;
if (int(Gorder/10**(10-i)) - int(Gorder/10**(11-i))*10) = i then
GScore = GScore+1;
end;
if (Rorder - int(Rorder/10)*10) = 0 then RScore = RScore+1;
if (Border - int(Border/10)*10) = 0 then BScore = BScore+1;
if (Gorder - int(Gorder/10)*10) = 0 then GScore = GScore+1;

        OScore = RScore + BScore + GScore;

        R_dis1 = 0.100;
        R_dis2 = 0.125;
        R_dis3 = 0.263;
        R_dis4 = 0.350;
        R_dis5 = 0.456;
        R_dis6 = 0.613;
        R_dis7 = 0.687;
        R_dis8 = 0.750;
        R_dis9 = 0.937;
        R_dis0 = 1.000;
        B_dis1 = 0.000;
        B_dis2 = 0.150;
        B_dis3 = 0.333;
        B_dis4 = 0.392;
        B_dis5 = 0.466;
        B_dis6 = 0.525;
        B_dis7 = 0.633;
        B_dis8 = 0.750;
        B_dis9 = 0.833;
        B_dis0 = 1.000;
        G_dis1 = 0.046;
        G_dis2 = 0.131;
        G_dis3 = 0.238;
        G_dis4 = 0.307;
        G_dis5 = 0.384;
        G_dis6 = 0.477;
        G_dis7 = 0.554;
        G_dis8 = 0.615;
        G_dis9 = 0.708;
        G_dis0 = 1.000;

d_R_dis1 = (R_dis1 - REDDIST1)*(R_dis1 - REDDIST1);
d_R_dis2 = (R_dis2 - REDDIST2)*(R_dis2 - REDDIST2);
d_R_dis3 = (R_dis3 - REDDIST3)*(R_dis3 - REDDIST3);
d_R_dis4 = (R_dis4 - REDDIST4)*(R_dis4 - REDDIST4);
d_R_dis5 = (R_dis5 - REDDIST5)*(R_dis5 - REDDIST5);
d_R_dis6 = (R_dis6 - REDDIST6)*(R_dis6 - REDDIST6);
d_R_dis7 = (R_dis7 - REDDIST7)*(R_dis7 - REDDIST7);
d_R_dis8 = (R_dis8 - REDDIST8)*(R_dis8 - REDDIST8);
d_R_dis9 = (R_dis9 - REDDIST9)*(R_dis9 - REDDIST9);
d_R_dis0 = (R_dis0 - REDDIST0)*(R_dis0 - REDDIST0);
d_B_dis1 = (B_dis1 - BLUDIST1)*(B_dis1 - BLUDIST1);
d_B_dis2 = (B_dis2 - BLUDIST2)*(B_dis2 - BLUDIST2);
d_B_dis3 = (B_dis3 - BLUDIST3)*(B_dis3 - BLUDIST3);
d_B_dis4 = (B_dis4 - BLUDIST4)*(B_dis4 - BLUDIST4);
```

```
d_B_dis5 = (B_dis5 - BLUDIST5)*(B_dis5 - BLUDIST5);
d_B_dis6 = (B_dis6 - BLUDIST6)*(B_dis6 - BLUDIST6);
d_B_dis7 = (B_dis7 - BLUDIST7)*(B_dis7 - BLUDIST7);
d_B_dis8 = (B_dis8 - BLUDIST8)*(B_dis8 - BLUDIST8);
d_B_dis9 = (B_dis9 - BLUDIST9)*(B_dis9 - BLUDIST9);
d_B_dis0 = (B_dis0 - BLUDIST0)*(B_dis0 - BLUDIST0);
d_G_dis1 = (G_dis1 - GREDIST1)*(G_dis1 - GREDIST1);
d_G_dis2 = (G_dis2 - GREDIST2)*(G_dis2 - GREDIST2);
d_G_dis3 = (G_dis3 - GREDIST3)*(G_dis3 - GREDIST3);
d_G_dis4 = (G_dis4 - GREDIST4)*(G_dis4 - GREDIST4);
d_G_dis5 = (G_dis5 - GREDIST5)*(G_dis5 - GREDIST5);
d_G_dis6 = (G_dis6 - GREDIST6)*(G_dis6 - GREDIST6);
d_G_dis7 = (G_dis7 - GREDIST7)*(G_dis7 - GREDIST7);
d_G_dis8 = (G_dis8 - GREDIST8)*(G_dis8 - GREDIST8);
d_G_dis9 = (G_dis9 - GREDIST9)*(G_dis9 - GREDIST9);
d_G_dis0 = (G_dis0 - GREDIST0)*(G_dis0 - GREDIST0);

d_err_R = (d_R_dis1 + d_R_dis2 + d_R_dis3 + d_R_dis4 + d_R_dis5 +
d_R_dis6 + d_R_dis7 + d_R_dis8 + d_R_dis9 + d_R_dis0);
d_err_B = (d_B_dis1 + d_B_dis2 + d_B_dis3 + d_B_dis4 + d_B_dis5 +
d_B_dis6 + d_B_dis7 + d_B_dis8 + d_B_dis9 + d_B_dis0);
d_err_G = (d_G_dis1 + d_G_dis2 + d_G_dis3 + d_G_dis4 + d_G_dis5 +
d_G_dis6 + d_G_dis7 + d_G_dis8 + d_G_dis9 + d_G_dis0);
run;
```

APPENDIX VIII: LIST OF ORGANISATIONS APPROACHED, PRESS RELEASE, POSTERS AND EXAMPLES OF LETTERS SENT TO ORGANISATIONS

- Richmond (Hogarth) Bridge Club.
- Richmond Bowls Club.
- NPL Chess Club, NPL, Teddington.
- Rotaract Clubs, Richmond, Twickenham.
- Richmond Round Table
- Twickenham Round Table
- St John's Health Centre Users' Group.
- Barnes Community Association.
- Cambrian Community Centre, Isleworth.
- Crane Community Centre, Twickenham.
- East Twickenham Neighbourhood Association.
- Hampton and Hampton Hill Community Association.
- Mortlake Hall Over 50's Group.
- St Luke's Community Trust.
- Whitton Community Centre.
- Amicale Francophone of Richmond.
- Probus Clubs: Teddington & Hampton; Barnes, Sheen and Mortlake; Roehampton (for Over 60's Retired Businessmen).
- Institute of Advanced Motorists.
- Hampton and District Motor Club.
- Richmond Scientific Society.
- Richmond Scrabble Club.
- Richmond Friendship Group: Twickenham; Kew. (Over 50's groups)
- 50's-60's Society: Richmond; Teddington.
- Kingston-upon-Thames Traveller's Association.
- London Appreciation Society.
- Richmond and District Rambler's Association.
- Women's institutes: Barnes;
- Hampton and Richmond Association of University Women.
- National Assembly of Women.
- National Association of Women's Clubs, Teddington.
- National Council of Women.
- All Hallows Church, Twickenham "Monday Group".
- Richmond Free Church, Women's League.
- St. Augustine's Church, Thursday Club.
- Townswomen's Guilds: Crane Park; East Sheen, Hampton & Hampton Hill; Whitton; Richmond; South Teddington & Hampton Wick.
- Twickenham Women Citizen's Association.
- Women's Institutes: Kew; Sheen; Twickenham; Richmond.

PRESS RELEASE

The University of London Centre for Transport Studies is carrying out research into individuals' ability to remember journeys, routes and landmarks. The project aims to study the effect that route guidance and information systems might have upon the fundamental processes of wayfinding and navigation. As part of this research we have designed an experiment which involves watching 3 short films showing 3 interconnecting journeys through the same area, followed by a series of tasks designed to test memory for these routes.

We urgently need more subjects to take part in this experiment, particularly from the following groups:

•Over 55's drivers and non-drivers (male/female)
•Non-drivers of all ages
•Female drivers of all ages
•Drivers who use their car as part of their work.

The experiment lasts approximately 90 minutes and takes place at Imperial College. However, if a group were interested and had a suitable venue we would be happy to take the experiment to them. Participants receive £5 for taking part in the experiment.

****

For more information please contact Paul Jackson of the Centre for Transport Studies on 0171 594 6037 or leave your name and a contact number on the answer machine at 0181 892 3085.

****

HOW GOOD IS YOUR MEMORY?

FIND OUT AND EARN £10!

The Centre for Transport Studies is currently running experiments looking at people's memory for places and journeys. The experiment lasts approximately 90 minutes and volunteers will receive £10 payment for taking part. If you would like to be considered as a volunteer please contact:

Paul Jackson
Room 609
Dept. of Civil Engineering
e-Mail: pgj@cv.ic.ac.uk
Telephone: 071 594 6037 (If dialling from inside Imperial just dial **ext. 46037**)

SUBJECTS REQUIRED! BE PAID FOR WATCHING FILMS!

We are carrying out research which requires subjects to watch 3 short films and to then carry out a series of tasks. The experiment lasts approximately 90 minutes and volunteers will receive £10 payment for taking part. If you would like to be considered as a volunteer, please contact:

Paul Jackson
Room 609
Dept. of Civil Engineering
e-Mail: pgj@cv.ic.ac.uk
Telephone: 071 594 6037 (If dialling from inside Imperial just dial **ext. 46037**)

September 18th, 1994

Dear Ms Page,
I am a researcher based at the University of London Centre for Transport Studies. I am writing to invite users of the Earls Court Drop-in Centre to take part in an experiment which we are currently running.

The Centre for Transport Studies is carrying out research into individuals' ability to remember journeys, routes and landmarks. As part of this research we have designed an experiment which involves watching 3 short films showing 3 journeys through the same area, followed by a series of tasks designed to test memory for these routes. We urgently need more subjects to take part in this experiment, particularly from the following groups:

- Over 55's drivers and non-drivers (male/female)
- Non-drivers of all ages
- Female drivers of all ages
- Drivers who use their car as part of their work.

The experiment lasts approximately 90 minutes and takes place at Imperial College. However, if a group were interested and had a suitable venue we would be happy to take the experiment to them. All participants receive £5 for taking part in the experiment. If you feel that this experiment might be of interest please feel free to contact me on the number above, or you can leave a message on the answer machine at 0181 892 3085. I look forward to hearing from you,
Yours sincerely

Paul Jackson

APPENDIX IX. EXPERIMENTAL DESIGN

EXPERIMENTAL DESIGN: (4x3x2x2). Between 5 and 10 subjects per group.

Group	Age	Gender	Driver
0	0	0	0
0	1	1	0
0	2	1	1
0	1	0	1
1	0	1	1
1	1	0	1
1	2	0	0
1	1	1	0
2	0	0	1
2	1	1	1
2	2	1	0
2	1	0	0
3	0	1	0
3	1	0	0
3	2	0	1
3	1	1	1

0=Video	0=under 25	0=Male	0=Driver
1=RTI	1=25-60	1=Female	1=Nondriver
2=Radio	2=over 60		
3=RTI+Radio			

APPENDIX X: PROFESSIONS OF THE PARTICIPANTS (TAKEN FROM THE QUESTIONNAIRES)

Student
Catering assistant
Architectural technician
Assistant to antique dealer
Scientific civil servant
Journalist
WP secretary
Driving instructor
Bus driver
Lecturer
Researcher
Administration assistant
Cleaner
Administration officer
Statistician
Accountant
Information officer
Unemployed
Secretary
Scaffolder
Research student
Security guard
PA
Technician
Languages Teacher
Research contracts administrator
Electrician
Day centre support officer
Tour guide
Librarian
Credit controller
Retired
Reinsurance underwriter
Transport planner

APPENDIX XI: NATIONALITIES OF THE PARTICIPANTS (TAKEN FROM THE QUESTIONAIRES).

British
French
German
Italian
Spanish
Portuguese
Norwegian
Iranian
Swedish
Chinese
Mexican
American
Cypriot
Singaporean
Russian
Indian
Pakistani
Romanian
Serbian
Croatian
Dutch
Greek
Hong Kong British
Malaysian
Polish
Sri Lankan
Egyptian
Iraqi
Danish

APPENDIX XII: QUESTIONNAIRE COMPLETED BY ALL PARTICIPANTS

For research purposes we would like you to answer the following questions, the information you provide will be used strictly for research purposes and will not be passed on to any third party.

1. **Your name** ..... **Your nationality** .....

2. **Your address** .....

3. **Your age** .....

4. **Are you male or female?** Male ..... Female ..... (Please tick the relevant space).

5. **What is your present occupation?** .....

   (If student, please indicate year of study 1.....2.....3.....4.....M.Sc.....Ph.D..... (tick one)

6. **Do you hold a full driving licence?** Yes [ ] ..... Go to question 7

   No [ ] ..... Please skip the

7. **How long have you held a full driving licence?** .....

8. **About how often do you drive nowadays?**

Everyday	[ ]
2-3 days a week	[ ]
About once a week	[ ]
Less often	[ ]

9. **Do you drive to and from your place of work?**

Everyday	[ ]
Most days	[ ]
Occasionally	[ ]
Never	[ ]

10. **How much driving would you say your work involves?**

Very much	[ ]
Quite a bit	[ ]
Not very much	[ ]
None at all	[ ]

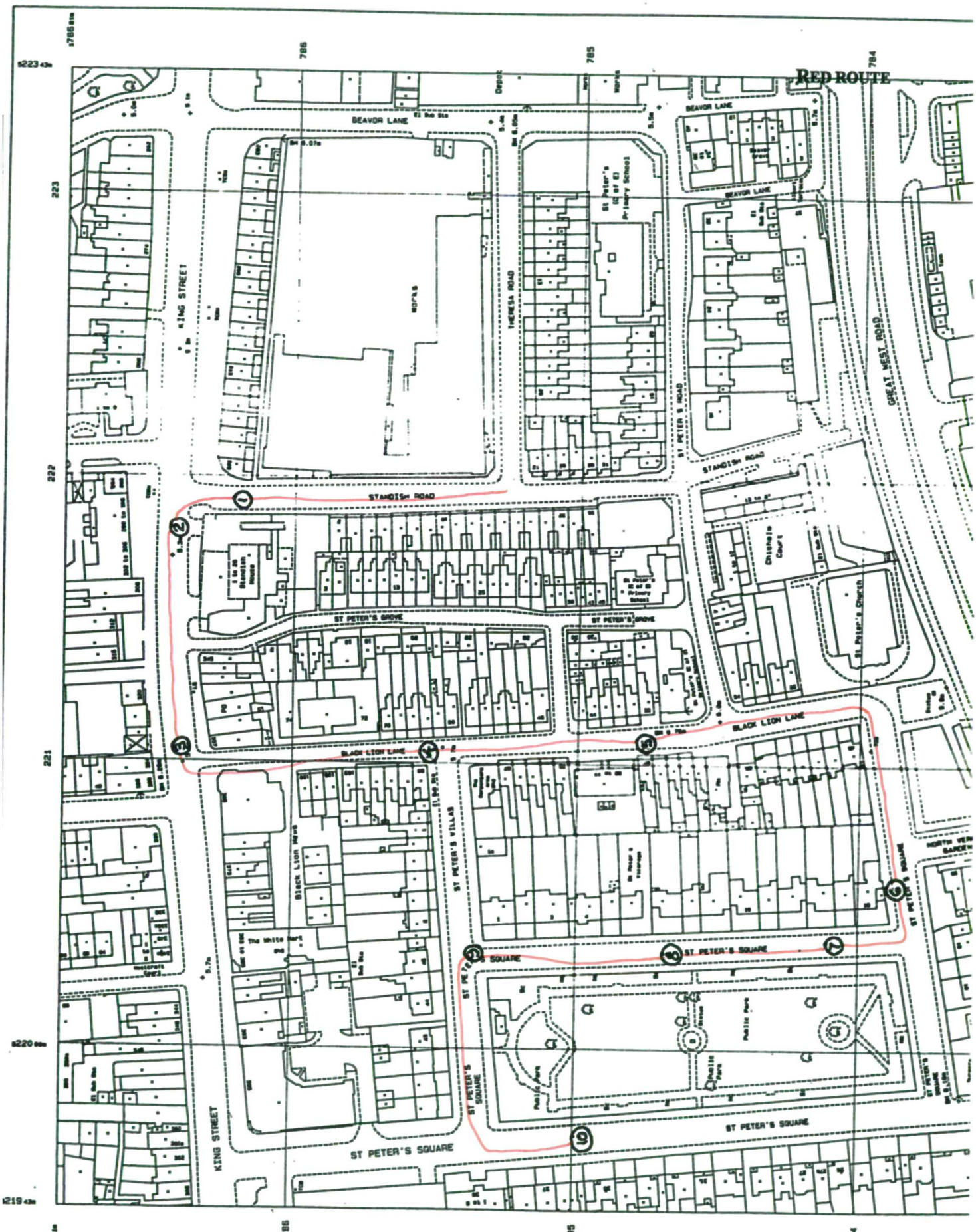
11. **Please estimate your average annual mileage** .....

Finally, we would like you to try and draw a sketch map of the area you have just seen in the three films, including as much detail as you can remember: For example: roads, road names, road signs, bus stops, landmarks, shops and any other features which you remember. Turn this page over and use as much space as you need to draw a map. There will be a cash prize awarded for the best map drawn. Thank you for taking part in this study.

N.B. IF YOU <u>REGULARLY</u> DRIVE A BICYCLE, MOTORBIKE OR MOPED OR ARE INVOLVED IN ORIENTEERING PLEASE INFORM THE EXPERIMENTER

APPENDIX XIII: SEQUENCING TASK

MAPS OF STUDY AREA SHOWING POSITION OF PHOTOGRAPHS USED


RED ROUTE
BEAVOR LANE
KING STREET
THERESA ROAD
ST PETER'S ROAD
GREAT WEST ROAD
STANDISH ROAD
ST PETER'S GROVE
BLACK LION LANE
ST PETER'S VILLAS
ST PETER'S SQUARE
Black Lion Hotel
Depot
Works
Public Park
1
2
3
4
5
6
7
8
9

BLUE ROUTE
BEAVOR LANE
STANDISH ROAD
ST PETER'S GROVE
BLACK LION LANE
ST PETER'S SQUARE
KING STREET
THERESA ROAD
GREAT WEST ROAD
Works
Depot
Public Park
1
2
3
4
5
6
7
8
9
10
11

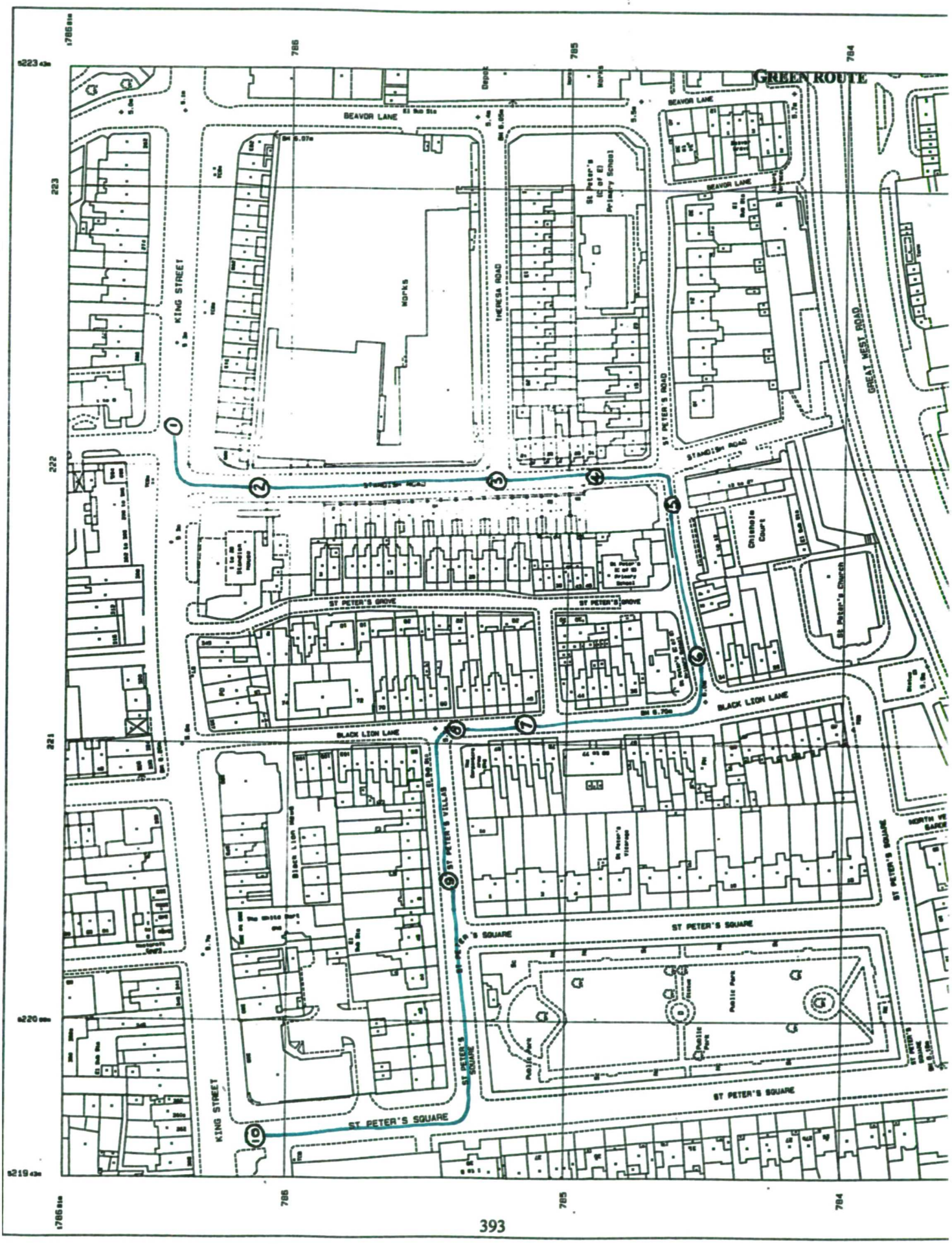

GREEN ROUTE
BEAVOR LANE
KING STREET
INFIRMARY
THERESA ROAD
St. Peter's (C of E) Primary School
ST PETER'S ROAD
GREAT WEST ROAD
STANDISH ROAD
Chisholm Court
St. Peter's Church
ST PETER'S GROVE
BLACK LION LANE
Black Lion Hotel
ST PETER'S VILLAS
ST PETER'S SQUARE
Public Park
786
785
784
223
222
221
220
219

TABLE OF SEQUENCES WITH FREQUENCIES (PHASE I)

RORDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1078964523	1	0.8	1	0.8
1230786459	1	0.8	2	1.5
1234506789	11	8.3	13	9.8
1234506978	1	0.8	14	10.5
1234507869	5	3.8	19	14.3
1234507896	7	5.3	26	19.5
1234507968	1	0.8	27	20.3
1234507986	1	0.8	28	21.1
1234508769	1	0.8	29	21.8
1234560789	6	4.5	35	26.3
1234560879	1	0.8	36	27.1
1234560978	2	1.5	38	28.6
1234567890	24	18.0	62	46.6
1234568790	3	2.3	65	48.9
1234568907	1	0.8	66	49.6
1234569078	2	1.5	68	51.1
1234569780	2	1.5	70	52.6
1234570689	1	0.8	71	53.4
1234570896	1	0.8	72	54.1
1234576890	2	1.5	74	55.6
1234578069	2	1.5	76	57.1
1234578690	7	5.3	83	62.4
1234578906	4	3.0	87	65.4
1234578960	11	8.3	98	73.7
1234579086	1	0.8	99	74.4
1234586790	1	0.8	100	75.2
1234587690	2	1.5	102	76.7
1234589607	1	0.8	103	77.4
1234589670	1	0.8	104	78.2
1234596078	1	0.8	105	78.9
1234597806	1	0.8	106	79.7
1234697805	1	0.8	107	80.5
1235467890	2	1.5	109	82.0
1235478960	1	0.8	110	82.7
1236457890	1	0.8	111	83.5
1236574890	1	0.8	112	84.2
1236745089	1	0.8	113	85.0
1236789045	1	0.8	114	85.7
1245037896	1	0.8	115	86.5
1246598370	1	0.8	116	87.2
1253467890	1	0.8	117	88.0
1324507869	1	0.8	118	88.7
1324507896	1	0.8	119	89.5
1324567890	1	0.8	120	90.2
1379208456	1	0.8	121	91.0
1562347890	1	0.8	122	91.7
2340657891	1	0.8	123	92.5
4507893126	1	0.8	124	93.2
4512378690	1	0.8	125	94.0
4578690123	1	0.8	126	94.7

5361248790	1	0.8	127	95.5
6138429705	1	0.8	128	96.2
7013298645	1	0.8	129	97.0
7825104936	1	0.8	130	97.7
7854109632	1	0.8	131	98.5
7890124356	1	0.8	132	99.2
9413287605	1	0.8	133	100.0

BORDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1234507896	1	0.8	1	0.8
1234567890	58	43.6	59	44.4
1234657890	2	1.5	61	45.9
1234675890	1	0.8	62	46.6
1234895670	1	0.8	63	47.4
1234956780	1	0.8	64	48.1
1235674890	1	0.8	65	48.9
1235678940	1	0.8	66	49.6
1238956740	1	0.8	67	50.4
1240375869	1	0.8	68	51.1
1243567890	4	3.0	72	54.1
1243856790	1	0.8	73	54.9
1245673890	2	1.5	75	56.4
1245678903	1	0.8	76	57.1
1245678930	1	0.8	77	57.9
1250867943	1	0.8	78	58.6
1253467890	25	18.8	103	77.4
1253467980	1	0.8	104	78.2
1253489670	1	0.8	105	78.9
1253647890	1	0.8	106	79.7
1253674890	1	0.8	107	80.5
1254367890	3	2.3	110	82.7
1254367980	1	0.8	111	83.5
1254637890	1	0.8	112	84.2
1256734890	5	3.8	117	88.0
1256734980	1	0.8	118	88.7
1256743890	3	2.3	121	91.0
1256783490	1	0.8	122	91.7
1256789340	1	0.8	123	92.5
1256798340	1	0.8	124	93.2
1258937604	1	0.8	125	94.0
1263457890	1	0.8	126	94.7
1267345890	1	0.8	127	95.5
1267498350	1	0.8	128	96.2
1289345670	1	0.8	129	97.0
1345678290	1	0.8	130	97.7
1892064573	1	0.8	131	98.5
2904153876	1	0.8	132	99.2
4567312890	1	0.8	133	100.0

GORDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1207956483	1	0.8	1	0.8
1234507869	1	0.8	2	1.5
1234567809	1	0.8	3	2.3
1234567890	59	44.4	62	46.6
1234568790	2	1.5	64	48.1
1234569780	6	4.5	70	52.6
1234576890	2	1.5	72	54.1
1234578690	1	0.8	73	54.9
1234578960	1	0.8	74	55.6
1234756890	1	0.8	75	56.4
1234789560	1	0.8	76	57.1
1234789650	1	0.8	78	58.6
1234956780	4	3.0	82	61.7
1234975680	1	0.8	83	62.4
1234978560	2	1.5	85	63.9
1234985670	1	0.8	86	64.7
1234987560	1	0.8	87	65.4
1235678490	1	0.8	88	66.2
1236784590	1	0.8	89	66.9
1237845690	2	1.5	91	68.4
1237894560	1	0.8	92	69.2
1243567890	1	0.8	93	69.9
1243785690	1	0.8	94	70.7
1245367890	1	0.8	95	71.4
1245678390	2	1.5	97	72.9
1256347890	1	0.8	98	73.7
1256349780	1	0.8	99	74.4
1256379048	1	0.8	100	75.2
1256783490	3	2.3	103	77.4
1278563490	1	0.8	104	78.2
1293456780	1	0.8	105	78.9
1297834560	2	1.5	107	80.5
1324567890	1	0.8	108	81.2
1324795680	1	0.8	109	82.0
1345627890	1	0.8	110	82.7
1347856290	1	0.8	111	83.5
1347928560	1	0.8	112	84.2
1387245690	1	0.8	113	85.0
1420653879	1	0.8	114	85.7
1423785609	1	0.8	115	86.5
1452397860	1	0.8	116	87.2
1456239780	1	0.8	117	88.0
1456723890	1	0.8	118	88.7
1456782390	1	0.8	119	89.5
1457230986	1	0.8	120	90.2
1562378094	1	0.8	121	91.0
1569832470	1	0.8	122	91.7
1782345690	2	1.5	124	93.2
1782349560	1	0.8	125	94.0
1783245690	1	0.8	126	94.7
1785623490	1	0.8	127	95.5
1923456780	1	0.8	128	96.2

1983274560	1	0.8	129	97.0
2134567890	1	0.8	130	97.7
5691423780	1	0.8	131	98.5
7231684095	1	0.8	132	99.2
7814293056	1	0.8	133	100.0

TABLE OF SEQUENCES WITH FREQUENCIES (PHASE II)

Red route

RORDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1078964523	1	1.3	1	1.3
1234506789	3	3.8	4	5.0
1234506978	1	1.3	5	6.3
1234507689	1	1.3	6	7.5
1234507869	9	11.3	15	18.8
1234507896	8	10.0	23	28.8
1234507986	1	1.3	24	30.0
1234509678	1	1.3	25	31.3
1234509786	1	1.3	26	32.5
1234567890	23	28.8	49	61.3
1234567980	1	1.3	50	62.5
1234568790	2	2.5	52	65.0
1234569078	1	1.3	53	66.3
1234569780	4	5.0	57	71.3
1234570698	1	1.3	58	72.5
1234576890	1	1.3	59	73.8
1234578690	5	6.3	64	80.0
1234578960	10	12.5	74	92.5
1234587069	1	1.3	75	93.8
1234587690	2	2.5	77	96.3
1234589076	1	1.3	78	97.5
1234786950	1	1.3	79	98.8
1235478690	1	1.3	80	100.0

Blue route

BORDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1234567890	44	55.0	44	55.0
1234675890	1	1.3	45	56.3
1235467890	1	1.3	46	57.5
1235674890	2	2.5	48	60.0
1238567490	1	1.3	49	61.3
1243567890	4	5.0	53	66.3
1245673890	1	1.3	54	67.5
1253467890	15	18.8	69	86.3
1253476890	1	1.3	70	87.5
1254367890	2	2.5	72	90.0

1254389670	2	2.5	74	92.5
1254678930	1	1.3	75	93.8
1256347890	1	1.3	76	95.0
1256734890	4	5.0	80	100.0

Green route

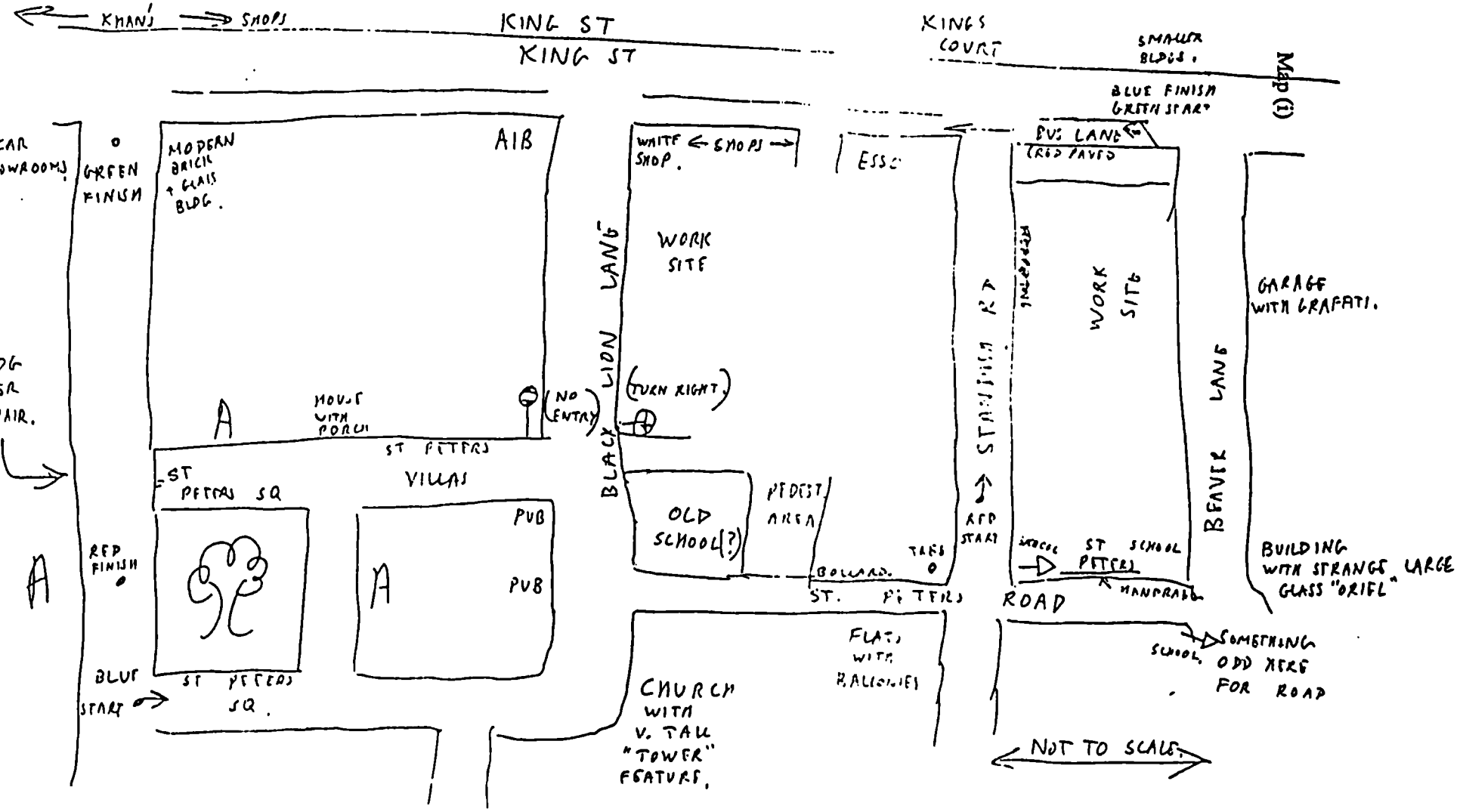
GORDER	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1234567890	63	78.8	63	78.8
1234569780	1	1.3	64	80.0
1234956780	1	1.3	65	81.3
1235678904	1	1.3	66	82.5
1243576890	1	1.3	67	83.8
1245639780	1	1.3	68	85.0
1245678390	2	2.5	70	87.5
1256349780	1	1.3	71	88.8
1293456780	1	1.3	72	90.0
1342567890	1	1.3	73	91.3
1345627890	1	1.3	74	92.5
1345678290	1	1.3	75	93.8
1347856290	1	1.3	76	95.0
1452397860	1	1.3	77	96.30
1562349780	1	1.3	78	97.5
1564932780	1	1.3	79	98.8
1782345690	1	1.3	80	100.0

APPENDIX XIV: EXAMPLES OF MAPS DRAWN BY SUBJECTS

The sketch maps on the following pages are examples which were selected as being representative of the demographic group of the sketcher. They are included because they exhibit specific qualities which were identified in the majority of the maps drawn by subjects from this same demographic group. For binding purposes some of the maps have had to be reduced.

Maps i - iv: Examples of sketch maps produced by male drivers

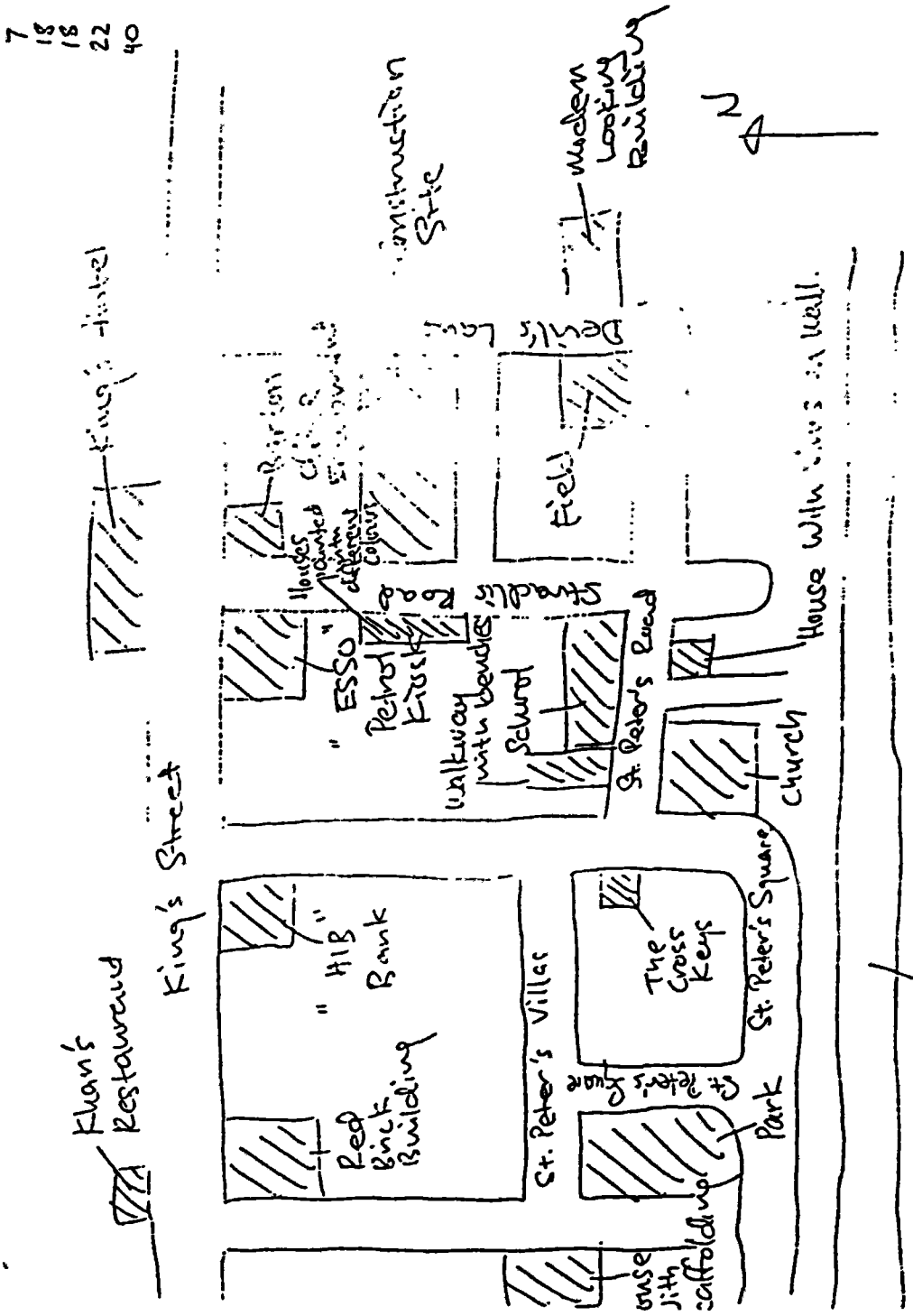
The first four maps were all drawn by male drivers. Map (i) was produced by a male driver aged 40. Maps (ii) and (iii) were both drawn by 21 year old male drivers. Map (iv) was drawn by a 20 year old male driver. The maps show a great deal of detailed information and exhibit a high level of integration and organisation. These subjects have clearly acquired configurational knowledge of the area.



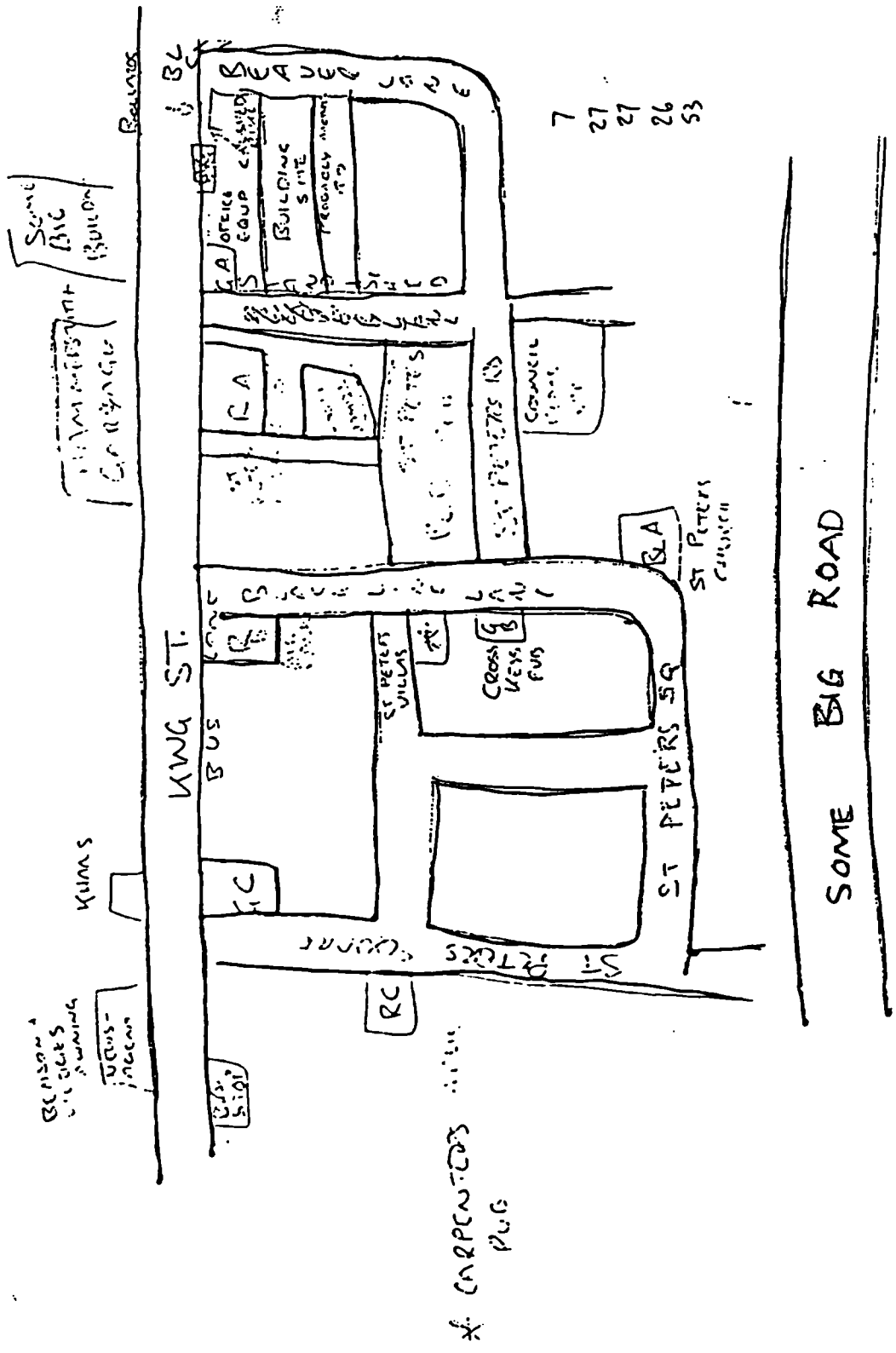
A' LARGER WHITE HOUSE

8 ROADS
35 CORRECT LANDMARKS (a)
27 ROAD SEGMENTS (b)
62 TOTAL (a+b)

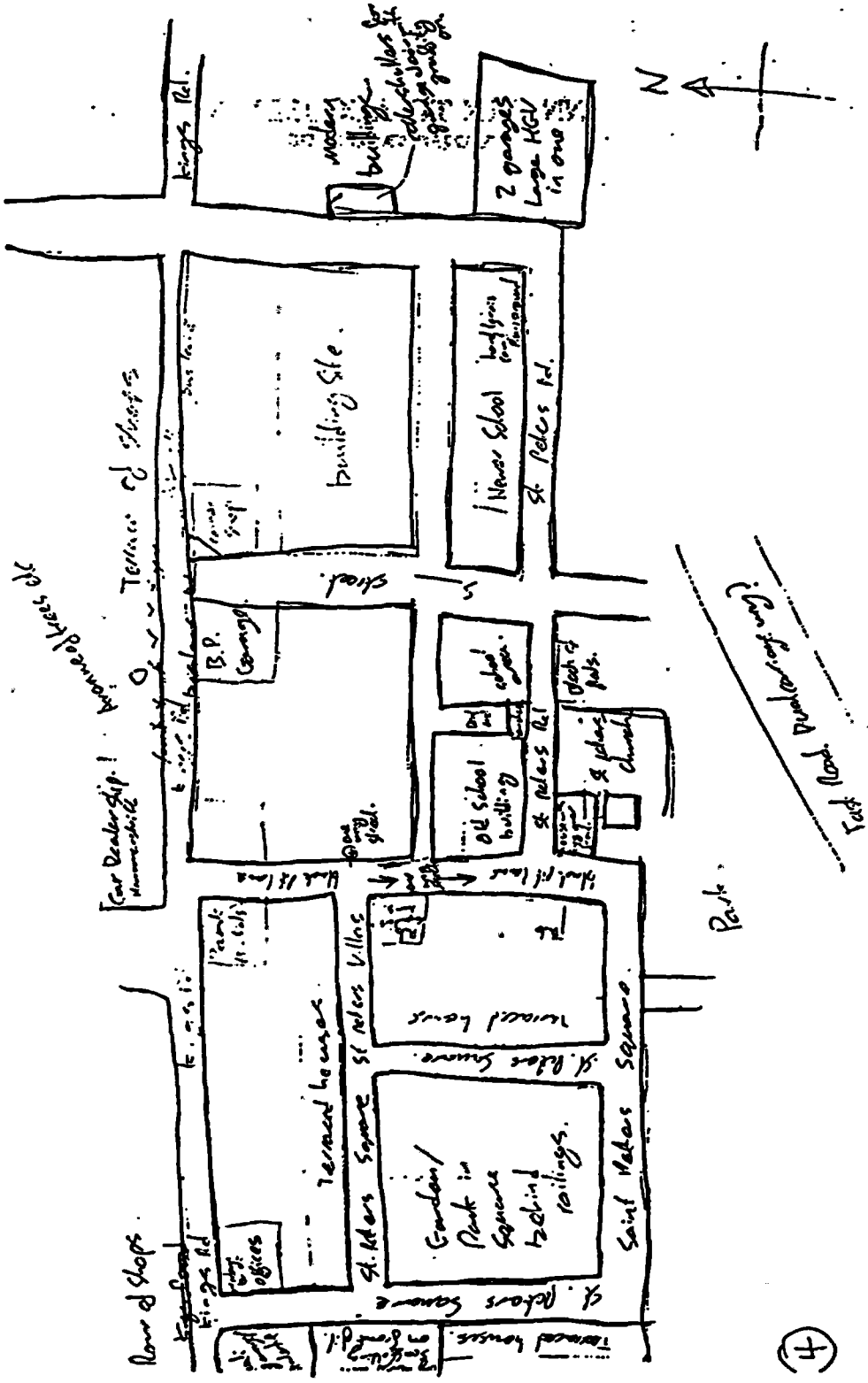
Map (ii)


7
18
18
22
40
King's Restaurant
King's Street
"HIB" Bank
Red Brick Building
St. Peter's Villas
The Cross Keys
St. Peter's Square
Park
House with
Main Road
ESSO Petrol
Walkway
Church
Field
Modern Looking Building
N

Map (iii)


KING ST.
BUS
ST PETERS SQ
SOME BIG ROAD
BUILDING SITE
ST PETERS VILLAS
RC
CA
7
27
27
26
53

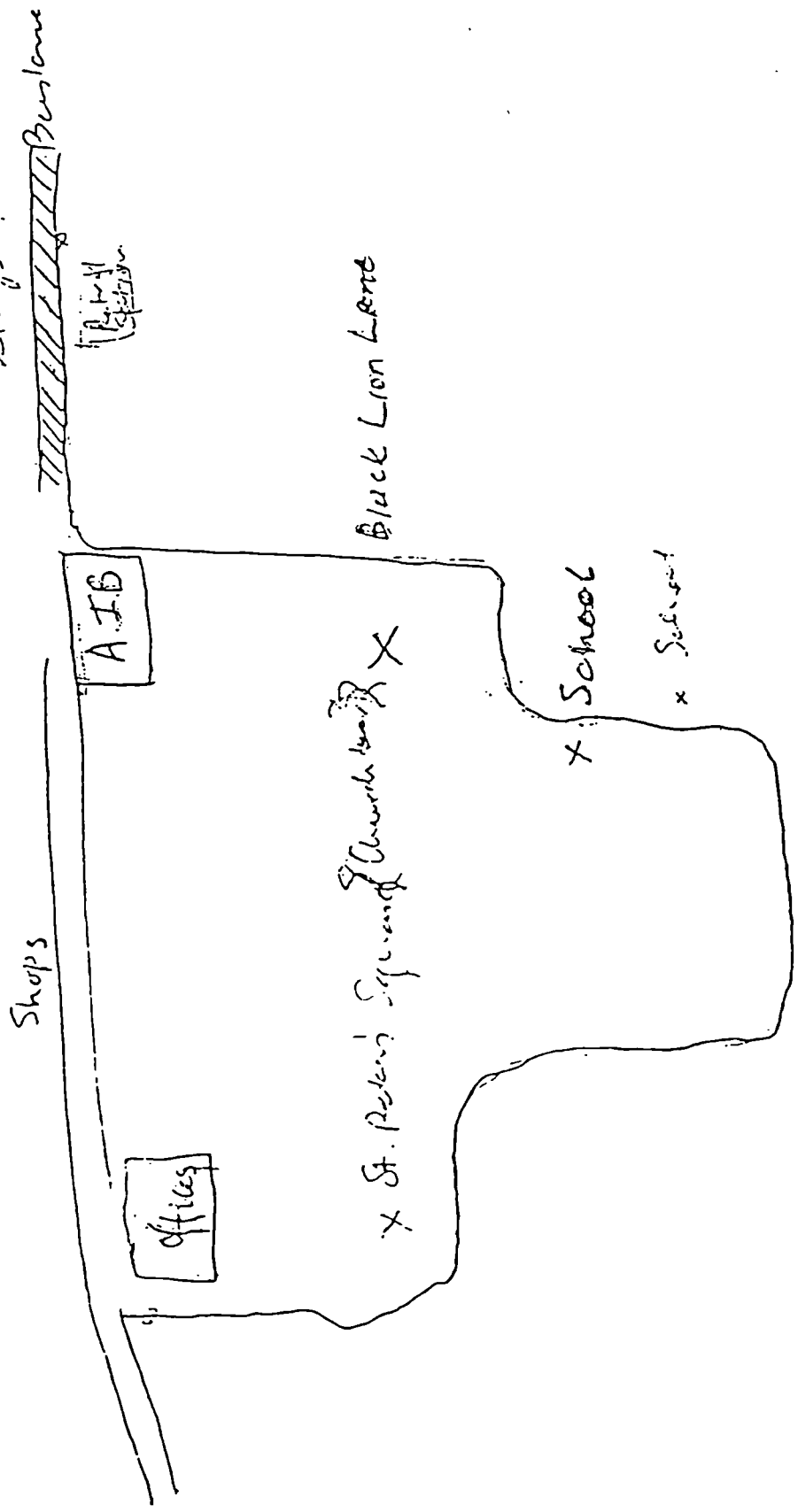
Map (iv)


N
Kings Rd.
2 garages Large HGV in one
Building Site.
Manor School
St Peters Rd.
Terrace Rd
B.P.
Old School building
St Peters Rd
St Peters Church
Park.
Terraced houses
St Peters Square
Terraced houses
Shops
Saint Peters Square
Garden/ Park in Square behind railings.
Terraced houses
Offices

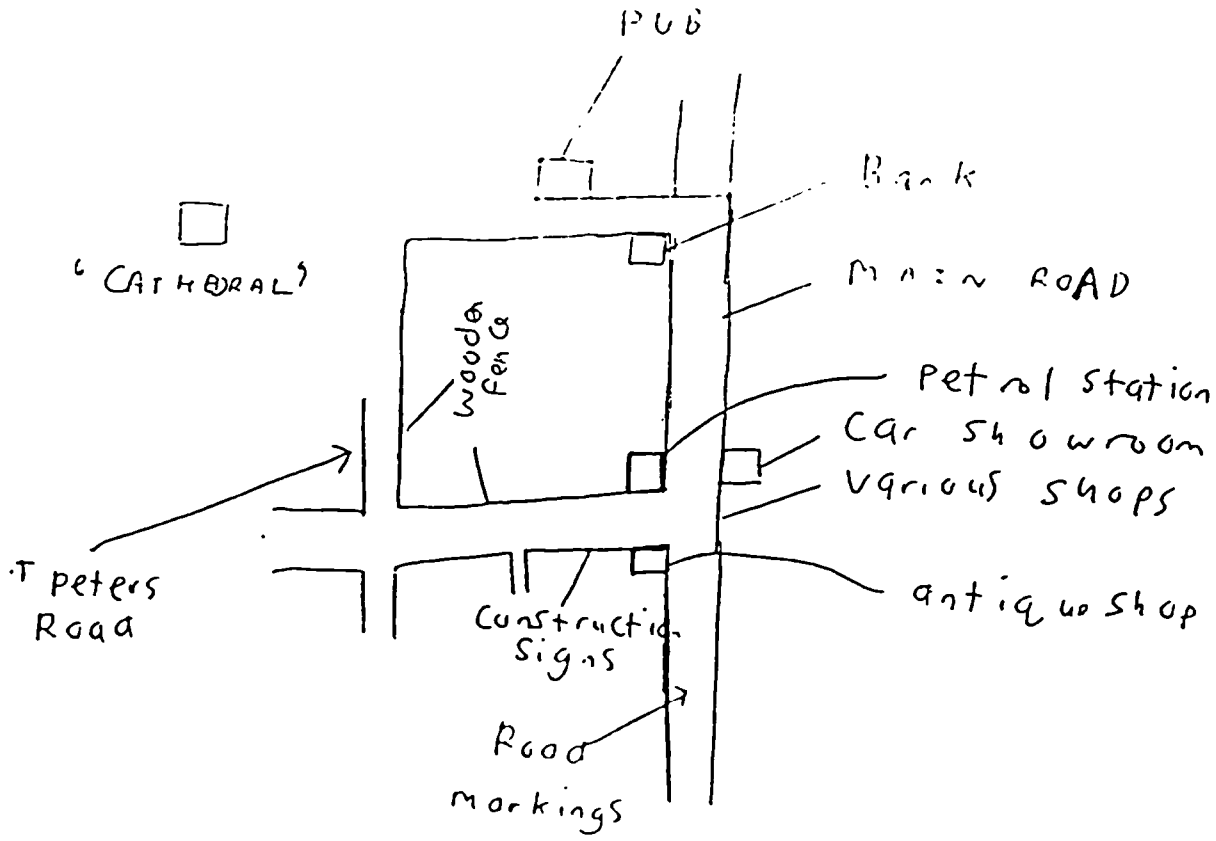
Maps v - viii: Examples of sketch maps produced by male non-drivers

The next four maps were all produced by male non-drivers. Map (v) was drawn by a 29 year old, map (vi) was produced by a 19 year old. Map (vii) is by an 18 year old male non-driver, while map (viii) was by a male non-driver aged 36. The first two maps show that the individuals have acquired some knowledge of the area and, particularly in the sketch map of the younger individual, have represented quite precise detail. However, the information represented could have been acquired from one of the routes, there has been little integration of knowledge acquired from separate sources. Maps (vii) and (viii) show sparser detail, but good route knowledge.

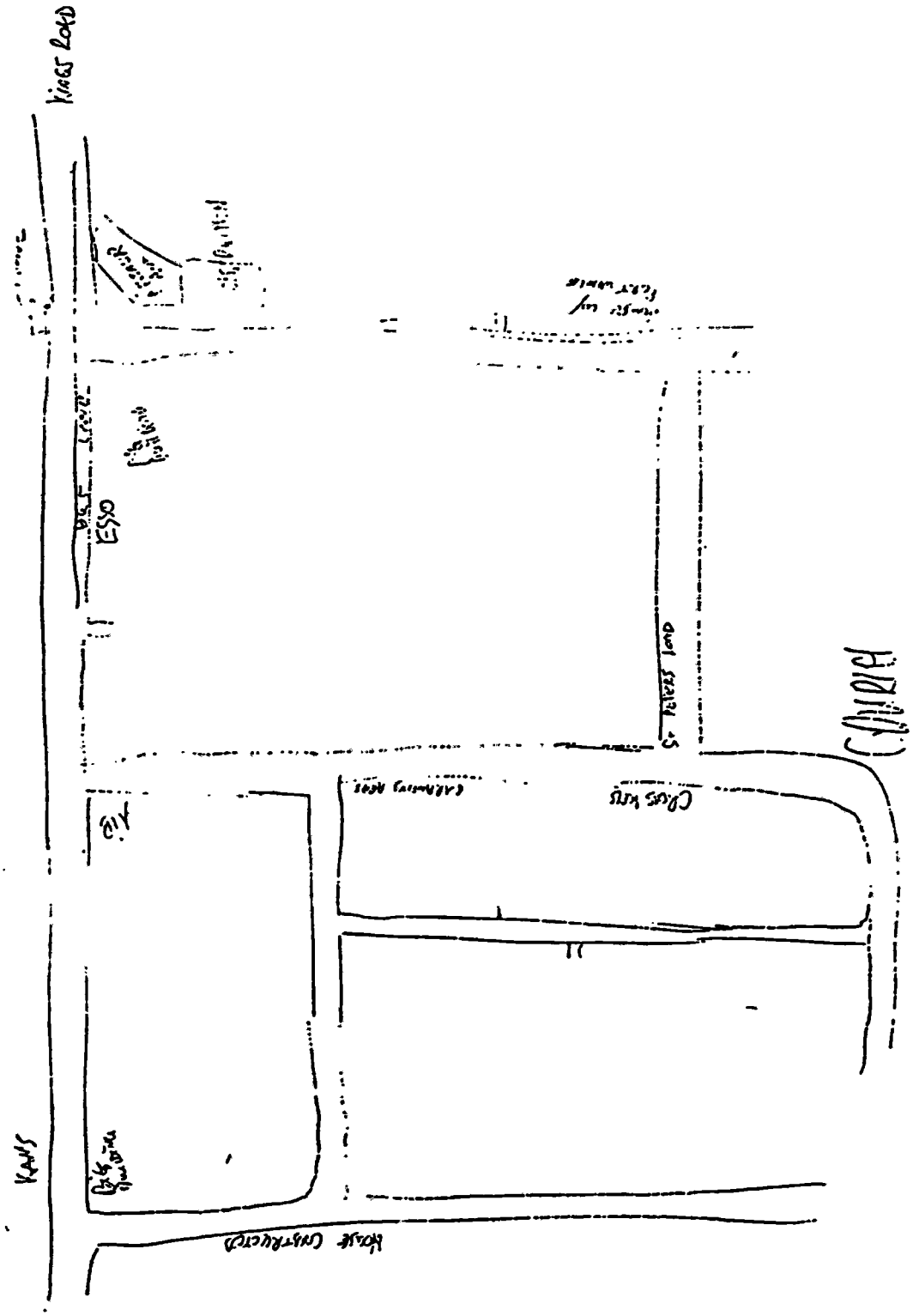
Map (v)



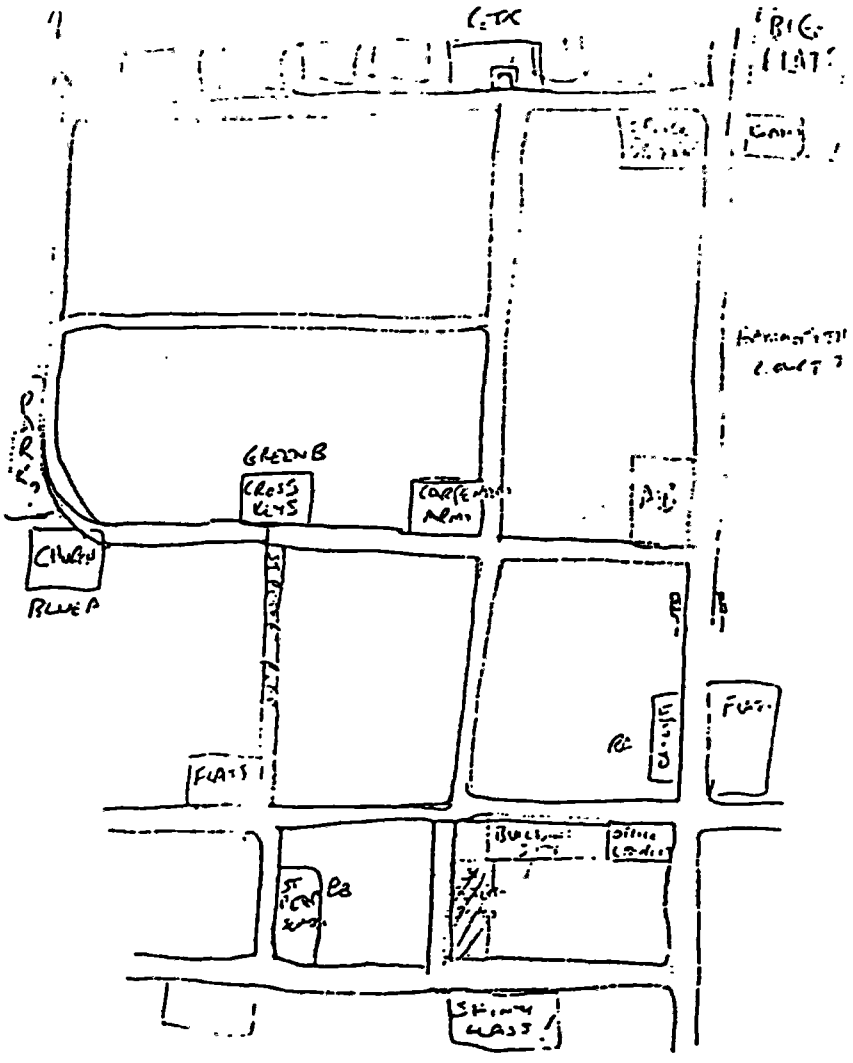
Map (vi)


PUB
Bank
CATHEDRAL
Main ROAD
Wooden Fence
Petrol station
Car showroom
various shops
St peters Road
Construction Signs
antique shop
Road markings

Map (vii)



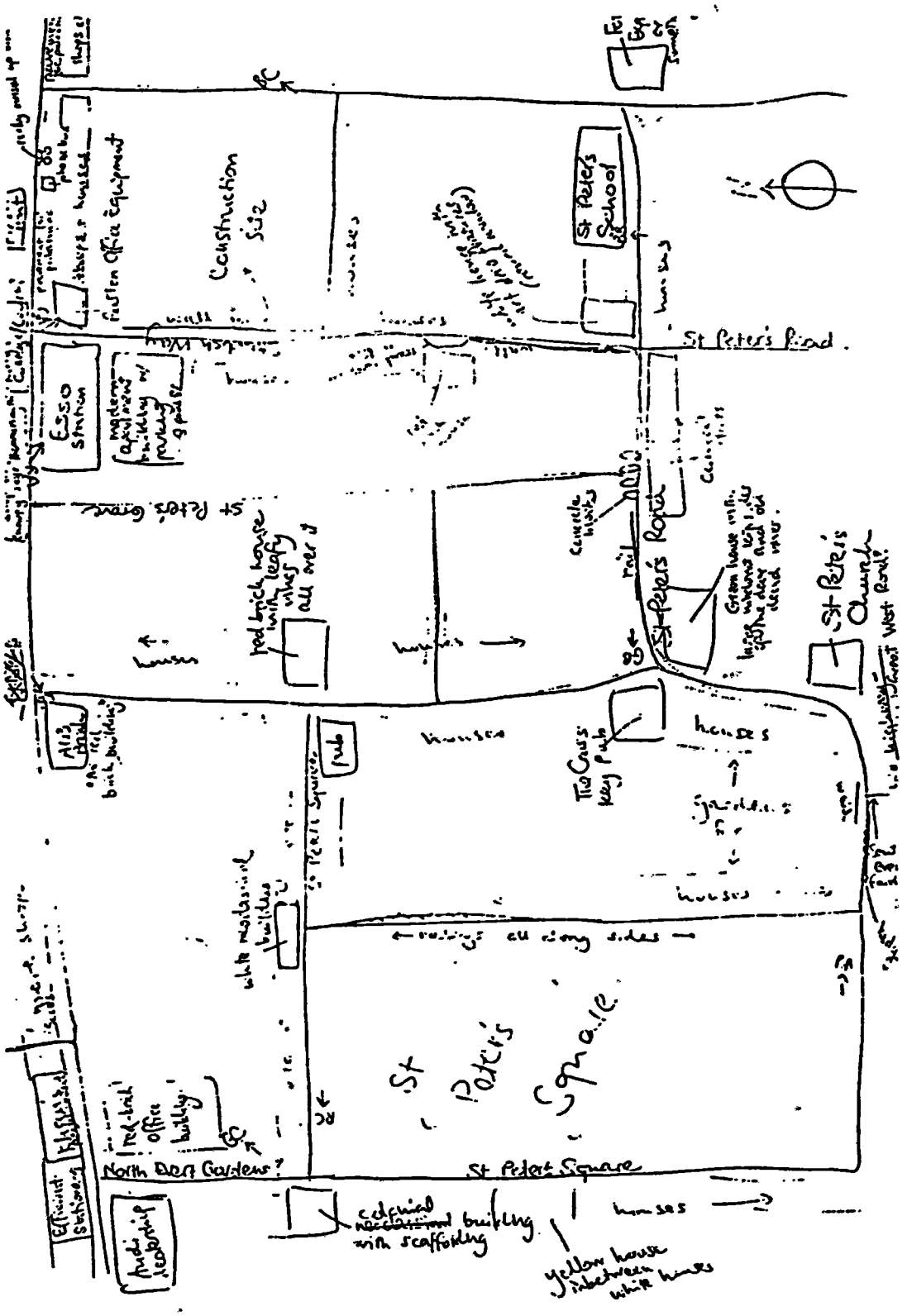
Map (viii)

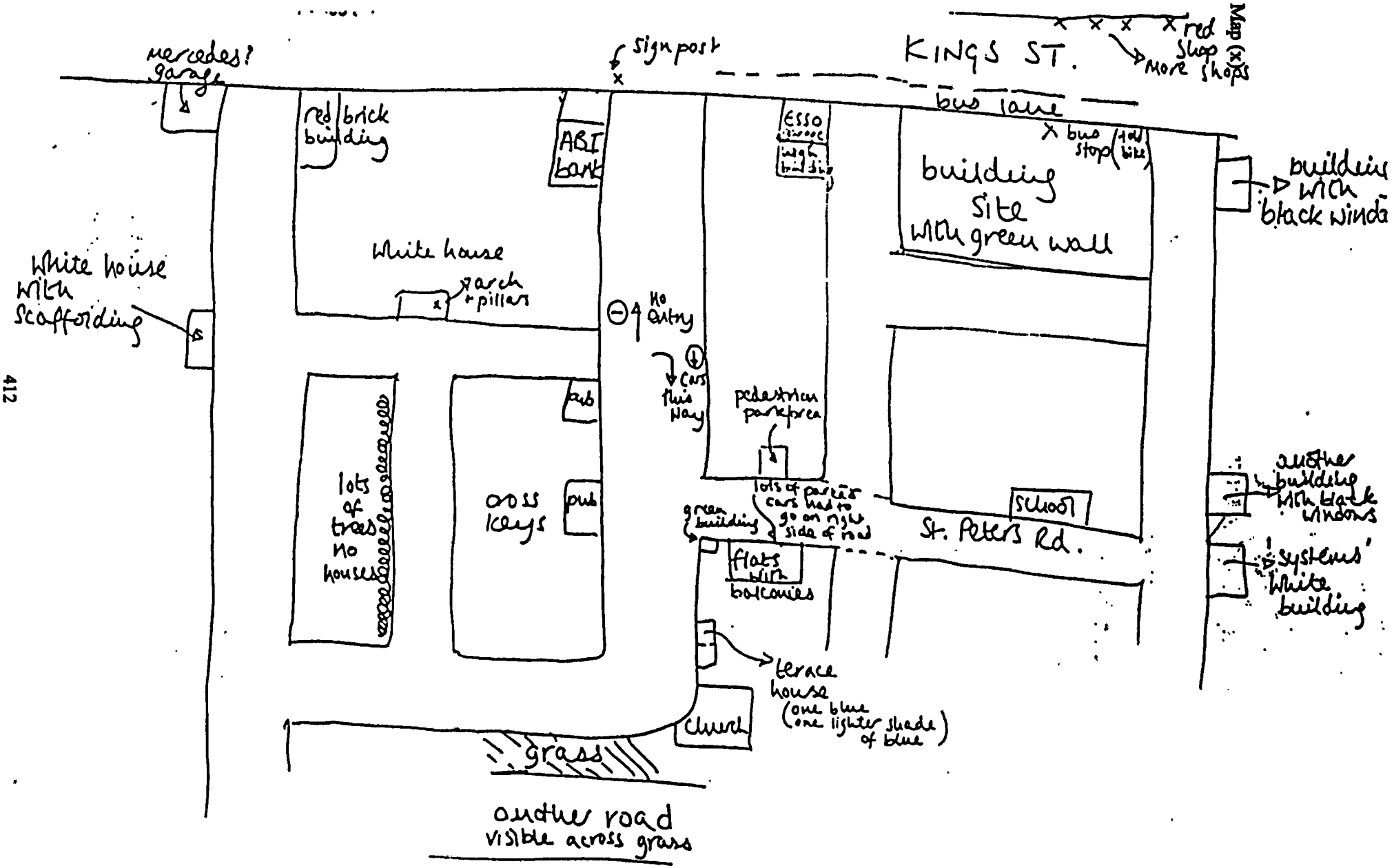


Maps ix - xii: Examples of sketch maps produced by female drivers

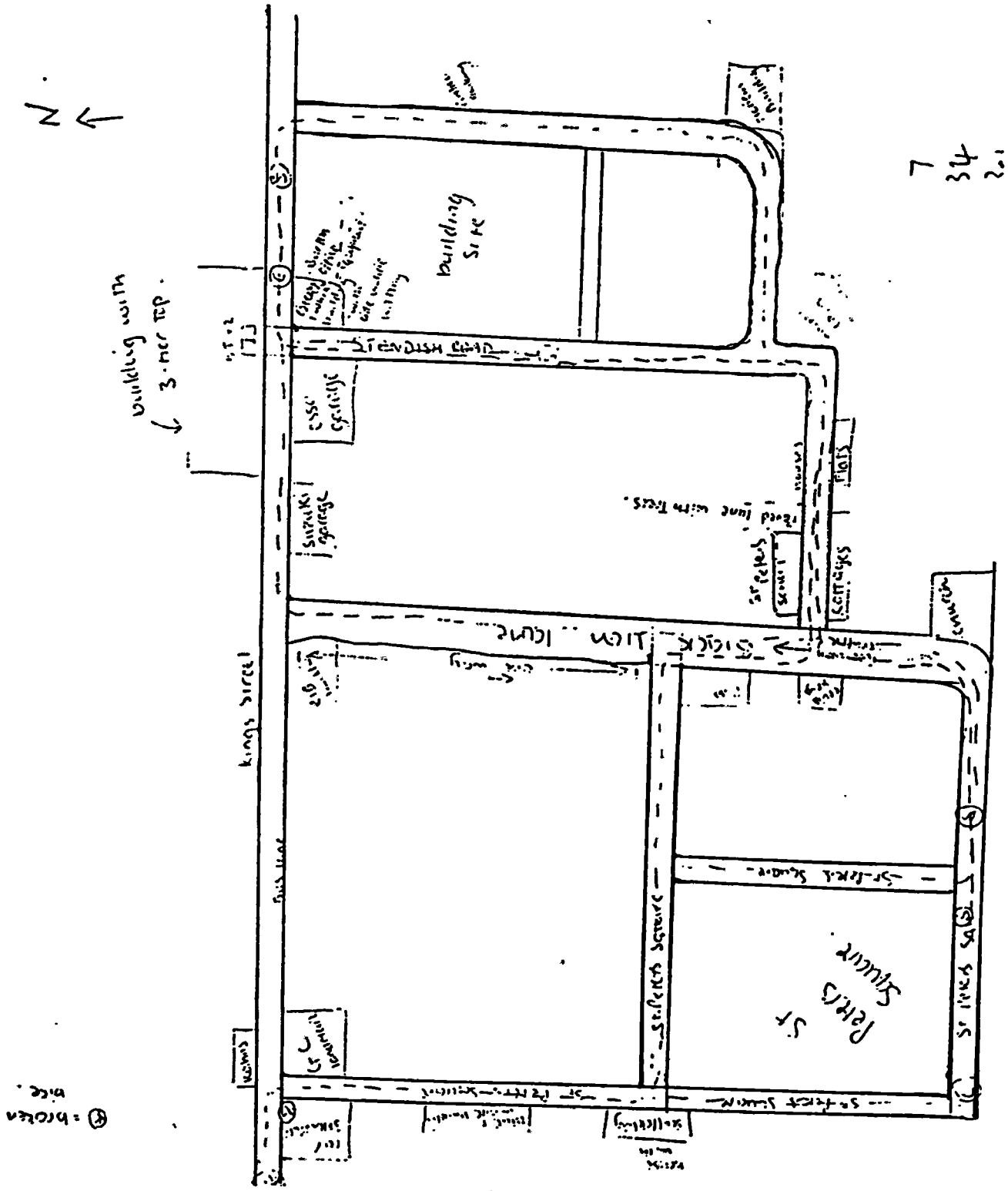
The next four maps were all produced by female drivers. Map (ix) was the most detailed of all the maps produced and was drawn by a 22 year old female who had been driving for 6.5 years. Map (x) also shows excellent detail, and was drawn by a 20 year old female who had been driving for 3.5 years. Map (xi) was drawn by a 21 year old female driver with 4.5 years driving experience and finally, map (xii) was drawn by a 21 year old female driver with 3 years driving experience. All four maps show evidence of excellent configurational knowledge. The common factor for all four participants is the fact that, despite their youth, they have acquired a good deal of driving experience.

Map (ix)

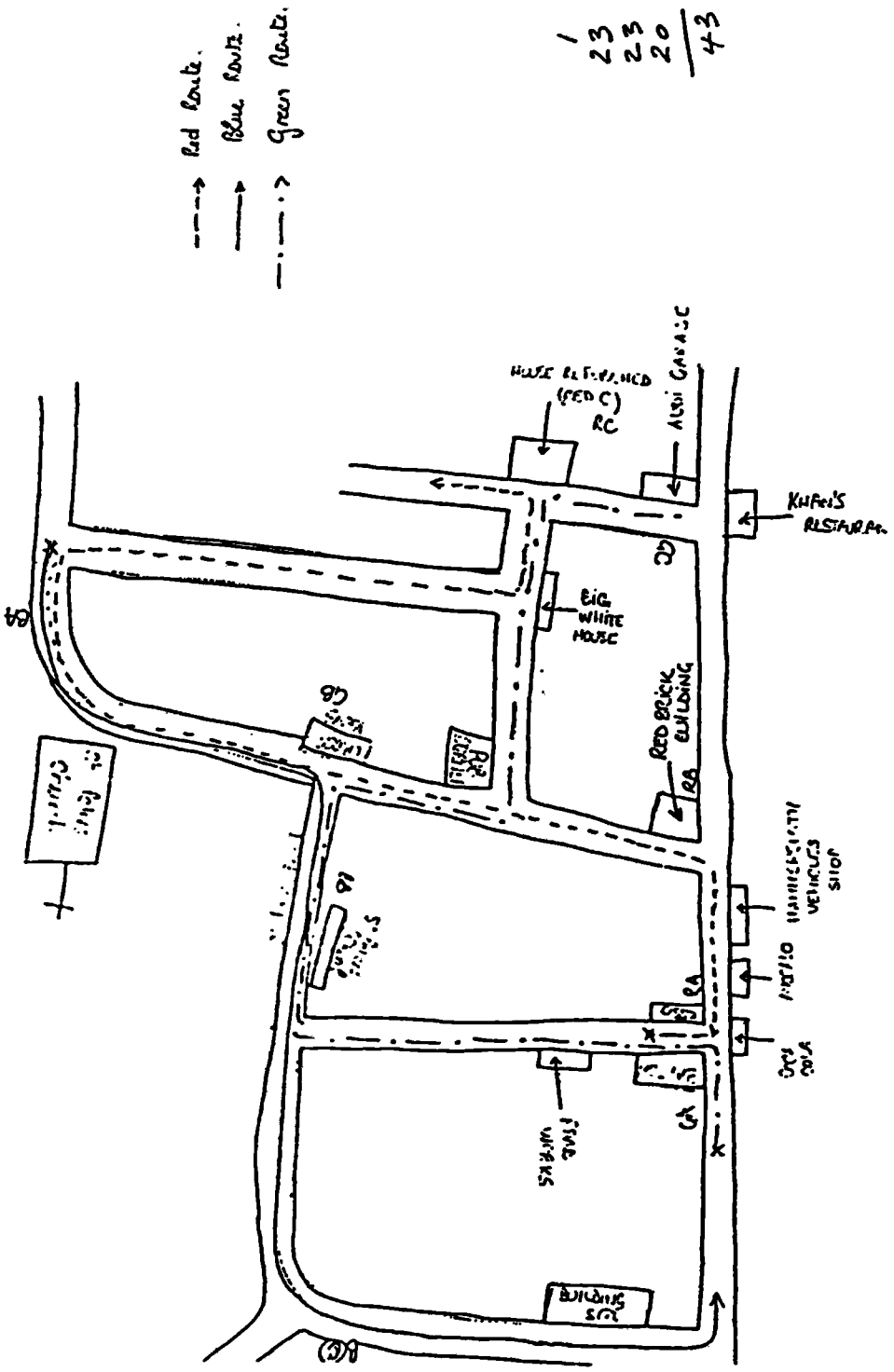

St Peters Road
St Peters Square
St Peters Square
North Block Gardens
Construction site
Esso Station
St Peters School
St Peters Church
Two Cross Key Pub
houses
houses
houses


Mercedes garage
signpost
KINGS ST.
red shop
more shops
Map (x)
bus lane
red brick building
ABI bank
ESSO
bus stop
building site with green wall
building with black windo
White house
White house with scaffolding
arch + pillars
No entry
cars this way
pedestrian parkpace
lots of trees no houses
pub
cross keys
lots of parkin cars had to go on right side of rod
green building
flats with balconies
School
St. Peters Rd.
another building with black windows
'systems' white building
terrace house (one blue one lighter shade of blue)
church
grass
another road visible across grass

Map (xi)



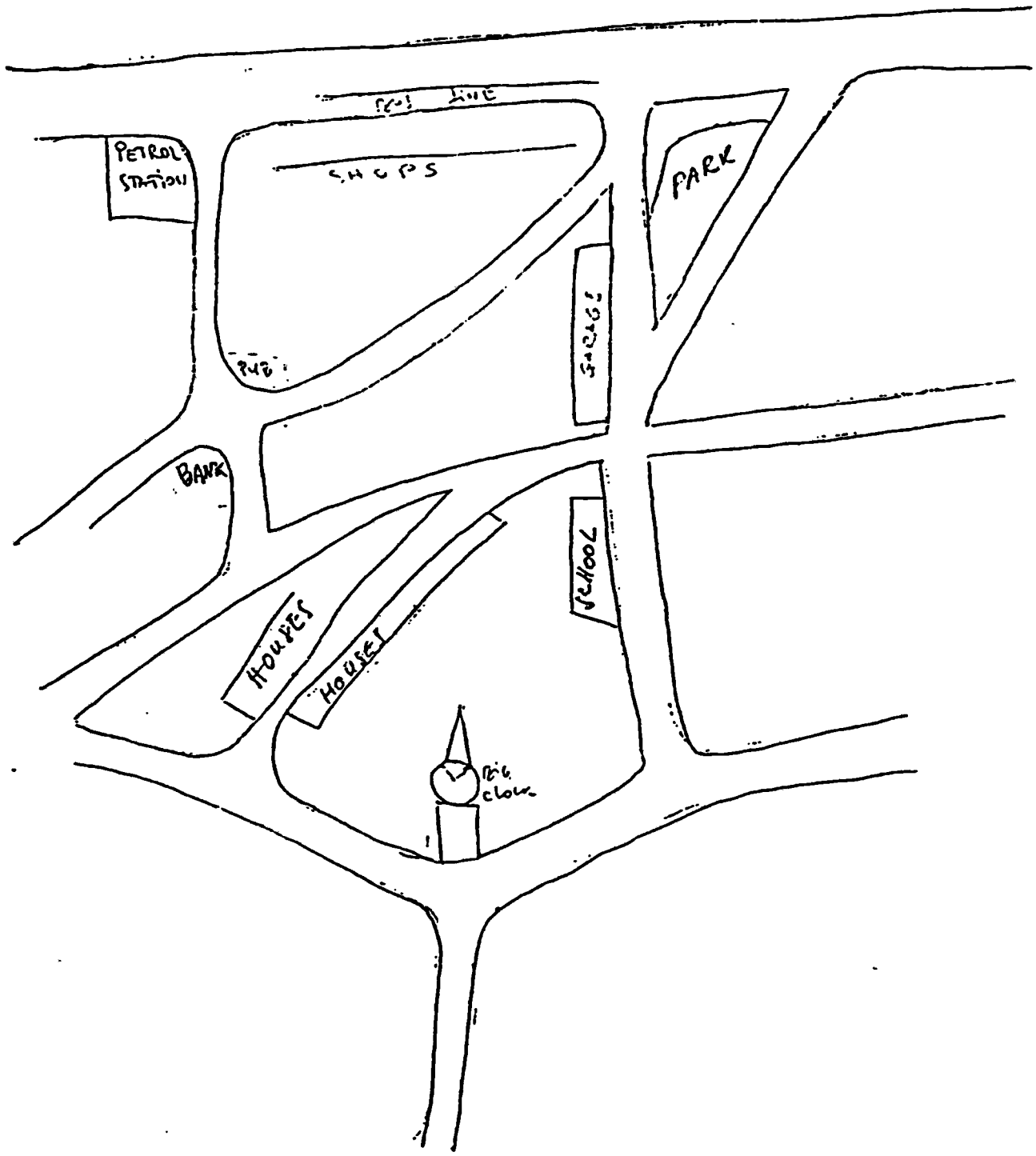
Map (xii)


Red Route.
Blue Route.
Green Route.
1
23
23
20
43
KUFRI'S
BIG WHITE HOUSE
RED BRICK BUILDING
RA
RC

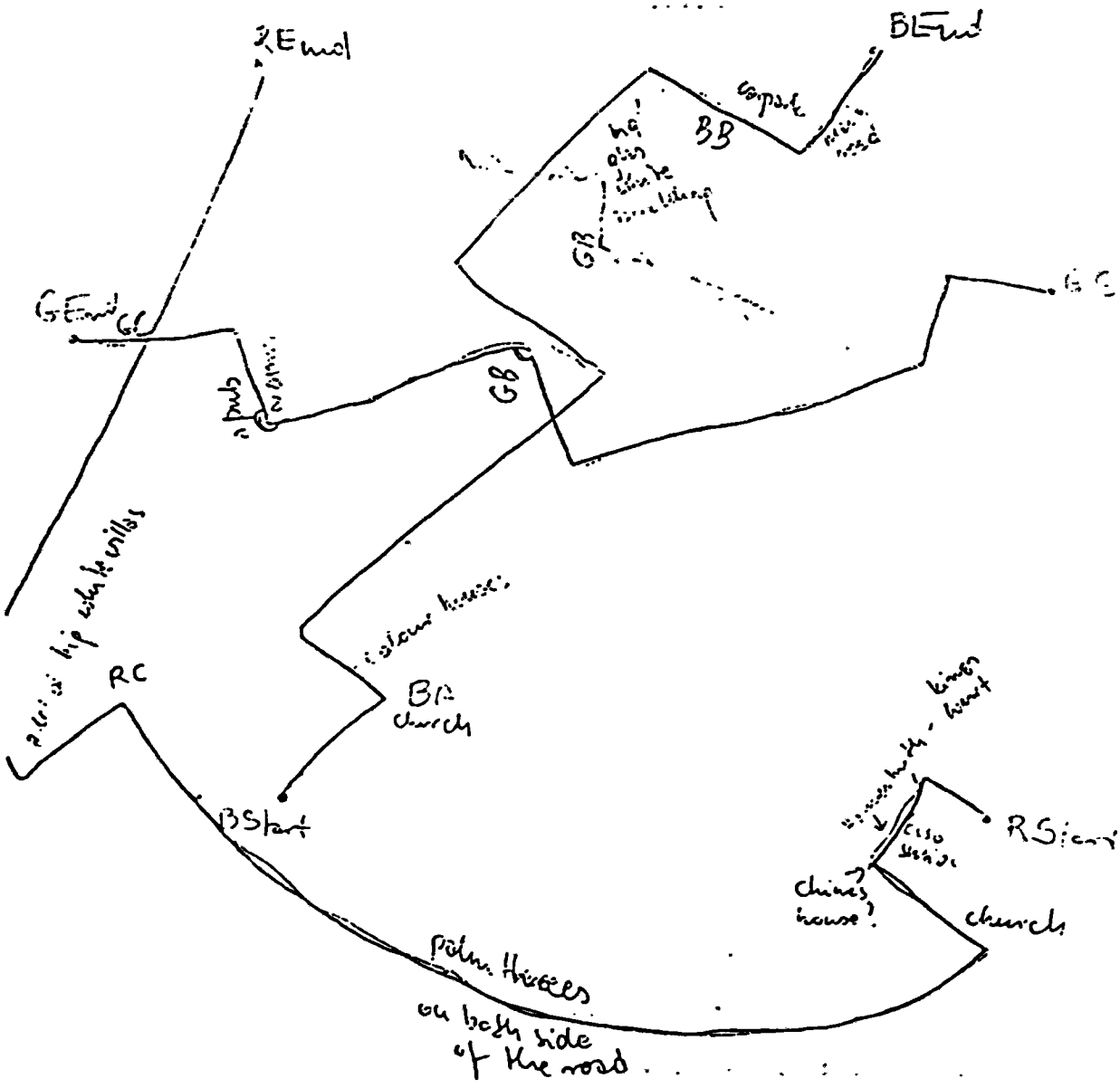
Maps xiii - xvi: Examples of sketch maps produced by female non-drivers

The next four maps were drawn by female non-drivers. Map (xiii) was drawn by a 34 year old female; maps (xiv), (xv) and (xvi) were all drawn by 24 year old females. As with their male counterparts, there was a distinct inability to integrate the information acquired from the three separately experienced routes. This is particularly evident in map (xiv). This individual has clearly acquired information about each individual route, most of which is quite accurate. However, she has been totally unable to integrate this information. Map (xiii) also shows problems with integration. Note that whereas the maps of male non-drivers tend to be sparsely detailed, these maps show a great deal of information, but in common with male non-drivers, poor integration.

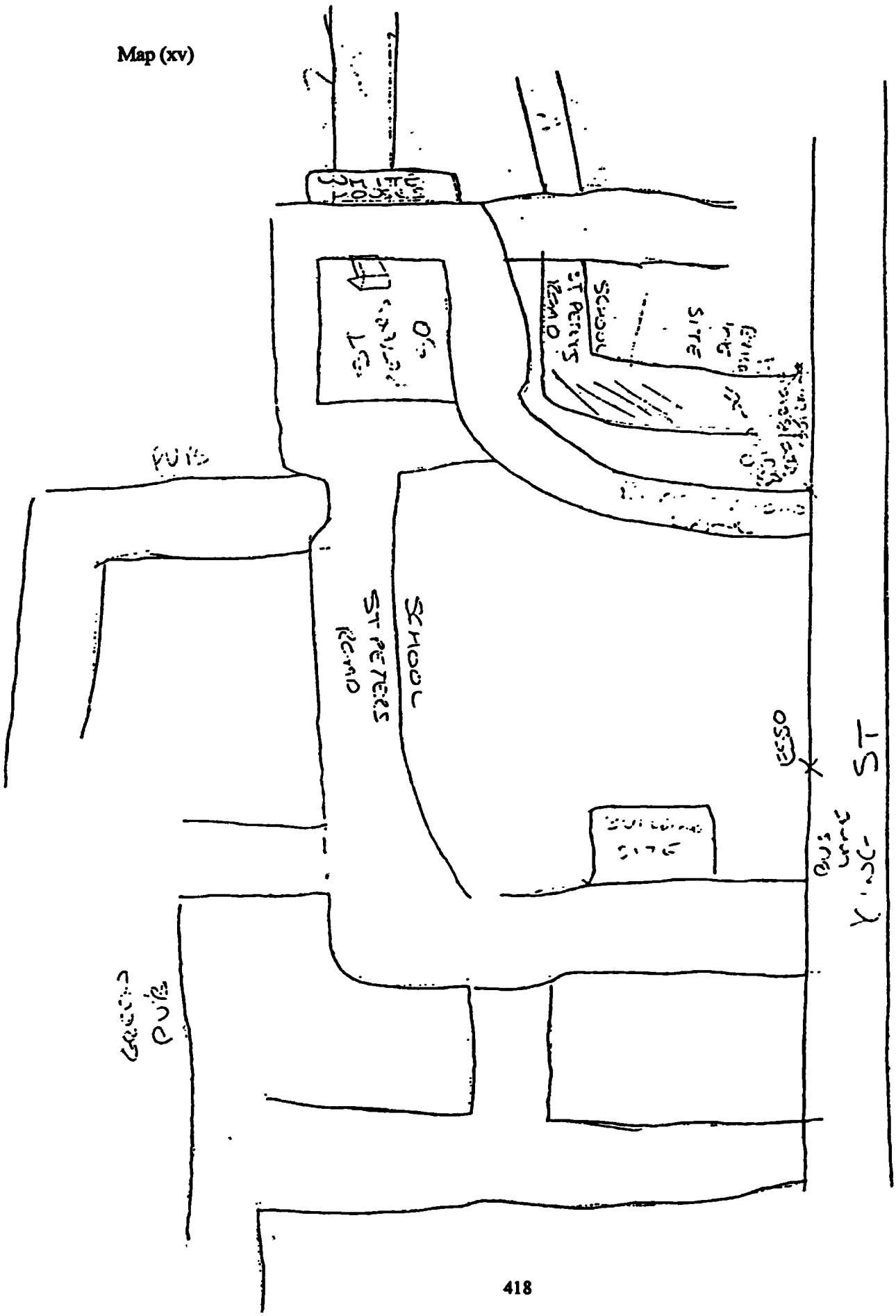
Map (xiii)


PETROL STATION
SHOPS
PARK
PUB
GARAGE
BANK
SCHOOL
HOUSES
HOUSES
BIG CLOCK

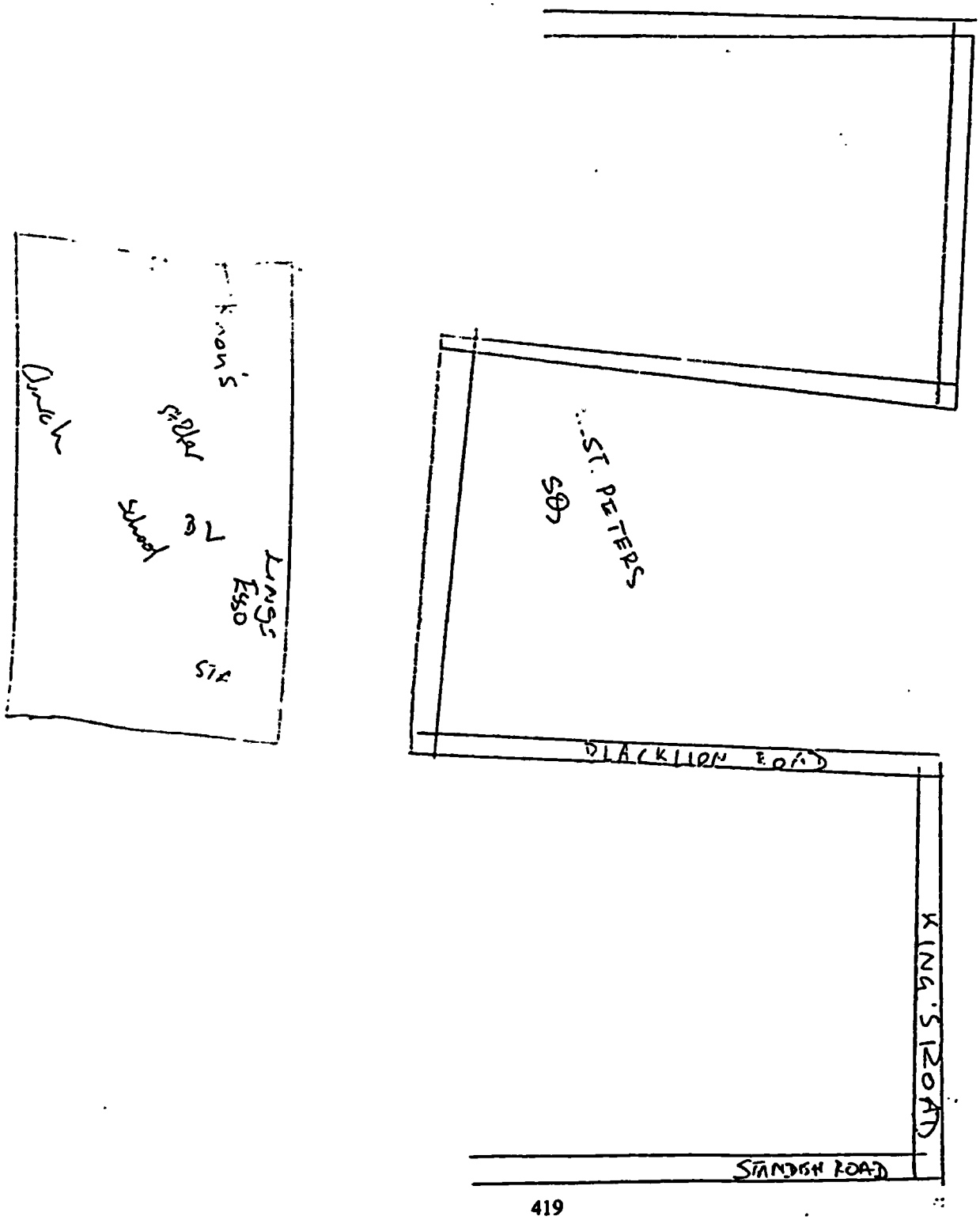
Map (xiv)


REnd
BEnd
BB
GB
GEnd
GB
RC
BChurch
BStart
RStart
church
Palm Trees
on both side
of the road

Map (xv)



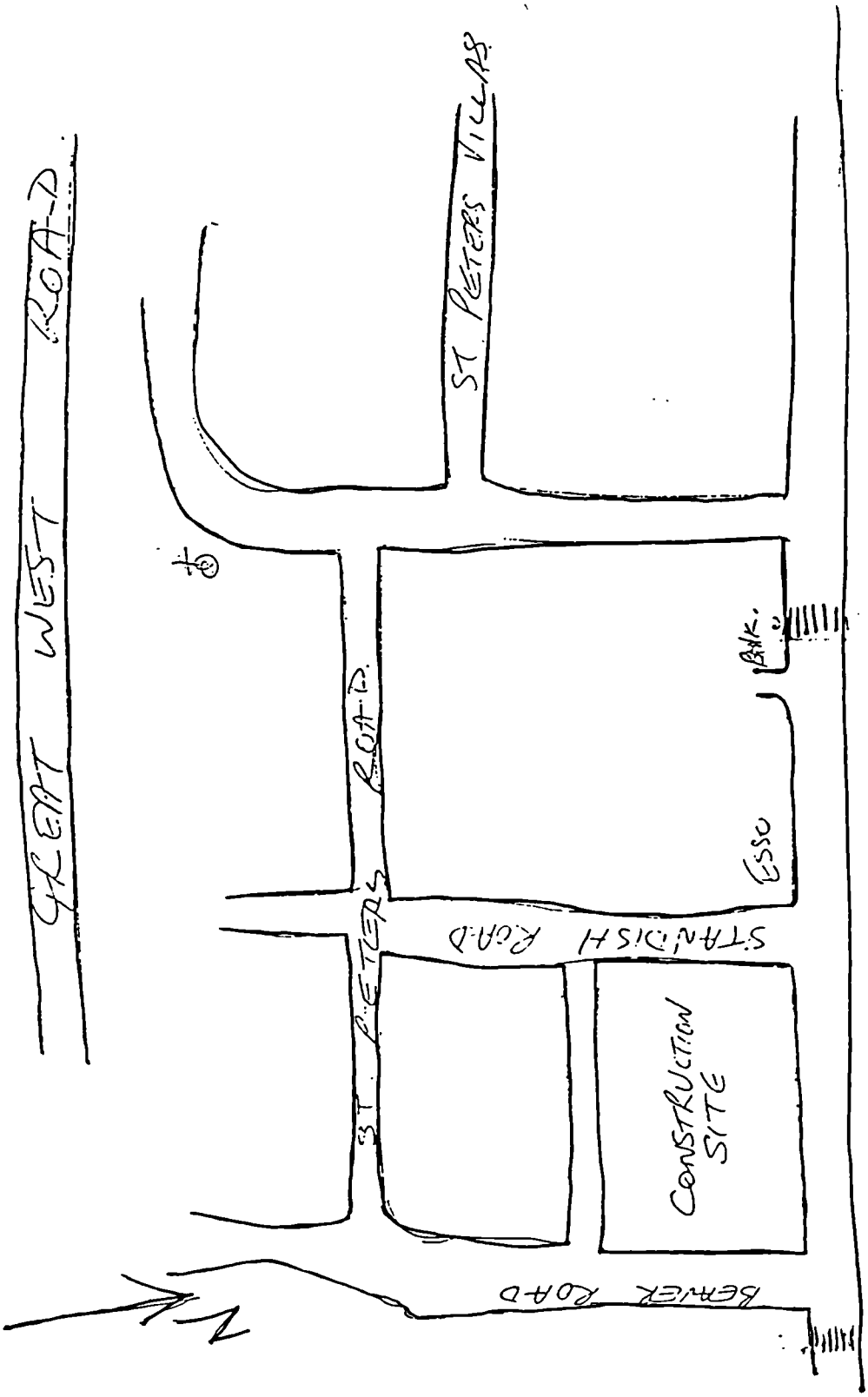
Map (xvi)


ST. PETERS
SQ
BLACKLION ROAD
KING'S ROAD
STANDISH ROAD
ESSO
SITE

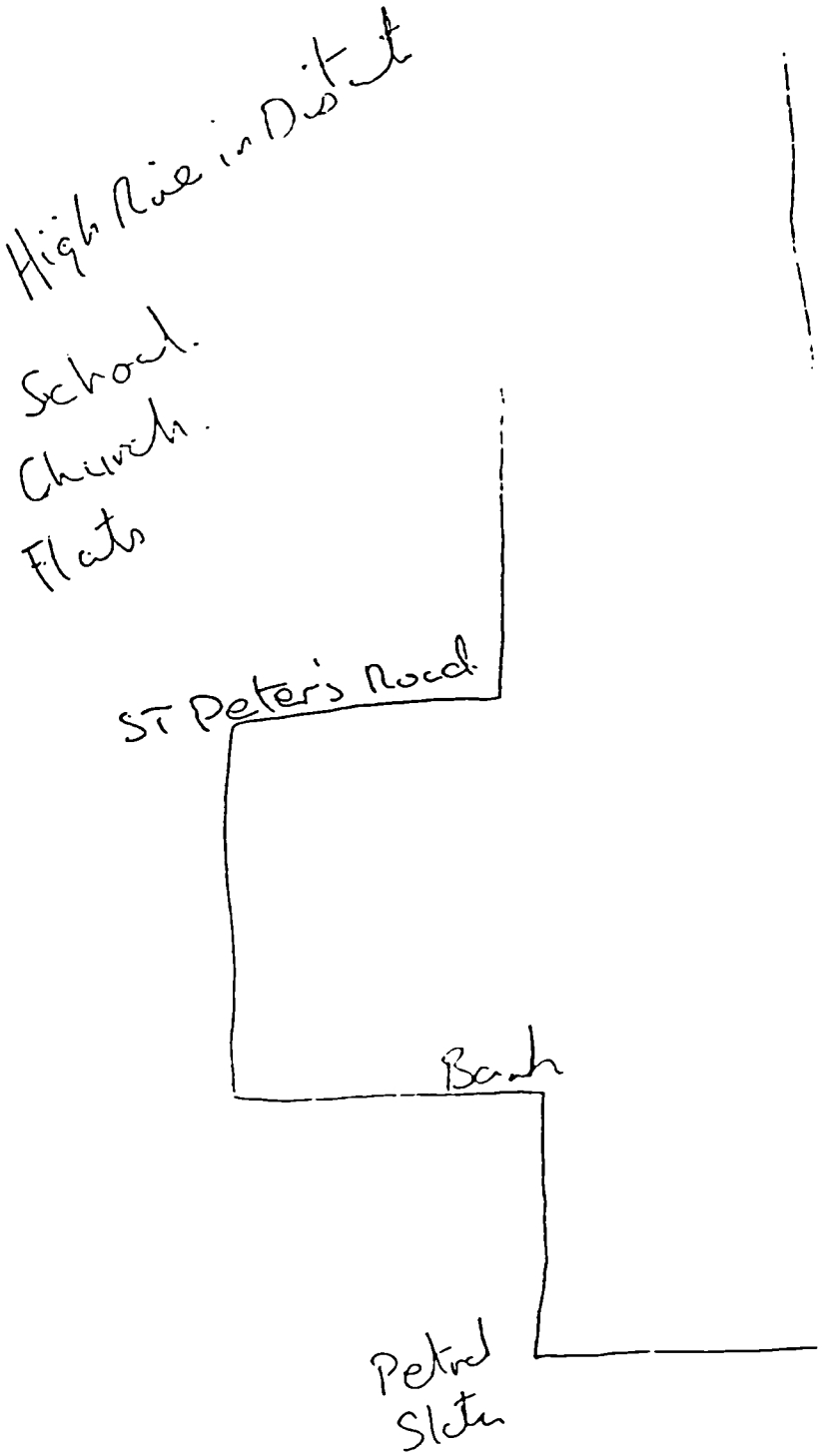
Maps xvii - xx: Examples of sketch maps produced by subjects aged 50 and over

Whilst age clearly had a debilitating effect upon subjects' ability to acquire a configurational representation of the area, older drivers tended to perform better than their non-driving counterparts. Maps (xvii) and (xviii) were drawn by a female driver aged 54 and a female non-driver aged 51 respectively. Map (xvii) shows good route knowledge and integration of the three routes, despite being sparsely detailed. The map also shows good knowledge of route names. Map (xviii), on the other hand, shows only very limited knowledge of one of the three routes. Map (xix) is drawn by a 64 year old male non-driver, and shows how difficult some subjects found the experiment. This subject has acquired knowledge of some of the landmarks in the study area, but very little else. Finally, map (XX) was drawn by one of the eldest subjects to take part in the experiment, an 80 year old male driver. The information contained in the sketch map could not have resulted from knowledge of one route only. Although the detail is sparse, this subject has managed to integrate information acquired from all three routes into a configurational representation of the area.

Map (xvii)

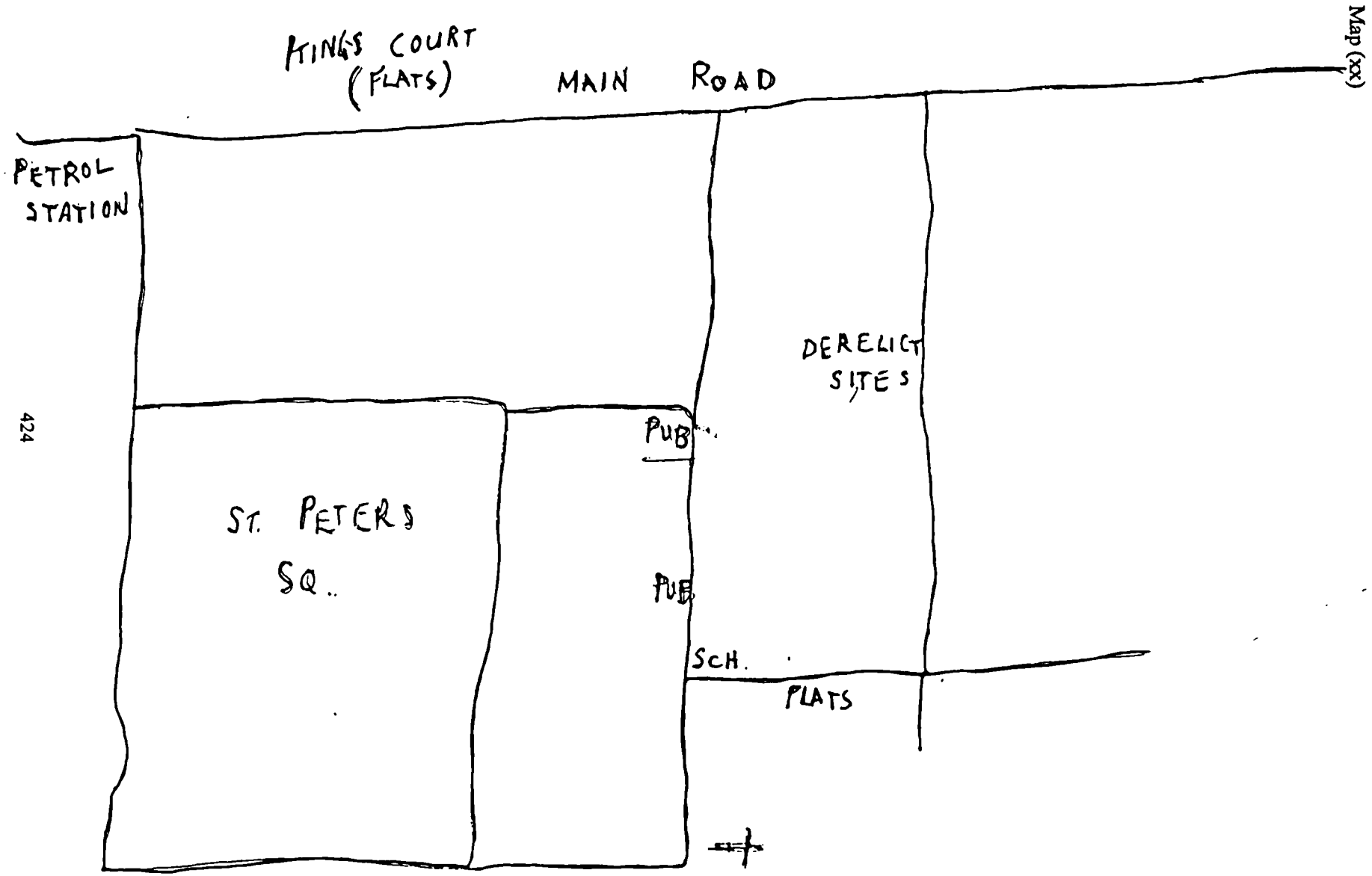

GREAT WEST ROAD
ST PETERS VILLAS
BANK
ESSO
STANDISH ROAD
ST PETERS ROAD
CONSTRUCTION SITE
BEWER ROAD

Map (xviii)


High Rise in Distt
School.
Church.
Flats
ST Peter's Road
Bank
Petrol
Stn

Map (xix)

KENSINGTON
HIGH ST
TO START
ST. PETERS
SCHOOL
CHURCH
OTHER CHURCH
CARPENTERS ARMS
PUB.
2 OTHERS
PUBS.
ONE HOUSE BEEN
DEMOLISHED


KINGS COURT
(FLATS)
MAIN ROAD
PETROL
STATION
DERELICT
SITES
PUB
ST. PETERS
SQ.
PUB
SCH.
FLATS

APPENDIX XV: OBSERVATIONS AND COMMENTS MADE FOLLOWING A SERIES OF TEST DRIVES IN A CAR EQUIPPED WITH THE BLAUPUNKT TRAVELPILOT SYSTEM

The Blaupunkt TravelPilot route guidance and navigation system is one of a number of in vehicle devices which aim to provide drivers with additional information about their journey. In the short term such information will be limited to route guidance advice assisting drivers in wayfinding and navigation. Overall, we were impressed with the system, and feel that it has the potential to provide drivers with a range of benefits. Our comments regarding what we perceive to be the system's flaws are given with the aim of improving an already excellent system. Whilst reading these comments one should bear in mind the following:

- The Blaupunkt TravelPilot system is aimed at a range of markets but is likely to include tourists using a hire vehicle. For this group in particular, it is essential that the instructions given are clear, concise, free of ambiguity and relevant to the immediate situational requirements;
- The Philips Carin system is due to be released in the near future, giving prospective purchasers of a route guidance system a choice of at least two devices. In a competitive market even slight refinements or improvements to the Blaupunkt TravelPilot system may be enough to give it the edge over the competition. Hence, while our comments might seem negative, we wish to make it clear that they are intended to be constructive, have a serious purpose and are not merely nit-picking.

Having test driven the vehicle and studied the instructions given by the Blaupunkt TravelPilot system at specific junctions we identify the following as areas for possible concern:

i) Erroneous data in the Blaupunkt TravelPilot database;
ii) Differences between instructions given and driver's view;
iii) Ambiguity of voice messages;
iv) Inconsistency of voice messages;
v) Routing criteria (primary roads) - safety.

In addition to the information acquired from the test drives we have also run a series of experiments providing route guidance information to over 200 people of ages ranging from 17 to 86. The focus of these experiments was the ability of different types of individual (e.g. different age groups) to cope with the same route guidance instructions. This research showed that some groups, particularly older drivers, might find it more difficult to cope with a secondary source of information (verbal instructions) whilst driving. Hence, whilst at times our comments might appear to be given from a somewhat pedantic viewpoint, this is because we are aware that, when it comes to understanding verbal messages whilst performing a complex task such as navigating, all drivers cannot be considered to be equal. In some of the situations described below one might feel that common sense should tell the user what is required - unfortunately common sense cannot be relied upon and is a poor defence should problems arise. Moreover, any new piece of technology introduced into the vehicle must be considered a possible source of distraction. It is also possible that for some drivers a secondary source of potentially distracting information might be enough to interfere with their otherwise safe driving, especially at junctions requiring a difficult manoeuvre (e.g. making a right turn from a side road onto a major road).

Errors in the Blaupunkt TravelPilot database

The test drives highlighted a number of errors in the Blaupunkt TravelPilot database. Some of these errors undoubtedly result from errors either at the data collection stage (missed information) or at the data entry stage. Clearly these are issues of which Blaupunkt TravelPilot are fully aware and are making every effort to address. However, certain of the database errors arise directly from the way that the database is set up. For example, it is clear that the system has problems with mini-

roundabouts and that this is due to the way that these features have been coded. Given that errors in the information received are likely to reduce user's confidence in the system, we would strongly support efforts to address this issue.

Differences between information given and the view that the driver sees

The Blaupunkt TravelPilot system provides drivers with information via:

a) verbal message instructions; and
b) an LCD display screen.

We found that, on the whole, the verbal instructions tended to agree with the driver's viewpoint. However, it was noted that on occasions the information displayed on the screen differed from the driver's view at that particular moment. The direction arrows on the display screen often disagreed with the driver's view. For example, when the instructions required that the driver remain on the same road the screen would display an ahead arrow, although often this would be contradicted by the presence of acute bends in the road. The `ahead arrow' is the most logical solution to such situations (the driver is simply required to remain on this road and is not required to deviate from this course of action). However, situations could arise where a driver is confused by the presence of an ahead arrow where the road clearly bends round. Perhaps a verbal message accompanying the ahead arrow such as "Follow the road round to the left" would help prevent confusion.

A more extreme example of such incongruities was apparent on one of the routes we filmed. At one point we came to a 90 degree bend in the road, and were to make a right turn about 50 metres after the bend. The display showed a right arrow and the instruction "Turn right after 50 metres" was given. However, this information was given on the approach to the left turn and, whilst we had no option but to follow the road around to the left, the right arrow on the screen could have been a potential source of confusion.

On occasions we also noted a time lag between our response to one piece of information and the screen registering our response and delivering the next piece of information. This resulted in the potentially confusing situation whereby the screen still showed the previous instruction for a few seconds. A particular example was the following sequence:

Screen	**Voice**	**Our response**
Left arrow	"Please turn next left"	We turn left,
Left arrow	No guidance given	We are now heading straight

The left arrow remained on the screen for approximately 13 seconds after we had made the left turn, during which time we passed another left turn. Whilst this was probably the result of being held up behind another vehicle (during which time we only moved a few feet) again the situation demonstrated a possible source of confusion.

As discussed above, such situations would not confuse the majority of system users, but it is possible that, for some users (our research would suggest elderly drivers are particularly at risk) this momentary sense of disorientation might be enough to distract from their primary task of safely controlling the vehicle.

Ambiguity of voice messages

Previous research has indicated that driver's commuting behaviour can be characterised as habitual (they tend to favour a particular route over alternatives). Drivers are also initially suspicious of new technologies such as route guidance systems. This suggests that the first few attempts to use the system will play a crucial part in the driver's long term acceptance of the device.

Consequently, it is essential that the information provided to users is unambiguous. The previous section mentioned potential sources of ambiguity evident in the display. This section deals with a slightly different form: ambiguity of the language used in voice messages. Again, for the majority of users these may not be problematic. Our research has shown, however, that some instructions, particularly those incorporating distance information, may cause problems for certain users.

Examples of ambiguous voice messages:

i) When travelling along a stretch of dual carriageway the following sequence of instructions was given:

"Bear left after 250 metres"

"Please bear next left"

The instruction to bear left after 250 metres could suggest either:

a) that the road will bend round to the right but we are required to take a left fork, or

b) that we need to get in to the left lane.

In this instance the requirement was b. However, the instruction "please bear next left" implies a more definite action is required than simply to stay in the left lane. In particular, the use of the word 'next' suggests a left turn is imminent.

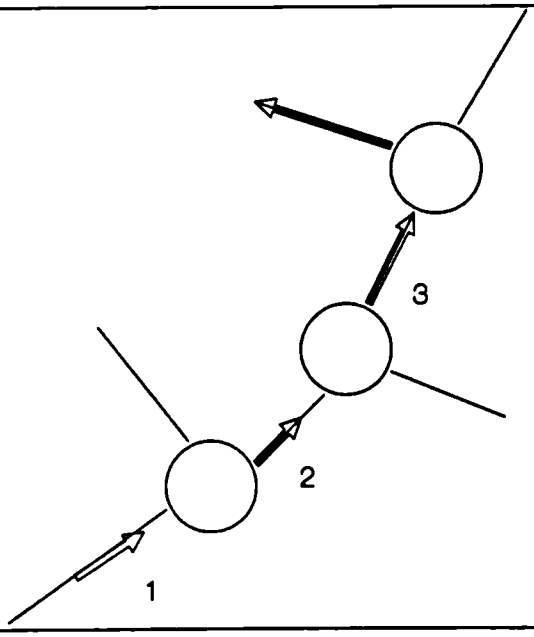
ii) Immediately after this sequence the following instructions were given:

"Leave the roundabout at the second exit" (1)

"Leave the roundabout at the next exit" (2)

"Leave the roundabout at the next exit" (3) (see Figure 1)

Figure 1



The use of 'next' in the phrase "Leave the roundabout at the next exit" is potentially ambiguous. This was particularly evident in this sequence where the road layout was as shown in Figure 1. When you can see the road layout as depicted in Figure 1 the instructions make sense (as long as you are aware that 'next exit' means first exit). However, when driving this route you are unaware that a second and a third roundabout are coming up, which could lead you to question the instructions, particularly repetitions. Part of this ambiguity lies in the way the system treats roundabouts, at present this appears to be highly variable. Unfortunately, there is no easy solution to such situations, one would need to know that there is a system of roundabouts ahead to understand the instructions. However, some of the ambiguity could be reduced if, instead of

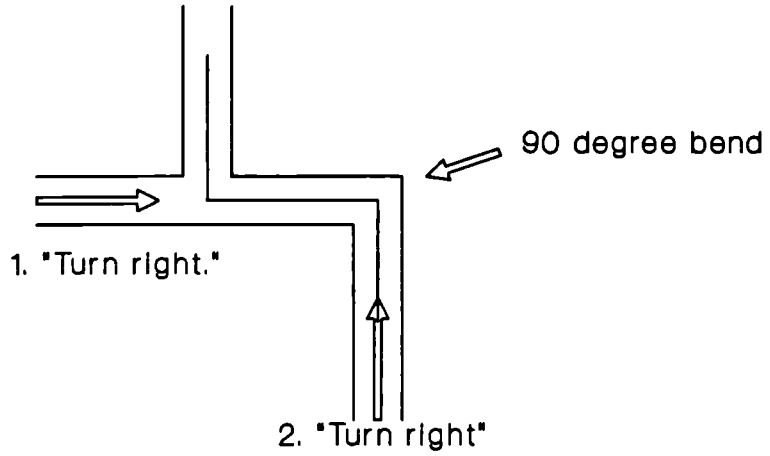
repeating an instruction the system was set up to give a slight variation: enough to let the driver know that the second instruction is not being given simply because they have not yet made the correct response.

Inconsistency of voice messages

We found that the system was inconsistent in the messages it gave. For example, Figure 2 shows the way the system dealt with a 90 degree turn approached from both directions.

Figure 2

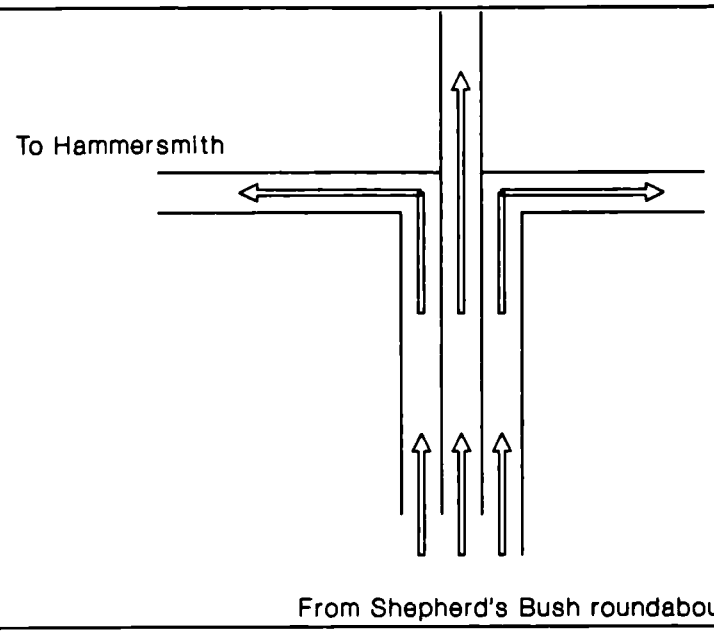
In position 1 the system treats the bend as a right turn.



In position 2 it ignores the bend and gives information about the subsequent right turn

Another inconsistency occurred with regard to instructions to bear left or bear right. In some circumstances the system instructed us to bear left (get into the left hand lane), while in other situations no instruction was given. An example occurred after leaving the Shepherd's Bush roundabout on our way back to Stamford Brook (Figure 3).

Figure 3



We found ourselves in the left lane which, some 30 seconds later, turned into a filter lane to turn left. In this instance it would have been useful to know that we needed to be in the middle lane (of three). On a number of other occasions we had been instructed to bear left or bear right suggesting that the technology to provide such a detailed instruction is available. In such situations lane information could be of crucial importance and would certainly provide the driver with additional salient information which, under normal circumstances, would only be available to someone familiar with the route.

Screen	**Voice**	**Our response**
Ahead arrow	"Continue to follow the road"	Maintain position and direction
Ahead arrow	No instruction	We are now in a filter lane to a left turn

This leads onto a related issue: information that the system doesn't give could be as confusing as ambiguous information. For example, on two occasions there were gaps of some minutes between instructions. This was because we were simply maintaining the same straight ahead heading (shown on the display screen). However, it would have been reassuring to be given the "Continue to follow the road" instruction on a more frequent basis. This could be of particular importance to a system user who has had some experience with the system and who is aware that during recalculations the system does not give information. Faced with receiving no information for a number of minutes one might think that an error had occurred (either in the system or in one's own interpretation of system instructions). In short, what the system doesn't tell you could affect confidence in the system.

Routing criteria

Thus far we have been concerned with possible sources of ambiguity in the instructions and the display screen. A potentially more serious issue is that which relates to the path selection criteria. We are aware that the system is set up to guide the driver along the major roads. However, on one occasion the system took us on a journey of over 3 miles, when the most direct route would have taken just 1.5 miles. Aside from the fact that such a route seems to counteract one of the major benefits of the system (time savings) a more serious issue was raised by Mike Williams. Mike is a

qualified driving instructor and, as such, is particularly aware of the levels of difficulty (and consequently risk) of making various types of turning manoeuvre. Using a numeric scale of difficulty where the most risky turn (turning right from a minor road onto a major road) is graded 5 and the least risky (making a left turn from a major road into a minor road) is graded 2 (see key overleaf), Mike was able to give us some indication of the risk associated with the route that the Blaupunkt TravelPilot system instructed us to take, and the risk associated with the most direct route. This produced the following results:

	Most direct route (1.5 miles)	**TravelPilot route (3 miles)**
	4	4
	4	4
	5	4
	2	4
		4
		2
		4
Totals	**15**	**26**

Key:
R turn minor road to major road= 5
R turn major road to minor road= 4
L turn minor road to major road = 3
L turn major road to minor road = 2
All roundabouts = 4
Crossroads R turn minor-major= 5
Crossroads L turn minor-major= 3

At present the Blaupunkt TravelPilot system has only one routing criterion: one's route is plotted along the primary routes available. Our observations of the system in operation, together with the results of our own research, would suggest that users would benefit from having additional options, for example - the ability to select a route based on least risky turning manoeuvres, which could be of particular benefit to drivers unfamiliar with the British road network, or for older drivers who might have more time available and hence are more concerned with safety than with time savings.

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