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# Visual Demand and the Introduction of Advanced Driver Information Systems into Road Vehicles

by

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# Abstract

This thesis contains six studies investigating the impact of advanced in-vehicle information systems on the visual demands of the driver. The experiments, while self-contained were conceived to relate together in a cohesive manner.

The first study investigated the reliability of visual behaviour assessment. Video tape records from experimental trials were analysed post-hoc. Significant test/re-test correlations were obtained.

Experiment two considered the visual demands of the driving task without intervention from new technologies. Results from road trials using an instrumented vehicle suggested changes in the subject's visual scanning which could be related to the roadway environment (i.e., rural, urban and motorway driving).

In experiment three the effects of the introduction of a driver information system were assessed using a congestion warning device on public roads. System use resulted in significantly greater: subjective mental workload, glance duration and frequency, and percentage time (eyes) away from the forward view; than the in-car entertainment system, or the control (normal driving).

Experiment four replicated experiment three in a fixed base driving simulator. It aimed to establish the value of the simulator for the assessment of driver visual demand. The same significant differences presented in the road trial were observed in the simulation study.

In the penultimate study, opportunities for the reduction of driver visual demand were investigated. The subjects were presented with: visual, auditory or visual and auditory route guidance information. Results suggest use of auditory information to supplement visual displays significantly reduces visual demand on the driver.

The final study considered the effect of information availability on the distribution of visual scanning. Driver control of in-vehicle information presentation enabled self-determination of visual scanning strategies. Information system control of information presentation was found to disrupt the driver's visual checking. The interface design was shown to force the driver to adopt different visual scanning strategies.

The contribution of the experimental work to the assessment of driver visual demand is discussed and the relationships between the experiments explored.

Acknowledgements

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My greatest thanks go to my wife Kate for her limitless support and understanding.

# Definitions

Many of these definitions are drawn from the draft ISO standard on visual demand measurement (ISO, 1996).

| Term | Definition |
|---|---|
| Accommodation | The adjustment of the lens of the eye to bring about focusing of light upon the retina. |
| ADIS | Advanced driver information system. |
| Fixation | Time that the eyes are accommodated to a particular target region. |
| Fixation time | Duration that the driver's gaze is stationary (disregarding saccadic movements) on a single fixation location. |
| Glance duration | Fixation time plus transition time to that fixation. |
| Glance frequency | The total number of glances to a particular location in the sample interval, where each glance is separated by at least one glance to a different location within a pre-prescribed task. |
| IVHS | Intelligent vehicle highway system. |
| Percentage time off road ahead | Sum of glance durations over a sample interval, for glances to all defined fixation locations other than the road ahead; expressed as a percentage. |
| RTI | Road transport informatic. |
| Saccade | Time period while the eyes are in motion between adjacent fixations. |
| Scan duration | This consists of two or more glances which are linked in a consecutive set of fixations to an area in the visual scene. |
| Task glance duration | Sum of glance durations to all defined fixation locations required to perform the task over the sample interval. |

continued...

| Term | Definition |
|---|---|
| Task glance frequency | Number of glances to defined fixation locations required to perform the task. |
| Time off road ahead | Sum of glance durations over a sample interval, for glances to all defined fixation locations other than the road ahead. |
| Total glance duration | Sum of glance durations within a specified target region. |
| Transition time | Time interval required for fixation to move from location j to location k. |
| Visual attention | "Facilitating the processing of displayed information falling within its *spotlight* beam. It is most common for foveal direction and direction of visual attention to be coincident..." (Hughes, 1989). |
| Visual demand | A function of the complexity (e.g., the legibility, readability, understandability), duration and amount of information being visually displayed, and the difficulty in extracting that information from the surrounding environment. |

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# Chapter 1

# Introduction

## 1.1. Chapter Summary

This Chapter describes the background to the research and puts the work undertaken into context. It summarises the current needs for various research activities and their importance to vision in the driving task. Some of the issues associated with the introduction of novel driver information systems are considered.

## 1.2. Introduction

The number of United Kingdom full licence holders has increased by 34% from 1976 to 1991 (DoT, 1992) with similar trends emerging throughout the world. The growth in vehicle users has contributed to increased congestion, reduced road quality and associated delays in journey time. Advanced driver information systems are now available to assist the driver's task and thereby potentially reduce the consequences on an over-burdened transportation system. For example, collision avoidance systems have the potential to reduce driver risk on more densely populated roads by supporting vehicle control. Route guidance systems could divert the driver away from specific points of congestion. However as Wierwille (1993a) stated "the majority of high-tech devices that might be introduced into a large percentage of vehicles are likely to increase rather than decrease the burden on the driver".

Historically, much of the development of driver information systems has been as a result of the system manufacturer's ability to take technology from elsewhere (e.g., military or aeronautical systems research) and apply it to the road vehicle. Little regard was taken of the affect such systems may have on the drivers' and other road users' safety. Such driver information systems are now becoming available in vehicles. Manufacturers, legislators and end users of these systems are as yet uninformed of the impact they may have upon the driver's visual behaviour and cognitive performance. In the United Kingdom the Department of Transport have recognised the need to control the release these products into the marketplace and have commissioned development of a code of practice to assist in their design, development and assessment (ICE, 1993).

Advanced driver information systems that are available now predominantly rely on the visual display of information. This Thesis was instigated in recognition of the lack of research regarding the visual impact of information systems on the driver and the difficulties in relating measures of driver visual behaviour with vehicle safety. Technological advances have facilitated the development of a range of new driver information systems intended to make travel more efficient and less arduous. Route guidance, vision enhancement, intelligent autonomous cruise control and collision avoidance systems (Beyreuther & Laidebeur, 1989). The introduction of such systems into vehicles could have serious safety consequences if permitted on an ad-hoc basis. "...recent studies have indicated a potential for auxiliary displays to interfere with safe performance of the driving task" (Noy, 1990). Therefore, "...there is an urgent need to develop principles and guidelines for the design of Advanced Driver Information Systems (ADIS) that are ergonomically compatible with the primary task of driving and support drivers' information needs" (Noy & Zaidel, 1991), page 1483. If a usable, valid and cost effective method of determining the visual demand associated with driver information systems could be achieved, there could be gains in terms of improved primary safety. The issue becomes particularly acute when the benefits from secondary safety mechanisms (i.e., airbags, side impact protection, seat belt pre-tensioners, etc.) may be approaching their current technological limits (Viano, Davis, LeFevre, & Scherba, 1991).

Driver information systems have been classified (Galer, 1993) into the following categories, those that:

- directly impinge on the driving task (e.g., collision/obstacle avoidance systems).
- provide information relevant to the driving task, environment, and driver. For example, information about weather conditions, traffic status, accidents, etc.
- influence the efficiency of driving (e.g., route navigation systems which provide the fastest, most scenic or fuel efficient route).
- are unrelated to driving. Such systems include devices like: portable data terminals, facsimile machines and cellular telephones.

It is hoped that the introduction of driver information systems will fulfil their promise of increased safety, efficiency and driver satisfaction. "However, the extent to which new technology can deliver such benefits depends on the ergonomics of the driver interface" (Noy, 1990), page 1533. If the interface is developed with the human information needs foremost, it is hoped that the distractions from these devices will be minimised.

The design of driver information systems should be carefully considered to reduce user distraction, errors and abuse. Distraction of the driver may result from poor interface design. For example, auditory warnings presented when the information does not warrant immediate attention. Errors can of course occur during use of any system. However, errors should be controlled by design so that driver risk can be minimised (Rasmussen, 1983). Misuse encouraged by the system suggests poor design of the interface. It increases the chances of operator error above those associated with driving prior to the introduction of the system. To illustrate, "It appears that under certain circumstances the driver will ignore traffic control devices, such as a stop sign, and continue on the pre-set route in obedience to the in-car message" (Hancock & Parasuraman, 1992), page 189.

## 1.3. Overall Aims

This thesis considers the conventional driving task and the visual demand related changes which may occur as a consequence of the introduction of advanced information systems in the vehicle. Specifically, it aims to explore:

- how visual demand is defined, measured and analysed
- the reliability of video tape transcription for measurement of visual demand
- drivers' normative visual behaviour
- which measures of visual demand are sensitive to the effects of the introduction of driver information systems in the vehicle, and what their limitations are
- assessment settings for visual demand measurement, and their relative merits
- opportunities for reduction of visual demand

- changes in the availability of information to the driver and its' affect on the distribution of visual scanning
- how visual demand measures can be applied to determine the safety of a driver information system.

### 1.3.1. *Project Rationale*

A conceptual model of visual demand is presented (adapted from Zimmer, 1990) to provide the reader with a framework to consider the empirical work conducted in this thesis (see Figure 1-1). *Visual demand* has been defined in the draft ISO standard on visual demand measurement methods (ISO, 1996) as 'a function of the complexity (e.g., the legibility, readability, understandability), duration and amount of information being visually displayed, and the difficulty of extracting that information from the surrounding environment'.

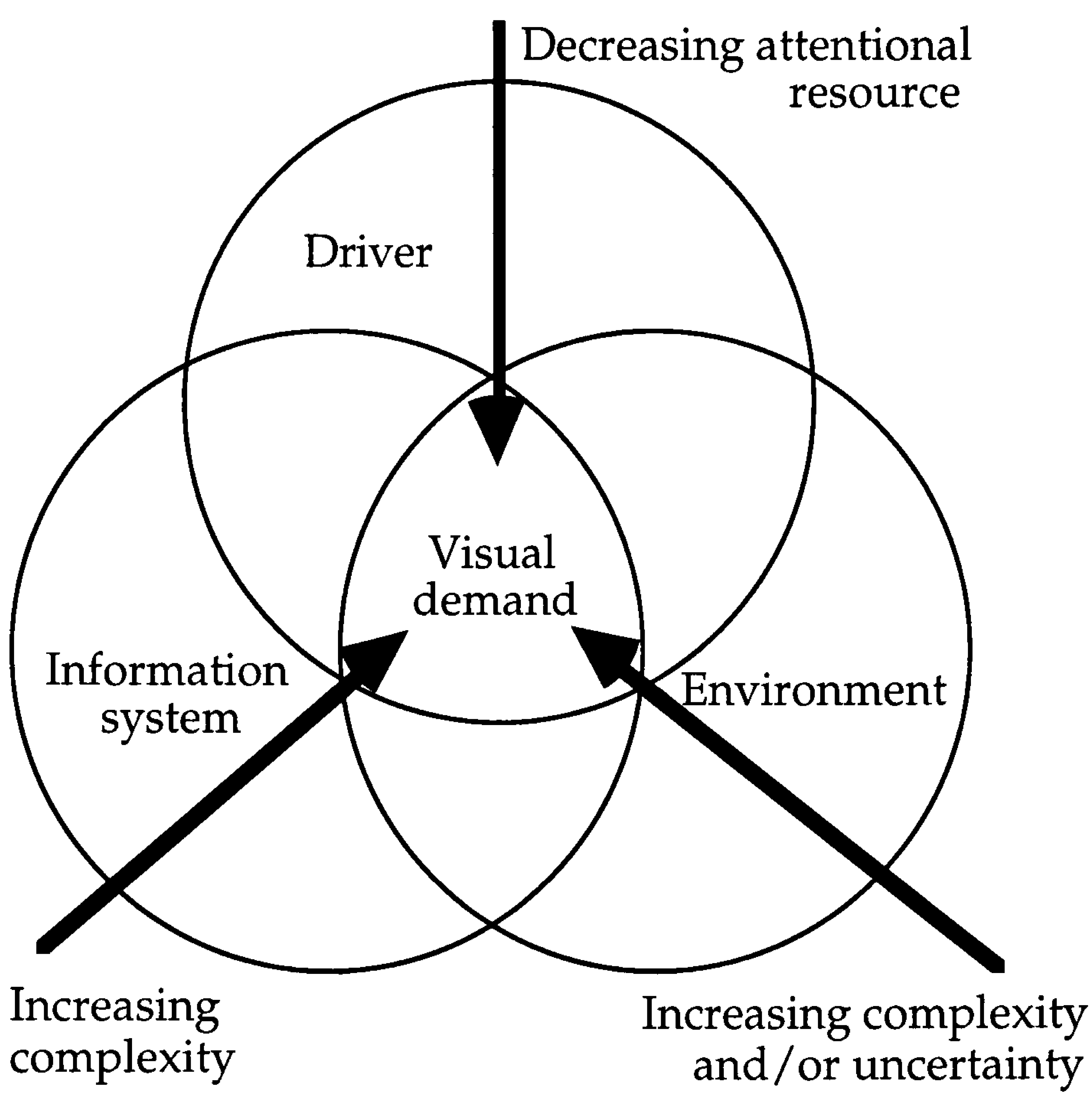



**Figure 1 - 1. Conceptual visual demand model**

The model (Figure 1-1) develops the inter-dependency of the driver, environment and information system. The relationship between the three regions represents influences on visual demand. Movement inward in the driver region is attributed to decreases in attentional resource (e.g., during conversation with a passenger). Thus, inward movement increases the area of the central region representing driver visual demand. Similarly, increases in environmental complexity and/or uncertainty, and complexity of the information system will produce greater visual demands.

Experimental work conducted and described in this thesis investigates the research aims by manipulating features of visual demand. Table 1 - 1 shows these features of visual demand and the aspects considered. Each study described in the subsequent chapters was conceived to address specific relationships within the model.

**Table 1 - 1. Focus areas for experimental work**

| | Driver | Information system | Environment |
|---|---|---|---|
| Chapter 5. Visual demand and the driving environment | ✔ | - | ✔ |
| Chapter 6. Utility of metrics for the evaluation of driver information systems | ✔ | ✔ | - |
| Chapter 7. Driving simulation for the evaluation of information systems | - | ✔ | ✔ |
| Chapter 8. Route guidance information: verbal, visual or both? | ✔ | ✔ | - |
| Chapter 9. Visual behaviour and the availability of advanced driver information | ✔ | ✔ | ✔ |

The experimental work in Chapter 5 was conducted to determine the normal proportion and distribution of driver visual behaviour and explore any differences that the road environment may impose. It examines the relationship between the driver and the environment.

Chapter 6 investigates the ability of various visual and mental demand measures to differentiate between imposed demands from information systems. The elements of the visual demand model considered are the driver and information system regions.

Chapter 7 reports empirical work to investigate the relationship between an information system and the assessment setting in which it is used. It addresses the differences between road trials and the use of a simulator for information system evaluation (i.e., the relationship between the evaluation environment and information system used).

Strategies are needed to reduce situations where the imposed visual demand on the driver may be unacceptably high. The study described in Chapter 8 considers the opportunities for reducing visual demand by using alternative modalities for the presentation of in-vehicle information (e.g., auditory signals). The effect of changes in the interface between the driver and the information system are considered.

The experiment reported in Chapter 9 describes changes in the distribution of drivers' visual scanning as a consequence of using different information systems. It explores the inter-relationship of the driver, environment and the information system.

The final aim in the project, quantification of acceptable limits for safe visual distraction is considered in the Discussion (Chapter 11).

Experimental work in this thesis was conducted to explore the relationships between three key influences on visual demand: the driver, environment and information systems used. The experiments described in chapters 5 - 9 (and supporting research in chapters 4, 5 and 10) have systematically addressed the issues felt to be prime influences on driver visual demand.

### *1.3.2. The Structure of the Thesis*

To assist the reading of this document, the structure of the thesis is shown in Figure 1 - 2. Each chapter has the same diagram at the beginning with the section of the thesis under examination marked in grey. The thesis can be considered as three main phases of work:

- quantification and measurement of visual demand
- factors which influence visual demand
- responses which can be taken to reduce or control unreasonable visual demands.

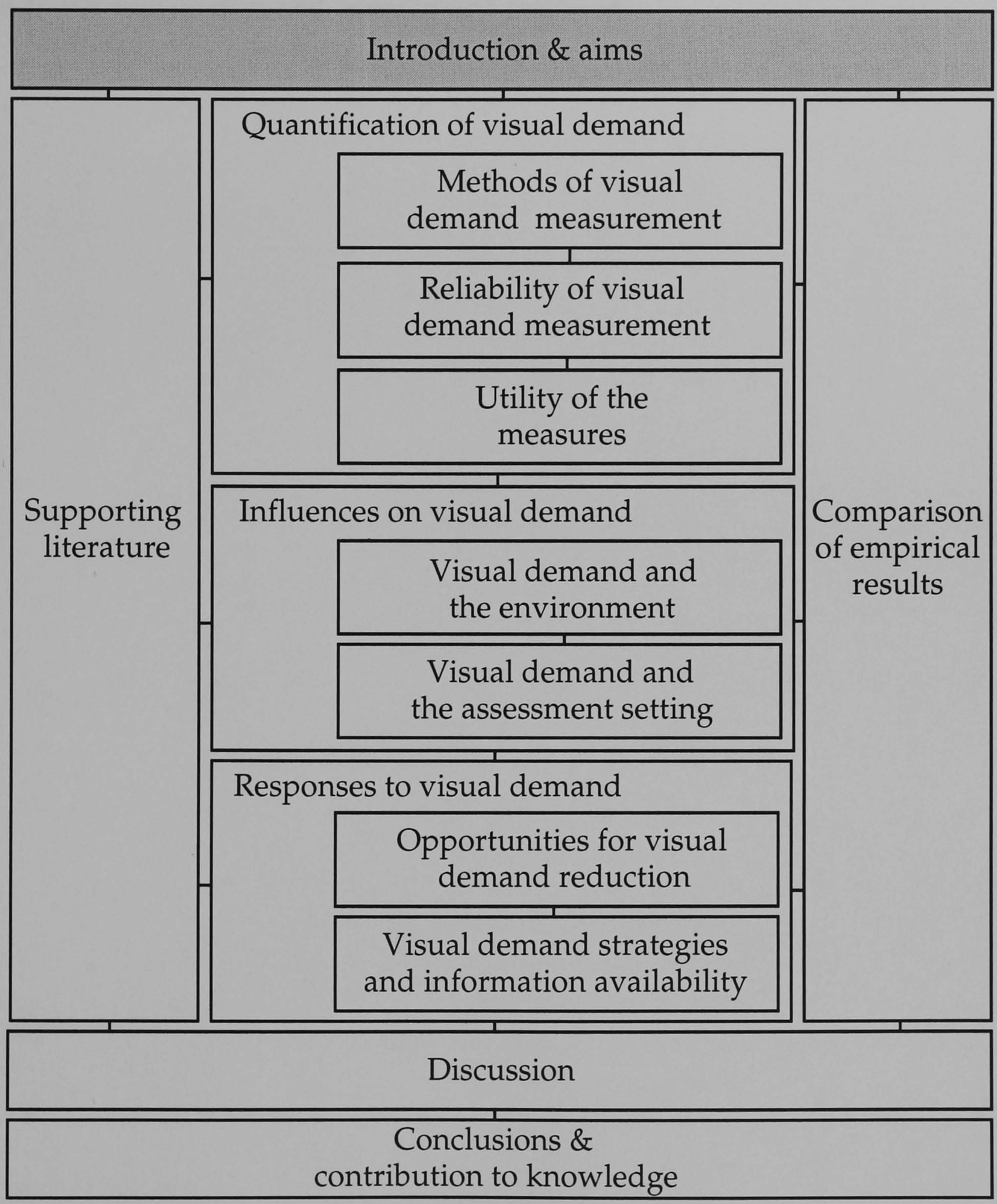



**Figure 1 - 2. Structure of the thesis**

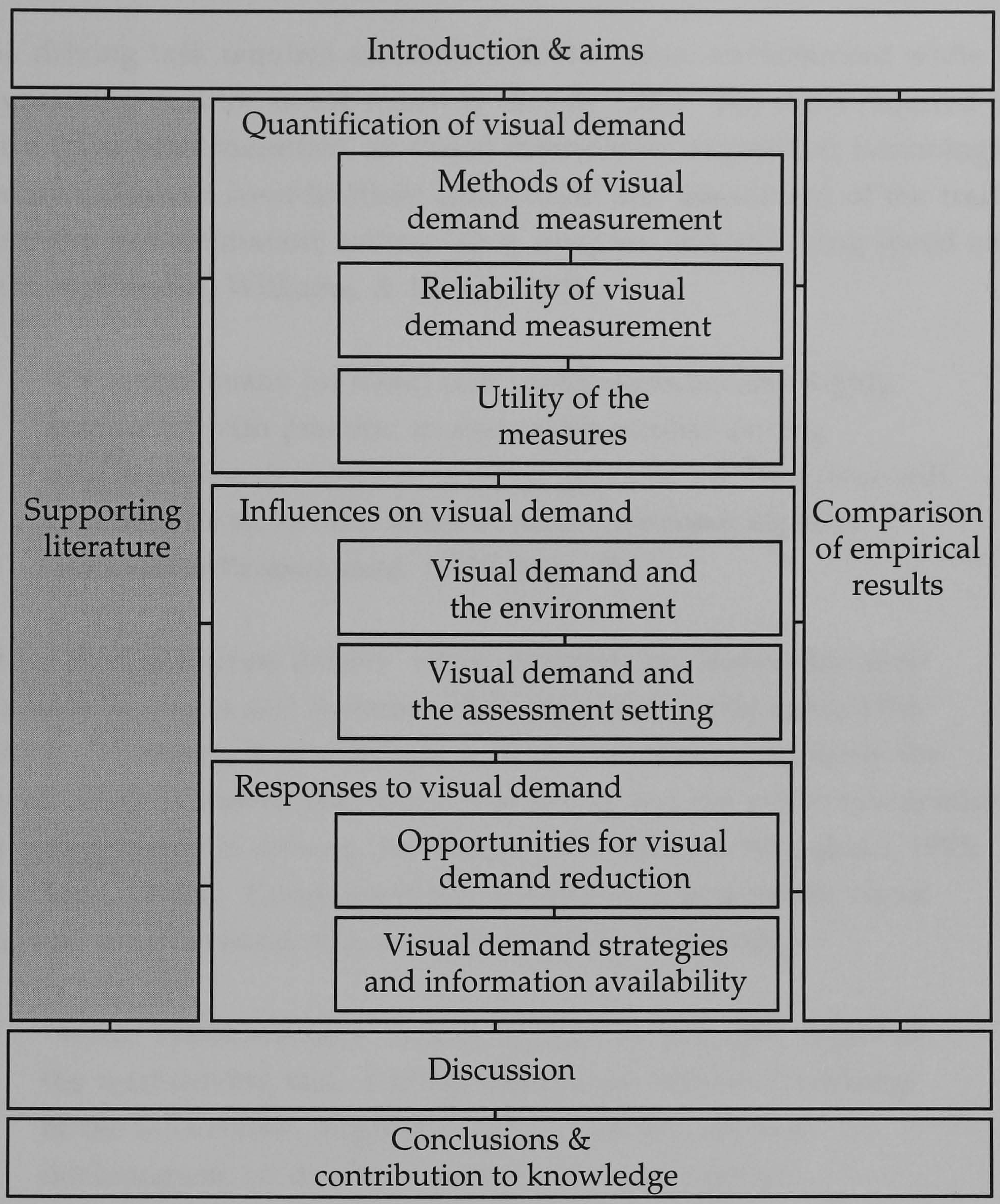
## 1.4. Chapter Conclusions

This chapter has introduced the aims and approach taken in this research to consider the visual demands imposed by the introduction of advanced information systems on the driving task. The increasing availability of in-vehicle information systems has been highlighted and specific research needs for visual demand assessment outlined.

# Chapter 2

# Driver Visual Demand: a Review of the Literature

# Driver Visual Demand: a Review of the Literature




## 2.1. Chapter Summary

This chapter discusses the literature related to the measures, influences and problems with the assessment of driver visual behaviour. It considers the nature of problems in the driving task and the relationship of the human visual system to these difficulties. Literature is discussed regarding the visual requirements to: maintain control of the vehicle; use conventional instruments and interact with advanced driver information systems.

## 2.2. Introduction

The driving task requires assessment of the visual environment while maintaining position in the roadway (Boyce, 1981). The skills required to drive have been identified as: visual information acquisition (scanning); perceptual-motor co-ordination; anticipation and assessment of the traffic situation; risk estimation; setting safety margins; and balancing speed and caution (Duncan, Williams, & Brown, 1991).

> "Of course, many [of these] task components become highly automated with practice, so that under normal driving conditions the demands of divided attention on the driver will generally be within the limits of their attentional capacity" (Hancock & Parasuraman, 1992), page 185.

Under most scenarios drivers' visual demands are lower than their available resources and therefore, they are able to safely control the vehicle. However, it is important to note that vision is arguably the largest single resource available to the driver and the major information processing input in driving (Hartmann, 1970; Sabey & Staughton, 1975; Wierwille, 1993a). Consequently, a investigation into driver visual demand must consider this demand-resource relationship.

> "While eye movement research focuses on only one aspect of the total driving task, it is significant that without knowledge of the information acquisition side of driving, no real development on driving theory such as information processing, anticipation, and learning can be developed" (Rockwell, 1972), page 326.

It is therefore considered valuable to provide a brief overview of several of the more influential models of driver behaviour.

### *2.2.1. Behavioural Models of Driving*

Accident analyses point to driver problems with information acquisition and processing as the major cause of human errors, and thereby of accidents (Boyce, 1981). Understanding the information processing requirements of the driving task may then, provide opportunities to improve driver safety. A number of different approaches have been developed to conceptualise the driving task.

The task has been considered in terms of: (1) strategic planning, (2) navigation, (3) traffic interaction, (4) road interaction and (5) vehicle handling & road following. (1),(2) and (4) were highlighted as promising areas where driver information systems offer potential for increased safety (Rumar, 1988). The effective ergonomic design of driver information systems to reduce visual demand may facilitate benefits while reducing any additional demands from the information system. To illustrate, consider the implementation of a route navigation system that imposes additional visual demand on the driver. *Strategic planning* would be assisted by an in-vehicle map-based interface (which would not be suitable for presentation to the driver while the vehicle is in motion). *Navigation* could be improved by providing drivers with only context relevant information (e.g., which way to turn at a junction, and not too early or late to be useful). Symbolic displays require less frequent and shorter glances than maps and thereby reduce the frequency the driver needs to consider an in-vehicle display. *Traffic and road interaction* may be improved by reducing the demands on the driver at peak periods by providing appropriate and timely advice on road status, hazards and navigation prior to a potentially hazardous situation. Thus, the use of advanced information systems may enable the driver to retain the maximum available information processing capacity so as to best consider unpredictable events.

Many driver behaviour models have developed into hierarchical representations of the task (Hale, Stoop, & Hommels, 1990; Janssen, Alm, Michon, & Smiley, 1993; Johnson & Dark, 1986) some of which appear to have been influenced by Rasmussen's (1983, 1986) ideas conceptualising information processing into skills, rules and knowledge. These levels can be seen to roughly translate into the equivalent strategic, manoeuvring and control elements of the drivers' task, see Figure 2 - 1.

If the relationship of visual inputs to the activities which may occur at each level in the framework is considered then at a *strategic level* the driver would make macro or global decisions, for example, s/he would make choices regarding the route to take the: fastest, most pleasant, least congested, etc. The visual cues of most relevance here may be wayfinding indicators (e.g., route sign information).

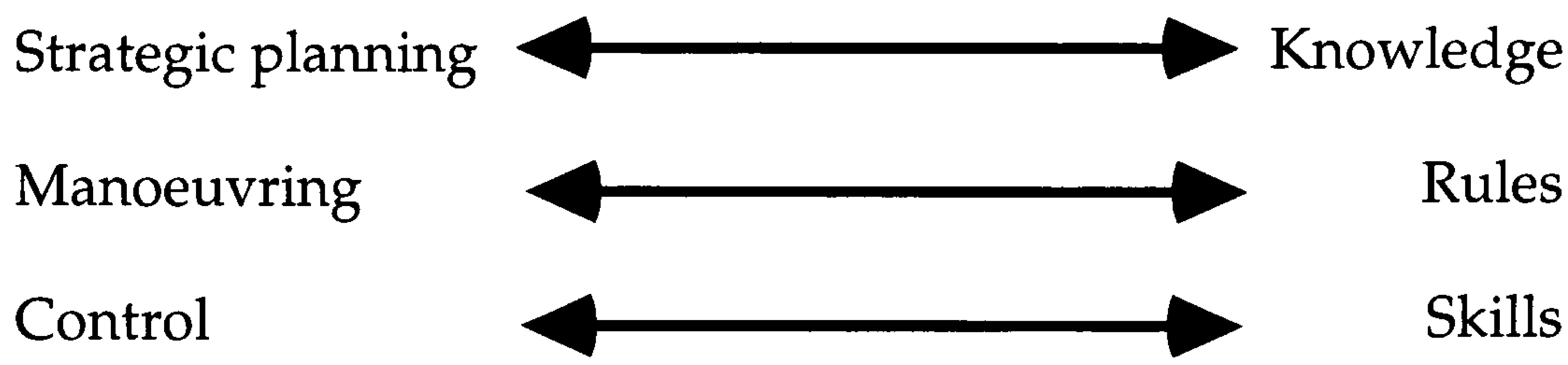



**Figure 2 - 1. The relationship of Rasmussen's ideas and the hierarchical structure of many driving models, adapted from Parkes (1991)**

Similarly, at the *control* level the driver is concerned with activities like operating the: brake, throttle, steering, and other vehicle control features. The experienced driver can be considered to have proceduralised these activities into a number of *if-then* rules, thereby increasing the amount of available attention for other roadway events (Anderson, 1987). The novice driver (who is in the process of formulating manoeuvring *rules*) can be seen typically to have little spare resource, as they are almost fully occupied trying to control and manoeuvre the vehicle.

Road interaction is embodied in the *manoeuvring* level of the task. Activities which could occur at this point include: maintaining and changing lanes, overtaking, reversing the vehicle, etc. The distinction between expert and novice drivers is even more apparent at this level of driver behaviour. Indeed, it has been shown that when compared to experts, novice drivers adopt different strategies when obtaining and manipulating visual information (Mourant & Rockwell, 1972). Experienced drivers were shown to maintain lane position peripherally, while novices tended to sample the visual scene using foveal fixations.

This multi-levelled approach provides a framework with which the influence of vision on the drivers' task can be observed.

## 2.3. Visual Requirements for Driving

Human vision can be considered as two sub-systems, foveal and peripheral. Foveal vision provides the driver with high resolution information about a restricted area (a visual angle of approximately 1°) about the point of fixation. Peripheral vision enables the driver to detect broad changes in colours, movements and contrasts (both temporal and spatial), but with low visual acuity. These systems are discussed in more detail below.

### *2.3.1. Peripheral Vision*

Normal peripheral vision encompasses a horizontal visual angle of 180°, and a vertical visual angle of 100°, see Figure 2 - 2 (DEFSTAN, 1986).

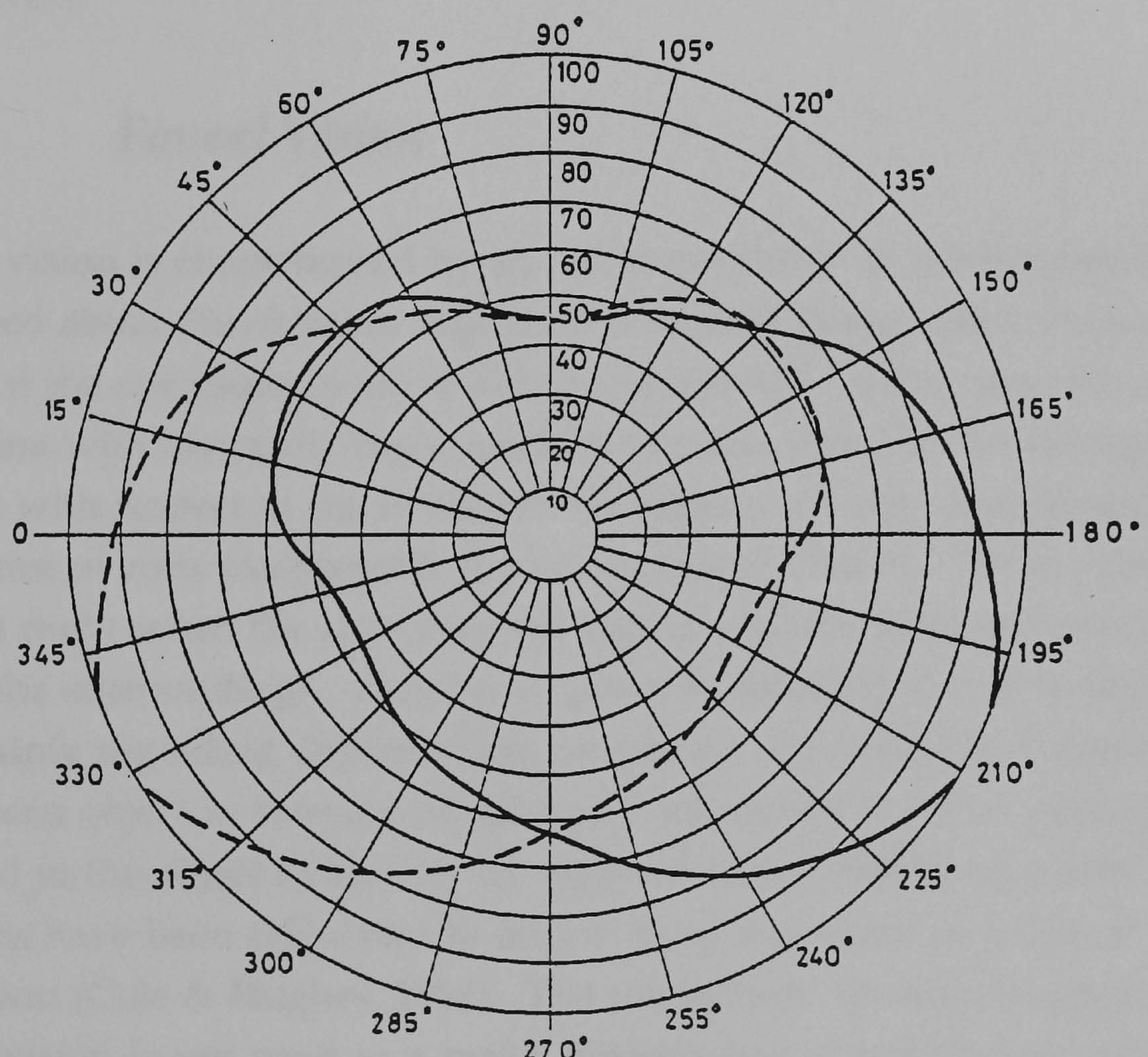



**Figure 2 - 2. The range of the peripheral visual system, from DEFSTAN (1986)**

Evidence has shown that peripheral processing is used to detect predictable visual information (Machworth & Morandi, 1967). "In normal freeway driving, the driver uses extra-foveal [peripheral] vision to maintain lateral placement while directional cues are simultaneously determined foveally" (Rockwell, 1972). Visual acuity (both static and dynamic) is reduced in the periphery (Boyce, 1981). Contrast sensitivity (temporal and spatial) is higher in the periphery than the fovea, although reaction time has been shown to increase with eccentricity (Pfeifer & Tomaske, 1986). Peripheral vision provides the driver with a wide range of visual information from which fixations are selected. Interestingly, increasing subjects' visual demand is argued to reduce the quality of peripheral vision (Muira, 1986). Additionally, as the field of view increases the subjects' reaction time to stimuli has also been shown to increase. It has been suggested (Muira, 1986) that peripheral visual performance is dependent more on the driving situation than the specific objects involved (i.e., a dog with an owner may impose little additional visual demand, whereas, a lone canine may demand more visual attention from the driver).

### *2.3.2. Foveal Vision*

Foveal vision is characterised by an increased ability to resolve detail and is located about the object of regard. It is termed foveal vision because the optics of the eye cause incident light to be focused on the *fovea*, the area of the retina with atypically high numbers of cones (used in the perception of colour) with respect to the surface of the retina, and correspondingly lower quantities of rods (responsible for monochrome vision). Foveal vision is poor at night when the rods play the key role in obtaining information about the surroundings. Peripheral vision enables the driver to reduce uncertainty regarding objects in the periphery. For example, a potentially dangerous object is detected peripherally and foveal vision is subsequently directed to the object to identify it. Approximately 95% of all driver's fixations have been calculated to be $\leq 8°$ from the centre or focus of expansion (Cole & Hughes, 1988). The researchers' findings suggest that foveal vision is not used as a major determinant of vehicle lane position.

The interaction of the two systems (foveal and peripheral vision) provides the human with a flexible mechanism for object detection and identification. Information gained is processed to enable the driver to react to the environment quickly and effectively. The visual system has evolved over many thousands of years to provide the information the human requires for survival. Cars have been available for less than a hundred years. This raises the following concerns, a) the suitability of the human visual system for the demands of the existing driving task, and b) the affects on driver visual demand from the introduction of advanced information systems.

### 2.3.3. *Other Visual Function*

Additional visual characteristics important to an understanding of the literature relating to driving are outlined below. Visual function can be seen to consistently decay with increasing age. The following review articles are recommended to the interested reader (Charman, 1986; Gioia & Morphew, 1986; Hartmann, 1970; Hills, 1980; Yarbus, 1967).

**Static and Dynamic Visual Acuity**

Static visual acuity refers to the individual's ability to resolve detail at threshold. Dynamic visual acuity is the threshold ability to resolve detail at the threshold of a moving object. Static visual acuity does not significantly decrease before the age of 60 years. However, dynamic visual acuity, has been shown to decrease earlier and faster (Shinar & Schieber, 1991). It is of concern that static visual acuity is currently used to determine the drivers' visual suitability for driving in the United Kingdom, whereas dynamic visual acuity is more appropriate with respect to the task demands. This is particularly so when considering the faster decline of dynamic visual acuity with age.

**Visual Field**

Johnson & Keltner (1983) suggest the useful visual angle of binocular vision does not decrease until sixty, after which there is a quick deterioration in effective visual field. More than 4% of drivers over sixty presented severe loss as a result of glaucoma or other retinal pathology.

**Motion Perception**

Determination of objects moving in the visual field "is perceptually critical for detecting imminently dangerous situations" (Shinar & Schieber, 1991), page 510. Judgement of speed and distance will depend on accurate motion perception and both have been shown to decrease with age (Sciafa, Kline, & Lyman, 1987).

**Contrast Sensitivity**

Advances in in-vehicle technology become irrelevant if the driver cannot resolve the detail of the display, or detect road signs to relate the information to the roadway. Contrast sensitivity has been used to predict discrimination of road signs. Roadway signs with spatial frequencies of 1.5 and 12 cycles per degree have been found to have significantly different discrimination distances (Evans & Ginsburg, 1985). Human spatial contrast sensitivity is highest at around 3.5 cycles per degree. The roadway structures should be optimised for the human capabilities, such that signs are easy to read at the distance when they need to be considered, thereby enabling drivers to perceive, comprehend and act on information from them, in good time.

**Glare**

Subjective feelings of visual discomfort (caused by glare) have been shown to be related to the difficulty of driving tasks (i.e., discomfort glare was shown to rise with increasing difficulty during a gap detection task, (Sivak, Flannagan, Ensing, & Simmonds, 1991). Both discomfort and disability glare may impose greater visual demand on the driving task. Disability glare may not impose visual discomfort on the driver but could impair performance, for example, sunlight may obscure an in-vehicle display.

An understanding of the optical and perceptual system provides the researcher with background to consider drivers' visual processes. Visual behaviour in vehicles has developed to make the most efficient use of the optical system for optimal task performance. What remains uncertain is the ability of the visual system (and other cognitive processes) to support driving in conjunction with the introduction of advanced driver information systems.

### 2.3.4. *Day vs. Night*

Approximately one quarter of all road driving occurs at night (Boyce, 1981). Yet, even though the traffic density is typically one third of the daytime equivalent, the number of road fatalities is likely to equal or exceed the number during the day (Fisher, 1977). Leibowitz et al. (1982) propose that night-time driving involves degradation of both peripheral and foveal vision. Further, they suggest drivers rely on peripheral visual cues when driving at speed, therefore at night they are unable to anticipate hazards which may be unpredictable and/or infrequent. Thus, it would be expected that the distribution of fixations away from the focus of expansion would be greater at night to compensate for the reduced availability of peripheral information. Foveal sampling at night is compounded by the relatively poor quality foveal vision. It would be an interesting area of further research to consider shifts in the distribution and magnitude of visual scanning at different times of the day.

**Night Myopia**

Anomalous (or night) myopia occurs when an individual fixates on a point nearer than the object of *intended* regard. It has been known to occur at night for some time (Leibowitz et al., 1982). The effect for the driver is that the detail of foveal vision is reduced. This may lead to problems resolving objects and judging distance and could be responsible for the increased accident rates observed during the night-time hours. Night myopia can be prevented by increasing the level of ambient illumination. Indeed, as Tanner (1958) stated, "...does roadway lighting have any effect on accident occurrence at all? The answer is positive". He showed that improving roadway lighting produced a marked reduction in the number of accidents occurring at night, typically about 30%. It can be concluded that at night the visual demands on the driver (prior to the introduction of information systems) are greater than during the day. The contrast in day and night visual demand is one of the few scenarios in which a direct comparison on safety grounds can be made. Tanner's (1958) research showed that improving the ambient lighting on roads reduced the imposed visual demand on the driver and decreased accidents.

**Roadway Lighting**

"Visual processes can be degraded by glare, fog, lack of illumination on the environment [and] vehicular design..." (Rockwell, 1972), page 316. Numerous studies have investigated the acceptable levels for roadway lighting (Luckiesh & Moss, 1934; Norman, 1944; Tinker, 1935; Voss, 1955). It is interesting to consider that the experimental manipulation of lighting results in variation in the visual demand of the driving task. Matanzo & Rockwell (1967) performed an experiment investigating the driver's ability to control the vehicle under reduced luminance. The independent variables were task performed and the luminance level. The experimenters manipulated visual conditions with optometrist frames and lenses which reduced the light entering the eye. Subjects undertook four tasks:

1. constant lane position, elected speed
2. constant lane position, constant speed
3. elected lane position, elected speed
4. elected lane position, constant speed

The results show that drivers elected speed was effected by a reduction in luminance level. Subjects slowed down during tasks 1 and 3. However, even under severely reduced luminance levels subjects were able to maintain speed when motivated to do so (i.e., tasks 2 and 4). Lane position was shown to be less effected by degraded visual conditions. All subjects exhibited a consistent error positioning the vehicle closer to a lane marker than the target distance. However, there was a significant difference in the task performed and the subjects' ability to maintain position. During tasks 3 and 4, the elected lane position conditions, the distance from the target position was greater (the vehicle was closer than required to the lane marking). In tasks 1 and 2 (constant lane position), there was a gradual trend to move the vehicle further away from the road markings as the luminance decreased. It is suggested by the experimenters that this reflects caution by the subjects, as the conditions became worse they increased their safety margin from the edge of the road.

It is worth questioning the value of lane deviation measures in the assessment of driver behaviour. Subjects ability to accurately (or not) maintain vehicle position in lane under artificial experimental conditions may not in fact be reflective of the skills required for driving. For example, although undoubtedly the driver must be able to maintain position in lane, this will be mediated by the roadway conditions. Narrow lanes and dense traffic require greater vigilance from the driver to maintain lateral position. In contrast, on wide, quiet roads vehicle position is not a prime safety concern. Matanzo & Rockwell's (1967) study shows that decreasing luminance changes the visual demand imposed on the driver with consequent decrements in task performance.

An Australian study explored the cost effectiveness of increasing road lighting at night (Skrene, 1976). Some variance was inherent in the experimental results, however, a significant relationship was demonstrated between light level and night/day casualty accident ratio. Interestingly, the link takes the shape of a law of diminishing returns. Specifically, road surface luminance's below approximately 1 $cd/m^2$ are considered insufficient for safe driving (Boyce, 1981). Such results have important implications for the design and implementation of driver information systems and the consequent visual demands they impose. For example, a relatively small increase in the level of ambient lighting of roads at night, may reduce the difficulty for the driver to extract information from the visual scene and therefore, increase the available cognitive resource with which s/he can utilise advanced information systems.

It has been estimated the over 90% of the information that the driver receives is visual (Hartmann, 1970; Sabey & Staughton, 1975). Regardless of the specific percentage, vision has been ranked the single most important source of information for the driver (Wierwille, 1993a) and "overloading of the visual pathway" (Wall, 1992) as a key area for accident prevention research. Further, the forward visual scene has been described as the primary information gathering source, and therefore all other information must be secondary (Wierwille, 1993b). Connoly (1968) reports that many of today's traffic conditions impose unreasonable loads on the driver's psychological sensing ability. The introduction of advanced driver information systems may further reduce the driver's available resources to safely contend with road infrastructure and environmental situations.

## 2.4. Visual Requirements to Control the Vehicle

One of the primary visual tasks for any driver is maintenance of longitudinal and lateral position on the road. Kramer & Neculau (1986) proposed a driver behaviour model based on lane-keeping activity. They argue that eye and steering movements are determined by environmental patterns. Further, if the environmental conditions can be adequately defined a model can be constructed. It is clear the perception of geometry, texture and gradient must play some role in negotiation of the vehicle through the roadway. The focus of expansion (Gibson, 1980) has been suggested as a primary target to aim the vehicle at during straight lane driving. However, Gordon (1966) argues that the aiming of the vehicle at the focus of expansion is too simplistic an approach. The point is illustrated using curvilinear motion (cornering) where the geometry of the bend is uncertain and liable to change. The ability to detect the external environment may be mediated by the visual characteristics of the roadway.

### *2.4.1. Visual Sampling Strategies*

Conscious and unconscious visual sampling strategies exist in the driving task (Rockwell, 1988; Senders, Kristofferson, Levision, Dietrich, & Ward, 1966; Wierwille et al., 1988). Eye movement behaviour has been said (Hughes, 1989) to be affected by:

- workload
- visual search
- visual ability
- spare visual capacity
- involuntary tendency to fixate on details with high information content.

**Foveal Time Sharing**

The driver initially samples the roadway peripherally (locating a feature of interest). Some information processing may occur at this point to prioritise the information. This can be weighted according to road situation, eye position, experience, and/or situational workload. To assess their relevance, the driver directs foveal vision to the features identified to extract the details required to control the vehicle safely, see Figure 2 - 3.

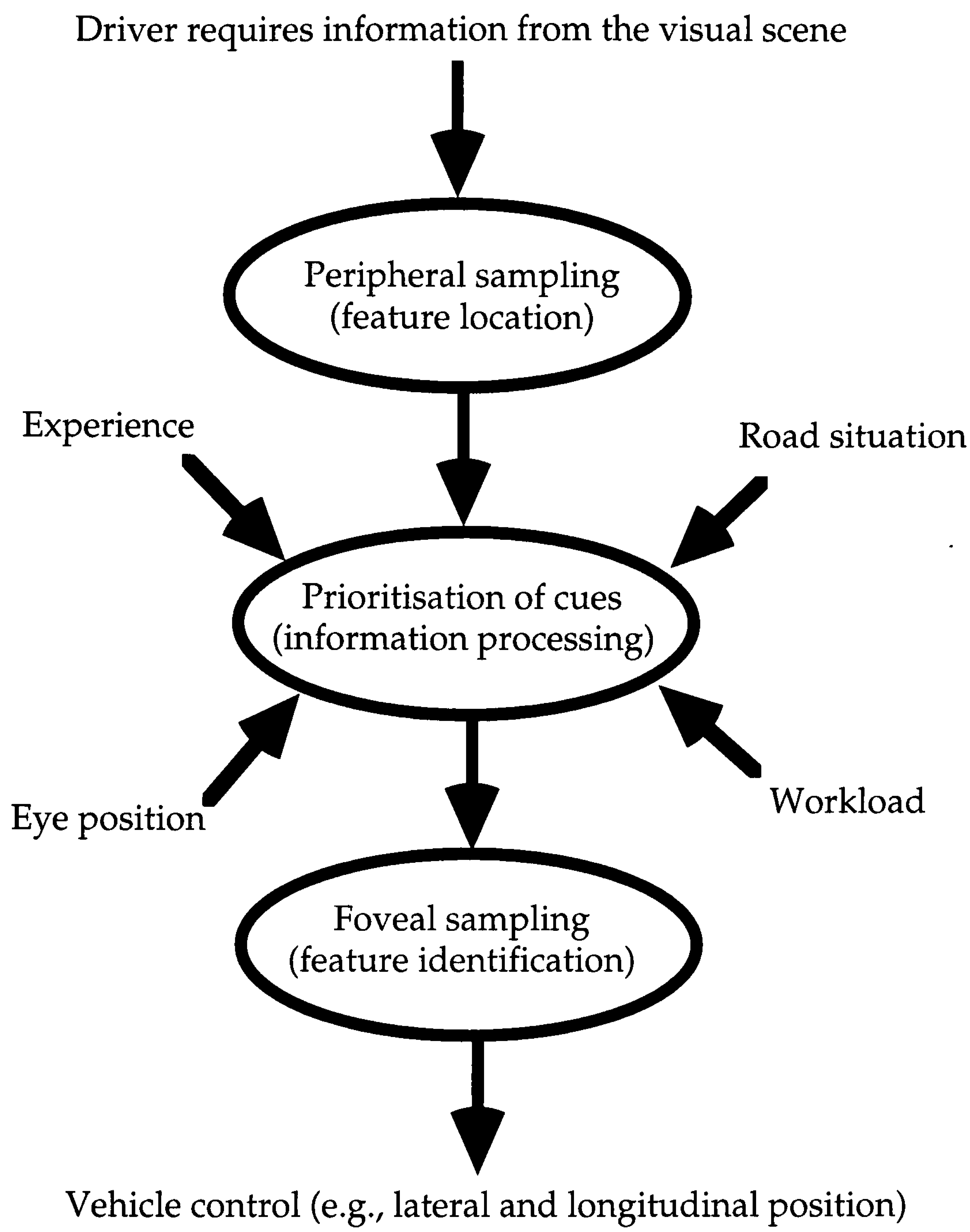



**Figure 2 - 3. Proposed structure of visual sampling**

Hence, "The only way that the driver can gather detailed visual information from sources at different positions is to move the foveal resource about in time, that is, to sample or time-share. This fact [time sharing] has profound implications for the design of in-vehicle displays" (Wierwille, 1993a), page 134. If the display demands foveal attention, by definition it must distract the driver from the primary task (i.e., observing the forward scene, Wierwille, 1993a).

**Peripheral Information Aquisition**

Good interface design may be used to facilitate the use of peripheral vision to extract information from a driver information system, for example, analogue speedometers can usually indicate the general speed range. In most situations, data gathered from peripheral vision are sufficient for the driver to comply with highway regulations. However, it has been suggested by Bhise (1971) that the foveal region has increased information processing speed per unit time when compared to the peripheral regions, such that the driver may be able to assimilate information quicker from the fovea. It is important to note though, that when recording driver visual behaviour, as Rockwell (1972) argues, the point of regard (i.e. the area of the visual field from which the eyes focus light on to the retinae) may not indicate the location from which the driver obtains information. They may be using peripheral cues to obtain what they require. "Visual perceptions are rarely based upon a momentary stimulation of fixed retina. Most of our perceptions of objects are derived from a succession of scanning movements, the succession of retinal images being translated into a single impression of form" (Lashley, 1954), although, "There is evidence that the targets of focused vision are closely related to the observer's cognition" (Yarbus, 1967).

**Spare Visual Capacity**

The drivers' time sharing of foveal fixations to regions of the visual scene is a result of the physiological and anatomical limitations of the human visual system (i.e., the limited foveal field of view within which the driver can resolve detail). Senders et al. (1966) investigated drivers' information processing requirements. Assumptions were made that drivers' visual attention is not required exclusively in attending to the road ahead. The research considered the effect of variation in the drivers' speed and the time available to view the forward scene. It sought to determine the validity of a model of driver visual scanning with reference to the real roadway. The model proposed that the driver acts as an information processor extracting visual information from the forward view and translates this into control actuations of the brakes, throttle and steering. They found good approximations to actual behaviour were predicted by the model. What is particularly interesting in the Senders et al. (1966) study, is that it explicitly addresses the amount of spare visual capacity drivers have. This was further considered by Hughes & Cole

(1986) who suggest that between 30% to 50% of drivers' visual scanning may be unrelated to driving. Senders et al. (1966) was one of the first investigations to employ occlusion as a methodology to consider the relationship of drivers' visual behaviour to their task performance. The results suggested less frequent glances to the forward view result in reduced speed, as do shorter glances to the forward view. Conversely, with increased speed the drivers needed to sample the roadway more frequently. For given occlusion and glance frequency times, a roadway with more severe curves resulted in lower speed. Senders et al. (1966) suggest that when the driver is faced with a greater attentional demand than they feel able to contend with, they slow down, look more frequently or look for a longer period of time, thereby, adjusting information uptake to an acceptable level. The behaviour would be consistent with the risk compensation theory proposed by Wilde (1994). Senders et al. (1966) propose that the methodology adopted in the paper "...will allow an objective measure, based on driver behaviour, of the attentional demand of any segment of road". It would be interesting to explore the utility of this approach for the evaluation of driver information systems, particularly in that the study considered driver behaviour only within acceptable performance limits. The introduction of driver information systems into vehicles may result in unacceptable demands on the driver in many situations.

Inappropriate allocation of visual sampling by the driver has been suggested to be far more frequently responsible for accident causation than mechanical failure or incorrect operation of vehicle controls (Rockwell, 1972). Rear end collisions and "run off road" accidents are cited as examples. Regardless of the focus of attention it is certain that more objective empirical data are required on the location, distribution and duration of drivers' visual behaviour.

Rockwell (1972) reviewed the role of eye movement analysis in driver information acquisition. He specifically focused on the role of peripheral vision and the concept of spare visual capacity. Rockwell (1972) argues that the location of fixations may not in fact indicate that the driver obtains information from the object fixated. The research suggests that fixations in driving tend to be less than 6° travel, with more than 90% located within 4° of the focus of expansion. The distribution of fixations reported would seem consistent with that observed by other researchers (e.g., Cole & Hughes, 1988). Individual glance fixations were reported to vary from 100 ms to 350 ms. It should be noted that a typical glance to a particular region of the visual scene would tend to consist of more than one fixation. Subjects were encouraged not to look at the road while driving on a straight section of roadway. In support of earlier research (Senders et al., 1966), mean occlusion time was found to be inversely proportional to velocity (i.e., as the vehicle's velocity increased the mean eyes closed duration decreased). However, the apparatus used to record eye movement behaviour must be regarded as cumbersome at best, see Figure 2 - 4. Indeed, it is stated in the paper that the equipment may have influenced the distribution of visual scanning.

The interesting point is made that "Most interstate driving requires less than 50% of a driver's perceptual capability" (Rockwell, 1972), page 322. Unfortunately, the mechanism to determine this percentage is not discussed. Drivers were said to frequently sample irrelevant information (e.g., "signs which are covered", page 322). Indeed, the driver may not be processing information from such task irrelevant objects at all. Rockwell (1972) suggested that fixations to objects other than those which may be considered necessary for driving (e.g., a lamp post) may be used to anchor visual perception for subsequent peripheral information.

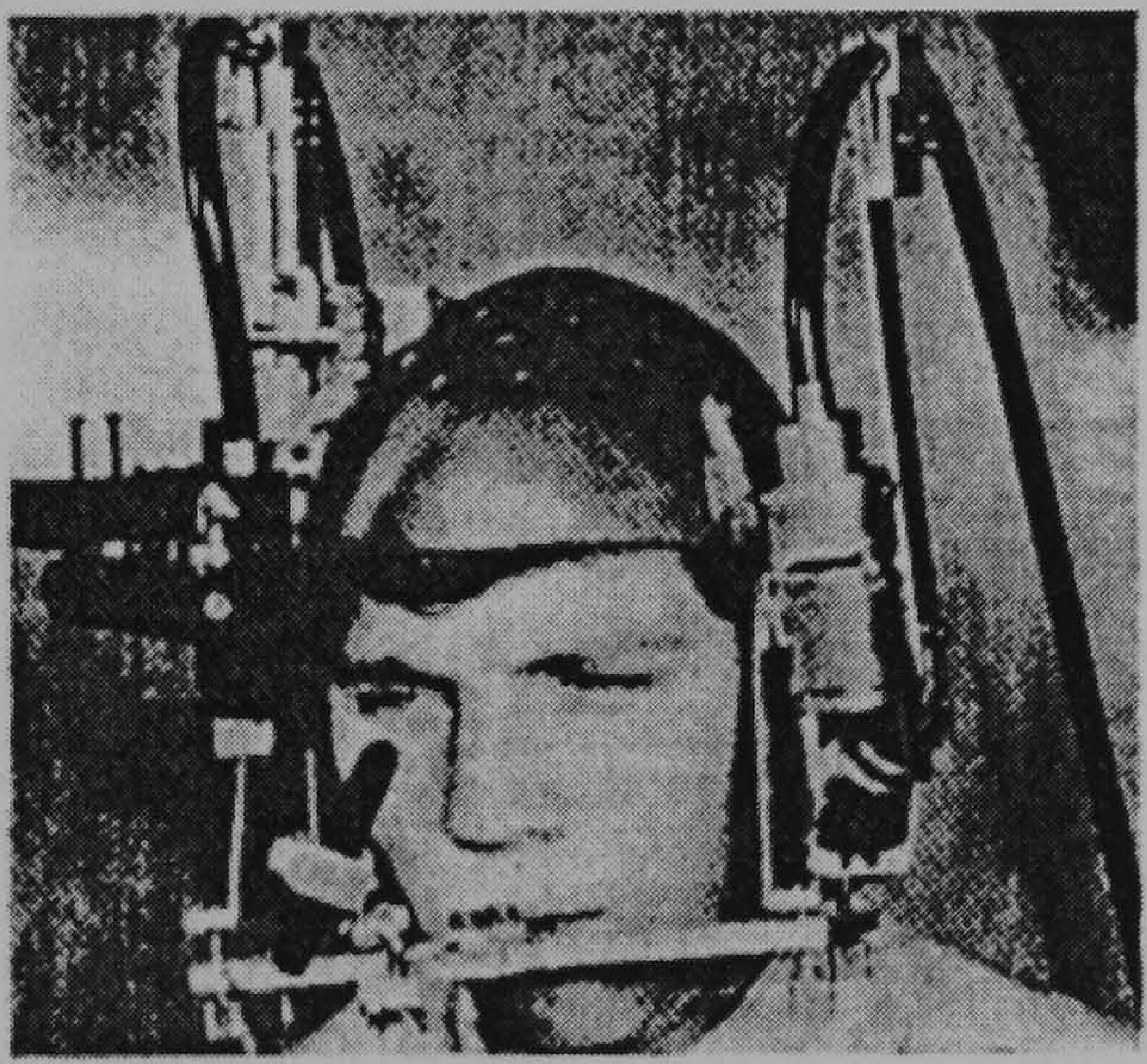


**Figure 2 - 4. Head-piece and input system for eye movement recording, from Rockwell (1972)**

Spare visual resources provide a potential opportunity for the implementation of driver information systems. The challenge remains how to utilise spare time periods where the driver can assimilate information, while not presenting information which may distract from visual behaviour required to maintain safe control of the vehicle at other times.

### 2.4.2. *Visual Attentional Processes*

Hughes & Cole (1986) suggest a difference between attention and focus of regard. The driver may be gazing at the forward view (the focus of regard) but not consciously attending to any single object or person (attention attractant). Twenty five subjects reported features that attracted their attention during a suburban drive of 21.9 km (13.6 mi). A laboratory study also with twenty five subjects performed the same task using a video film of the road route. The subjects were required make concurrent verbal reports. The results of the study showed that 30% - 50% of attention was directed to objects "not related to driving" (e.g., advertising). Further, they state: "eye fixations may in fact be a poor indicator of what is noticed.", page 376. It is suggested that this could reflect subjects' spare visual capacity. Interestingly, approximately, 15% - 20% of attention was attributed to traffic control devices (e.g., traffic information signs and lights). It is argued that the drivers could not attend to all traffic information devices with this deployment of visual resources. The road trial experiment contained a condition where the subjects were passengers. "No substantial differential effect on attentive behaviour" was observed during the passenger and driver conditions. On this basis the authors of the paper suggest that "the visual information presented by the movie film is sufficient to generate attentive processes characteristic of driving". A key criticism of the study was that the drivers were instructed to verbalise continuously. The authors report that this may have resulted in the collection of information which would not normally be the focus of attention, and thus confounding the analysis of results.

In both experiments a total of 7721 reports were made by the fifty subjects. These were classified using a taxonomy adopted from similar work (Lynch & Rivkin, 1959; Renge, 1980). The classification was as follows:

- road related
- traffic control devices
- vehicles
- people

- immediate road surround
- general surround
- vegetation
- advertising

The roadway in the experiment was divided into three regions, *residential, arterial* and *shopping centre.* The number of observations was shown to be significantly greater in the shopping centre area. It is possible that the total number of discrete elements per visual angle per unit time was higher in this region, or that the relevance/consequence of ignoring cues in this region was greater. In support of the latter hypothesis their was no difference in the number of reports not relating to driving. Specifically, the subjects were not more distracted by non-driving objects in the shopping centre region, they were reporting the driving relevant objects more frequently.

> "It appears that the visual information available to the observer and the context (i.e., the driver's view) are sufficient to determine visual sampling behaviour and the distribution of attention. The physical and motor actions do not appear to have any substantial influence on visual sampling behaviour under ordinary driving conditions" (Hughes & Cole, 1986), page 388.

It is felt that although the motor actions may not influence visual behaviour, cognitive activity certainly will. This issue is explored further in the experimental work reported in chapters 5, 8 and 9.

**What Causes Variation in Glance Duration?**

Hughes (1989) suggested that variations in fixation duration (considered here as glance) are dependent on: task type, task importance, the nature of the information processing and the overall cognitive demands. Individual scanning strategies may change the nature of the driver's visual behaviour. Hughes' (1989) research is cited as an example where, as the visual complexity and number of stimuli in the roadway is increased (in a driving simulator), drivers were observed to change fixation frequency. This resulted in fixation [or glance] duration reduction from 440 ms to 409 ms. It was found that in a visually rich environment (shopping centre) successive fixations to the road surround were 60% when compared to 51% in simulated residential driving. Hughes suggests that visual properties (i.e., visual clutter or bits of information per area per unit time), and driver information goals are both important determinants the distribution of attention in visual scanning.

It is interesting to consider the relationship between glance duration and glance frequency. How much will the visual demand of a system influence the structure of the driver's interaction with an in-vehicle information system? Will some systems prevent the driver from selecting the most sensible strategies to extract visual information from a device? This issue is pursued in more detail in Chapter 9.

Hughes (1989) conducted work exploring strategies to change the distribution of drivers' visual scanning. During undirected driving (in a vehicle simulator) subjects were observed to glance to the left of the road (Australian research, left hand lane driving) 18% of the time. In a target detection condition the proportion of fixations to the left increased to 41%. As might be expected the proportion of glances to the focus of expansion decreased correspondingly, from 25% to 14%. The situation investigated was somewhat artificial, in that such dramatic changes in visual behaviour would be unlikely to occur on public roads. However, the findings show that drivers adopt specific visual scanning strategies that influence the distribution of visual behaviour throughout the forward scene.

### *2.4.3. Summary: Lateral and Longitudinal Control of the Vehicle*

Basic vehicle control can be summarised as:

- a predominantly visual task in which spare capacity typically exists (Hughes & Cole, 1986; Rockwell, 1972)
- requiring peripheral vision for lateral vehicle position (Gordon, 1966; Rockwell, 1972)
- a time sharing activity because of the limitations of the foveal visual system (Wierwille, 1993b)
- using successive foveal fixations to determine general heading and longitudinal position (Gibson, 1980; Rockwell, 1972)

- becoming easier with the development of skill, with the consequence of increasing available attention for other tasks (Wickens, 1984)
- requiring visual-motor co-ordination (Wierwille, 1993b)
- being affected by changes in: task workload (Matanzo & Rockwell, 1967), environmental workload (Faber & Gallagher, 1972; Hughes & Cole, 1986; Senders et al., 1966; Senders, Kristofferson, Levision, Dietrich, & Ward, 1967), visual ability (Boyce, 1981; Hagenzieker, 1990; Leibowitz et al., 1982) and individual motives/strategies (Wierwille et al., 1988).

Published literature regarding the driver's visual system discusses their ability to control the vehicle and avoid obstacles on a moment to moment basis. However, the driving task requires much more than basic vehicle control. Displays which enrich the information available to the driver ease the process of vehicle control by enabling anticipation (e.g., engine noise and the speedometer provide, in addition to the already available optic flow information, cues regarding safe velocities to negotiate corners). Therefore, it is important to consider the information sources that support the driver's strategic and manoeuvring activities, especially to ensure they support and do not overload the driver.

## 2.5. Visual Activity with Conventional In-Vehicle Information

All cars provide the driver with information regarding the status of the vehicle, for example, vehicle speed, fuel level and engine temperature. This information is typically presented to the driver using analogue indicators or hazard tell-tales (lights that function only during a warning condition). In an aircraft, the pilot must frequently monitor the cockpit displays. However, in the car, constant checking of such displays is usually not required. Also, in the aircraft the pilot may safely glance away from the forward view for extended periods of time, whereas, in the car such behaviour would prove to be hazardous. Research has shown that drivers employ a rational, visual, adaptive sampling strategy when performing vehicle related tasks (Wierwille, 1987). Wierwille (1993a) suggests that visual tasks are conducted by a series of exchanged glances to the instrument and forward view, as can be seen in Figure 2 - 5. Some tasks may only require a single glance, for example the speedometer. Whereas, other in-vehicle tasks typically require several glances. It is indicated (Wierwille, 1993a) that "Normal drivers develop this time sharing (sampling) strategy, because it is the only way they can meet competing visual requirements of driving per se and carrying out in-vehicle tasks", page 136. The research underlying Figure 2 - 5 presents the view that glances tend to be of similar duration and for more complex tasks the number of glances increases.

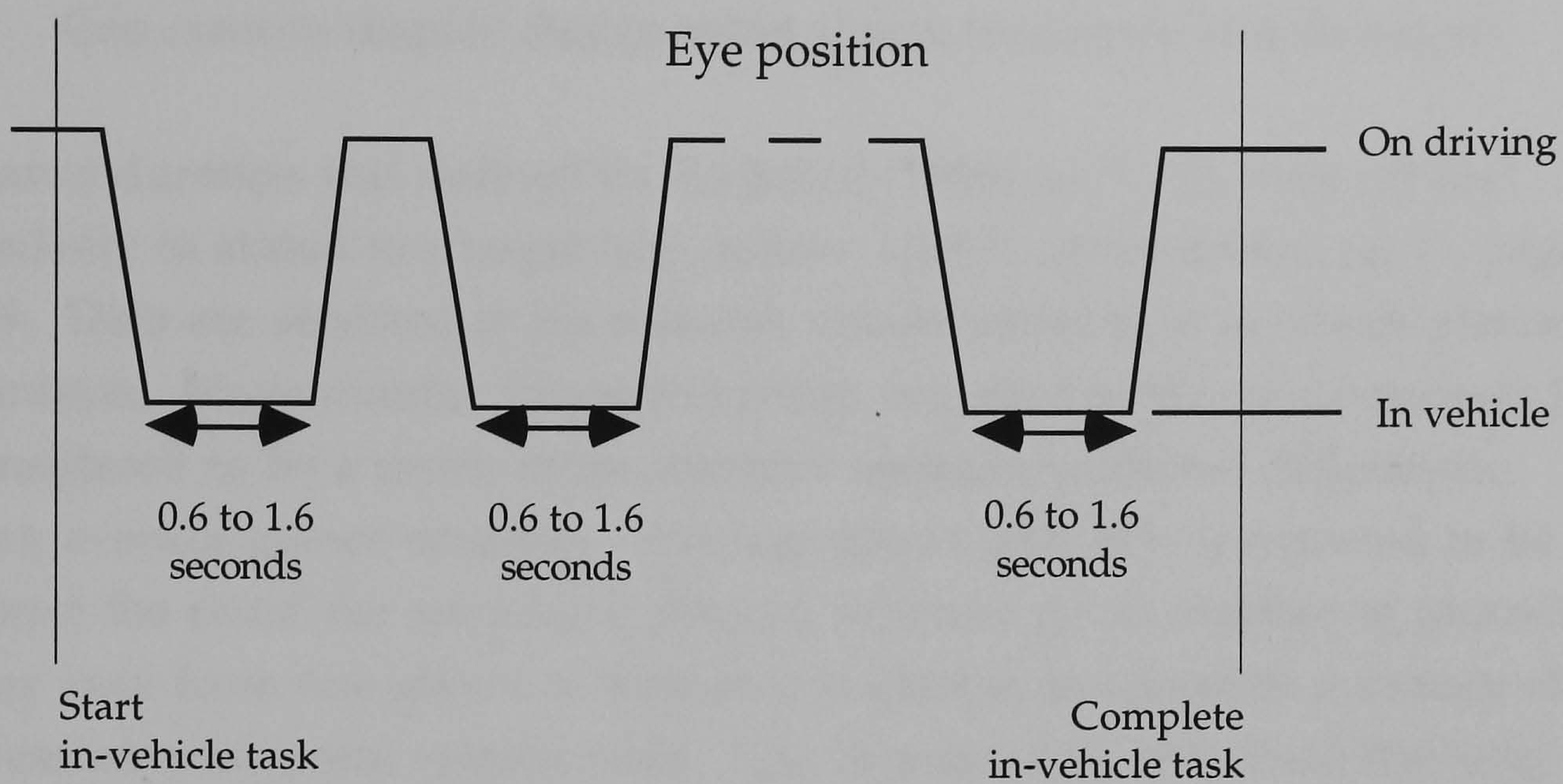



**Figure 2 - 5. Sampling model of in-vehicle task performance, from Wierwille (1993a)**

Effective design of in-vehicle controls should encourage functions to be operated without the need to fixate on them, and therefore glance away from the forward view. For example, rotary heater controls can be located by drivers in a familiar vehicle without looking to them at all. In addition, the control may be adjusted as spatial rotational cues are provided, again removing the need to glance to the control/display. Slider type controls tend not to provide spatial cues other than fully active or fully inactive.

The visual impact of conventional controls was investigated in a study which compared stalk and panel mounted devices (Moussa-Hamouda & Howard, 1977). Five stalk and three panel controls were compared. The results suggested that glance duration was slightly longer for stalk controls, and glance frequency increased as reach distance increased.

The visual demand of in-vehicle tasks was further considered by Rockwell (1988), who posed the following questions as aims for driver visual behaviour research:

- Do drivers have spare visual capacity? How much? How does this change with driver and traffic factors?
- How does one represent with visual cost of in-vehicle electronic displays (i.e., using glance duration, glance frequency or errors)?
- Can control/display design affect glance frequency and duration?

Glance duration was defined by Rockwell (1988), as "...the time off the roadway to attend to a target (e.g., mirror, stereo, speedometer, etc.)", page 319. Data are reported in his research which concentrate on mean glance duration. Mean number of glances (often reported as glance frequency) is considered to be a much more sensitive measure of driver differences than average glance duration. Average glance duration is reported to be 'about the same' for successive glances, whereas mean number of glances may vary from one glance to four or five glances to complete a variety of in-car entertainment system tasks. Use of mean data may hide the long glances which could arguably be those glance durations most reflective of unsafe interaction with a driver information system. This issue is explored in more detail by Lansdown & Fowkes (in press).

Rockwell (1988) reports that glance durations remain consistent across a variety of in-vehicle tasks. Average glance durations for three experiments were very similar (1.27 secs to 1.42 secs), and were shown to be not significantly different across the studies. Standard deviations were also reported to be "remarkably consistent, but rather large". The large range in the data would suggest that use of mean glance duration may not, in fact, be the most reliable measure for the assessment of driver visual demand. Further, it contradicts Wierwille's (1993a) assertion that glance duration varies little (see Figure 2 - 5).

There is no consensus in the research on the duration of glances. Some researchers suggest glance durations vary little during in-vehicle display use (Rockwell, 1988; Wierwille, 1993a). However, others have demonstrated significant differences in glance durations during use of complex in-vehicle systems (Bhise, Forbes, & Faber, 1986; Fairclough et al., 1991; Fairclough & Parkes, 1990; Lansdown & Fowkes, in press).

Data reported by Rockwell (1988) demonstrates that qualitatively different tasks will present different visual demands. Distributions of glance duration and glance frequency for drivers' scanning to the driver left mirror and in-car radio are shown in figures 2 - 6 and 2 - 7 respectively. It can be seen that the distribution of glances to the radio is larger, for both the range and frequency, than the left mirror.

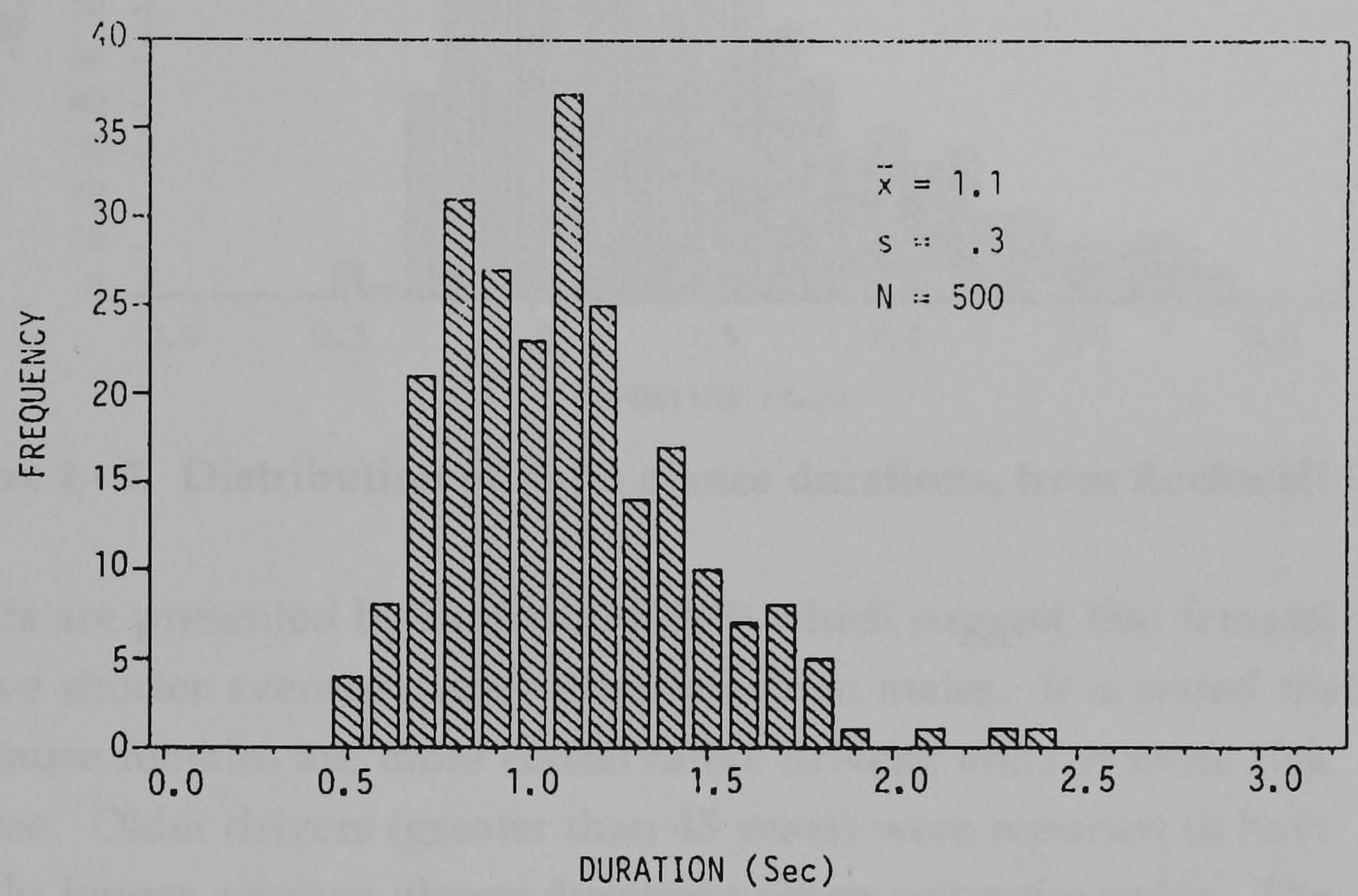



**Figure 2 - 6. Distribution of left mirror glance durations, from Rockwell (1988)**

The maximum visual distraction duration for use of a driver information system has been sought by many researchers. Rockwell (1988) suggests that a visual demand (glance duration) of three seconds is unreasonable. However, this point is mediated by the need to consider the context of the glance (e.g., traffic density at the time of glance). Whether this is mean or maximum single glance duration is not reported. The concept of a *two second rule* (i.e., that drivers avoid glancing away from the forward view for more that two seconds) is presented, presumably, as a self-controlling mechanism for drivers' visual sampling. It is reported (Rockwell, 1988) that "When complex displays require glance duration beyond the 90th percentile, most drivers are clearly facing special visual workload problems", page 322. It must be assumed that this distribution refers to that illustrated in Figure 2 - 7. However, the logic of the statement is apparent.

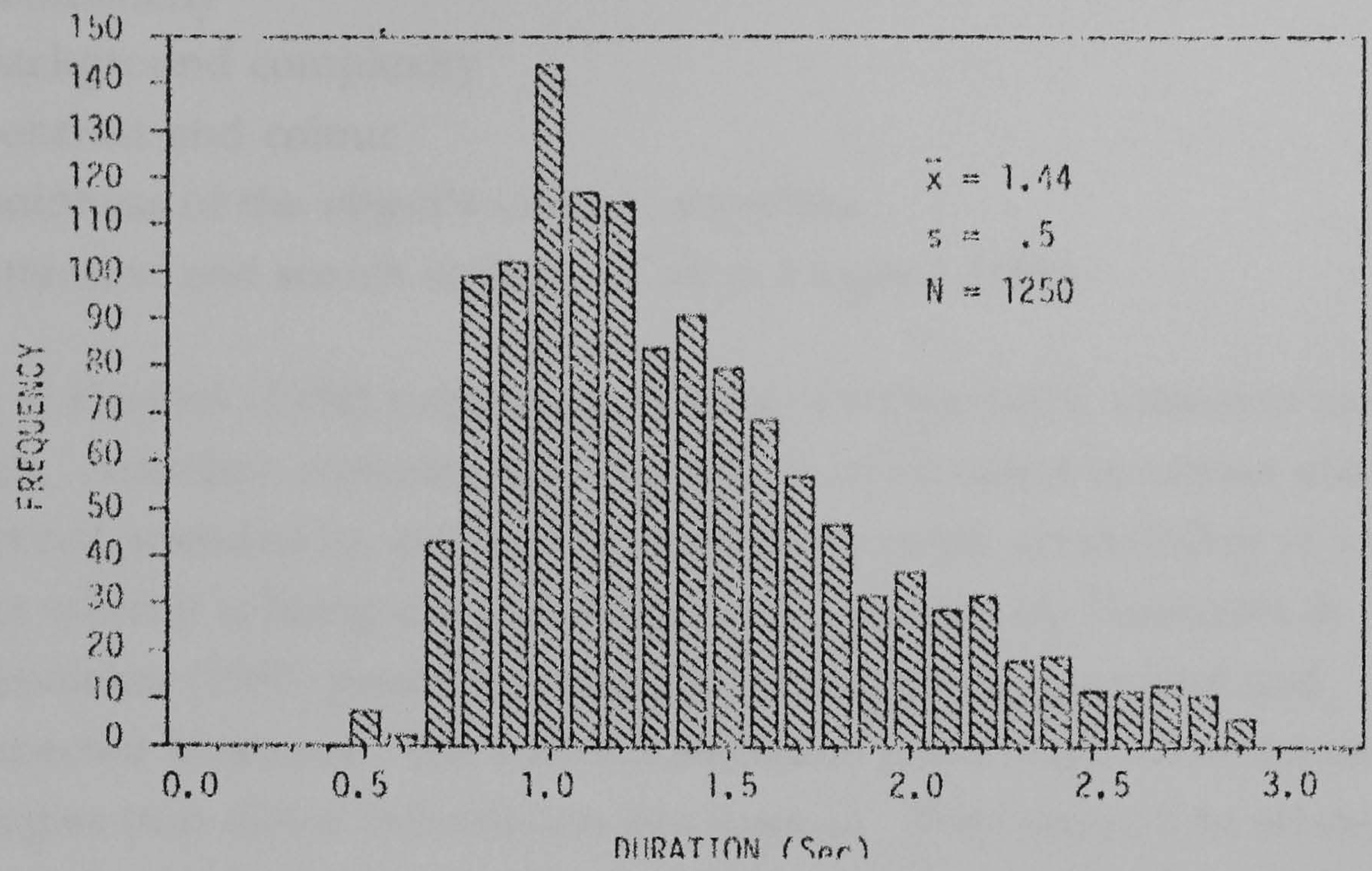



**Figure 2 - 7. Distribution of radio glance durations, from Rockwell (1988)**

Results are presented by Rockwell (1988) which suggest that females tend to have shorter average glance durations than males. It is stated that this is because females are more conservative drivers, and/or more risk adverse. Older drivers (greater than 45 years) were reported to have slightly longer average glance durations when using the radio. The difference is more significant when considering the mean number of glances. Older drivers performed 20% more glances (across all radio tasks) than younger subjects, and made more radio use errors.

Traffic density was shown to substantially affect average glance duration. Subjects were required to perform tasks using an in-car radio while controlling the vehicle "on curves and in high speed, short headway driving.", page 323. Average glance durations were shown to be significantly shorter (20%) for use of the mirrors and the in-car entertainment system in conditions of high traffic density.

**Conspicuity and Attention**

The probability of attracting the driver's attention is said to be influenced by the conspicuity of the object. Conspicuity has been described as "the probability of an object being seen in a very short time < 200 ms" (Cole & Jenkins, 1980). It will be affected by:

- eccentricity
- background complexity
- contrast and colour
- boldness of the object's internal structure
- attention and search strategy (Cole & Hughes, 1988)

Cole & Hughes (1984) suggest two forms of conspicuity, attention and search. Attention conspicuity is the ability of an object to attract attention when not attended to, and search conspicuity is the accessibility of an object when it is being directly sought out. A study by Theeuwes & Hagenzieker (1993) presented subjects with targets in expected and unexpected locations. The subjects exhibited scene dependent scanning strategies (top-down information processing). They seemed to strategically prepare for likely cues and only search expected regions. The results were contrary to bottom up strategies of object perception that have been proposed by Engel (1977). Biederman (1972) suggests that processing of the visual scene is critically dependent on its spatial arrangement. Objects in unnatural positions would impair recognition of scenes. Location and identification of objects with poor conspicuity may require additional visual demand from the driver, reducing the available resource for additional tasks.

### 2.5.1. *Summary: Visual Sampling and the Use of Conventional Instruments*

The driver's use of in-vehicle instruments and control of the vehicle may be summarised by the following general statements:

- glance behaviour to an in-vehicle display tends to alternate between it and the forward view of the vehicle (Wierwille, 1993a)
- poor placement of displays and allocation of controls increases their visual demands (Moussa-Hamouda & Howard, 1977)
- age, gender and traffic density have been shown to increase the difficulty in utilising vehicle displays and controls (Rockwell, 1988)
- glance frequency to in-vehicle displays increases as a consequence of the complexity of the task (Rockwell, 1988; Wierwille, 1993a)
- glance durations to in-car systems may vary significantly between tasks.

Visual activities are motivated by the need to control the position of the vehicle, to extract information from conventional displays and traffic signs and to interact with other road users. For example, checking the vehicle is not overheating, fuel is not empty or that the radio is tuned to a particular frequency. Thus, the driver visually extracts information to support manoeuvring and strategic aspects of driving.

The impact of the introduction of advanced driver information systems can now be considered with an understanding of the underlying visual demands of the driving task and the strategies drivers employ to meet them. Wierwille (1993a) states that the design of advanced driver information systems should consider not just the visual aspects of the system, but also the hand-eye coordination and manual control demands required to operate them. Poor interaction between the controls and displays may result in increased visual demand. It is important to note that the imposed visual demands relating to conventional driver tasks can be quite high (Wierwille, 1988a).

## 2.6. Visual Demand and the Introduction of Advanced Driver Information Systems

Current developments in electronic control and communication systems have made possible the introduction of complex displays of information in the vehicle. One example is route guidance, with many prototype systems produced in recent years. These reflect a wide range of approaches to information presentation in the vehicle. Some systems have used relatively simple symbolic, static information displays, whilst others have applied multi-coloured scrolling maps. Regardless of the approach to design, the crucial question raised is whether the introduction of advanced information displays may unnecessarily distract the driver from the primary task (i.e., perceiving the road environment and controlling the vehicle safely through it). To operationalise this question, the scope of available visual behaviour measures must be quantified.

### 2.6.1. *Information Acquisition*

Driver fixation times have been found to be longer when extracting information from alpha-numeric signs (529 ms) than from symbolic displays (312 ms; Mori & Abdel-Halim, 1981). Hughes (1989) suggests that fixation times and measures of operator performance can be used for the development of visually presented information. Mori & Abdel-Halim (1981) present data indicating that only 11% of driver fixations to road signs were long enough to extract the information contained in them. The data demonstrate a shortfall between the visual demands of a task and the human operator's ability to meet them (Hughes, 1989). However, the relevance of the traffic information to the driver was not related to the duration of glances.

Dingus, Antin, Hulse, & Wierwille (1989) investigated the visual demands of conventional driving tasks and the use of a computerised moving map display. The experiment was conducted using an instrumented vehicle on public highways. Results indicated:

- visual demand (defined as the sum of glance durations into the car) varied widely across the tasks
- total glance duration was shown to have a minimum of 0.78 seconds (reading the speedometer) and a maximum of 10.63 secs (establishing the road name of the next turning)
- single glance durations varied from 0.62 seconds to 1.66 seconds, and
- the mean glance frequency ranged from 1.26 glances to 6.64 glances.

The study reinforced the picture of visual sampling which emerges from the research (i.e., the glance durations were subject to some variation but remain within a relatively small range, and glance frequency appears more representative of increases in task complexity). It is argued that "Most importantly, drivers do not, on the average, allow their single glance times to exceed about 1.6 seconds, even for complex information-gathering tasks"(Wierwille, 1993a), page 137. Wierwille (1993a) advocates that single mean glance durations of 1.25 seconds are acceptable, shorter are preferred. Glance frequencies of six or less are considered acceptable, particularly if the mean single glance duration is less than 1.25 seconds. Although this appears intuitively reasonable, no basis is presented for the proposal of these limits. However, Wierwille (1993a) defends these assertions, stating that visual demand research is lacking and further work is required to form a more valid basis for such judgements. Research should aim to assist design and keep glance durations to a minimum. The consequences of high glance frequency and extended glance duration are not discussed. It may be that poor design is reflected by high glance frequency, but a single three second glance will be considerably more hazardous than six half second glances.

**Driver Performance and Visual Demand**

Identification of a metric that is reflective of the impact of an information system on the driver has been the aim of many researchers. Zwahlen, Adams, & DeBald (1988) considered further the issues of maximum time away from the forward view, presented by Rockwell (1988). The much cited paper on the introduction of an in-vehicle touch screen display into the vehicle, adopted the driver's ability to maintain position in lane as a measure of safety. The subjects were required to drive along a disused runway at 40 mph while attempting to use a simulation of a device. The lane deviations were obtained from a paint dropper the results of which were analysed post-hoc.

Zwahlen et al. (1988) related increased lane deviations to different road widths. They state: "One important measure of driver performance is the amount by which an automobile's path deviates from the centre of the lane while the driver is operating the CRT touch panel since even small deviations of a few feet may prove fatal", page 337. The authors report (based on obtained vehicle standard deviations) "if a six foot wide car were travelling in a 12 foot wide, straight lane under ideal conditions (sunny, calm, dry pavement) at 40 mph then there would be a 3% chance of the vehicle laterally deviating out of the lane (either to the right or left) while the driver was operating the CRT touch panel. If the lane were reduced to 10 feet then the probability of the vehicle laterally exceeding the lane increases to 15%", page 341. They state that the percentages were based on best case and under more demanding circumstances the lane exceedance would be more likely. While small deviations in lane may prove extremely hazardous, it is the author's view that as stated previously, the environmental constraints of the roadway will influence the drivers' propensity to deviate in lane. It is hypothesised that the negative consequences of poor control will influence the effort the driver invests in maintaining position in lane. That is, narrow lanes would result in better maintenance of road position than wide lanes, particularly during busy traffic.

The ecological validity of an experimental task clearly confounds the generalisability of the drivers' visual behaviour. In Zwahlen et al's (1988) paper, subjects were required to concentrate on either a) successful operation of the CRT touch panel (looking directly and continuously until the experimental task was completed), or b) both the CRT and driving performance (subjects were instructed to look up to the forward view as often as required to maintain lateral position in lane). Condition a) may have resulted in data which would be in no way reflective of the manner in which drivers would interact with such systems in the real road system. Zwahlen et al. (1988) do state that "It appears that when the subjects were allowed to look outside the vehicle while operating the CRT touch panel, they made only limited use of this opportunity and did not improve the standard deviation of the lateral lane position", page 339. However, the external environment (a disused runway) would not have offered the information drivers would normally receive on the public roads. Results may suggest that the task was so visually demanding that subjects disregarded the consequences of a lack of vehicle control. The disused runway setting could have reduced the caution drivers would have demonstrated had the experimental setting been more realistic. Zwahlen et al.'s (1988) experiment also investigated the influence of the position of the driver information system on visual behaviour. No significant difference in average glance frequency was found in either high or low in-vehicle positions.

A conceptual model of driver information acquisition was proposed, see Figure 2 - 8. The model was developed from previously published research (Senders et al., 1966). There are evident similarities with this model and that proposed by Wierwille (1993a, see Figure 2 - 5). The consideration of road/traffic information in relation to visual behaviour and available working memory, makes the model particularly worthy of note.

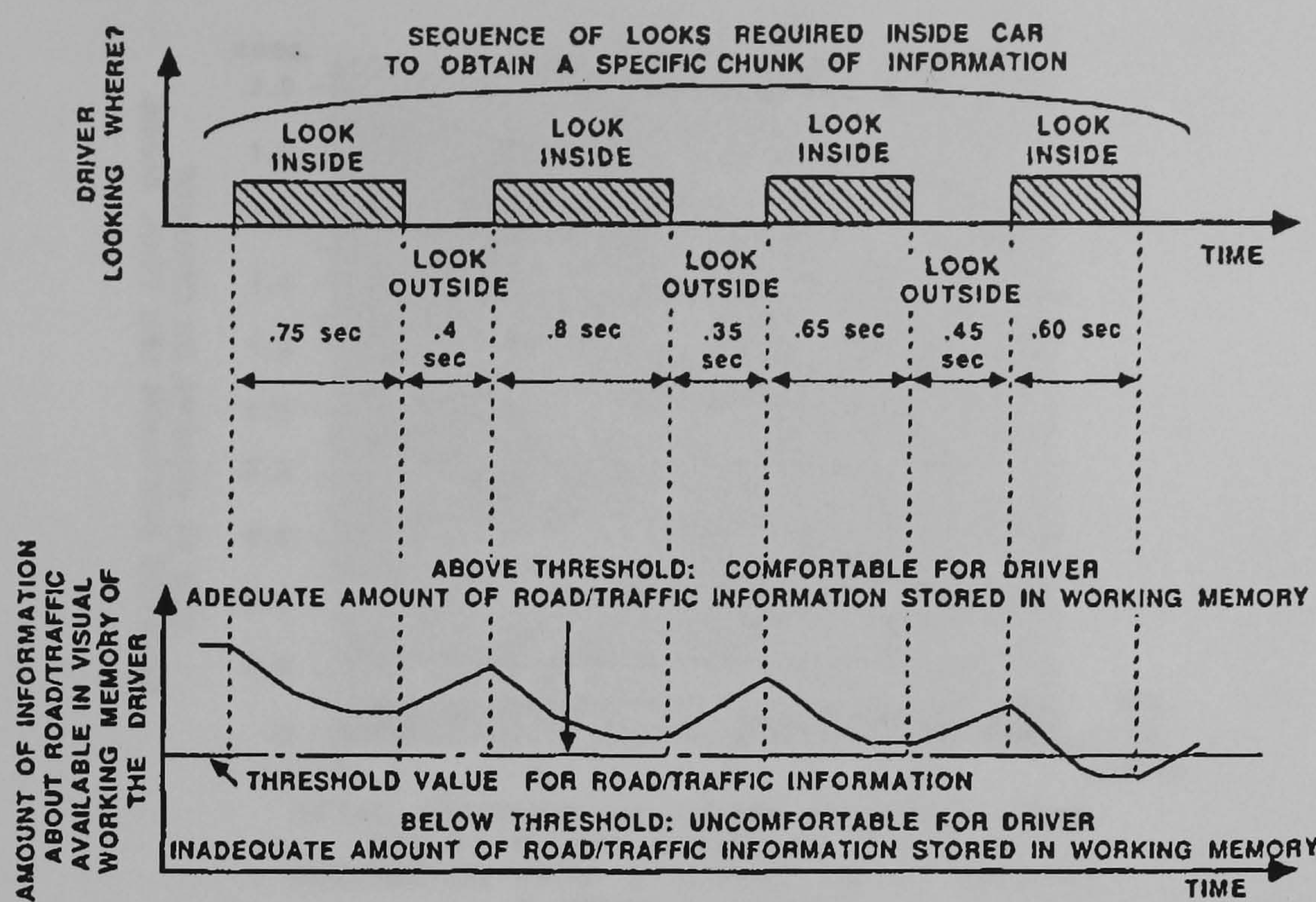



**Figure 2 - 8. Conceptual model for driver information acquisition and processing, from Zwahlen et al. (1988)**

The model was used to develop a tentative design guide for the design of driver information systems, see Figure 2 - 9. Zwahlen et al. (1988) hypothesise that "if more than three looks are required inside the vehicle to obtain a specific chunk of information during a relatively short period of time [four seconds in Figure 2 - 9] then the task becomes uncomfortable for the driver, since at the fourth look inside the vehicle an inadequate amount of road and traffic information is stored in the visual working memory of the driver", page 337. However, the statement is presumably based on Figure 2 - 8 and this does not adequately consider the context in which glances into the vehicle occur. For example, a visually barren environment would be unlikely to overload the visual and cognitive resources of the driver. However, the model provides insight and could perhaps be applied in a worst case (i.e., busy inner-city multi-lane junction manoeuvres). Regardless, the model requires some statement of the context to which it may be used. It is unfortunate that the lack of ecological validity of the test environment is not discussed in the paper. The model has much intuitive appeal in the simplicity of its application. The guide requires further refinement to define what is meant by specific chunk of information and whether average glance duration is more appropriate than maximum glance duration. Additionally, the method of translating experimental results to the design guide is not stated.

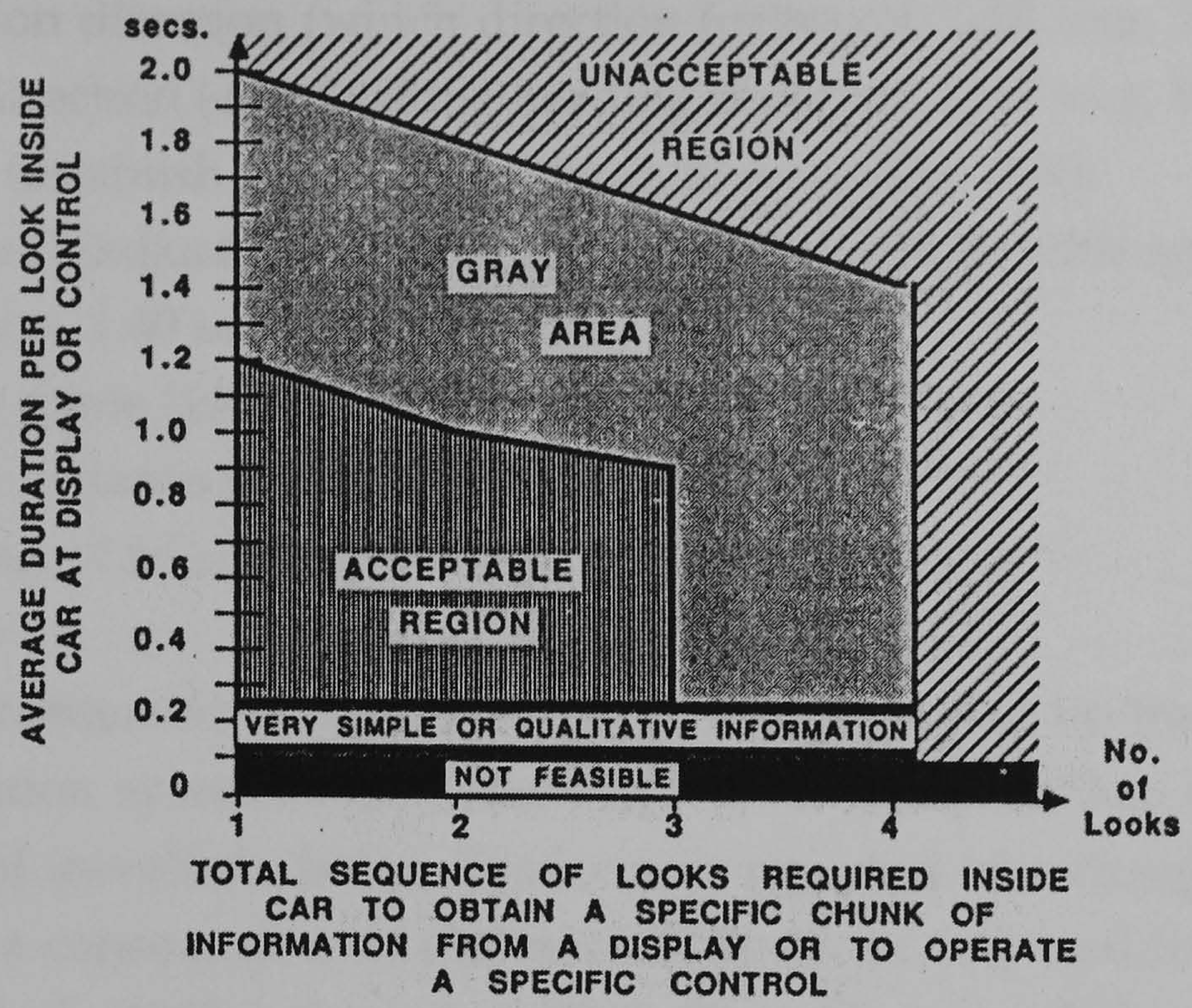



**Figure 2 - 9. Proposed tentative design guide to be used when designing sophisticated in-vehicle displays or CRT touch panel controls and/or applications, from Zwahlen et al. (1988)**

**Conventional and Navigation System Visual Demands**

Wierwille, Hulse, Antin, & Dingus (1988a) conducted two experiments to investigate the attentional demands of an in-vehicle navigation system. The first study compared the navigation system's visual demands with conventional in-vehicle tasks. All tasks were considered (both conventional and navigation system) to determine which had high attentional demands. The total time spent glancing at tasks was ranked to determine the most visually demanding. The total glance times which were high for navigation tasks were:

- roadway name (determine the next road name on the route, 10.63 secs, SD = 5.80)
- roadway distance (to the next turning, 8.84 secs, SD = 5.20)
- cross street (establish the name of the next street, regardless of relationship to the intended route, 8.63 secs, SD = 4.86).

The frequency of task performance is not stated and thus the representativeness of the data is unclear. Small samples for judgements of attentional demand may have confounded results. High single glance times were reported for the following navigation tasks:

- destination direction (which direction for travel, 1.20 secs, SD = 0.73)
- correct direction (decide if the heading is correct, 1.45 secs, SD = 0.67)
- heading (establish general heading, 1.30 secs, SD = 0.56)
- zoom level (adjust the display to the correct setting with respect to the destination, 1.40 secs, SD = 0.65)
- roadway name (1.63 secs, SD = 0.80)
- roadway distance (1.53 secs, SD = 0.65)
- cross street (1.66 secs, SD = 0.82).

The experimenters state that the information presented by the moving map navigation system was "somewhat" more complex than the conventional in-vehicle tasks. Evidence is reported of a change in visual demand as a consequence of the availability of the required information. Wierwille et al. (1988a) show that when the subjects needed to zoom in or out (i.e., when the information required was not immediately available) the mean total glance durations doubled. The results were based on the three most visually demanding navigation system tasks. Visual attentional demand could be reduced by a semi-intelligent interface (e.g., the zoom level could be pre-defined to act in a particular manner), continuously adjusting the zoom to an optimal level. However, this would be a significant design issue. System initiated changes in information availability, like zoom level could confuse the driver in the timing and the perceived distances represented by the route guidance system. Important also to note is that several of the conventional tasks investigated were shown to present high visual demands, namely total glance time:

- radio tuning (7.60 secs, SD = 3.41)
- engaging cruise control (4.82 secs, SD = 3.80)
- powered mirror adjustment (5.71 secs, SD = 2.78).

Standard deviations for the radio tuning and engaging cruise control tasks were also large with respect to the mean values. The wide variance associated with these tasks could have been a consequence of unfamiliarity with the task.

Age was found to affect the information acquisition efficiency, as previously suggested by Rockwell (1972). Drivers over fifty years of age were found to take more time to complete tasks. Glance durations were also longer and the number of errors higher. Driver age range was reported to be 18 to 73 years. Unfortunately, no further information is included so that the distributions of ages cannot be determined, and hence whether the results are representative is uncertain. Similarly the older driver cohort may have confounded the experimental results as they are not representative of the majority of the driving population. The data were consistent with the reported decreases in visual and cognitive performance in older subjects (Carr, Jackson, Madden, & Cohen, 1992; Evans, 1994; Hancock & Parasuraman, 1992; Rockwell, 1972).

**Attentional Demand**

The second experiment by Wierwille et al. (1988a) investigated three route guidance strategies: memorised route, conventional paper map and computerised moving map. Three routes were defined for the experiment to encompass:

- four lane divided highways
- two lane, two way highway, and
- residential streets.

The authors report that the drivers' glance durations to the roadway centre were considerably shorter when using the moving map navigator than the other conditions. They suggest that this is a consequence of "time sharing between the roadway and navigator display", page 313. Total time to complete the routes was significantly different. Post-hoc analysis (Newman-Keuls) revealed that the memorised route (mean = 11.04 mins) was significantly quicker than the computerised moving map (mean = 15.95 mins) or paper map (mean = 15.55 mins). This was supported by the proportion of time spent glancing to the navigator overall when compared to the visual scanning related to memorised route driving.

The total distribution of visual scanning was classified into:

- EYEDRIVE (the proportion of total eye dwell time on roadway centre, mirrors, and conventional instruments)
- EYEMAP/NAV (the proportion of total eye dwell time to the map or computerised moving map display).

Table 2 - 1 shows the results of the EYEDRIVE and EYEMAP/NAV analysis. The computerised moving map (navigator) can be seen to significantly demand more visual attention than either the paper map or memorised route condition. It is assumed that the data do not sum to 100% because the *roadway off centre* is not included in the EYEDRIVE measures, see Wierwille (1993a).

**Table 2 - 1. Means and Newman-Keuls post-hoc comparison* on EYEDRIVE and EYEMAP/NAV, from Wierwille et al. (1988a)**

| | Measure | |
|---|---|---|
| Navigation Method | EYEDRIVE | EYEMAP/NAV |
| Memorised route | 0.898 (A) | 0.000 (C) |
| Paper map | 0.815 (B) | 0.068 (B) |
| Navigator | 0.602 (C) | 0.331 (A) |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05)*

Under some circumstances use of advanced driver information systems may demand unreasonable attention, potentially compromising safety. Researchers (Fairclough et al., 1991; Lansdown, 1996; Wierwille et al., 1988b) have argued that drivers are able to rationally adapt their behaviour to compensate for the additional demands imposed. Wierwille et al's (1988a) data report subjects' city driving as more taxing than two or four lane highways. The assumption was based on the number and difficulty of the control and display actuations. Higher traffic density was stated to produce more conservative driving. The finding was based on greater attention allocated to the driving and less to navigational tasks. Wierwille et al. (1988b) suggest that these features support the theory that drivers' behaviour changes as a result of task demands (i.e., as the driving task becomes difficult more attention is apportioned to control of the vehicle).

Two experiments were reported (Wierwille et al., 1988b) which considered the anticipated and unanticipated reactions to driving demands. More specifically, they aimed to determine whether drivers can adapt visual scanning (when under high demand) to concentrate more to the forward view and less to the navigation system.

Attentional demand may be considered to be a function of the roadway itself. It is suggested that normal attentional demands related to the roadway are largely anticipated. The driver is able to preview the immediate scene to apportion the visual resources necessary to deal with the road ahead. Anticipated objective attentional demand was manipulated by controlling the "sight distance, curvature, road width and lane restrictions" (Wierwille et al., 1988b), page 662. Subjective attentional demand for the experimental routes was determined in a separate exercise using five graduate human factors students. A nine point scale was employed at specific points corresponding to high attentional demand. In addition, the following factors were to be considered in the judgement of attentional demand:

- ability to look away from the road
- straight or curved road
- possibility of unanticipated traffic
- the effect of junctions and the need to interact with other vehicles.

The experimental timing was not stated in the study. A criticism could be levelled against the work because potential variation in the traffic density may have confounded results (i.e., quiet weekend driving on a two lane highway is likely to present lower attentional demand than the same section of road on a Friday when individuals are leaving work). It is suggested that to minimise such confounding variables, experimental work should be conducted at times when traffic variation can be minimised (e.g., during the working week and avoiding rush-hour travel times).

The results of the first experiment were subjected to regression analysis, see figures 2 - 10, 2 - 11, 2 - 12 and 2 -13. The objective (calculated) rating of attentional demand for EYEDRIVE (proportion of time glancing to vehicle related driving areas) can be seen in Figure 2 - 10. Wierwille at al. (1988b) suggest the objective attentional demand increases as the proportion of driving related glances increases. In Figure 2 - 11 glances to the navigation system decrease with a corresponding increase in objective attentional demand.

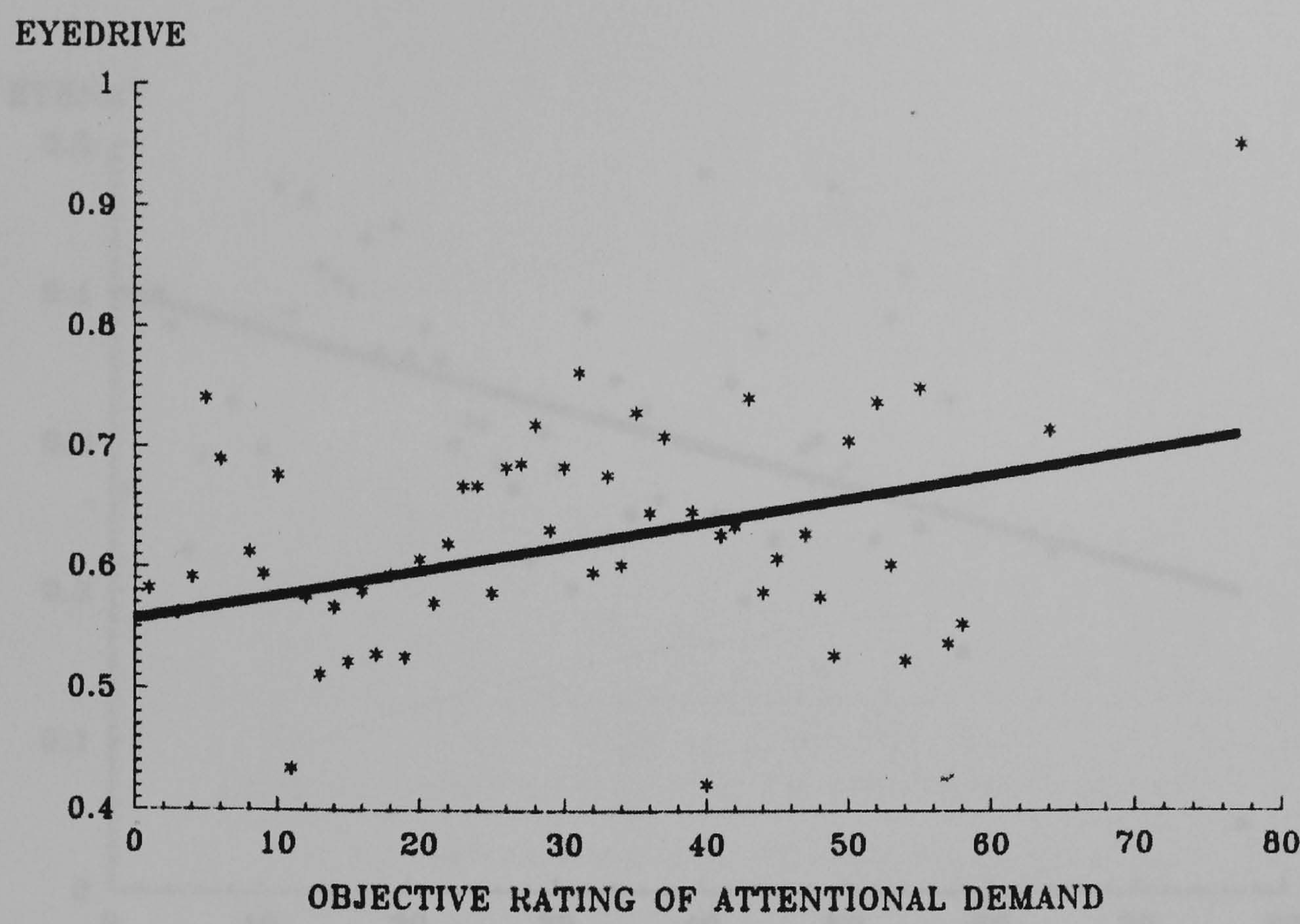



**Figure 2 - 10. Objective attentional demand: EYEDRIVE, from Wierwille et al. (1988b)**

Similarly, the subjective data support the same trend as the objective data. That is, as the anticipated attentional demand increased, the proportion of time glancing to the navigation system reduced and the subjects' visual scanning to the driving related regions increased, see figures 2 -12 and 2 - 13.

However, it is unfortunate that Wierwille et al. (1988b) were not able to further define the boundaries of the regions of the visual scene. The classification of visual behaviour into EYEDRIVE and EYENAV may be somewhat misleading. To illustrate, it is argued in the paper that as anticipated attentional demand increases the drivers shift their visual scanning from the navigation system to the driving related regions of the visual scene. However, the subjects may have been using these driving related glances to obtain information relevant to the navigation system (i.e., road names and priority signs or information). Detection of road signs may occur at sufficient distances that the visual angle would remain within the assumed region of the forward view with respect to the focus of expansion.

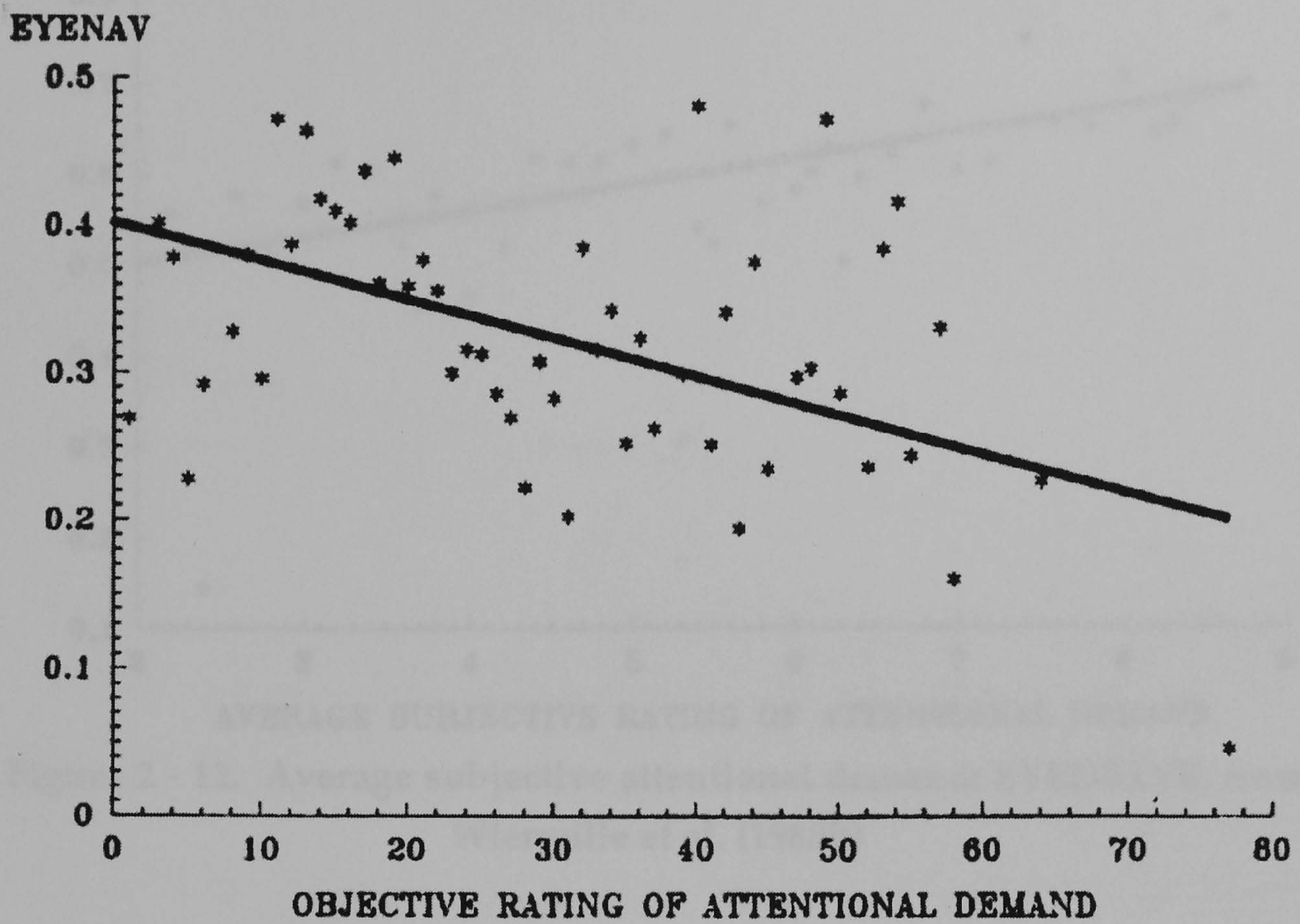



**Figure 2 - 11. Objective attentional demand: EYENAV, from Wierwille et al. (1988b)**

Further analysis of the data from experiment one was conducted by dividing the objective data into three equal sized groups corresponding to: low, medium and high attentional demand. The basis for classification of the groups is not defined in the paper. The same taxonomy was applied to the subjective data. Significantly longer average glance lengths to the roadway centre were observed in the low attentional demand group (1.70 secs), when compared to the medium (1.46 secs) and high groups (1.49 secs). Average glance lengths to the navigation system were significantly different in all groups: low (1.48 secs), medium (1.10 secs) and high (1.23 secs). The significant difference between the medium and high demand groups (duration increasing with demand) is suggested to be a result of the drivers need to re-orient with the navigation system's moving map late in a turn sequence.

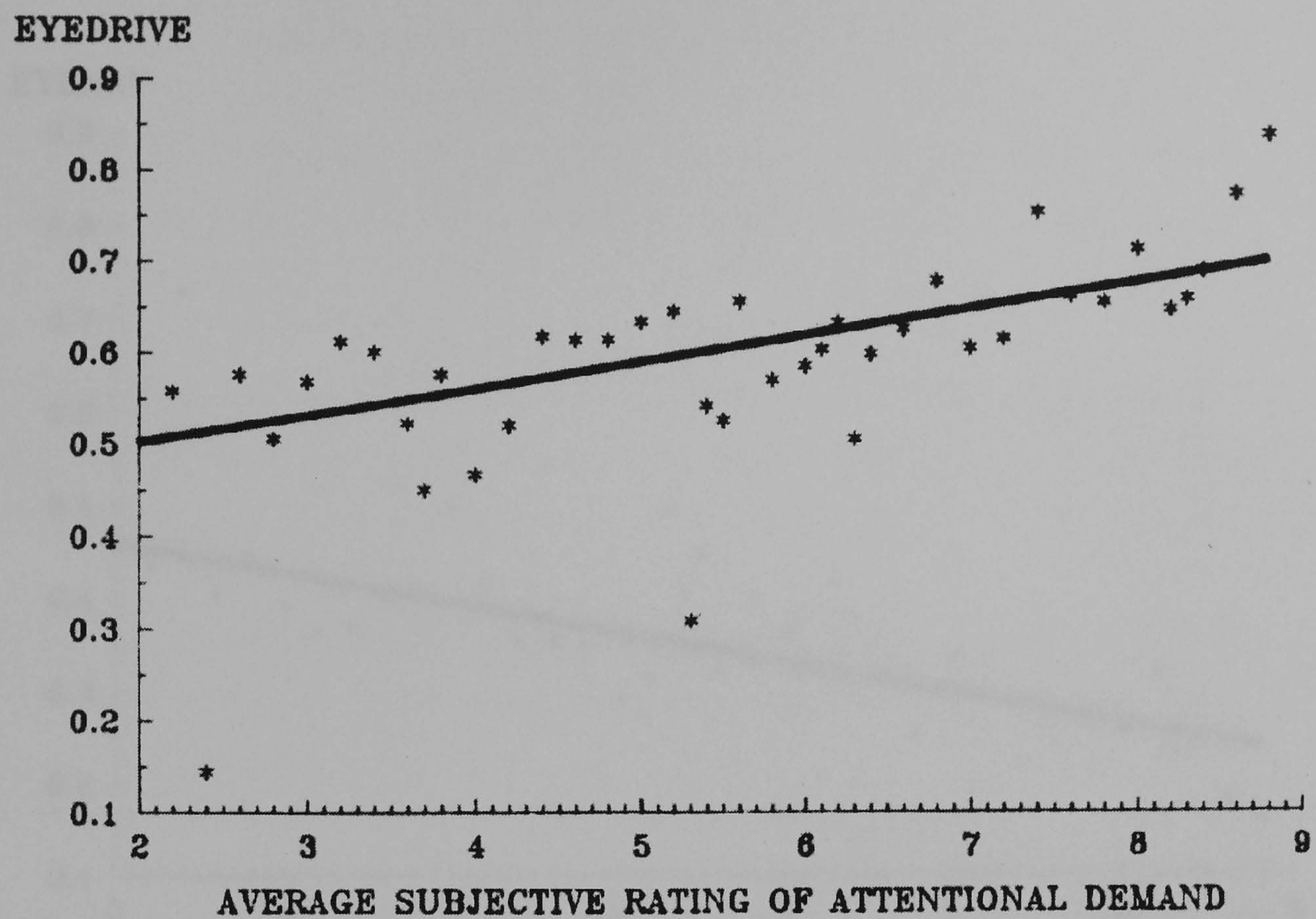



**Figure 2 - 12. Average subjective attentional demand: EYEDRIVE, from Wierwille et al. (1988b)**

In the second experiment unanticipated attentional demand was manipulated as the independent variable. Incident analysis was employed on three routes of approximately eight miles of "industrial plants, and shopping centres, and along main streets of small towns", page 663. Traffic density was reported as moderate to heavy. It is argued in the paper that because *incidents* are unpredictable, the attentional demand of such events must be largely unanticipated. The same subjects were used as those in experiment one. Visual behaviour was recorded on-line by an experimenter seated in the rear of the vehicle. This was performed by depressing a button when the eyes were stationary and releasing it when fixation changed. Although some error checking was performed by the addition of different tones corresponding to eye movement, the accuracy of the approach is uncertain. It should be stated however, that such an approach would be likely to capture the broad distribution of visual behaviour and therefore differentiate between normal duration glances and potentially dangerous extended duration glances.

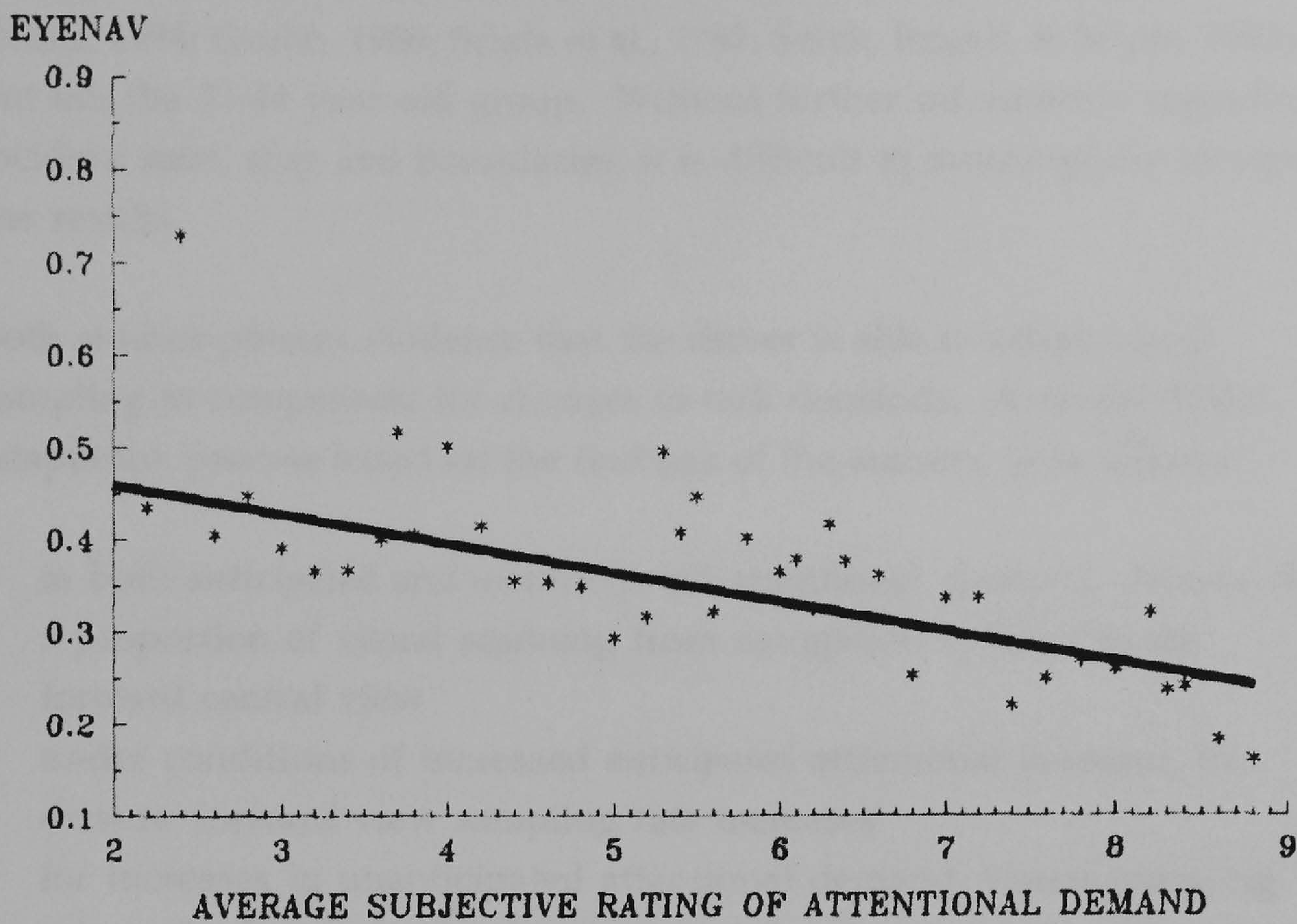



**Figure 2 -13. Average subjective attentional demand: EYENAV, from Wierwille et al. (1988b)**

The procedure for the classification of incidents is unclear, except that they were defined to "normally require careful watching by the driver and therefore require high visual attentional demand", page 663. Incidents were detected using only the forward view camera to avoid experimenter bias (which may have been introduced from observation of the subjects' visual behaviour), 135 were identified. Comparisons are made between: incidents and low and high demand traffic groups. The probability of glances to the roadway centre was significantly lower in the light traffic (0.51) than the heavy (0.61) and incident (0.63) groups. During incident scenarios the probability of navigation system glances was significantly lower (0.19) than both the light (0.31) and heavy (0.26) traffic groups. Mean glance duration to the forward view was significantly different in all three groups: light (1.2 secs) and heavy (1.9 secs) and incidents (3.0 secs). Interestingly, a classification based on age established that the mean glance time to the roadway centre to be significantly lower for younger drivers, aged 18-30 (1.5 secs) when compared to 31-44 year old drivers (2.5 secs) and older drivers, 45+ (2.2 secs). One might expect from the literature that the older (45+) group would present longer glance durations consequent with the reduced visual function (Carr et al., 1992; Evans & Ginsburg, 1985; Evans, 1994; Grubb, 1986; Sciafa et al., 1987; Szlyk, Brigell, & Seiple, 1993), but not the 31-44 year old group. Without further information regarding incident start, stop and boundaries, it is difficult to meaningfully interpret the results.

Both studies present evidence that the driver is able to adapt visual sampling to compensate for changes in task demands. A model of the adaptation process based on the findings of the authors, is as follows:

- in both *anticipated* and *unanticipated* attentional demand, drivers shift a proportion of visual scanning from navigation systems to the forward central view
- under conditions of increased *anticipated* attentional demand, the drivers' forward view sampling rate increases
- for increases in unanticipated attentional demand, visual sampling rate to the forward view decreases and the glance duration increases.

The safety of public road trials precludes maximal loading of the driver. Consequently, the data presented support rational adaptation for sub-maximal task demands. However, one would expect the driver to be able to deal with these task demands. A significant problem remains in the prediction of the point at which task complexity exceeds the driver's ability to contend with it, and which information systems will demand more visual attention from the driver than they can safely provide.

### *2.6.2. Distribution of Visual Scanning*

Driver information systems have also been shown to disrupt visual scanning as a result of their introduction. Data taken from Antin, Dingus, Hulse, & Wierwille (1988) was used by Wierwille (1993b) to illustrate the value of glance and link value probability diagrams to differentiate driver visual behaviour. For example, normal driving (Figure 2 - 14), use of a paper map to navigate (Figure 2 - 15) and use of a computerised moving map display (Figure 2 - 16) can be seen to shift the distribution of visual scanning.

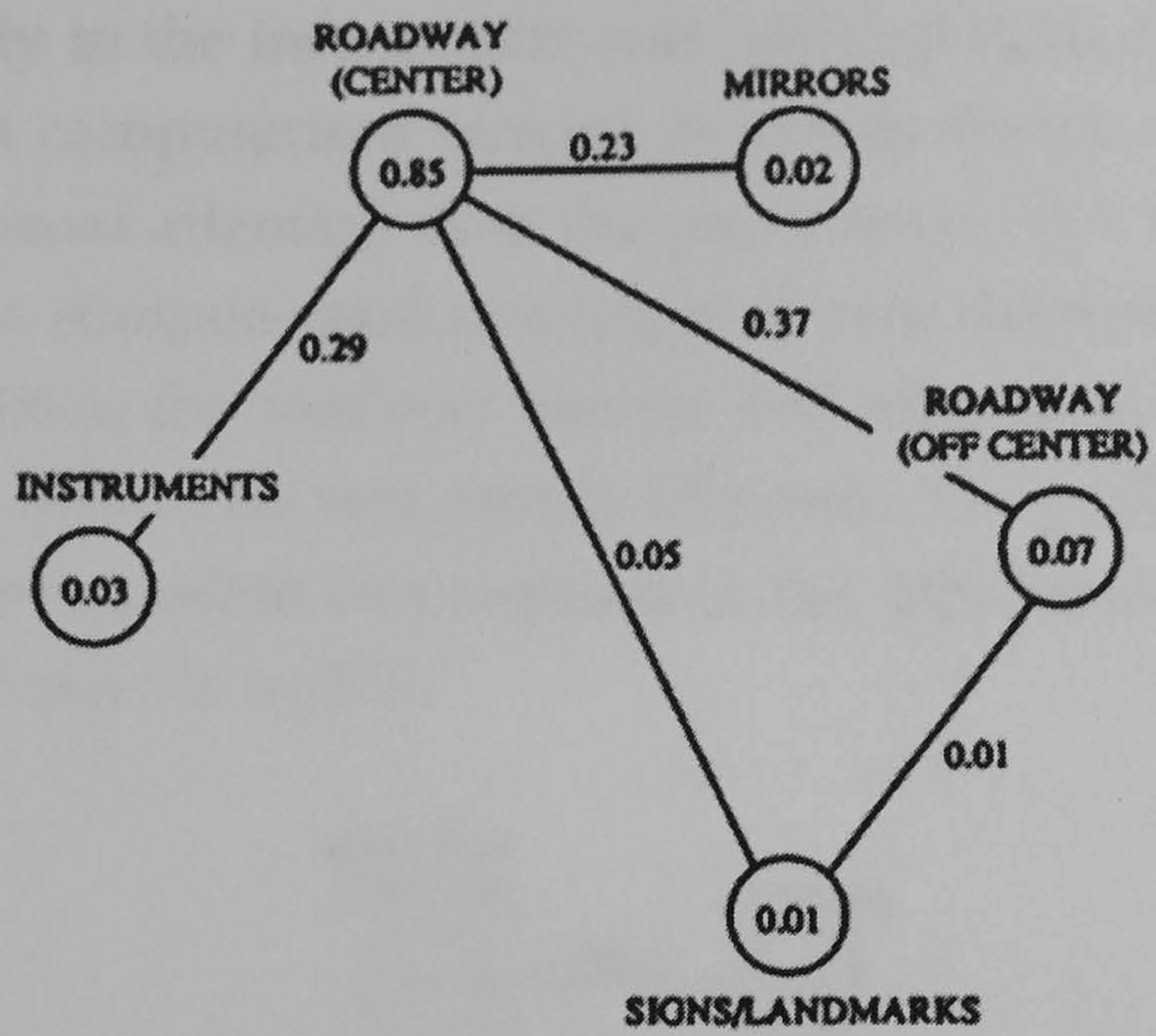



**Figure 2 -14. Glance and link value probability: driving a known route, from Wierwille (1993a)**

It can be seen that the introduction of a navigation task results in changes in the proportions of visual scanning. Circled numbers in the figures represent the probability of the eye dwelling on a particular visual region/object. The numbers on the spines indicate the probability of glancing from one area to the area connected. Paper map use seems not to reduce the driver's normal checking of instruments and mirrors, but to lessen the percentage of time glancing to the roadway centre. Thus, visual attention is diverted from the roadway centre to the information system.

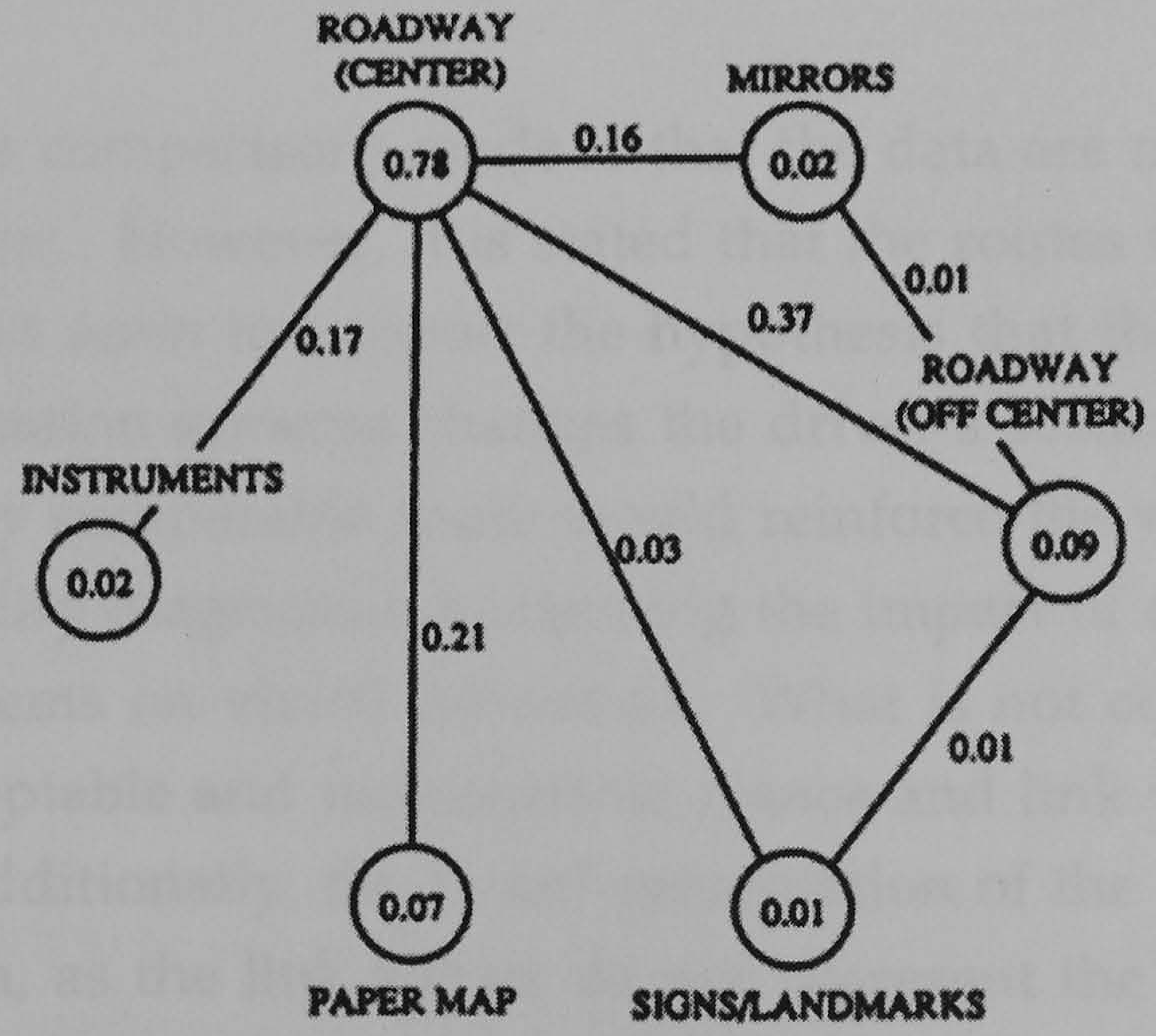



**Figure 2 - 15. Glance and link value probability: driving with a paper map, from Wierwille (1993a)**

Glance probability to the instruments was reduced from 3% to 2%. Subjects' use of a computerised moving map was shown to demand radically more visual attention than the paper map, 33% and 7% respectively. The computerised moving map was demonstrated to shift visual attention from the roadway (centre and off-centre) while the other normal scanning behaviour was hardly affected. The probability of glancing to the instruments was reduced in the same manner as use of a paper map (i.e., from 3% to 2%).

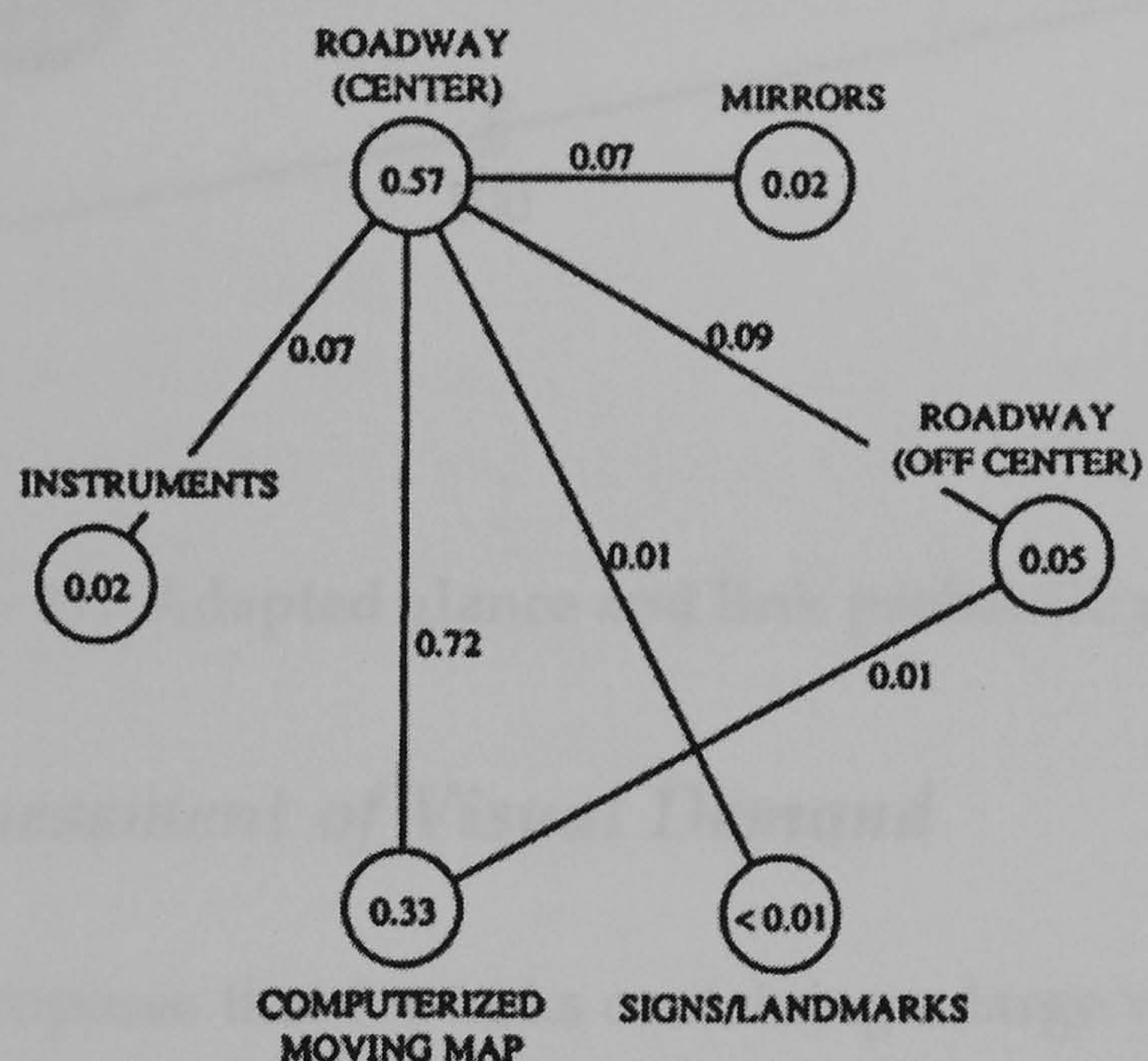



**Figure 2 -16. Glance and link value probability: driving with a computerised moving map display, from Wierwille (1993a)**

A criticism of the comparisons made is that the data are not from the same experimental route. However, it is stated that the routes were comparable. The results would seem to support the hypothesis that the introduction of advanced information systems changes the driver's scanning. Further work with a truly comparable route would reinforce the value of glance and link probability diagrams for assessing the impact of driver information systems on visual behaviour. What is not considered is the criterion for acceptable and unacceptable glance and link value probabilities. Additionally, the visual presentation of the data may lead to misinterpretation, as the link values do not represent the actual length of the corresponding line. If the data could be presented as in Figure 2 - 17 the graphical impression may be easier to assimilate. In Figure 2 - 17 the data are portrayed as pie charts in circles (representing the probability of eye dwell) and the distances between regions are the reciprocal of the link probability (i.e., the driver glances between the nearer regions more often) thus it is hoped a strong relationship between them is better represented.

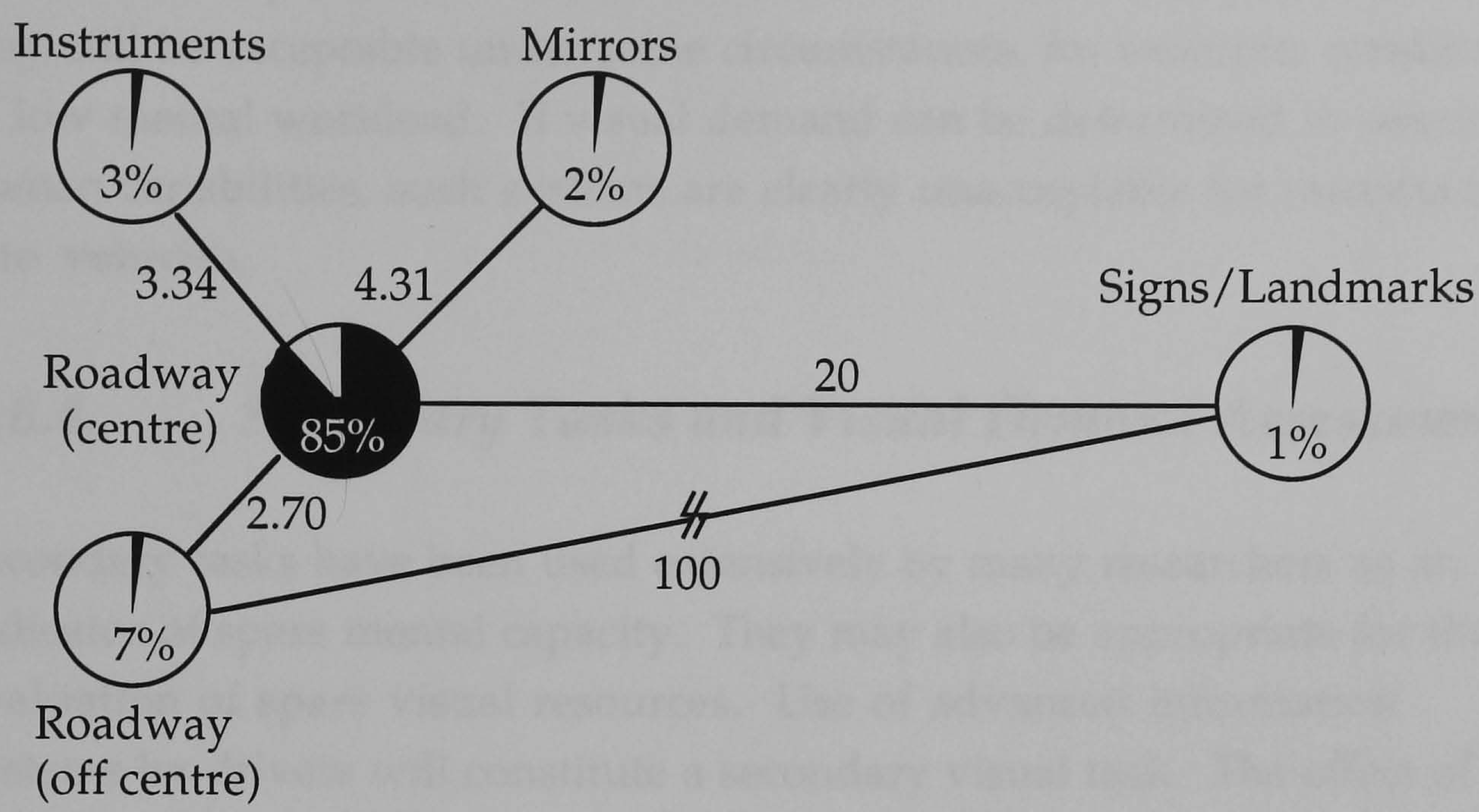



**Figure 2 - 17. Adapted glance and link probability diagram**

### 2.6.3. *Assessment of Visual Demand*

Hughes (1989) proposes that for tasks containing a large visual component, the operators' visual behaviour and the visual demand imposed by the task should be evaluated.

The visual demand associated with a task can be considered as separate and distinct from the operator's normal visual behaviour (Hughes, 1989). The visual demands of the entire driving task may not need to be considered. Additional demands of in-vehicle tasks, over and above normal visual requirements are suggested to require separate evaluation.

To ensure information presented by the system is effectively and easily acquired by the operator, Hughes (1989) argues this can be achieved by investigation of:

- the information sources required for the task (which may be established for example, by task analysis), and
- the effort required in acquisition of the visual information (which could be influenced by the allocation of functions between the driving task and the in-vehicle device).

Consider whether visual demands limit driving performance, or overload the driver's capabilities. Visual demands which limit task performance may still be acceptable under some circumstances, for example, conditions of low mental workload. If visual demand can be determined to overload human capabilities, such systems are clearly unacceptable for introduction into vehicles.

### 2.6.4. *Secondary Tasks and Visual Demand Assessment*

Secondary tasks have been used extensively by many researchers as an indicator of spare mental capacity. They may also be appropriate for the evaluation of spare visual resources. Use of advanced information systems by drivers will constitute a secondary visual task. The effect of such secondary activities on performance of the primary task (vehicle control) is a key safety focus of system evaluation. The employment of a secondary visual task will almost certainly degrade primary task performance in some fashion, see Figure 2 - 18.

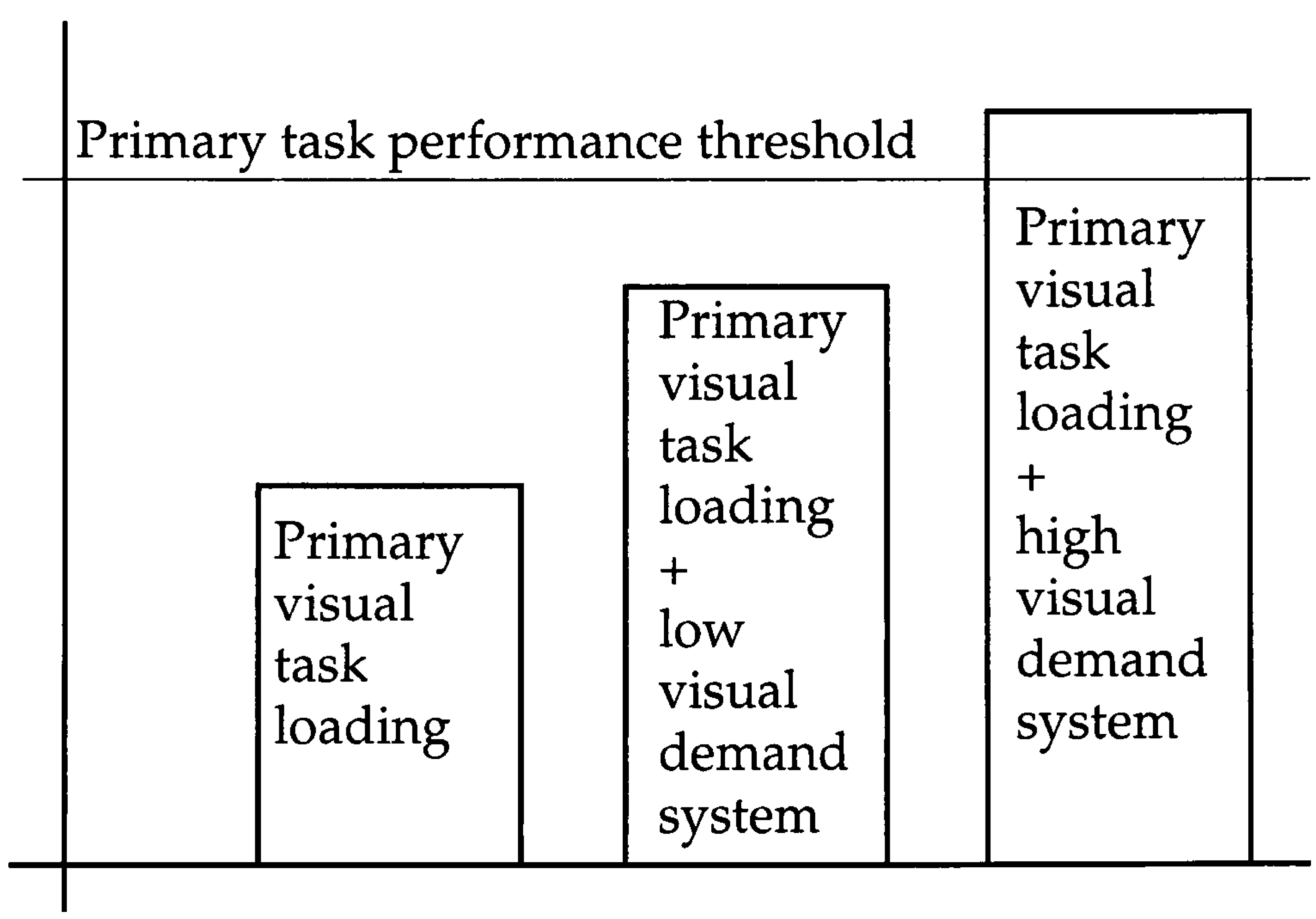



**Figure 2 - 18. Theoretical primary task performance and the introduction of visually demanding tasks**

Wierwille (1993a) developed a more detailed model of in-vehicle sampling from these themes which is outlined below, see Figure 2 - 19. He does suggest that the model is somewhat "deterministic". However, it enables the researcher to consider the implications of the different influences on the driver and accurately represents the majority of visual deviations from the forward view, while introducing the concept of *uncertainty buildup*.

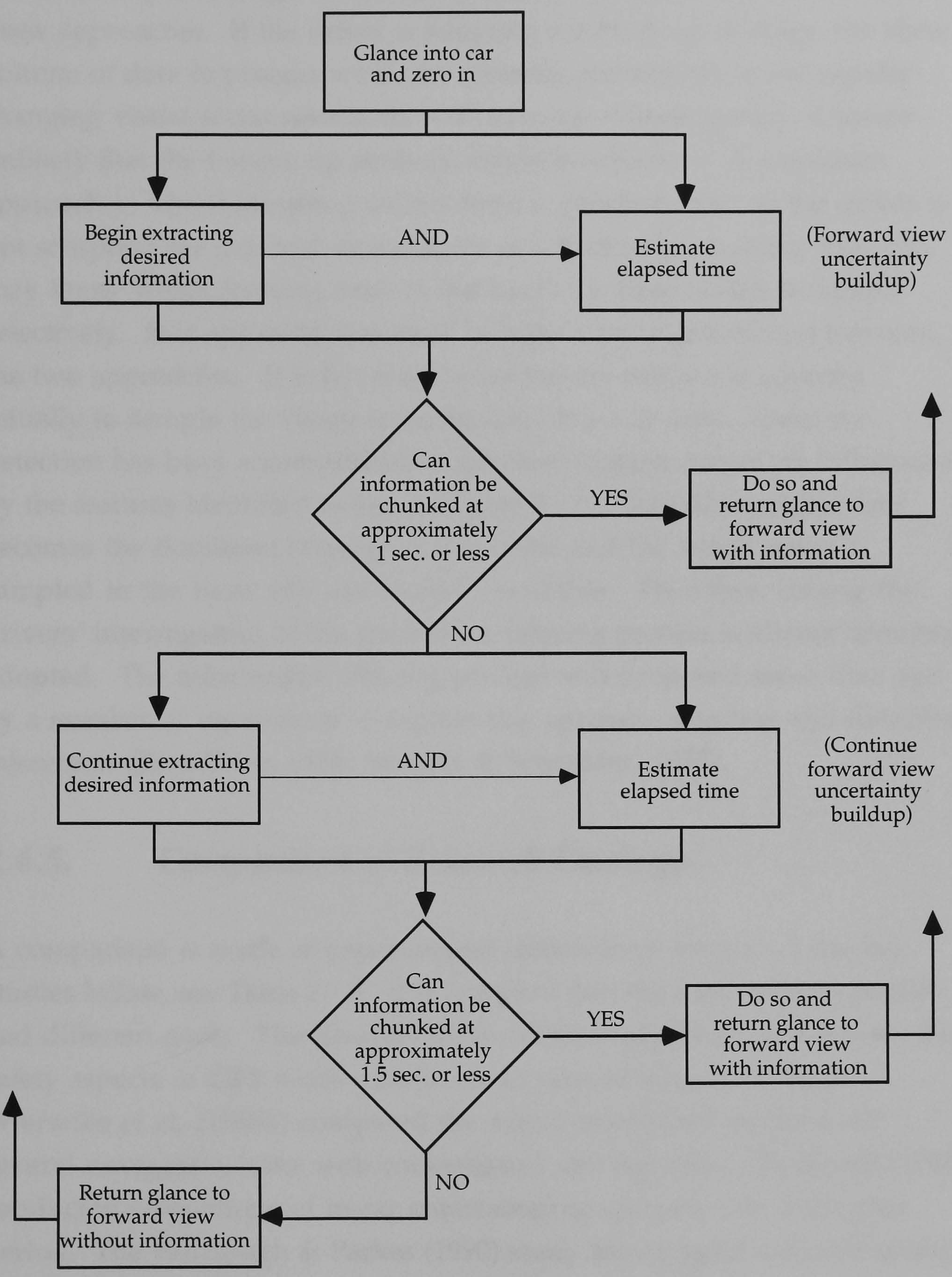



**Figure 2 -19. In-vehicle sampling, from Wierwille (1993a)**

The driver may be adopting two different strategies to facilitate visual search. They could be sampling the whole visual environment and filtering down to the required information for driving (bottom up information processing), or s/he may decide what information they require in a particular situation and select only that (top down information processing). There are a number of logical flaws with each of these approaches. If the driver is adopting a bottom up strategy, the sheer volume of data to process would be colossal, particularly in the rapidly changing visual scene associated with driving. Consequently, it seems unlikely that the bottom up strategy would be effective. A top down approach to visual sampling suffers from a different flaw. If the driver is not sampling the external visual scene in a bottom up fashion, how can they know which features exist in the roadway, from which to sample selectively. It is apparent that there is some form of interaction between the two approaches. It is felt that the bottom up method is adopted initially to sample the visual scene broadly at a low level. Once the detection has been accomplished, a selection process occurs (as influenced by the features identified earlier in Figure 2 - 3). Top down processing becomes the dominant strategy at this point and the visual scene is sampled in the most efficient manner available. Therefore, during the drivers' interrogation of the roadway a filtering process is almost certainly adopted. The information filtering concept was proposed some time ago by a number of researchers to explain this apparent selection and detection misnomer (Broadbent, 1958; Shiffrin & Schneider, 1977).

### *2.6.5. Comparison of Research Findings*

A comparison is made of experimental results from several of the key studies below, see Table 2 - 2. It is apparent that the experimental studies had different goals. The Zwahlen et al. (1988) study aimed to evaluate the safety aspects of CRT touch panels, on an unused airport runway. Wierwille et al. (1988a) compared the visual attentional demands of several navigation tasks with conventional driving tasks. Rockwell (1988) conducted evaluations of in-car entertainment systems over a six year period. The Fairclough & Parkes (1990) study investigated subject's ability to use a paper map and a text instruction based route guidance system. Irrespective of these differences, one would expect some relationship between the measures of driver visual behaviour. Important to note here, is the difficulty in correlating obtained results. Insufficient research has been conducted to develop a commonly specified format for the collection of visual behaviour measures. Such an approach would, if adopted, facilitate meta-analysis cross-comparison of further experimental work.

**Table 2 - 2. Reported visual demand**

| Author(s) | Mean glance frequency | Mean glance duration (secs) | Mean task completion times (secs) | Time off task while using system (%) |
|---|---|---|---|---|
| Zwahlen et al. (1988) | 1.46 to 2.79 | 0.32 to 2.0 | 5.02 to 8.39 | ? |
| Wierwille et al. (1988a) | 1.26 to 6.52 | 0.62 to 1.63 | 0.78 to 10.63 | 7 to 33 |
| Rockwell (1988) | 1.25 | 1.27 to 1.42 | ? | ? |
| Fairclough & Parkes (1990) | 160 & 234 (per condition) | 1.3 & 1.8 | ? | 12.1 to 22.1 |

## 2.6.6. *Summary: Visual Demand and Advanced Driver Information Systems*

The time sharing between vehicle control and driver information system use is fundamental to understanding the imposed visual demand on the driver. The driver must be able to extract the required information within an acceptable glance duration. Many in-vehicle tasks have been shown to be quite reasonable in terms of the visual demand they impose on the driver. For example, Rockwell (1988) and Wierwille et al. (1988a) evaluated as acceptable, the visual distraction of a number of typical in-vehicle tasks. However, task related variability in visual demand has been demonstrated, and some tasks assessed as highly visually demanding (Dingus et al., 1989).

The following main themes can be drawn from the literature relating to the introduction of driver information systems into vehicles:

- diverse methodologies make the comparison of experimental results difficult
- task complexity influences visual demand (i.e., increased task complexity tends to result primarily in increased glance frequency and to some extent glance duration, Dingus et al., 1989)
- thresholds for safe in-vehicle visual behaviour have been proposed. For example, a maximum acceptable glance duration of two secs (Rockwell, 1988; Zwahlen et al., 1988), 1.25 secs (Wierwille, 1993a); or glance durations in excess of the 90th percentile (Rockwell, 1988). Such taxonomies remain limited in their basis for proposal and context of application
- some advanced driver information system tasks impose unreasonable visual demand (Dingus et al., 1989). Additionally, certain conventional tasks also present high visual demands (Dingus et al., 1989; Wierwille et al., 1988a)
- there are individual differences in visual demand (i.e., older drivers experience increased visual demand when using in-vehicle information systems (Carr et al., 1992; Evans, 1994; Hancock, Wulf, Thom, & Fassnacht, 1990))
- when visual demand cannot be anticipated, drivers' glances to the forward scene decrease in frequency and increase in duration (Wierwille et al., 1988b)
- under anticipated and unanticipated visual demand, glances to driving related regions of the visual scene increase, while the non-driving related glances decrease (e.g., to a moving map display, Wierwille et al. 1988b). Glance frequency may also increase
- the introduction of driver information systems will shift visual attention from the forward view to the system (Fairclough et al., 1991; Lansdown, 1996; Wierwille et al., 1988).

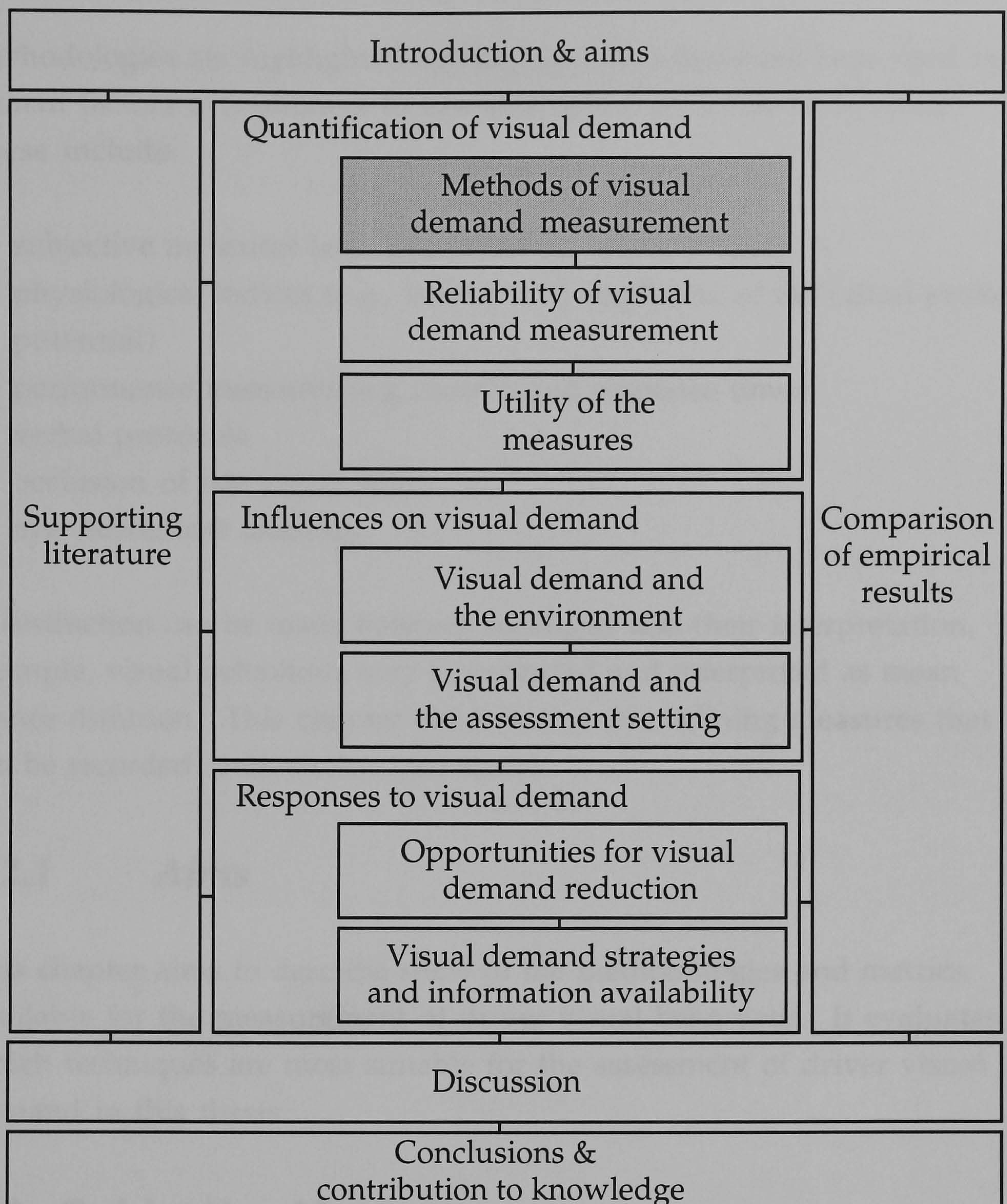
## 2.7. Chapter Conclusions

Literature relevant to the visual demands imposed by the introduction of driver information systems into vehicles has been described in this chapter. It has presented evidence in support of foveal time sharing during information extraction and increases in the available resources of the driver with task experience. However, attentional resources have been shown to be affected by environmental, traffic and individual factors. Research was outlined for the measurement of driver visual demand. Rarely has this been compared with control data or the methodologies adopted described in sufficient detail to facilitate replication of the experimental work. Several models of in-vehicle sampling have been proposed, but all current models fail to fully represent driver visual behaviour using advanced information systems. The empirical work described in the subsequent chapters addresses some of these shortcomings.

# Chapter 3

# Methods for Assessment of Information Systems

# Methods for Assessment of Information Systems




## 3.1. Chapter Summary

A number of metrics have been used in visual behaviour measurement relating to the assessment of advanced driver information systems. An overview is given to aid the reader's understanding of their role in the assessment of drivers' visual function. The importance of visual inputs in driving and the complex nature of the task lead to the conclusion that indices of both visual and cognitive behaviour should be recorded as an absolute minimum.

## 3.2. Introduction

Methodologies are highlighted by Hughes (1989) that have been used by human factors practitioners to evaluate driver information systems. These include:

- subjective measures (e.g., psychometric rating scales)
- physiological indices (e.g., latency and amplitude of the visual evoked potential)
- performance measures (e.g., search and response times)
- verbal protocols
- occlusion of the visual field
- eye movement analysis.

A distinction can be made between measures and their interpretation. For example, visual behaviour may be recorded and interpreted as mean glance duration. This chapter concentrates on outlining measures that can be recorded, unless otherwise stated.

### *3.2.1 Aims*

This chapter aims to describe some of the methodologies and metrics available for the measurement of driver visual behaviour. It evaluates which techniques are most suitable for the assessment of driver visual demand in this thesis.

## 3.3. Subjective Measures

In the context of this research, consideration of subjective measures of driver performance is restricted to mental workload assessment. The cognitive component of the driving task may represent a significant demand on the driver, possibly compromising their ability to control the vehicle. Attempts to find the best route using a computerised map display in the vehicle have been shown to exhibit this effect (Wierwille, 1993a). Broadbent (1958) and Moray (1981) have proposed that cognitive loading may result in rejection of apparently irrelevant stimuli and perceptual narrowing. Cognitive load, it has also been suggested, demands foveal vision, thereby suppressing normal visual scanning to other regions of the visual scene (Wierwille, 1993a).

Several techniques have been developed for the assessment of subjective mental workload. A summary table of some of the more prominent techniques can be seen in Table 3 - 1. It is not the purpose of this document to consider in detail the relative merits of such approaches, the interested reader is referred to review articles by Hill, Iavecchia, Byers, Bittner, Zaklad, & Christ (1992); Jordan & Johnson (1985); Schlegel (1993); Wierwille & Casali (1983) and Wierwille & Eggemeier (1993).

**Table 3 -1. Summary of subjective mental workload assessment methods**

| Technique | Originating reference |
|---|---|
| Cooper-Harper | Cooper & Harper (1969) |
| Overall workload | Vidulich & Tsang (1987) |
| Subjective workload assessment technique (SWAT) | Reid, Shingledecker, & Eggemeier (1981) |
| NASA TLX (Task Load Index) | Hart & Staveland, (1988) |
| NASA R-TLX (Raw Task Load Index) | Byers, Bittner, & Hill (1989) |

Cooper-Harper and the Modified Cooper-Harper (MCH) rating scales (Wierwille & Casali, 1983) have been criticised as non-diagnostic methods. The criticism stems from the single scale employed by these techniques. The SWAT and NASA TLX (Task Load Index) provide more insight into the specific nature of the mental workload because of the individual component parts used to determine overall mental workload in these methods. SWAT was suggested to result in greater variation when compared to NASA TLX (Hart and Staveland, 1988), further, the three components which constitute SWAT (mental effort load, psychological stress load and time load) were thought not to represent the full range of factors constituting mental workload.

The NASA TLX was developed for the space programme to determine subjective mental workload (Hart & Staveland, 1988). It involves subjects performing a paired comparison on six component elements which constitute the overall mental workload. A study by Jordan & Johnson (1985) suggests that the use of a top of the range in-car radio cassette results in significantly higher mental workload than a control condition. The nature of the drivers' interaction with such systems is suggested to be similar to that associated with the new generation of driver information systems. R-TLX (Raw Task Load Index) was advocated by Byers et al. (1989) as a method for assessment of mental workload that is easier for subjects to perform than the TLX. The difference between R-TLX and TLX is that the paired comparisons stage is no longer used. High correlations have been found between TLX and R-TLX (Byers et al., 1989). The method has been adapted and validated for use in automotive research (Fairclough, 1991). Consequently, experimental work presented in this thesis used the adapted NASA R-TLX.

## 3.4. Physiological Measures

Several techniques have been employed to determine the driver's level of stress, including: heart rate, sinus arrhythmia and galvanic skin response. Fairclough & Parkes (1991) consider psycho-physiological measures to be a direct index of mental workload because they measure the nervous activity of the operator during the task. The interested reader is referred to the following articles Brookhuis, Schrievers, Tarriere, Petit, & Chaput, (1991); Fairclough (1990); Fairclough & Parkes (1991); Sheridan, Meyer, Roy, Decker, Yanagishima, & Kishi (1991). Physiological indices have the disadvantage that they are, by and large intrusive measures and the preparation of subjects may affect task performance. Physiological measures have further been criticised as requiring experienced operators and specialised equipment for valid use (Kramer, 1991).

## 3.5. Performance Measures

Performance measures can be considered either as primary or secondary task indices. Primary tasks are those that the driver must competently perform to maintain safe vehicle control. Zwahlen et al. (1988) used position in lane as an index of primary task performance. The similar measure time to line [road edge] crossing was proposed as a valid predictor of driver task performance (Godthelp, 1986). Lane deviation measures are a function of visual distraction from the roadway and driver visual-motor coordination. Secondary task measures include backwards counting and/or reaction time to a stimulus. Secondary task measures have been employed to measure spare mental capacity (Schlegel, 1993). Driving in heavy traffic has been shown to reduce secondary task performance (Brown & Poulton, 1961; as cited in Peacock & Karowowski, 1993). The intrusion of the secondary task on the primary task must be carefully considered. Performance in low workload conditions has been shown to decrease with the addition of a secondary activity (Wierwille & Gutmann, 1978). However, the effect was not found under high workload conditions.

## 3.6. Verbal Protocols

Verbal protocols are the recording and classification of subjects thinking aloud (Ericson & Simon, 1993). Verbal protocols have been used in the measurement of drivers' attention by Hughes & Cole (1986). The research employed verbal protocol analysis to compare objects of regard for subjects driving and observing the same visual scenes in the laboratory. They cite their results as supporting evidence for the use of verbal protocol analysis as a valid reflection of driver visual allocation. A potential problem with use of verbal protocols in driving may be the proceduralisation of the task (Anderson, 1987). To illustrate, verbal protocols are presumed to be the verbalisation of the contents of working memory. However, the expert driver may no longer be employing characteristic if-then rules used by novices and therefore, may not be consciously attending to the object of regard. As a result the focus of regard would no longer be active in working memory and thus not necessarily available for vocalisation.

## 3.7. Eye Movement

Consideration of drivers' visual behaviour involves two processes, eye movement data collection and eye movement analysis. Methods for the collection of visual behaviour data will be considered first. This will be followed by discussion of the metrics which can be obtained from such data. Carr (1988) reviewed eye movement recording equipment, from which much of the information below is summarised.

### 3.7.1 *Occlusion*

Visual occlusion, while classified by Hughes (1989) as a separate driver measurement technique, is considered as a manipulation of primary task performance. Several strategies have been adopted by researchers employing this method. These can be classified as experimenter (Rockwell, 1972; Senders et al., 1967) and subject control (Senders et al., 1967) over the occluding mechanism. Typically, occlusion would be achieved using a helmet with an automated visor, see Figure 3 - 1. It is assumed that the restriction of visual information forces the driver to glance first to the regions of highest priority.

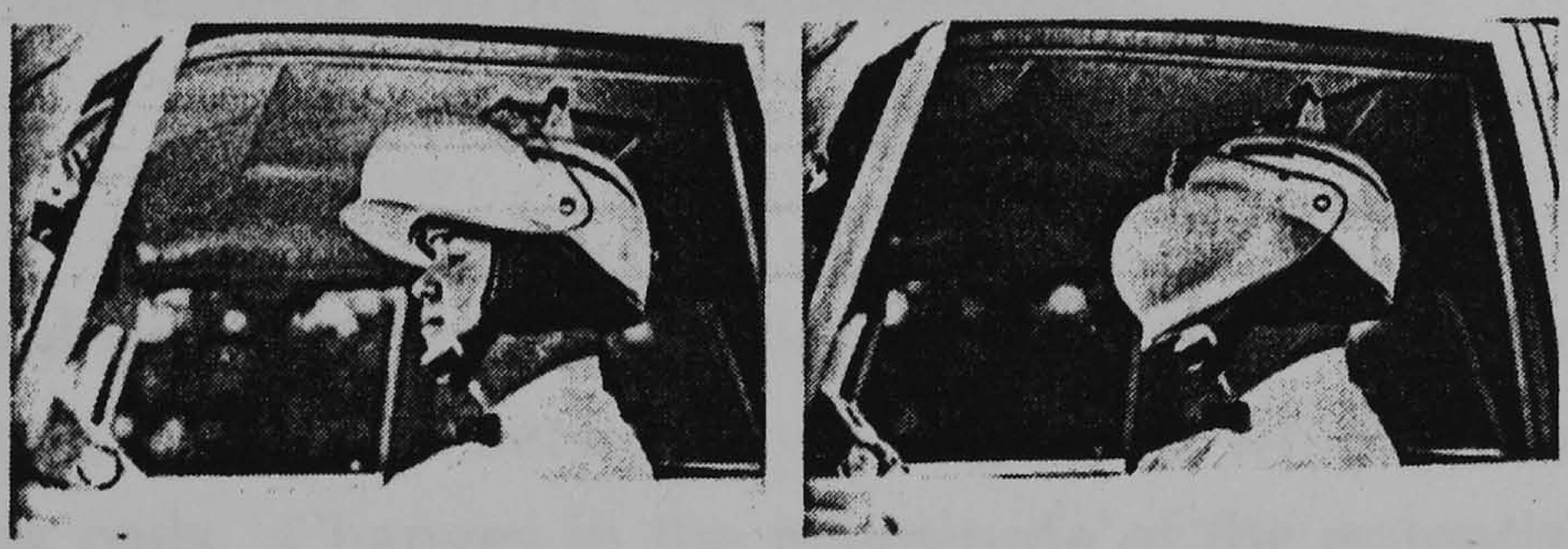


**Figure 3 - 1. Occlusion helmet, from Senders et al. (1967)**

### 3.7.2 *Eye Tracking Equipment*

Eye tracking technologies have the advantage over simple camera-based video recording systems in that they have the ability to determine the point of fixation (e.g., a glance specifically to a road sign, rather than the roadway). There are several methods of obtaining information relating to the position of the eye, including: limbus tracking, pupil tracking, corneal reflex, search coil, electro-oculography and purkinje image tracking.

**Limbus Tracking**
Typically in this technique the eye is illuminated by an infra-red source. Photo-diodes are used to detect reflections from the eye. Movement is identified by the different quantities of light reflected by the (light coloured) sclera and the (relatively dark) iris. Evoked potential differences are used to determine movement. Limbus tracking systems primarily

detect horizontal movement, although vertical motion can be recorded to a reduced degree of accuracy.

**Corneal Reflex**

The cornea is illuminated with a point source, usually infra-red. Movement of the cornea causes the light source to be reflected in the direction of eye movement. The changes in position of the reflected light source can be calibrated to enable detection of fixation location.

**Pupil Tracking**

Algorithms are applied to infra-red images of the pupil to calculate its centre. The centre of the pupil is assumed to represent the direction of gaze. Pupil tracking systems can also be employed to determine pupil size. If corneal reflection is also monitored, this can be used to compensate for small head movements during experimentation.

**Search Coil**

In this method subjects wear small coils attached to the eyes using suction. The individuals are placed between two large coils which induce a voltage in the smaller coils. Changes in the magnitude of the potential difference enable eye tracking which is independent of head movement.

**Electro-Oculography (EOG)**

Eye movement is detected by measurement of induced potentials in electrodes positioned around the eye, or eyes. Electrodes are typically positioned above, below and laterally with respect to each eye. Optionally, an additional electrode may be used as a reference or ground signal, attached to the ear or similar location. Motion of the extrinsic muscles of the eye induce a potential that can subsequently be measured by the electrodes.

**Purkinje Image Tracking**

Light passing through the optical media of the eye produce several reflections (i.e., purkinje images). The first and fourth of the purkinje images are recorded in this method and their motion is used to calculate eye movement.

**Manual Transcription**
Experimenters employing this method position themselves where they can observe the driver's face. Eye movements are recorded on computer with key presses or by using tally charts during driving. The reliability of the technique will depend on the experimenter's vigilance and skill.

**Video Tape Transcription**
Video cameras are used to record the driver's face and forward view out of the vehicle (at a minimum). The camera images are mixed together and recorded on to video tape. The data are transcribed from the video tape to manually record changes in the position of the eyes. This technique is limited in that it cannot be used to determine point of regard, only the general direction of gaze.

### 3.7.3 *Eye Movement Interpretation*

Regardless of the data collection method numerous measures of eye movement can be calculated. The following equations and explanations have been defined in the draft ISO standard *Video-based Measurement of Driver Visual Demand* (ISO, 1996). The derivations are not the work of the author but have been selectively applied in this thesis for the calculation of driver visual behaviour.

Glance frequency (or number of glances)$_j$ = Total number of glances to location j, where each is separated by at least one glance to a different location.

$$\text{Mean Glance Duration}_j = \frac{(\sum_{i=l}^{n} \textit{Glance Durations}(i))}{\textit{Number of Glances}_j} \tag{1}$$

The mean glance duration to location j is the sum of all glance durations to location j divided by the number of glances to location j in the sample interval, see Equation 1.

$$\text{Total Glance Time}_j = \sum_{i=l}^{n} \textit{Glance Duration}_j(i) \tag{2}$$

Total glance time to fixation location j is the sum of all glance durations to fixation location j in the sample interval, as shown in Equation 2.

$$\text{Proportion Total Glance Time}_j = \frac{\textit{Total Glance Time}_j}{\textit{Sample Interval}} \quad (3)$$

The total glance time (or percentage of time) associated with a fixation location j (e.g., an in-vehicle device) in the sample interval, see Equation 3.

$$\text{Mean Transition Time}_{jk} = \sum_{i=1}^{n} \frac{\textit{gaze shift}_{jk}(i)}{n_{jk}} \quad (4)$$

Gaze $\text{shift}_{jk}$ (i) is the transition time for the eyes to shift gaze from location j to location k for transition i; $n_{jk}$ = number of transitions from location j to location k in the sample interval, as shown in Equation 4.

$$\text{Fixation Probability, } p_j = \frac{\textit{number of frames with gaze on location j}}{\textit{total number of frames in sample interval}} \quad (5)$$

Fixation probability is the probability that location j was fixated on during the sample interval, see Equation 5.

$$\text{Link Value Probability, } P_{Ljk} = \frac{\frac{n_{jk}}{N} + \frac{n_{kj}}{N}}{N - \sum_{j=1}^{Q} \frac{n_{jj}}{N}} \quad (6)$$

Link value probability is the probability that a fixation to location j will be followed by a fixation to location k or a fixation to location k will be followed by a fixation to location j, see Equation 6.

Where:

$n_{jk}$ = the number of transitions from location j to location k, j not equal to k.

$n_{kj}$ = the number of transitions from location k to location j, k not equal to j.

$n_{jj}$ = the number of transitions from location j to location j, (i.e., successive frames where the driver's fixation location remains the same).

N = the total number of transitions (across all locations, not just j and k) in the sample interval.

Q = the number of unique fixation locations.

It should be noted that $P_{Ljk}$ is only defined for $j < k$. Thus, the number of link probabilities for a situation in which there are Q locations is given by $[Q(Q-1)]/2$.

## 3.8. Discussion

While it is clear that recommendation regarding the selection of visual and cognitive demand measures cannot be made, it is hoped that this brief review provides the reader with some insight into the benefits and limitations of several commonly applied techniques. It has been previously argued (see Chapter 2) that the driver functions at different levels (e.g., strategic, manoeuvring and control) during task performance (Rasmussen, 1983). Some researchers propose that a specific measure will only address some of the theoretical levels of the task (Parkes, 1991), see Table 3 - 2. Therefore, a battery of measures may address more of the various levels and provide a richer reflection of the visual and cognitive attentional demands on the driver.

**Table 3 - 2. Theoretical driving task levels and corresponding data collection metrics, from Parkes (1991)**

| | Driving task level | | | |
|---|---|---|---|---|
| Type of Data | Strategic | Manoeuvring | Control | Reactive |
| Vehicle dynamics | ✘ | ? | ✔ | ✘ |
| Drivers' control actions | ✘ | ✔ | ✔ | ? |
| Visual behaviour | ✘ | ? | ✔ | ? |
| Physiological indices | ✘ | ✘ | ? | ✔ |
| Verbal protocols | ✔ | ✔ | ✘ | ✘ |
| Interviews | ✔ | ✔ | ✘ | ✔ |

Video tape transcription was employed during this research for the measurement of driver visual behaviour because of limitations in the alternative methods. Electro-oculography was not selected because of the intrusive nature of the measure and the additional demands imposed on the subjects' time. Similarly, eye-mark cameras were considered but rejected because the head mounted apparatus is obtrusive and prone to movement during experimental work. These systems are currently expensive and the increased resolution of the video tapes is typically reduced to the level of simple camera based video recordings. For example, if the researcher is primarily interested in deviations from the forward view as indicators of increased visual demand, detail at the level of the point of fixation is not required. Additionally, eye-mark data must be transcribed by hand in the same manner as simple camera based systems because the specified regions of the visual scene change as the vehicle negotiates the roadway (e.g., the spatial location of the roadway will shift as a vehicle turns a corner, see Figure 3 - 2).

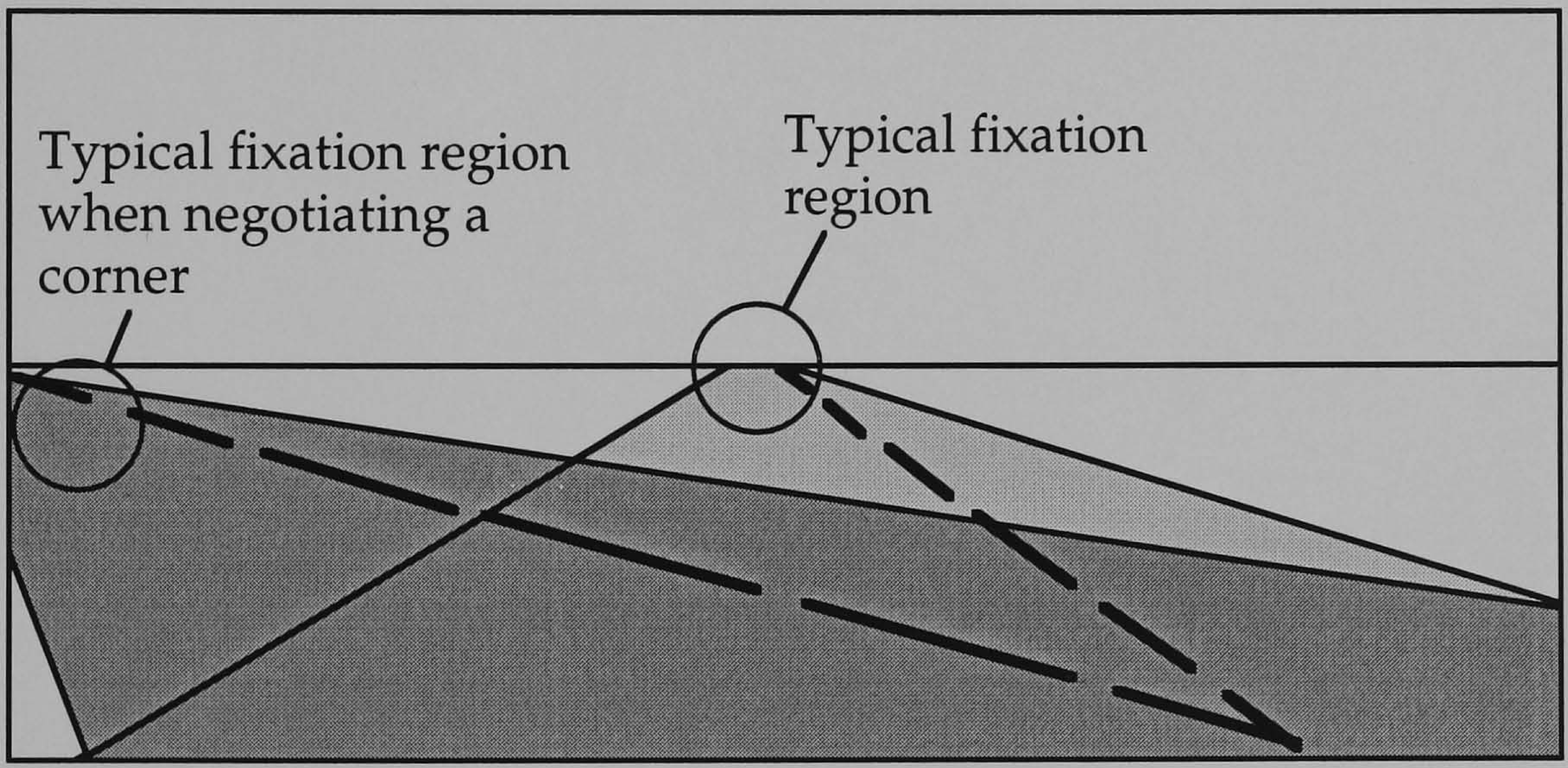



**Figure 3 - 2. Schematic of the visual road position change as a vehicle continues straight on and, negotiates a corner**

Visual behaviour data was therefore collected using simple camera video tape records and transcribed by hand to a spreadsheet for calculation of eye movement statistics. Interpretations from the raw data can be seen in the subsequent chapters. Subjective mental workload was quantified using the adapted NASA R-TLX because of its proven reliability, diagnostic value and ease of application, when compared with other available techniques.

## 3.9. Chapter Conclusions

Technologies for collection of data on driver visual, cognitive and performance behaviour have been reviewed. Relative merits of subjective, physiological, performance, verbal protocols and eye movement techniques were highlighted. The distinction between eye movement data collection (e.g., pupil tracking) and eye movement analysis (e.g., percentage time per region) is made. In the light of a need for a multi-levelled approach to driver assessment, video tape transcription and adapted R-TLX were selected for use in the experimental work reported in this thesis.

# Chapter 4

# Drivers' Visual Behaviour: Is Video Tape Transcription Reliable?

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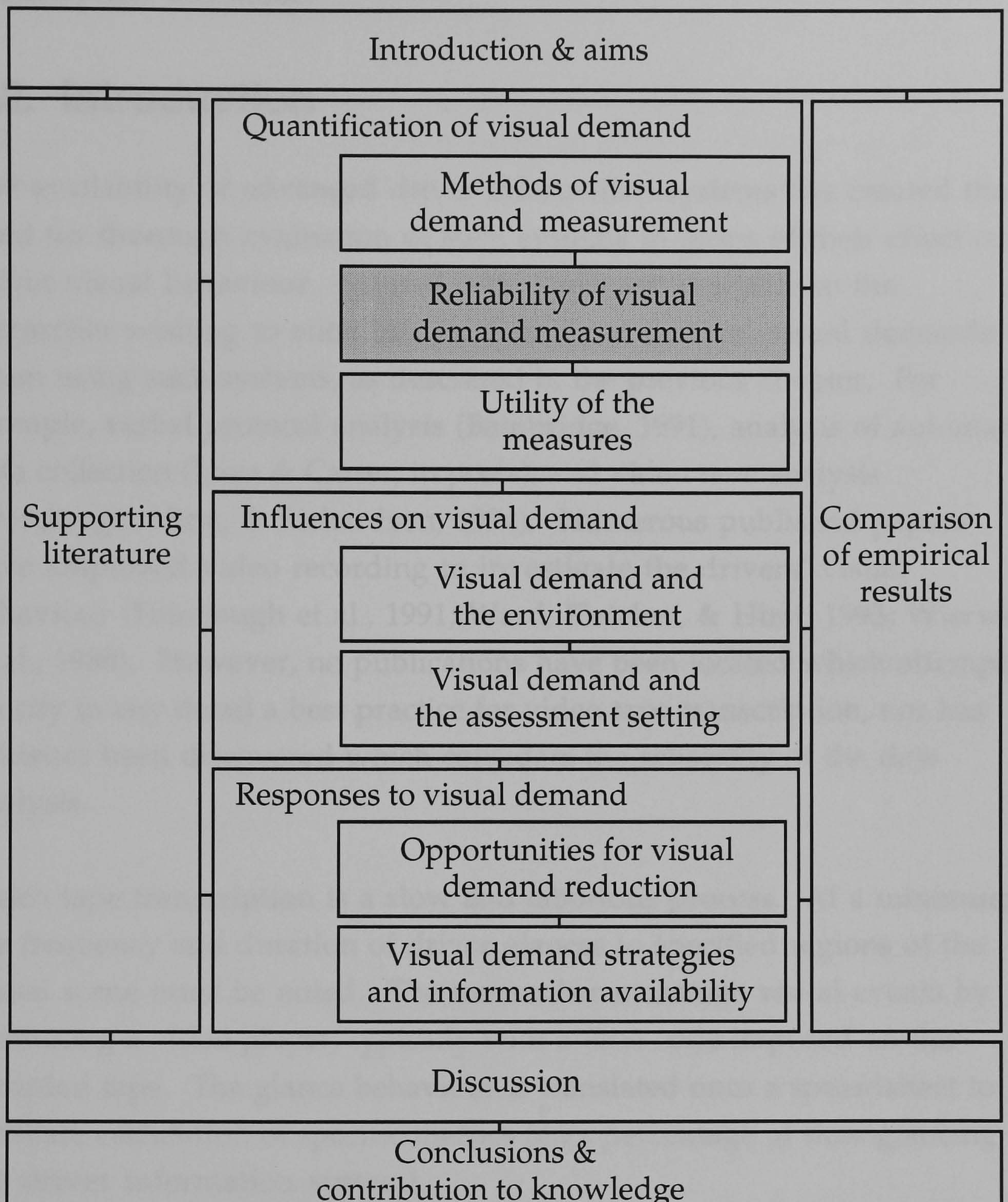



## 4.1. Chapter Summary

This chapter describes the experimental work conduced to investigate a) the reliability of video tape transcription of driver visual behaviour, and b) the relative value of two different regimes for transcription. It was conducted to ensure that data collection for subsequent experimental work would be both efficient and reliable. Significantly high correlations were found between the two regimes considered (i.e., frame by frame and subjective analysis techniques). Identification of mean glance frequency and glance duration was good. Low numbers of false positives were observed, although some limitations were found with the video transcription technique.

## 4.2. Introduction

The availability of advanced driver information systems has created the need for thorough evaluation of such systems in terms of their effect on driver visual behaviour. Several techniques are available to the researcher wishing to elicit information about drivers' visual demands when using such systems, as described in the previous chapter. For example, verbal protocol analysis (Bainbridge, 1991), analysis of automated data collection (Laya & Carter, in press), and video tape analysis (Fairclough, Hirst, & Richardson, 1994). Numerous published papers have employed video recording to investigate the drivers' visual behaviour (Fairclough et al., 1991; Ward, Fletcher, & Hirst, 1993; Wierwille et al., 1988). However, no publications have been located which attempt to specify in any detail a best practice for video tape transcription, nor has evidence been discovered which considers the reliability of the data analysis.

Video tape transcription is a slow and laborious process. At a minimum, the frequency and duration of driver glances to specified regions of the visual scene must be noted. The transcriber measures visual events by examining a video player, typically with a time code imposed on the recorded tape. The glance behaviour is translated onto a spreadsheet to facilitate calculation of specific metrics (e.g., percentage of time glancing to the driver information system).

### 4.2.1 *Aims*

The research described in this chapter aimed to:

- examine the reliability of video tape analysis for collection of drivers' visual behaviour
- assess two strategies for video transcription to determine their suitability for the task.

# 4.3. Method

## 4.3.1 *Experimental Design*

The study had two conditions, frame by frame and subjective analysis video tape transcription. Frame by frame analysis involved winding through each frame of a video tape calculating the dwell time to pre-specified regions of the visual scene. Subjective analysis required the subjects to estimate to the nearest half second the dwell time to the pre-specified regions of the visual scene. The independent variable was the type of video tape transcription, the dependent variables were the subjects' accuracy in terms of transcription of video tape records of driver visual behaviour, that is:

- glance frequencies
- glance duration
- false positives (subject's assumption of a glance away from the forward scene when no glance occurred).

## 4.3.2 *Procedure*

The following procedure was followed:

- the subjects were presented with one of two instruction sheets depending on the condition which they were performing, see appendices A - 1 and A - 2
- the experimenter read to the subjects a further explanatory text expanding on the instruction sheet and describing the aims of the study, see Appendix A - 3
- subjects' questions were answered
- they analysed a section of video footage approximately 3.75 minutes long, noting the distribution of the drivers' glance frequencies and durations throughout the visual scene. The video tape record considered was an extract of an experimental trial on motorway and rural roads.

The benchmark data for determination of subjects' accuracy was established by the experimenter analysing the video tape record three times and checking the location and duration of each glance three times. It contained 45 glances away from the forward view. Glance duration and frequency for the regions of the visual scene can be seen in Table 4 - 1.

### 4.3.3 *Equipment and Apparatus*

The following equipment was used in the experiment:

- a video recorder with a frame by frame jog/shuttle facility (with an accuracy of 0.05 seconds per frame)
- a colour monitor displaying monochrome images
- subject data sheets, see appendix A - 4
- video tape footage of an urban drive

**Table 4 - 1. Benchmark transcription glance frequencies and durations for each visual region (SD in parenthesis)**

| | Glance frequency | Mean glance duration (secs) |
|---|---|---|
| Driver mirror | 33 | 0.67 (0.12) |
| Right region | 7 | 1.41 (0.83) |
| Left Region | 4 | 1.45 (1.42) |
| Instrument panel | 1 | 0.3 - |

### 4.3.4 *Subjects*

The subjects were all employees of the Motor Industry Research Association selected to be representative of those people who might analyse such data in the future. None had performed video transcription prior to the experiment. Thirty subjects participated in the trial, fourteen males and sixteen females. The ages ranged from 20 to 60 years (mean = 30.63, SD = 11.21). Half the subjects were randomly assigned to each condition. All subjects had normal or corrected to normal vision. Further information regarding methodological considerations is given in Appendix E.

## 4.4. Results

The results from each condition were compared with the benchmark transcription. One subjects' data was removed from frame by frame and two subjects from subjective analysis as a result of extreme outliers in the data. Inspection suggested that these subjects were not attempting to perform the experimental task correctly.

### 4.4.1 *Identification of Glance Frequency*

On average, frame by frame transcription of video records resulted in correct identification of 91.9% (SD = 9.2%) of glances away from the forward view and 90.3% (SD = 8.8%) of glances during subjective analysis transcription. Correct identification of a glance occurrence encompassed a tolerance of ± 1 sec with respect to the video tape clock signal. The tolerance was introduced to consider situations where the start of a glance away from the forward view occurred at the point when the time signature changed (i.e., where the glance could reasonably have been interpreted to occur, for example, at twelve minutes and one second or twelve minutes and two seconds into the trial). Glances that were missed by the subjects are not presented here as they can be concluded from the number of successfully identified glances and known total number of glances.

### 4.4.2 *Identification of Glance Durations*

Table 4 - 2 shows the relative percentages of correctly timed glance durations. It can be seen that these are lower in the subjective analysis condition, but not significantly so. Tolerance was introduced in the calculation of correct glance durations to encompass situations in which glances were reported as numerically different but similar (e.g., a glance duration of 0.8 seconds may be reported by subjects as 0.6 seconds). Consequently, a glance duration tolerance of ± 50% of the total glance length was applied to the data. The tolerance was expressed in percentage terms as the reasonable error was presumed to increase with the absolute magnitude of the glance. For example, a small tolerance for a short glance and a larger one for a long deviation from the forward view.

Some glances were correctly identified by the subjects but the duration of the glance was not estimated to within the stated tolerance (± 50% of total glance duration). Frame by frame and subjective evaluation out of tolerance errors were 14.6% and 26.7% respectively.

**Table 4 - 2. Mean percentage of correct glance durations (SD in parentheses)**

| | Frame by Frame (%) | Subjective Analysis (%) |
|---|---|---|
| Driver mirror | 85 (12) | 73 (10) |
| Right region | 64 (22) | 45 (24) |
| Left region | 54 (24) | 35 (24) |
| Instrument panel | 7 (27) | 23 (44) |

### 4.4.3 *False Positives*

Table 4 - 3 shows the mean number of glance events recorded by subjects which did not occur. It can be seen that there appears to be a low and region specific error rate. More errors occur in the left region than the others regardless of the transcription technique adopted.

**Table 4 - 3. Mean false positives (SD in parentheses)**

| | Frame by Frame | Subjective Analysis |
|---|---|---|
| Driver mirror | 1.93 (1.1) | 1.46 (1.3) |
| Right region | 1.21 (1.0) | 1.38 (1.1) |
| Left region | 2.57 (2.4) | 3.77 (3.4) |
| Instrument panel | 1.00 (2.2) | 0.62 (1.0) |
| Mean | 1.68 (1.7) | 1.81 (1.7) |

### 4.4.4 *Correlation of Measures*

Figure 4 - 1 shows a correlation of the percentage means for correct event detection and correct glance durations for the driver mirror, right region, left region and instrument panel. Frame by frame and subjective analysis methods were found to be significantly correlated $p < 0.05$ (Fisher's r to z), $r = 0.9$, $r^2 = 0.81$.

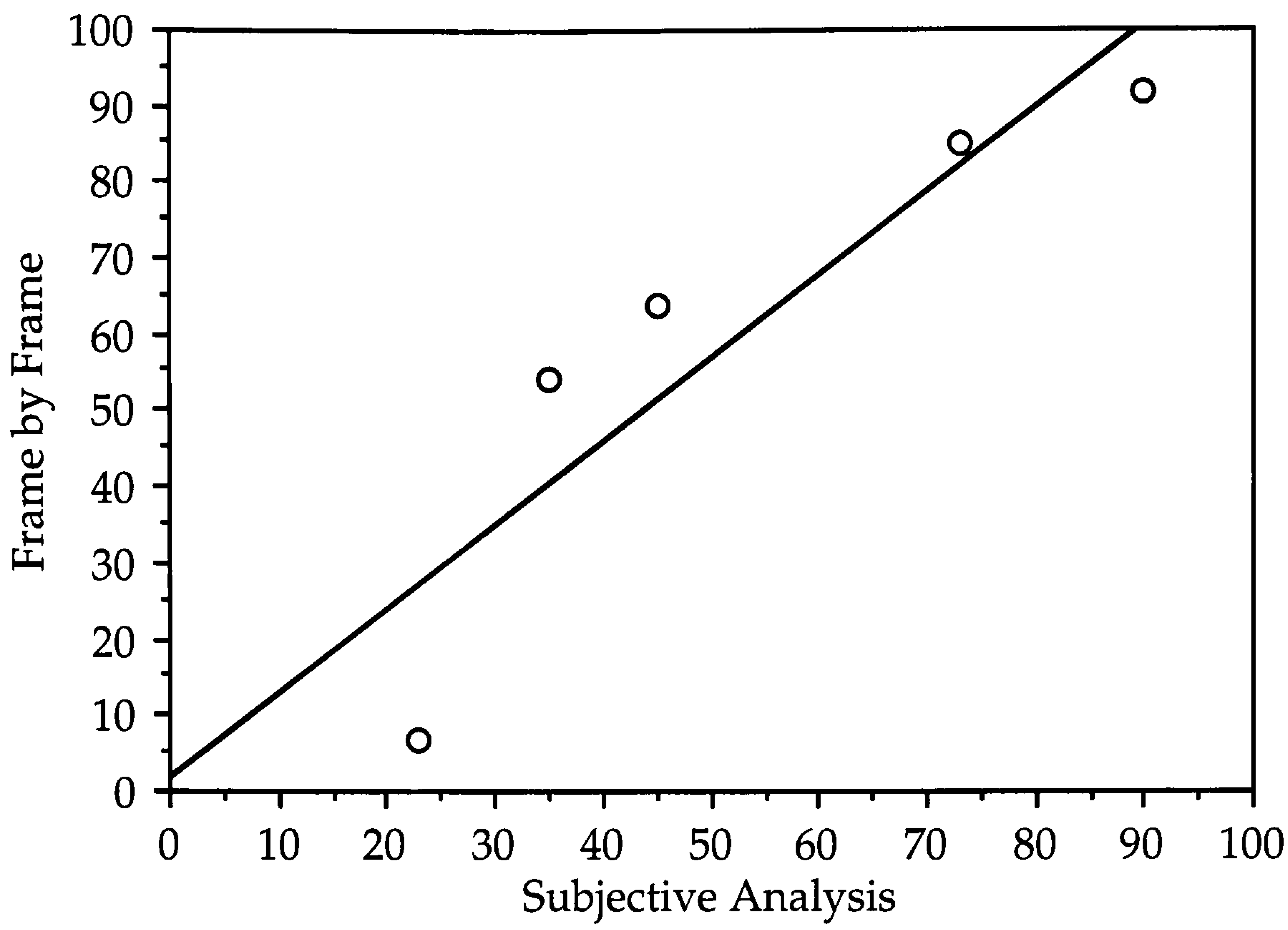



**Figure 4 - 1. Correlation of frame by frame and subjective analysis video transcription**

## 4.5. Discussion

The results demonstrated that video transcription subjects could correctly identify high proportions of glance frequencies and estimate glance durations. Significant correlations were obtained when comparing the results of both transcription methods (i.e., frame by frame and subjective analysis). The number of incorrectly identified glances (false positives) was low (i.e., 1.68 and 1.81 mean errors for the frame by frame and subjective analysis transcriptions respectively).

Identification of glance frequency was good in both conditions (i.e., > 90% of glances were detected), but detection of specific glance events is poor. Subjects were better at identifying glance frequencies when more glances occurred in the particular region. For example, in the benchmark transcription, 33 glances were to the driver mirror and four to the left region, see Table 4 - 1. The percentage of correctly identified glance durations was higher to the driver mirror than the left region, see Table 4 - 2. In frame by frame and subjective analysis the number of correct estimations of the glance duration to the instrument panel was low, 7% and 23% respectively. Video transcription is an insensitive method for the identification of specific glances of short duration. This appears true for both transcription methods. What is uncertain, and cannot be concluded from the data is whether the use of the instrument panel glance is representative of a flaw in the transcription technique. Video tape transcription in the context of visual demand assessment is concerned with the identification of glances of questionably extended duration. It would be interesting to consider longer sections of driver behaviour with a higher proportion of extended duration glances.

The long duration of some individual glances may have made the accurate classification of glance duration more error prone, as the degrees of freedom increased (e.g., classification of a glance of 1 sec with a 0.1 second fidelity generates lower error probability than a 5 second glance with the same 0.1 sec fidelity). It was hoped that the introduction of glance duration tolerance of ± 50% of total glance length would go some way to reduce this confounding effect. Thus, a glance duration defined as one second in the benchmark transcription, would be correctly identified by subjects, if declared to be within the range of 0.5 to 1.5 seconds glance duration. The problem with classification of glance duration can be seen in Table 4 - 1 and Table 4 - 2, where the longer glance durations (i.e., right and left region) were less accurately transcribed than the shorter glance durations (i.e., driver mirror).

The *false positives* represent the situations where the signal is not present, yet the subjects record that it is (i.e., type two errors). The overall number of false positives remains small in relation to the total number of glances (mean frame by frame false positives = 1.68 and subjective analysis false positives = 1.81; total number of glances = 45), see Table 4 - 1 and 4 - 3. Thus, erroneous subject interpretation of visual behaviour by subjects was low.

The findings suggest that the analysis of drivers' visual behaviour using video tape transcription yields equivalent results using either method, frame by frame or subjective analysis. Importantly, subjective analysis and frame by frame analysis correlate significantly with the benchmark transcription suggesting both methods reliably reflect in-depth analysis. Therefore, it is suggested that either method would be suitable for assessment of video tape results by individuals with limited instruction, see appendices A - 1, A - 2 and A - 3. Subjective analysis offers the great benefit in that it is far less labour intensive than frame by frame analysis. It is estimated that the 30:1 (analysis to data collection) ratio (Parkes, 1995) could be considerably reduced by an assessor performing subjective analysis transcription.

This study has concentrated on the micro issues associated with video analysis of driver visual behaviour (i.e., the reliability of establishing glance duration and frequency). Further study is required to explore the macro issues associated with this type of assessment. Specification of start and stop points for experimental conditions could influence the accuracy of transcribed video tape data. For example, visual behaviour at junctions may confound experimental results if extended glances are included in one subject's data and not another. It is suggested that conditions should be balanced in terms of the duration, traffic density and the number and geometry of junctions.

Data filtering has been used by many researchers during driver visual behaviour research (Dingus et al., 1989; Wierwille et al., 1988; Wierwille et al., 1988). For example, exclusion of visual behaviour while the car is stationary at a junction, when the driver is in no danger from prolonged fixations away from the forward view. Slicing or removal of data to consider only sections of video taped visual behaviour remains a valid approach for analysis of some facets of driver visual behaviour. The criterion for filtering must be clearly defined if experimental findings can be replicated or compared. There remains a large body of research to be conducted into these more global decisions about assessment of driver's visual scanning.

Both transcription methods demonstrate similar interpretations of driver visual behaviour. Use of a subjective analysis approach for the assessment of driver visual behaviour yields benefits in the time required to transcribe video records. However, there is an inevitable loss of fidelity when estimation is required to classify glance behaviour. It is felt that the assessment task must be considered in the context of the research aims, these being quantification of the visual demand from advanced driver information systems. Subjective analysis transcription of driver glances will not discriminate a glance of 0.57 seconds from a glance of 0.42 seconds, both would be interpreted as 0.5 seconds deviations from the forward view. Safety critical visual deviations from the forward view will, in most situations, be of the order of seconds not tenths or hundredths of seconds. A subjective analysis approach is quite able to differentiate between a glance of 0.39 seconds and another more concerning 3.51 second glance, interpreting them as 0.5 seconds and 3.5 seconds respectively.

Analysis of video tape records of driver visual behaviour involve two processes, *transcription* of the records and *analysis* of obtained information. This experiment was concerned with determining the reliability and improving the efficiency of transcription. Video tape records have the benefit that the equipment costs are relatively low and widely available. Therefore, the potential for comparison across experimental studies is improved. Use of video records for the assessment of driver visual demand does not preclude the additional benefits that may be gained from more sophisticated techniques, as outlined in Chapter 3. However, it is the interpretation of transcribed data which urgently requires a consensus within the transportation human factors community. This issue is considered in more detail in the following chapters.

Motivation of personnel to perform the transcription task may influence the accuracy of obtained results. Data from three individuals (10% of the subjects) were removed from the analysis (as stated previously) because of outliers in their data. Inspection of the data revealed that they were clearly not attempting to perform the experimental task to the best of their abilities. Two issues arise from this finding. First, subject selection for video transcription tasks should attempt to employ individuals who have either incentive to perform accurately or motivation to do so. Second, it is recommended that checking be performed to determine the accuracy of individuals undertaking this form of work, both initially and at regular intervals thereafter.

Calculation of the definitive results used to benchmark subject performance could have been more rigorously determined. The analysis of the video clip three times, with three considerations of each glance by the experimenter provides some confidence in the reliability of the benchmark data. However, it would have been preferable for the same protocol to be performed by at least one other individual and preferably two or three. Similarly, all subjects considered one driver's visual behaviour. Further investigation could consider the potential variation between drivers and their distributions of visual behaviour (i.e., by transcription of several subjects video records). Regardless, if some undetected confounding influence was inherent in the sample, it was applied consistently to all the subjects' data. Performance with the transcription strategies would still be determined by comparison with the same benchmark.

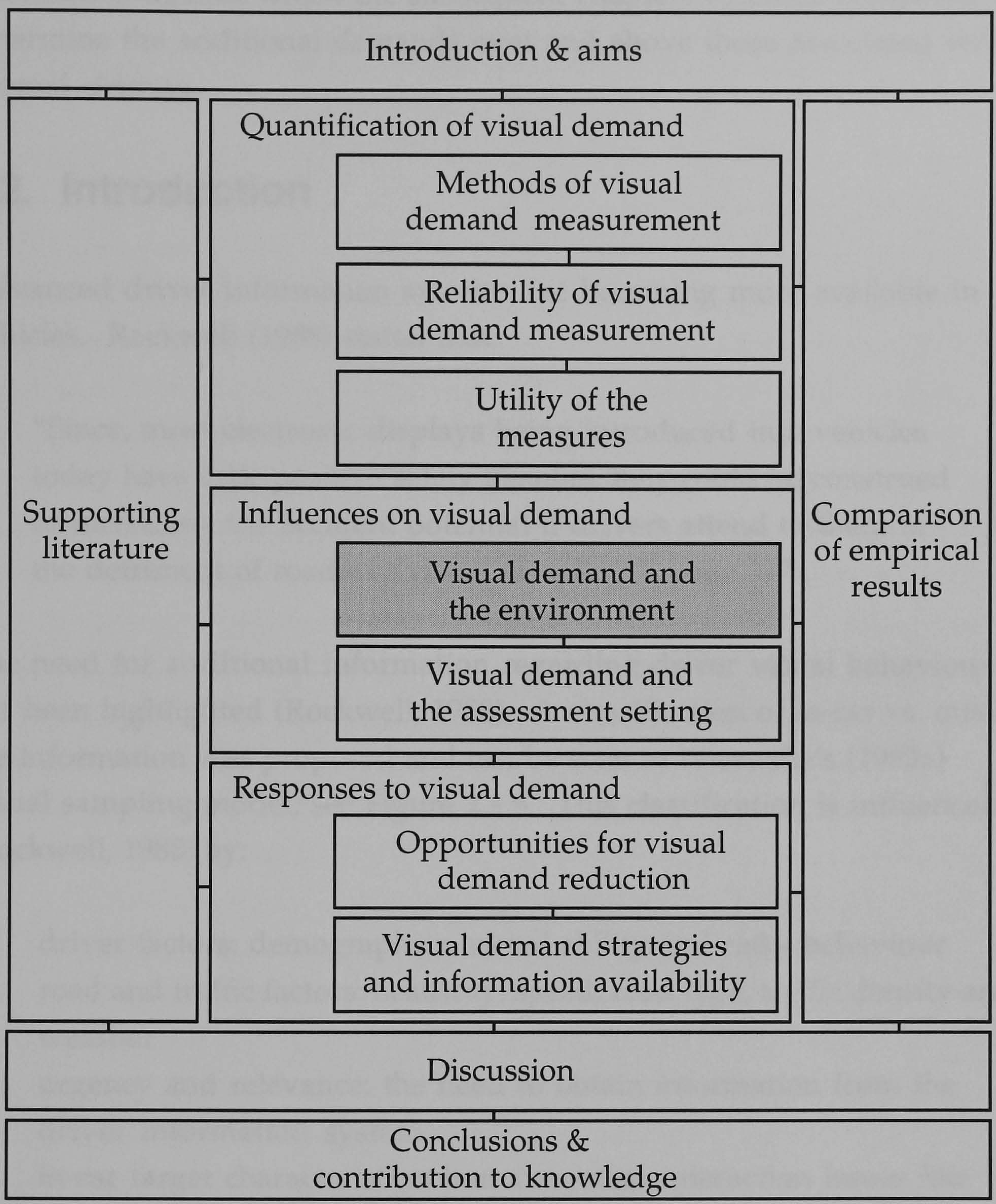
## 4.6. Chapter Conclusions

Analysis of video tape data using a subjective analysis may provide a cost effective approach for the researcher interested in drivers' visual behaviour, while retaining the sensitivity to detect safety questionable glance durations. It is felt that the experimental results presented here offer some initial encouraging evidence of the reliability of the approach (i.e., accurate identification of glance frequencies and durations, while low numbers of false positive glances were found with either method). Both frame by frame and subjective analysis of video tape data were shown to be poor at identification of single, short duration glances, but better applied to the determination of distributions of glance behaviour and extended duration glances (as required for the assessment of advanced driver information system visual demand). Further work is required to expand on these findings and explore the broader issues surrounding assessment of visual behaviour. This study provides evidence of the reliability of subjective analysis transcription for the assessment of driver visual demand (within the context of information system use). On this basis, the approach is adopted for the assessment of visual behaviour in the experimental work described in chapters 6, 7, 8 and 9.

# Chapter 5

# Visual Demand and the Driving Environment

# Visual Demand and the Driving Environment




## 5.1. Chapter Summary

This chapter describes experimental work examining normal driving behaviour in terms of visual scanning and mental workload. It investigates the variation in visual demand and subjective mental workload in different traffic environments (i.e., rural, urban and motorway driving). The purpose of the experiments was to gain an understanding of the normal driving task prior to the introduction of advanced driver information systems. It was conducted to obtain information against which the subsequent chapters could be compared to determine the additional demands over and above those associated with normal driving.

## 5.2. Introduction

Advanced driver information systems are becoming more available in vehicles. Rockwell (1988) stated that:

> "Since, most electronic displays being introduced into vehicles today have little positive safety benefits, they could be construed as increasing the accident potential if drivers attend to them to the detriment of roadway visual sampling.", page 317.

The need for additional information regarding driver visual behaviour has been highlighted (Rockwell, 1988). A classification of in-car vs. outside car information was proposed and can be seen in Wierwille's (1993a) visual sampling model, see Figure 2 - 5. This classification is influenced (Rockwell, 1988) by:

- driver factors: demographics, visual ability and risky behaviour
- road and traffic factors: headway, speed, road type, traffic density and weather
- urgency and relevance: the need to obtain information from the driver information system
- in-car target characteristics: human-system interaction issues like display shape, size, contrast and dialogue management.

Visual behaviour can be empirically investigated by examining the driver's spare visual capacity, the distribution of their scanning and the impact of changes in the driving environment on his/her fixations. This chapter is concerned with the environmental influences on driver visual demand.

### 5.2.1. *Spare Visual Capacity*

In most situations the driver retains considerable spare visual capacity to deal with additional cognitive and visual demands (Rockwell, 1972). However, under some circumstances the driver may experience maximal demands from the driving situation. Hughes & Cole (1986) conducted experiments to investigate *attention grabbing* elements of the driving task. Two experiments were performed which have been discussed in more detail in Chapter 2. To recap, subjects' verbal reports of attention attractants were collected in a field trial. In the second experiment a film of the field trial was presented to subjects in a laboratory and the same experimental procedure followed. The experimental route was divided into three regions: *residential, arterial* and *shopping centre.* The results suggested that (in both driving and laboratory conditions) in the *shopping centre* sections of the route, the frequency of attention attractant reports was significantly higher than in either the residential or arterial sections. It would appear that the drivers were glancing more often in to the visually complex environment. Driving related glances significantly increased in the shopping centre when compared to the residential driving. The classification for glances is described in more detail in Chapter 2. In both *arterial* and *shopping centre* regions more attention was paid to advertising than in the *residential* areas. Interestingly, this was balanced by reduced attention attributed to other non-driving related regions of the visual scene. Thus, overall (in *arterial* and *shopping centre* regions) the attention paid to driving related features increased. Hughes & Cole (1986) suggested that this visual attention (30% to 50%) may be spare resource. Further, they suggested that the removal of advertising would result in a shift of attention to other non-driving related objects. Suzuki, Nakamura, & Ogasawara (1966) measured eye movements and also suggests that 50% of available visual attention is not related to driving, supporting Hughes & Cole's (1986) proposition.

Rockwell (1972) discusses spare visual capacity, referring to drivers "...deliberately sampling, at repeated intervals completely irrelevant information, such as signs that are covered", page 322. Further, he suggests that fixation on an object is no guarantee that the feature is being processed by the driver. Drivers may be fixating in this manner to remain active, attempt see through the obscuring item or as part of a process to determine the relevance of the stimulus. Under most circumstances drivers appear to retain spare capacity. However, this may be dependent on the efficient deployment of visual resources to obtain information from targets in the visual scene.

### 5.2.2. *Driver Visual Scanning*

Quantification of driver visual workload requires some basis upon which to measure the change brought about by the introduction of advanced in-vehicle systems. It is therefore important to understand the duration, frequency and distribution of the driver's attention to the visual field without in-vehicle systems. Mourant et al. (1970) used eye-mark cameras to record driver's eye movements while investigating the impact of *familiarity* with the experimental route. They established changes in the patterns of visual scanning as a consequence of increased familiarity with the driven route. Route familiarity resulted in lower percentages of time spent glancing to road signs. *Saccadic travel distance* (transition time) was also observed to decrease on familiar routes when glancing to other traffic, lane and road markings, bridges and road signs. The experimenters report *out of view* or time away from the forward view statistics (data was only presented for one of the subjects), as shown in Table 5 - 1. Important to note is that 30.2% of the driver's total time driving was spent *not* glancing to the forward view.

**Table 5 - 1. Out of view statistics (one subject), from Mourant et al. (1970)**

| Eye movement | Time (secs) | Percentage of total time | Mean time per look (secs) |
|---|---|---|---|
| Looking in the rear view mirror | 10.8 | 6.9 | 0.61 |
| Looking in side mirror | 3.9 | 2.5 | 0.66 |
| Monitoring speedometer | 9.8 | 6.2 | 0.72 |
| Blinking | 8.5 | 5.4 | 0.16 |
| Other | 14.0 | 9.2 | - |

Mourant et al. (1970) propose the following as general principles of driver visual scanning:

- drivers rarely fixate on the road or road markings
- the regions surrounding the focus of expansion demand the highest proportions of visual attention
- as familiarity with the route increases the proportion of looking ahead time increases (by 7.9%), time away from the forward view decreases (by 6.4%) along with a (2.1%) decrease in time glancing to road signs.

The study demonstrates that the visual demand imposed by the roadway changes as a function of the information the driver requires to safely negotiate the network (i.e., the visual demand of roadway information, signs, etc., decreases with familiarity with the route). Thus, subjects can be seen to re-assign visual attention from one region to another, however, the total proportion of glances remains similar. The experiment may be criticised in that the subject group was small (n = 8) and the routes undertaken short (2.7 and 2.5 miles). The subjects' visual behaviour may not represent accurately that of the driving population.

It would appear that under moderate to low visual demand conditions the driver typically fixates primarily around the focus of expansion, with a large number of apparently non-essential fixations to other regions of the visual scene. Rockwell (1972), as stated previously, supports the view that most fixations are small (less than 6° travel) and remain closely located about the focus of expansion (90% of observed fixations being ± 4°). Fixation duration is reported by Rockwell (1972) to be typically between 100 ms and 350 ms. It must be remembered that a typical glance, in the driving context, would be constituted from several fixations about a pre-determined region. Thus a driving glance would be longer than the fixation durations reported by Rockwell. Similarly, the disparity between Rockwell's (1972) 10% of fixations away from the focus of expansion, Hughes & Cole's (1986) 30% - 50% and Mourant et al.'s (1970) 30.2% of fixations not to the forward view, must be considered in terms of the tasks conducted. During Rockwell's research the drivers performed car following tasks on unopened sections of state highway. Whereas, in the studies by Hughes and Cole and Mourant et al., the subjects were driving freely. Thus, in the car following experiment the subjects may have been more concerned about maintaining longitudinal position (and therefore require more fixations to that region) than the free driving studies.

### 5.2.3. *Environmental Influences*

Visual behaviour has been reported to be influenced by changes in environmental workload (Faber & Gallagher, 1972; Senders et al., 1966; Senders et al., 1967). For example, driving through a complex junction or busy road may be considered to impose more workload on the driver than a quiet country drive. Experimental manipulation of the road environment has resulted in changes in the drivers' visual behaviour (Rockwell, 1972), that is:

> "Using spatial and temporal analysis it was found that drivers in open road driving at 65 mph on the same test section give essentially the same pattern of eye movements. Changing the test section landscape background introduced statistically significant changes in spatial density plots even though the road geometry and the task remained the same.", page 324.

The distribution of glances throughout the visual scene has been demonstrated to change as a consequence of the environment the driver is in. This was investigated by Hughes (1988). Drivers were observed to fixate for different percentages of the total driving time to different regions of the visual scene, see Table 5 - 2. Thus, the visual complexity of the environment appeared to influence the visual demand imposed on the driver and in turn the distribution of visual scanning employed. Hughes (1988) reports that as *visual complexity* increases glance frequency also increases, and glance duration decreases (from 440 ms in residential streets to 409 ms in shopping areas). This relationship can be visualised in Figure 5 - 1. It is unclear whether the more frequent glances are a result of increases in the complexity of the information available or the drivers' interest in the target.

**Table 5 - 2. Fixation percentage to different regions of the visual scene, from Hughes (1988)**

| Environment | Visual region | Percentage of fixations per region (%) |
|---|---|---|
| Residential streets | left of the road | 34 |
| Residential streets | roadway | 21 |
| Complex shopping area | left of the road | 45 |
| Complex shopping area | roadway | ? * |

* *Data not available from original reference.*

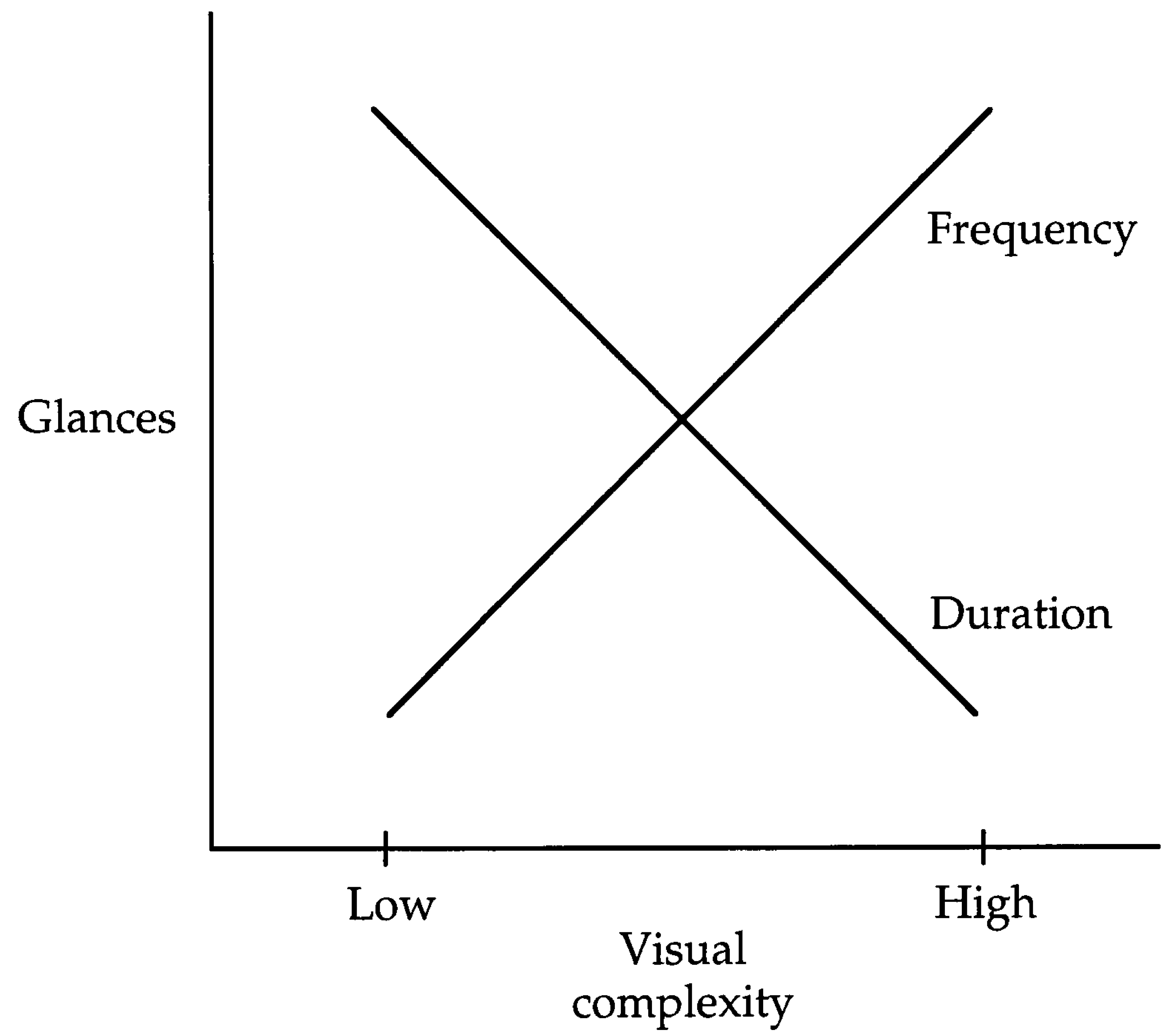



**Figure 5 - 1. Conceptual relationship between environmental complexity and glance duration and frequency**

In a different study, Hughes & Cole (1986) found that as roadway visual demand increases:

- fixations were further from the focus of expansion
- fixations were more frequently to the left of the road (where roadway information would typically be presented, while driving on the left in Australia)

The introduction of a primary tracking task led to:

- an increase in the number of central fixations
- an increase in the concentration of fixations closer to the focus of expansion
- during undirected (by experimenter) inspection of the driving scene, 18% of fixations were to the left of the road, in directed search for target stimuli, 41% of fixations occur to the left
- fixations to the focus of expansion were reduced, from 25% to 14% for the undirected and directed tasks respectively
- rate of changing fixation increased from 63.6/min to 116.4/min for the free search and directed search conditions.

Road type was also demonstrated (Spijkers, 1992) to affect the distribution of visual scanning. The study was primarily concerned with the effects of driving speed on drivers' visual scanning. However, the researchers report visual behaviour data relating to *urban freeway, urban street* and *rural road* driving. Mean fixation time and percentage of fixations data are presented for ease of comparison. Table 5 - 3 shows that a larger percentage of time was spent glancing to the roadway in the *rural road* condition than the other conditions. The experimenters suggest that this constitutes increased visual demand in the rural driving. However, it may be that the lack of attention grabbing distracters in the visually barren rural environment may have not provided demanding alternative targets for driver fixation.

**Table 5 - 3. Percentage of lane fixation time, speed limit 50 mph, from Spijkers (1992)**

| | Urban freeway | Urban street | Rural road |
|---|---|---|---|
| Mean | 70.79 | 71.25 | 78.75 |
| Standard deviation | 10.20 | 2.95 | 6.98 |

A greater percentage of *driving relevant* fixations occurred in the urban street condition, see Table 5 - 4. It is suggested that the finding was attributable to a large number of fixations categorised in the paper as *other traffic*.

**Table 5 - 4. Percentage of driving relevant fixations, speed limit 50 mph, from Spijkers (1992)**

| | Urban freeway | Urban street | Rural road |
|---|---|---|---|
| Mean | 3.15 | 7.38 | 2.95 |
| Standard deviation | 0.92 | 0.82 | 1.24 |

Non-driving relevant glances were consequently lower in the urban street drive than the other two conditions, see Table 5 - 5. Consideration of tables 5 - 4 and 5 - 5 suggests that the visual attention may have shifted from the driving relevant fixations and non-relevant fixations across the three conditions. For example, in both the urban freeway and rural road conditions the proportions of visual attention attributed to the driving relevant glances are similar, as are the non-driving relevant fixations. In the urban street condition the allocation of visual attention appears reversed, suggesting that the visual demands of this environment are very different to those imposed in the other conditions, that is, the environment required more visual attention to perform the driving task safely, therefore, less spare visual resource was available to attend to non-driving relevant fixations.

**Table 5 - 5. Percentage of driving irrelevant fixations, speed limit 50 mph, from Spijkers (1992)**

| | Urban freeway | Urban street | Rural road |
|---|---|---|---|
| Mean | 21.32 | 11.56 | 14.93 |
| Standard deviation | 9.97 | 2.18 | 9.02 |

### 5.2.4. *Aims*

This study aimed to determine normative data for driver visual behaviour and subjective mental workload. It also investigated visual and cognitive demands on the driver in different road environments (i.e., rural, urban and motorway driving).

## 5.3. Method

### 5.3.1. *Experimental Design*

The experiment had a one factor repeated measures design. The independent variable was the road type driven: rural, urban or motorway. Dependent variables were visual behaviour and subjective mental workload. Presentation of conditions was pseudo-randomised. It was anticipated that visual attentional demand and subjective mental workload would be highest in the urban condition. Further, it was anticipated that motorway driving would impose higher visual demand on the driver than the rural condition as a result of the higher speeds involved. Further information regarding methodological considerations is given in Appendix E.

### 5.3.2. *Procedure*

Each subject followed the protocol outlined below:

- an overview of the aims of the study was read to the subjects, see Appendix C - 1
- informed consent was obtained, see Appendix B - 1
- the subjects were given time to familiarise themselves with the experimental vehicle
- they drove the vehicle for 10 - 15 minutes prior to data collection commencing
- the experimental vehicle was driven by the subjects on a pre-determined route encompassing, rural, urban and motorway driving
- after each condition subjective mental workload was measured using adapted NASA R-TLX (Fairclough, 1991) examples of the assessment forms are shown in Appendix C - 2 and C - 3
- a post-experimental de-briefing was conducted, to answer questions and record comments.

### 5.3.3. *Equipment and Apparatus*

An instrumented vehicle (SAAB 9000i) was used for the experiment. The relevant features of the vehicle were:

- a portable video recorder
- two video cameras (one recording the driver's face, the other the forward scene)
- equipment to time code the video tape
- video mixing apparatus to combine the images from the two cameras with the time codes.

## 5.3.4. *Subjects*

Eight licensed drivers with greater than two years experience participated in the trial, six males and two females. Unfortunately, data for two of the males was lost due to equipment error. However, the subjective mental workload scores were available. The ages ranged from 21 to 28 years (mean = 24.67, SD = 2.42). All had normal or corrected to normal vision and were naive to the research aims.

## 5.3.5. *Video Tape Transcription*

The subject's visual behaviour was analysed post-hoc from video tape records. The visual scene was divided into five regions: forward view, driver mirror, right region, left region and into vehicle (encompassing the instrument panel), see figures 5 - 2 and 5 - 3.

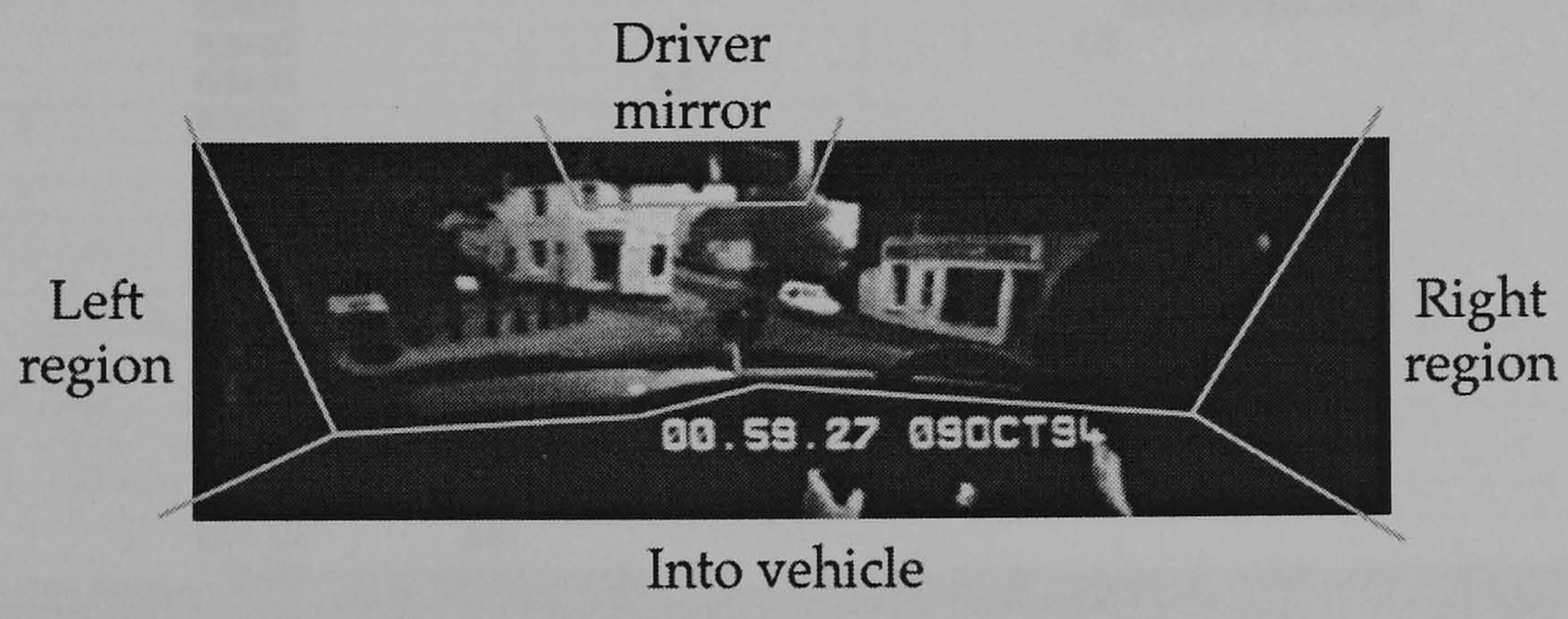
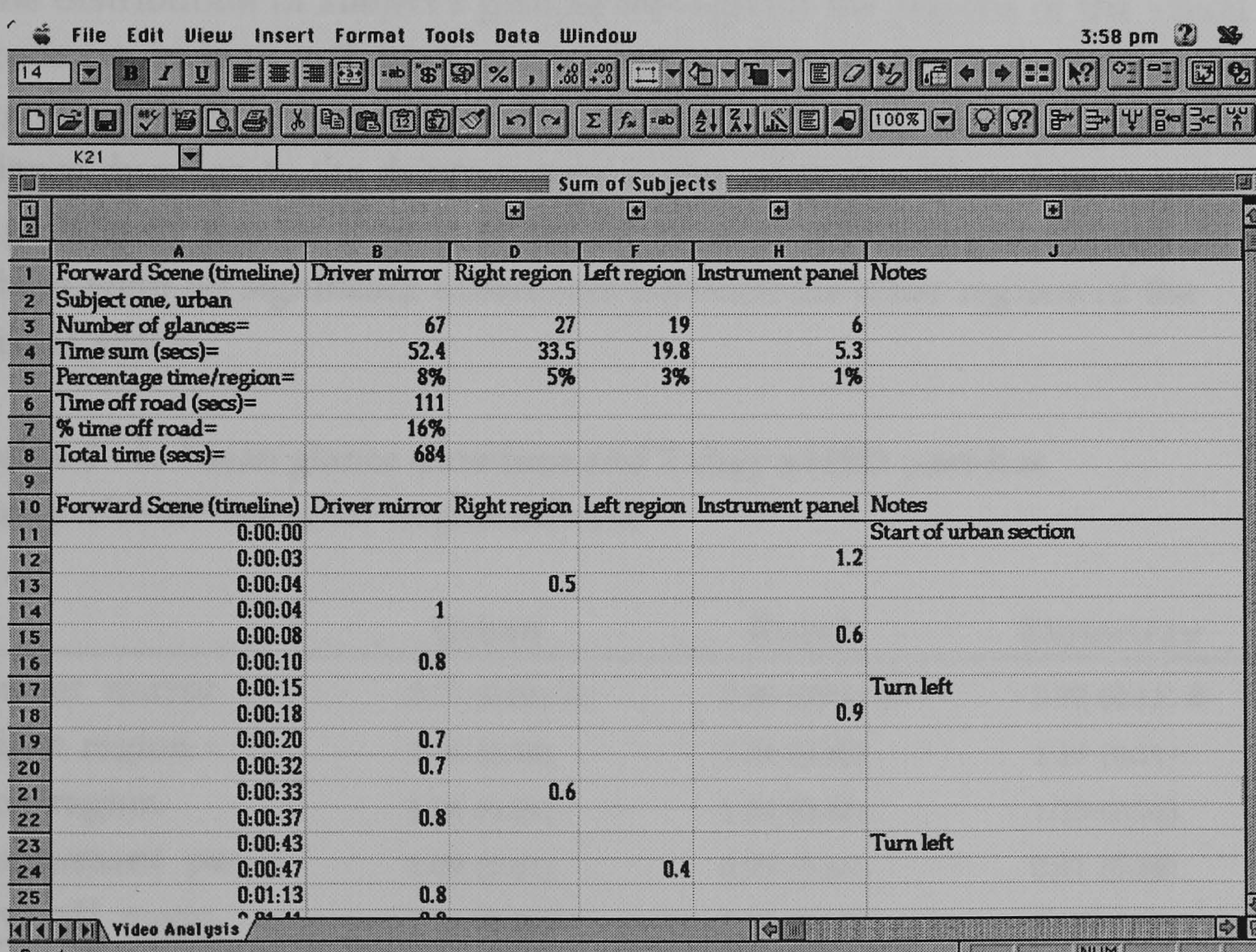



**Figure 5 - 2. Visual regions looking to the forward view**

Visual behaviour was transcribed in terms of the number and duration of visual deviations from the forward view. To illustrate further: the time in minutes and seconds when an event occurred, (for example, the subject looking to the interior driver mirror); the location of the view (interior driver mirror) and the duration of the glance (e.g., 0.8 secs) were recorded.

Resolution for the transcription of video data was restricted by the video recorder's twenty frames per second limit. Glance frequency per minute (gf/min) to each region was obtained and percentage time per region calculated, see Figure 5 - 4.


**Figure 5 - 3. The visual regions looking to the driver's face**




| | A | B | D | F | H | J |
|---|---|---|---|---|---|---|
| 1 | Forward Scene (timeline) | Driver mirror | Right region | Left region | Instrument panel | Notes |
| 2 | Subject one, urban | | | | | |
| 3 | Number of glances= | 67 | 27 | 19 | 6 | |
| 4 | Time sum (secs)= | 52.4 | 33.5 | 19.8 | 5.3 | |
| 5 | Percentage time/region= | 8% | 5% | 3% | 1% | |
| 6 | Time off road (secs)= | 111 | | | | |
| 7 | % time off road= | 16% | | | | |
| 8 | Total time (secs)= | 684 | | | | |
| 9 | | | | | | |
| 10 | Forward Scene (timeline) | Driver mirror | Right region | Left region | Instrument panel | Notes |
| 11 | 0:00:00 | | | | | Start of urban section |
| 12 | 0:00:03 | | | | 1.2 | |
| 13 | 0:00:04 | | 0.5 | | | |
| 14 | 0:00:04 | 1 | | | | |
| 15 | 0:00:08 | | | | 0.6 | |
| 16 | 0:00:10 | 0.8 | | | | |
| 17 | 0:00:15 | | | | | Turn left |
| 18 | 0:00:18 | | | | 0.9 | |
| 19 | 0:00:20 | 0.7 | | | | |
| 20 | 0:00:32 | 0.7 | | | | |
| 21 | 0:00:33 | | 0.6 | | | |
| 22 | 0:00:37 | 0.8 | | | | |
| 23 | 0:00:43 | | | | | Turn left |
| 24 | 0:00:47 | | | 0.4 | | |
| 25 | 0:01:13 | 0.8 | | | | |

**Figure 5 - 4. Sample video tape transcription**

## 5.3.6. *Experimental Route*

The route undertaken by the subjects was divided into three regions: rural, urban and motorway. Each section was balanced in terms of the time required to drive (approximately 15 minutes per region) and the order of presentation. The experiment involved one hour of driving per subject including the familiarisation and transfer sections. Peak travel periods were avoided to minimise traffic variability across trials.

## 5.4. Results

The results are presented in two sections: video analysis and subjective mental workload. Tukey's honestly significant difference (HSD) was used for post-hoc testing.

### *5.4.1. Video Analysis*

**Glance Duration**

The distribution of subject's glances throughout the regions of the visual scene can be seen in Table 5 - 6. Subjects' glances to the driver mirror were significantly different ($F\ (2,5) = 8.5$, $p < 0.01$). Post-hoc analysis revealed glance duration to the driver mirror in the urban condition was significantly shorter than in either the rural or motorway conditions. There were no significant differences between the other regions of the visual scene.

**Table 5 - 6. Mean glance durations and Tukey's HSD post-hoc comparisons* (secs, SD in parenthesis)**

| | Urban | Rural | Motorway |
|---|---|---|---|
| Driver mirror | 0.77 (0.03) A | 0.93 (0.01) B | 0.92 (0.11) B |
| Right region | 1.26 (0.14) | 1.36 (0.40) | 1.17 (0.11) |
| Left region | 1.34 (0.21) | 1.44 (0.32) | 1.20 (0.24) |
| Instrument panel | 1.09 (0.61) | 0.95 (0.16) | 0.91 (0.18) |
| Overall mean | 1.16 (0.19) | 1.17 (0.10) | 1.05 (0.14) |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05). For example, mean glance duration to the driver mirror was significantly lower in the urban condition than either the rural or motorway driving.*

**Glance Frequency per Minute**

The number of glances to the regions of the visual scene were significantly different for the right region ($F\ (2,5) = 6.373$, $p < 0.05$), left region ($F\ (2,5) = 5.374$, $p < 0.05$), instrument panel ($F\ (2,5) = 8.176$, $p < 0.01$) and the overall mean glance frequency (F (2,5) = 9.619, p < 0.005), see Table 5 - 7. Drivers glanced to the right significantly less frequently during the rural drive than either motorway or urban conditions. Subjects were found to glance more frequently to the left region during urban driving than in rural or motorway driving. In urban driving subjects' glance frequencies to the instrument panel were significantly lower than during motorway driving. However, there were no significant differences in the instrument panel glance frequencies between either: the rural and urban or the rural and motorway conditions. Analysis of the overall mean glance frequency revealed that subjects glanced away from the forward view significantly more often on the motorway than the rural drive.

**Table 5 - 7. Mean glance frequency per minute (gf/min) and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Urban | Rural | Motorway |
|---|---|---|---|
| Driver mirror | 3.06 (1.67) | 3.53 (2.47) | 5.47 (2.34) |
| Right region | 3.28 (0.74) A | 1.80 (0.58) B | 3.44 (1.10) A |
| Left region | 1.30 (0.27) A | 0.81 (0.43) B | 0.64 (0.32) B |
| Instrument panel | 0.36 (0.14) A | 0.79 (0.76) A & B | 1.49 (0.78) B |
| Overall mean | 2.01 (0.50) A & B | 1.76 (0.61) A | 2.74 (0.46) B |

* *Means with the same letter are not significantly different* ($\underline{\alpha}$ = 0.05).

**Percentage Time per Region**

The percentage of time allocated to the regions of the visual scene was significantly different for the forward view (F (2,5) = 8.789, p < 0.01), driver mirror (F (2,5) = 4.165, p < 0.05), left region (F (2,5) = 5.588, p < 0.05) and the instrument panel (F (2,5) = 5.909, p < 0.05) for all conditions, see Table 5 - 8. The percentage of time looking to the forward view was significantly greater in the rural condition when compared to motorway driving. Visual allocation to the driver mirror was found to be significantly different. However, the conservative nature of Tukey's HSD revealed no individual differences between means. Drivers' total percentage of time spent glancing to the left region was significantly higher during the urban condition than during motorway driving. In motorway driving subjects glanced to the instrument panel significantly more often than during urban driving. However, there were no significant differences in the percentage time looking to the instrument panel between either the rural and urban, or the rural and motorway conditions.

**Table 5 - 8. Mean percentage of time per region and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Urban (%) | Rural (%) | Motorway (%) |
|---|---|---|---|
| Forward view | 85.0 (3.2) A & B | 87.0 (3.2) A | 81.0 (3.3) B |
| Driver mirror | 4.0 (2.3) | 5.2 (2.6) | 8.2 (3.9) |
| Right region | 7.0 (2.1) | 4.0 (1.8) | 6.8 (2.3) |
| Left region | 3.0 (0.6) A | 2.3 (1.2) A & B | 1.3 (0.5) B |
| Instrument panel | 0.7 (0.5) A | 1.5 (1.4) A & B | 2.5 (1.5) B |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05).*

## 5.4.2. *Subjective Mental Workload*

The subjective mental workload ratings (NASA R-TLX) can be seen in Tables 5 - 9 and 5 - 10.

**Mean Mental Workload**

Mean mental workload was significantly different across the three conditions ($F(2,7) = 8.383$, $p < 0.005$). Post-hoc analysis revealed the urban driving imposed significantly greater mental workload than either the motorway or rural conditions.

**Table 5 - 9. Mean mental workload and Tukey's HSD post-hoc comparisons* (1-100, SD in parenthesis)**

| | Urban | Rural | Motorway |
|---|---|---|---|
| Mean mental workload | 44.13 (15.44) A | 29.00 (9.30) B | 33.13 (14.72) B |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05).*

**Component Mental Workload**

Component mental workload scores are shown in Table 5 -10. *Mental demand* ($F(2,7) = 4.488$, $p < 0.05$), *physical demand* ($F(2,7) = 8.454$, $p < 0.005$) and *time pressure* ($F(2,7) = 7.46$, $p < 0.005$) were significantly different in the experimental conditions. Subjects rated the driving task to be significantly more mentally demanding in the urban condition than the rural. Drivers stated that during the urban and motorway conditions they felt under significantly more time pressure to perform the driving task than the rural condition. The results also suggest significantly greater physical demand required to perform the task in the urban condition than either the rural or motorway driving.

**Table 5 - 10. Component mental workload and Tukey's HSD post-hoc comparisons* (1- 100, SD in parenthesis)**

| | Urban | Rural | Motorway |
|---|---|---|---|
| Mental demand | 57.00 (20.52) A | 34.88 (17.03) B | 45.75 (26.32) A & B |
| Mental effort | 58.88 (21.16) | 42.63 (17.46) | 46.00 (24.10) |
| Physical demand | 44.25 (19.54) A | 27.38 (13.56) B | 21.50 (14.33) B |
| Time pressure | 36.75 (16.11) A | 14.13 (5.96) B | 31.38 (16.60) A |
| Distraction | 29.75 (19.08) | 33.38 (22.41) | 24.25 (19.28) |
| Stress level | 38.25 (16.77) | 21.63 (12.52) | 29.75 (16.30) |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

## 5.5. Discussion

This experiment has attempted to establish some normative measures of driver visual behaviour and mental workload. Additionally, the affect of changes in the environment was considered for rural, urban and motorway driving.

Significant differences were established between the experimental conditions for the measures of visual behaviour and subjective mental workload. Glance durations to the driver mirror; glance frequency to the right & left regions and instrument panel; the percentage of time glancing to the forward view, driver mirror, left region and instrument panel were all significantly different. Mean subjective mental workload, mental demand, physical demand and time pressure were all significantly different across conditions.

### 5.5.1. *Rural Driving*

Rural driving in the U.K. involves negotiation of predominantly single lane roads, a de-restricted speed limit of 60 mph (97 kph) and a typically low traffic density. The driver may reasonably expect to encounter sharp turns and a wide variety of junction types. Subjects spent more time glancing to the forward view during rural driving (87%) than the motorway condition (81%). Rural driving may have provided less driving relevant visual distracters than motorway driving. Drivers could have been more able to concentrate on the forward view in this condition than during motorway driving where greater awareness of the surrounding traffic events is required (e.g., the vehicle must safely negotiate three lanes of traffic rather than one).

On average, subjects glanced to the right region (mirror and window) less frequently during rural driving (20 gf/min) than motorway (35.17 gf/min) or urban (38.5 gf/min) conditions. Urban driving was a more visually rich environment with respect to potential driving hazards than the rural condition. Increased right region checking in the urban environment may have been caused by more traffic at junctions than the rural drive. Hence, the delays to emerging traffic would require additional visual checking particularly from the right region (i.e., the immediate direction of oncoming traffic). Motorway driving requires right and left mirror and window checking prior to lane changing or overtaking manoeuvres. Drivers reported subjectively lower mental workload for the sub-scale *time pressure* during the rural condition. It is felt that the reduced density of other traffic related events may have been responsible for this finding.

### 5.5.2. *Motorway Driving*

The motorway network may be characterised as typically having three lanes, a speed limit of 70 mph (113 kph) and a high traffic density (dependent on the time of travel). The roads tend to have long gentle geometry requiring gradual steering adjustments. There are no roundabouts or traffic-light junctions, entry or exit is by slip road. Driver glance frequency may be considered as a measure of the perceived need to extract information from the environment. Subjects' average glance frequency was found to be higher during motorway driving (27.88 gf/min) than rural (18.95 gf/min). Thus, increased glance frequency during motorway driving may have reflected the greater complexity of the motorway visual environment and more demanding driving (i.e., the subjects felt the need to sample objects in their visual environment more frequently during the motorway condition than the rural).

Interestingly, the percentage of time glancing to the instrument panel was greater during motorway driving than urban. No significant difference was found between the time checking the instrument panel between the rural and motorway conditions. It may have been the driver's self-regulation of speed that was responsible for this behaviour. During rural driving maintenance of speed may be limited by the complexity of the road layout, forcing the driver to slow the vehicle to negotiate bends, etc. In urban driving the close proximity of junctions and the traffic density precludes high speeds. Hence, in both urban and rural driving speed is effectively regulated for the driver. During motorway driving the road layout encourages speed in excess of the regulated limit, traffic density permitting. It is therefore the responsibility the driver to maintain 70 mph (113 km). Consequently, without geographical restrictions the driver must sample the instrument panel more frequently to obtain the required information. The drivers may have been concentrating in the urban condition more than the others and therefore reluctant to glance to the instrument panel. Indeed, this hypothesis is supported by the significantly higher *mental demands* found in the urban condition.

### 5.5.3. *Urban Driving*

Towns and cities may include driving on from one to four or more lanes. In this study only urban roads with a single carriageway were used. The speed limit is 30 mph (48 kph) or 40 mph (64 kph) in some regions and traffic density is widely variable. Road geometry will also vary considerably with many types of road junction in use. The majority of the significant findings of this study relate to changes in driver visual behaviour and subjective mental workload during urban driving.

Subjects' glance durations to the driver mirror were significantly shorter in urban driving. This may have reflected the fact that in the urban environment hazards in the forward view were more frequent and the time to potential incident would be shorter (e.g., a dog or child running in front of the vehicle). The increased amount of hazards may have made drivers reluctant to glance away from the forward view for longer than absolutely necessary. Glances to the left region were more frequent during urban driving. This possibly reflected greater caution on the part of the driver when emerging from right turn junctions. Similarly, the percentage of time spent looking in the left region was significantly greater than during motorway driving. The number of times subjects checked the instrument panel during urban driving (0.36 gf/min) was significantly lower than during motorway driving (1.49 gf/min). The driver could have either been reluctant to glance away from the forward view in this complex environment or not require speedometer information as they were aware that they were not exceeding the speed limit.

Subjective assessment of mental workload supports the objective visual behaviour measures. Drivers found the urban condition more taxing than either the motorway or rural drives. Overall mean mental workload was significantly greater during urban driving (44.13) when compared to motorway (33.13) and rural driving (29.00). The subjects reported that the mental demand the driving task imposed was significantly higher during the urban drive than the rural. Similarly, they felt that they needed to expend more physical demand to perform the task during urban driving. This may have been manifested in a greater number of gear changes or clutch actuations to maintain a lower speed in traffic. It should be noted that at no time was traffic density high during urban driving (e.g., close to or at a standstill, for an extended period). Hughes & Cole (1986) report that driver visual and cognitive demands were higher during shopping centre driving relative to residential or arterial driving. Clearly, no direct comparison can be made between the studies but a broad similarity remains.

### 5.5.4. *Spare Visual Capacity*

Post-hoc video tape transcription provides general information regarding the location of driver fixations. Consequently, the technique cannot determine if the driver is glancing to a road sign (driving relevant) or an advertisement (driving irrelevant). The transcriber is unable to state the specific location of fixation, only the general direction of regard (i.e., forward view, left (mirror and window) & right (mirror and window) regions and the instrument panel). Spare visual capacity was suggested to be between 30% and 50% (Hughes & Cole, 1986) , and 30.2% (Mourant et al., 1970). Although not directly comparable, results from this study (percentage of time allocated to the forward view: urban 85%, rural 87%, and motorway 81%) suggest that the allocation is somewhat lower, more in line with the 90% of fixations being within ± 4° of the focus of expansion suggested by Rockwell (1972). It may be assumed that had the drivers been maximally visually loaded, or near maximally loaded, they would have reported higher subjective mental workload estimates of mental demand. It would also be expected that the proportion of visual allocation to the forward view would increase (Wierwille et al., 1988).

### 5.5.5. *Driver Visual Scanning*

Consideration of the experimental results suggests that although driver visual behaviour differences exist in the road environments considered, several general trends emerged. Mean glance duration was reasonably consistent, varying from 1.05 seconds to 1.17 seconds across all conditions. The distribution of mean glance durations across the regions of the visual scene tends to be just below one second for *vehicle in motion* regions (driver mirror and instrument panel) and just above one second for *vehicle stationary* regions (right and left mirrors and windows). Glance frequency appears to be more influenced by changes in the driving environment, increasing with the complexity of the visual environment/task. Spijkers' (1992) findings (percentage of time fixating the lane) support the trend identified in this study. They were lowest in urban freeway (motorway in this study); higher in urban rural (urban in this study) and highest in rural (rural in this study) road environments.

The study was limited in several respects. The results should be treated tentatively as the subject group was small, with the corresponding effect on the power of statistical tests employed (visual behaviour n = 6, subjective mental workload, n = 8). The results would be most appropriately considered as an informative exploration of visual and mental workload to establish general trends relating to the distribution of the features of driver visual behaviour. There were inherent differences in the length and geometry of the road types. For example, the motorway contained no roundabouts. While these differences were of interest, it would be beneficial to isolate road features and compare these more directly (i.e., straight sections of road, overtaking manoeuvres, bends, merge lanes, etc.) for the three conditions. However, the findings of this study suggest that the visual demands associated with road type and environment do differ and therefore warrant further investigation.

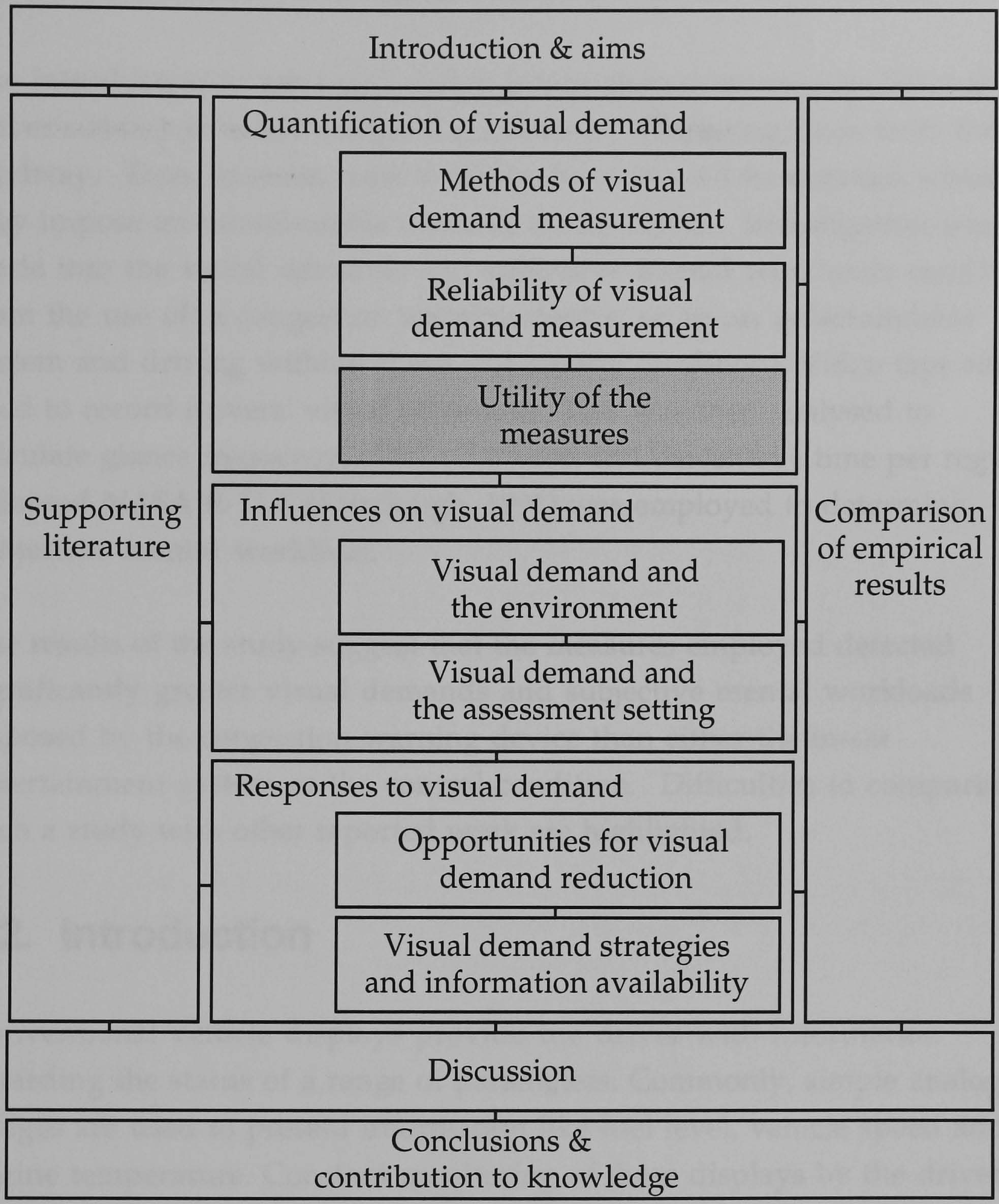
## 5.6. Chapter Conclusions

The chapter has described an experimental investigation into the visual and cognitive demands imposed in three environments: rural, urban and motorway driving. The study established normative data regarding driver behaviour in the experimental conditions. Further, significant differences were determined between the environments. Generally, urban driving was found to impose greater visual and cognitive demands on the driver than rural or motorway driving, although other condition specific effects were observed. Drivers exhibited spare visual capacity. The findings suggest that results from experimental work may not be easily generalised to all road types as the visual demand inherent in a particular road may be significantly greater than another. Selection of experimental routes should therefore be carefully considered to encompass a broad range of road types and junctions.

# Chapter 6

# Utility of Metrics for the Evaluation of Driver Information Systems

# Utility of Metrics for the Evaluation of Driver Information Systems




## 6.1. Chapter Summary

This chapter discusses some of the specific issues surrounding the use of visual demand measures for the evaluation of driver information systems in a road trial setting[1]. The study was conceived to investigate the

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[1] It is based on the experimental work presented at the 1995 Vision in Vehicles conference in Derby, United Kingdom (Lansdown & Fowkes, in press)

advantages and limitations of visual behaviour metrics that can be calculated from video tape data. It explores their value in differentiating between different levels of imposed visual demand.

The introduction of advanced driver information systems may affect the driver's ability to safely control the vehicle by distracting them from the roadway. These systems must therefore be evaluated to ascertain whether they impose an unreasonable demand on the driver. Investigation was made into the visual demands and subjective mental workloads resulting from the use of: a congestion warning device; an in-car entertainment system and driving without these (the control condition). Video tape was used to record drivers' visual behaviour This was then analysed to calculate glance frequency, glance duration and percentage time per region. Adapted NASA R-TLX (Fairclough, 1991) was employed to determine subjective mental workload.

The results of the study suggest that the measures employed detected significantly greater visual demands and subjective mental workloads imposed by the congestion warning device than either the in-car entertainment system or the control condition. Difficulties in comparing such a study with other reported work are highlighted.

## 6.2. Introduction

Conventional vehicle displays provide the driver with information regarding the status of a range of parameters. Commonly, simple analogue gauges are used to present information like fuel level, vehicle speed and engine temperature. Constant monitoring of these displays by the driver is not generally required for safe control of the vehicle. Indeed, some vehicle functions (e.g., coolant temperature) commonly have additional warnings that indicate only when a hazardous condition is present.

However, recent developments in advanced electronic and communication systems make possible the introduction into the vehicle of information displays of a much more complex nature. For example, route guidance, with many prototype systems produced in recent years. These systems reflect a wide range of approaches to information presentation. Some have used relatively simple symbolic, static information displays, whilst others have used multi-coloured scrolling maps. The crucial question raised by these concepts is whether the introduction of the information displays may distract the driver from his/her primary tasks (i.e., maintaining safe control of the vehicle). Research into the impact of new information systems in actual and simulated environments has been the subject of considerable interest. Unfortunately, different methodologies and aims have been used and thus the results are difficult to compare meaningfully. The need for the generation of more analogous results from experimental work was highlighted by Fowkes & Lansdown (in press). For example, some researchers have reported longer glance durations to the forward view during increased visual demands (Wierwille et al., 1988); other results describe the same visual behaviour by stating that shorter glances are observed to the information system (Lansdown & Fowkes, in press). Common terms of reference are required in visual demand research.

This chapter considers the relative impact of the operation of a congestion warning device or an in-car entertainment system, in terms of visual demands while driving. This is compared with the control condition of driving without an information system. The in-car entertainment system and congestion warning device were used as generic examples of systems that may impose additional demands on the driver, over and above the normal task. The systems were not selected for evaluation but as mechanisms to impose increasing visual demands on the driver.

### 6.2.1. *Aims*

This experimental investigation aimed to determine the utility of visual and cognitive metrics for the quantification of increased visual demand. Further, to establish which measures were sensitive to the introduction of information systems into vehicles and the increased demands they may impose on the driver.

# 6.3. Method

## 6.3.1. *Experimental Design*

The experiment had a repeated measures design with three levels: in-car entertainment system, congestion warning device and control condition. The experimental route was approximately 21 km (13 mi) in length. It encompassed approximately 10 km (6.2 mi) of motorway, 5.5 km (3.4 mi) of rural and 5.5 km (3.4 mi) of urban driving. There were two roundabouts, five left and three right turns. A typical completion time for the route was nineteen minutes. Further information regarding methodological considerations is given in Appendix E.

The independent variable was the type of task performed. The dependent variables were the visual behaviour of the drivers and their subjective mental workload ratings.

## 6.3.2. *Procedure*

A description of the study was read to the subjects, consent obtained (a map of the experimental route was shown) and any questions answered. A short training exercise was conducted to ensure the subjects could operate both the in-car entertainment system and the congestion warning device. They were shown how to perform each of the experimental tasks and were tested for proficiency. Further instructions were given if necessary. The subjects were re-tested until they could competently perform the tasks with the vehicle stationary. The subjects drove the experimental vehicle for approximately fifteen minutes to familiarise themselves with its characteristics. Pre-test levels of subjective mental workload were assessed using adapted NASA R-TLX (Fairclough, 1991).

All subjects drove the route three times, and the order of presentation was counter-balanced across conditions. The subjects were given navigational information by the experimenter and at specific points on the route the experimenter asked the subject to either: obtain information from the congestion warning device or, perform an activity using the in-car entertainment system, see Figure 6 - 1. During each experimental condition the subjects completed six tasks, two at each of three task complexities. It was stressed by the experimenter that the tasks should be performed "in your own time" and only "when you are sure it is safe to do so". The classification of the experimental tasks can be seen in Table 6 - 1. Mental workload measures were obtained after each condition. At the end of the experiment a questionnaire was administered which established subjective opinions and background information.

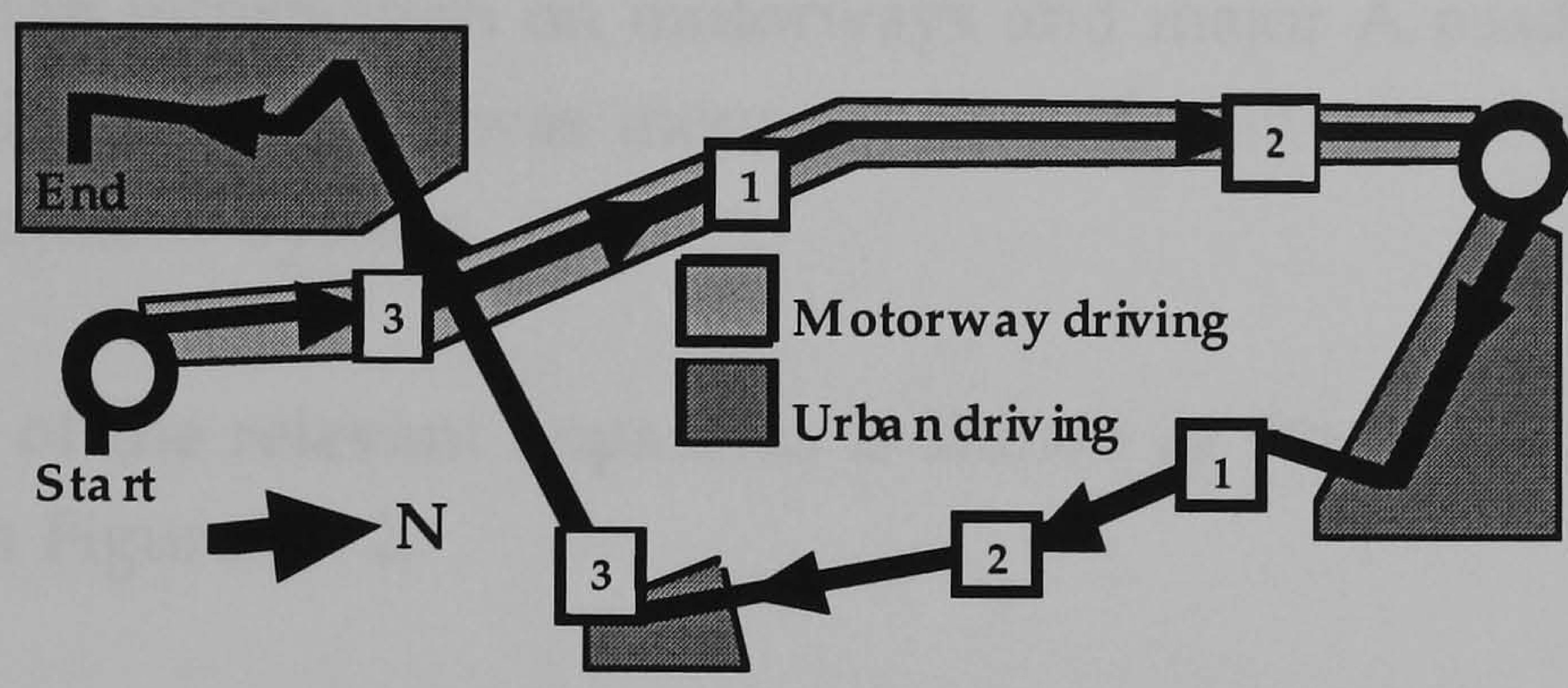



**Figure 6 - 1. Schematic diagram of the experimental route showing position and complexity of the experimental tasks**

**Table 6 - 1. Classification of experimental tasks**

| Complexity | Control | In-car entertainment system | Congestion warning device |
|---|---|---|---|
| Lowest (no control actuation required). | No task. | Determine the tuned frequency of the radio. | Determine whether congestion exists (yes/no) on a specific road. |
| Intermediate (double control actuation required). | No task. | Scroll through single button pre-set station selector to a specified station. | Determine the direction of congestion on a specific road. |
| Highest (treble control actuation required). | No task. | Tune the radio to a specified station using the manual tune. | Determine the speed and direction of congestion on a specific road. |

### 6.3.3. *Equipment and Apparatus*

The following apparatus was used in the experiment:

- An instrumented vehicle (SAAB 9000i), see Chapter 5.
- a standard manufacturer installed in-car entertainment system, located in a central position.
- a congestion warning device, providing the driver with route congestion information on motorways and major A roads to assist route planning. This was mounted immediately above the in-car entertainment system.

The position of the relevant apparatus is shown in the annotated video tape image in Figure 6 - 2.

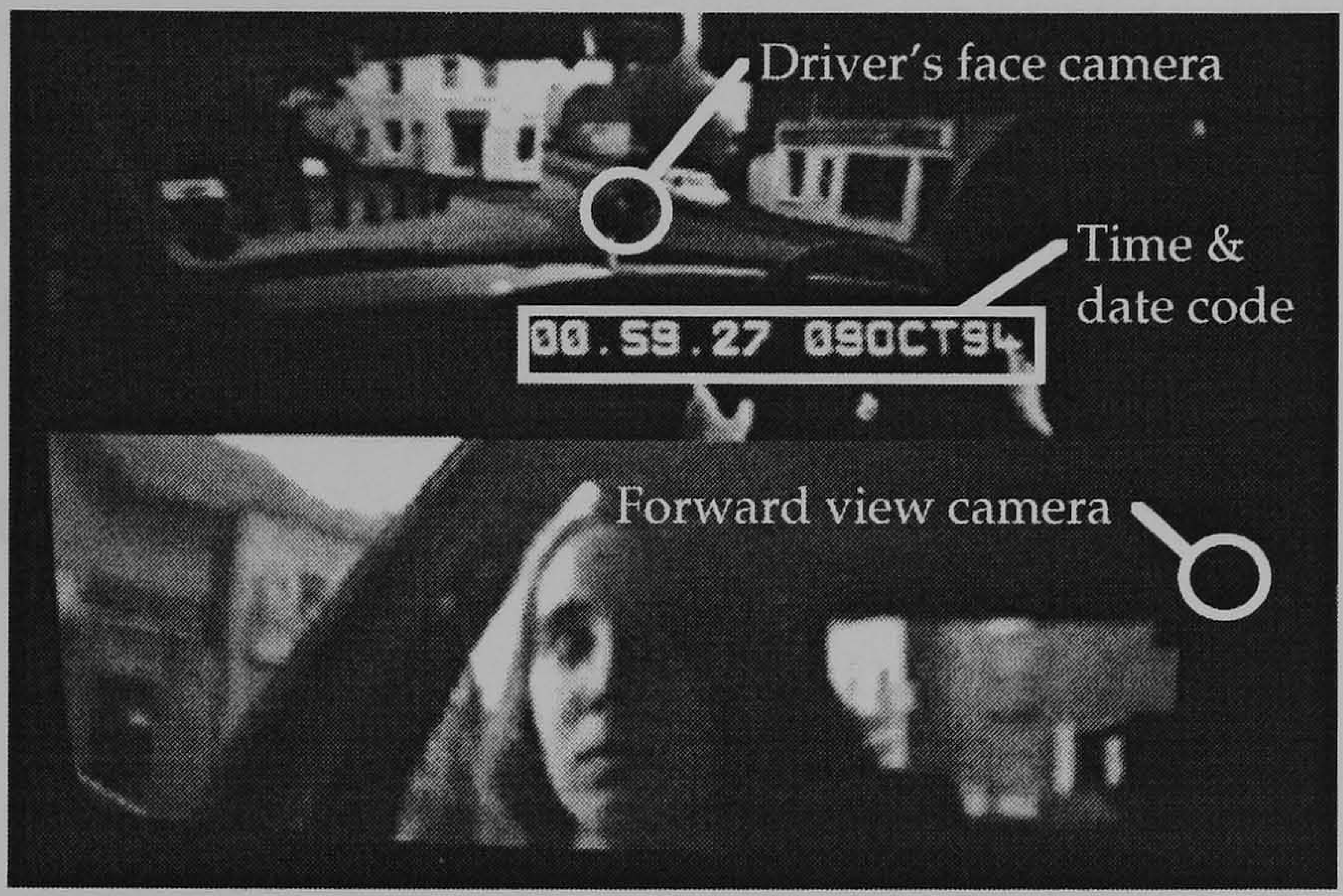



**Figure 6 - 2. Video image indicating relevant equipment**

### 6.3.4. *Subjects*

Eighteen subjects took part in the experiment, ten were male. Subjects' ages ranged from 21 years to 36 years, with a mean of 27 years. All possessed full U.K. driving licences (for more than two years) and had normal or corrected to normal vision.

### 6.3.5. *Video Tape Transcription*

Video tape records of the driver's face and forward view were analysed manually after the trial by subjective analysis, see Chapter 4. The glance frequencies and glance durations (minimum classification duration = 0.5 sec) were transcribed by hand. Visual behaviour was classified into the following regions: driver's mirror (or ceiling of the vehicle), left region (window and mirror), right region (window and mirror), instrument panel (and/or glances into the vehicle) and the information system (congestion warning device or in-car entertainment system). The pilot study identified the classification regions were large enough not to require individual calibration for each subject. The underlying assumption of the analysis was that glances away from the forward view will result in increased reaction time to a potential hazard. As a consequence the elapsed time and duration of glances away from the forward view were recorded. For example, at ten minutes and fifty six seconds into the trial, the driver glanced to the congestion warning device for 1.5 secs, followed by a 0.5 sec glance to the driver mirror. Specific start and stop points were identified for the route to ensure consistent data analysis. The raw data were recorded onto a spreadsheet for subsequent analysis.

## 6.4. Results

### 6.4.1. *Time to Complete Route*

Mean completion time for the control condition was 18 mins 49 secs (SD = 58.81 secs), 18 mins 56 secs (SD = 1:34.7 secs) for the in-car entertainment system and 19 mins 10 secs (SD = 1:04.8 secs) for the congestion warning device. There were no significant differences between the time to complete the three conditions.

### 6.4.2. *Subjective Mental Workload*

The imposed mean mental workload was shown to be significantly different between all conditions ($F (2,17) = 29.29$, $p < 0.001$). These results can be seen in Table 6- 2. The congestion warning device imposed significantly greater subjective mental workload than the other conditions for the sub-scale workload elements: *Mental Demand, Mental Effort, Time Pressure, Distraction* and *Stress Level.*

**Table 6 - 2. Component mental workload and Tukey's HSD post-hoc comparisons* (1-100, SD in parenthesis)**

| | Control | In-car entertainment system | Congestion warning device |
|---|---|---|---|
| Mental demand | 32.6 (17.4) A | 40.6 (19.1) A | 64.7 (23.2) B |
| Mental effort | 32.6 (19.8) A | 45.5 (23.7) A | 69.0 (21.7) B |
| Physical demand | 17.6 (13.2) A | 29.3 (24.0) A & B | 40.4 (26.3) B |
| Time pressure | 19.2 (15.1) A | 27.9 (22.4) A | 39.9 (26.0) B |
| Distraction | 21.4 (19.1) A | 46.9 (22.3) B | 71.8 (26.6) C |
| Stress level | 20.4 (15.6) A | 35.7 (20.8) B | 51.8 (23.1) C |
| Mean mental workload | 24.0 (13.6) A | 37.7 (18.6) B | 56.3 (18.7) C |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

## 6.4.3. *Glance Frequency per Minute*

Subjects' glance frequency per minute (gf/min) to the information systems ($F (2,17) = 35.228$, $p < 0.0001$) and overall mean ($F (2,17) = 49.336$, $p < 0.0001$) were highly significantly different, see Table 6 - 3. The number of glances to the congestion warning device was significantly higher than either the in-car entertainment system or the control. Subjects glanced significantly more frequently during the congestion warning device condition than the in-car entertainment system condition; which was also glanced at significantly more frequently than the control. There were no significant differences in glance frequency to the other regions of the visual scene.

## 6.4.4. *Glance Duration*

The duration of the subjects' glances to the information systems was also significantly different ($F (2,17) = 49.46$, $p < 0.0001$), see Table 6- 4. Mean glance duration to each of the information systems was significantly different with the longest glance durations to the congestion warning device. No effects were found for glance durations to the other regions of the visual scene.

**Table 6 - 3. Glance frequency per minute (gf/min) and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control | In-car entertainment system | Congestion warning device |
|---|---|---|---|
| Driver mirror | 5.26 (2.44) | 4.95 (1.79) | 4.88 (1.85) |
| Right region | 2.14 (0.90) | 2.23 (0.70) | 2.17 (0.78) |
| Left region | 1.21 (0.77) | 0.98 (0.69) | 1.07 (0.63) |
| Instrument panel | 1.32 (0.86) | 1.30 (0.77) | 1.11 (0.62) |
| Information system** | 2.48 (0.66) A | 2.06 (0.72) A | 4.94 (1.58) B |
| Mean | 2.02 (0.54) A | 2.41 (0.52) B | 2.83 (0.61) C |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

** *The control was calculated from the mean of the glances to all the other regions of the visual scene (i.e., glances to the left and right mirrors and windows, the driver mirror and instrument panel).*

**Table 6 - 4. Mean glance duration and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control | In-car entertainment system | Congestion warning device |
|---|---|---|---|
| Driver mirror | 0.54 (0.06) | 0.53 (0.03) | 0.53 (0.03) |
| Right region | 0.82 (0.21) | 0.85 (0.24) | 0.83 (0.28) |
| Left region | 0.64 (0.10) | 0.66 (0.15) | 0.65 (0.17) |
| Instrument panel | 0.53 (0.06) | 0.56 (0.07) | 0.56 (0.07) |
| Information system** | 0.63 (0.06) A | 0.88 (0.13) B | 1.07 (0.20) C |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

** *The control was calculated from the mean of the glances to all the other regions of the visual scene (i.e., glances to the left and right mirrors and windows, the driver mirror and instrument panel).*

## 6.4.5. *Percentage Time per Region*

The percentage of time the subjects spent looking away from the forward scene ($F(2,17) = 77.09$, $p < 0.0001$) and to the information systems was ($F(2,17) = 65.16$, $p < 0.0001$) highly significantly different, see Table 6 - 5. The total time allocated to the congestion warning device was significantly greater than in the in-car entertainment system or the control condition. Correspondingly, the total time to the forward view was significantly lower in the congestion warning device condition than either of the other two conditions.

**Table 6 - 5. Percentage time per region and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control (%) | In-car entertainment system (%) | Congestion warning device (%) |
|---|---|---|---|
| Driver mirror | 4.6 (2.2) | 4.7 (2.1) | 4.3 (1.4) |
| Right region | 2.8 (1.1) | 3.1 (0.9) | 2.7 (1.0) |
| Left region | 1.3 (0.8) | 1.2 (1.1) | 1.2 (0.9) |
| Instrument panel | 1.2 (1.0) | 1.3 (0.8) | 1.0 (0.5) |
| Information system | 2.5 (0.7) A | 3.8 (1.3) A | 8.6 (2.7) B |
| Forward view | 89.8 (2.6) A | 86.1 (3.2) B | 82.1 (3.6) C |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

## 6.4.6. *Long Glances*

The percentage distribution of long glances is shown in Table 6 - 6. It can be seen that high percentages of long glances occur when using the in-car entertainment system and congestion warning device with respect to the control. The control condition is calculated from the subjects' glances to the driver mirror and instument panel. The glances to the left and right regions were excluded because of a number of *long safe* glances which would confound the results (i.e., when the vehicle was stationary at a junction and in no additional danger as a consequence of extended glances away from the forward view).

**Table 6 - 6. Percentage of long duration glances**

| Time (secs) | Control (%, n=2244) | In-car entertainment system (%, n=881) | Congestion warning device (%, n=1686) |
|---|---|---|---|
| ≥ 1.0 | 3.88 | 58.12 | 68.68 |
| ≥ 1.5 | 1.02 | 11.92 | 24.61 |
| ≥ 2.0 | 0.58 | 4.65 | 12.10 |
| ≥ 2.5 | 0.36 | 0.57 | 2.19 |

## 6.5. Discussion

The main aim of this study was to determine whether the measures discriminated between the experimental conditions: control, in-car entertainment system and congestion warning device. This would provide information on their utility for information system assessment. The measures used demonstrated the congestion warning device consistently imposed a significantly greater demand on the driver's visual resources and mental workload than the in-car entertainment system and/or the control. The in-car entertainment system was also observed to impose significantly greater demands than the control. The results from the individual measures and the difficulty in comparing these with driver safety are discussed below.

### 6.5.1. *Subjective Mental Workload*

The subjective assessment of driver workload using the adapted NASA R-TLX gives a valuable insight into their perceived workloads. The congestion warning device imposed a significantly greater overall mental workload on the subjects than did the in-car entertainment system or just driving (the control). Other researchers have shown differences between information systems (e.g., Fairclough & Parkes, 1990). However, these differences have not been considered in context with normal driving. That is, the relative merits of two or more systems are assessed but the impact of the information system over and above the demands of normal driving have not been determined. It is particularly interesting that use of the in-car entertainment system was shown to impose significantly greater subjective mental workloads than the control. The result may have occurred as a consequence of the experimental design. Attempts were made to control the number of control/display interactions required to perform the tasks using the in-car entertainment system and congestion warning device. Thus, tasks performed in the conditions were contrived to equalise the demands imposed by the two information systems relative to the control condition. Therefore, subjects may have been using the in-car entertainment system more frequently than under more *normal* conditions. It was hoped that controlling the required interactions in this manner would identify visual and cognitive distraction issues attributable to differences in the information systems and not the task complexity.

### 6.5.2. *Data Analysis*

The analysis of visual behaviour from video tape evidence can be a lengthy and laborious process. Using a minimum glance duration of a 0.5 sec, analysis was shown to take typically two to three working days (15-22 hours) for one hour of video tape (see Chapter 4). Increasing the resolution with which the video tapes are examined will inevitably extend the time required for analysis of the data (e.g., using a minimum glance duration of 0.01 secs rather than 0.5 secs). However, it is questionable what further gains in fidelity may be had from such data (see Chapter 4). For example, a glance duration interpreted as either 4.5 seconds or 4.61 seconds may still be judged to be unacceptably long. Thus, a minimum glance duration resolution of 0.5 secs provides the important information regarding the distribution of potentially unsafe glances without compromising the validity of the data collection technique.

### 6.5.3. *Glance Frequency*

Glance frequency has been used as a measure which reflects the difficulty of information uptake for the driver (Wierwille, 1993). It has been applied to both the glances to specific regions of the driver's field of view and the total number of glances away from the forward view. Whether glance frequency is best applied as a measure of a *task performance* (e.g., how many glances occurred during changing of a cassette tape), or over the *entire experimental period* (e.g., how many glances occurred during the whole condition) remains unclear. This experiment employed the latter approach with the rationale that if significantly different results could be obtained with the junction activity included, results would certainly be significant if data were filtered. Junctions (as has been stated previously) may entail a number of glances of extended frequency or duration which could skew some measures of central tendency (e.g., the mean). While the *task performance* approach is certainly less labour intensive, it raises uncomfortable questions regarding the points at which the task is to be considered started or stopped. The issue would become particularly salient for route guidance tasks (which present information when approaching junctions) where extended left and right scanning could be confused with normal visual checking. *Data slicing* makes it impossible to compare experimental data across studies without rigorous specification of inclusion or exclusion criterion. For example, a task may be specified to begin immediately after auditory instructions have been given to subjects and end when the activity is completed. It may be unclear how data are managed when subjects fail to successfully perform the activity. The glance frequency per minute results reported here represent a relative measure of increased visual demand (over and above normal driving, the control) and as such can only broadly be compared with previously published research.

It has been suggested that drivers will not gaze at an information system for extended periods (Rockwell, 1988; Wierwille, 1993a). They are presumed to increase the number of glances to a display rather than the duration of glances (Wierwille, 1993a). The results in this study would support this assumption to some degree in that the frequency of glances to the congestion warning device was shown to be significantly greater than to the in-car entertainment system or the control condition. While there can be little doubt that glance frequency will differentiate between a poor and well designed information system, it cannot be assumed that a high glance frequency (per specific interaction or entire experimental condition) represents potentially hazardous driver information system use. The driver may be sensibly deploying visual resources in response to the immediate traffic environment.

### 6.5.4. *Glance Duration*

It is assumed that extended glances away from the forward view are associated with potential increased reaction time to a hazard. Therefore, driver information systems that encourage extended glances during use may result in a increase in distraction. This study demonstrates that drivers' mean glance durations were significantly longer when using the congestion warning device (1.07 secs) than the in-car entertainment system (0.88 secs) or the control (0.63 secs). The experimental results can be seen to be within the range of glance durations obtained by the previous studies (0.32 secs to 1.80 secs), see Table 2 - 2. However, only a general comparison can be made as a consequence of the individual differences between the studies (i.e., the experimenters were investigating different systems and/or environments). The interested reader is referred to Chapter 2 for further discussion of these studies.

For evaluation purposes Zwahlen et al. (1988) suggested a maximum glance duration of two seconds for the safe use of driver information systems. Results from this study showed that 12.1% of glances to the congestion warning device were longer than this two second criterion, see Table 6 - 6. Mean glance durations of more than two seconds were greater to the in-car entertainment system than the control, 4.7% of glances and 0.6% respectively. Similarly, one may not directly compare results to the two second criterion as the paper by Zwahlen et al. (1987) tentatively suggested a mean glance duration of two seconds in any given *interaction period* (i.e., task performance) not the entire experimental condition, see Figure 2 - 9. It does however, provide a criterion for the relative increase in visual demand across conditions. It is also interesting to compare the experimental results of Fairclough and Parkes (1990). They aimed to distinguish between map and text based route guidance information. It is apparent that the experimental tasks were quite different from this study. However, 18% of the glances to a map and 8% to a symbol and voice system were longer than two seconds. Unfortunately no representative control was included in the paper. The lack of a commonly specified format for the outcomes of visual demand experimentation again precludes anything other than speculative comparison of results. It is a matter for debate whether the use of an in-car entertainment system or the congestion warning device in this study (which is licensed for use on U.K. roads) represents an acceptable level of visual demand within the driving context. Fairclough and Parkes (1990) offer the map as a presumed unacceptable system for comparison with the text based system as the acceptable alternative.

Criterion based rules, like the *two seconds* example advocated by Zwahlen et al. (1987) are difficult to apply in the constantly changing driving environment. An experienced driver, intelligently allocating resources to an information system in suitable environmental conditions, may quite safely employ two second glances. However, an inexperienced driver using a system which demands visual attention at a specific time, potentially the very time at which s/he should be attending to the roadway, may result in a one second glance compromising road safety. No conclusive research has been found which relates the *context dependence* of visual behaviour. Subjects in this study were observed to engage in extended glance durations in some inappropriate circumstances, contrary to the suggested visual behaviour proposed by some driver models (Senders et al., 1967; Wierwille, 1993), this issue is investigated in more detail in Chapter 9. It is suggested that the models need to be modified to consider these visual demand induced errors.

### 6.5.5. *Percentage of Time per Region*

The percentage of time glancing to the forward view provides a broad index of the overall impact of introducing a driver information system into the vehicle. It may be difficult to define the task completion times as a function of the system under evaluation (i.e., the interaction time when using a route guidance system may be quite different to that required for intelligent autonomous cruise control systems). As a consequence, the design guide suggested by Zwahlen et al. (1987) may be limited in this respect. A calculation of forward view percentage time in this study demonstrated the same trend illustrated by the other measures. That is, while using the congestion warning device subjects looked to the forward view for significantly less time (82.1%) than during the in-car entertainment system condition, (84.1%) and in the control (89.8%). The percentage time to the forward view will not provide information regarding the micro issues of driver-system interaction (e.g., critical incident analysis at junctions), but it does give insight into the influence of an information system on visual demand at a macro level.

### 6.5.6. *Comparison of Measures*

It is interesting to consider the similarities between the mental workload and the visual behaviour results. The same significant trend was obtained for mean mental workload and glance frequency, glance duration and percentage time to the information systems. If the same relationships could be validated in different driving scenarios, with a number of information systems, the additional value of visual behaviour measures may be questioned. That is, if subjective mental workload measures reveal high demands imposed on the driver by an information system, recording and analysing of visual behaviour may be expensive and redundant. It would also be important to consider systems in which the driver's control over the availability and presentation of information is different. To illustrate, the congestion warning device used in this study essentially provided the subjects with information which they could choose to ignore. However, a route guidance system would require a response from the drivers within a fixed time frame. This issue is explored in Chapter 9.

The study had several limitations. The subjects should be considered novice users of the congestion warning device even though a training and testing regime was employed in the experiment. Therefore, while their interactions with the system would be representative of the demands initially imposed on users, the sensitivity of the metrics to the introductions of such devices may have been greater than should be expected with expert users. Similarly, the demands imposed by devices like the congestion warning system could reasonably be expected to reduce with regular use. It was unfortunate that the vehicle speed could not be recorded during the experimental trial. It would have been interesting to compare driving performance data with the visual and cognitive measures collected to determine changes in the quality of driving performance as a consequence of increased demand from an information system.

## 6.6. Chapter Conclusions

This research builds on the experimental work undertaken in Chapter 5 relating to driver visual demand and the changes associated with road type. It considered the benefits and limitations of several visual behaviour measures for the evaluation of visual demand, namely, glance frequency, glance duration, percentage time per region and extended glance duration. It aimed to determine the sensitivity of these measures to differences in the level of imposed visual demand. The research established:

- all of the visual measures adopted gave the same results (i.e., use of a congestion warning device imposed significantly greater visual demand than use of an in-car entertainment system or normal driving)

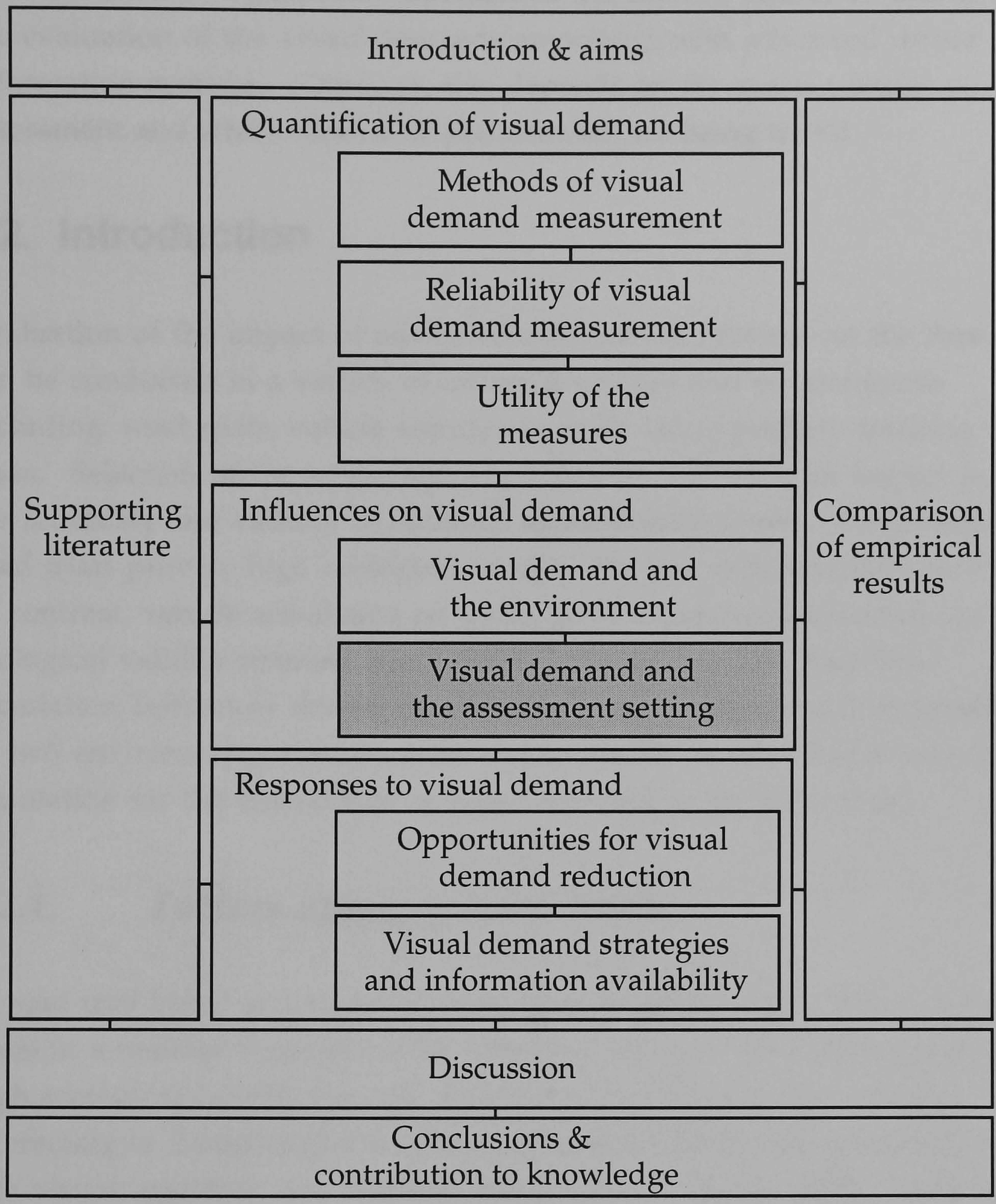
- the mental workload measures demonstrated the same consistent relationship as the visual behaviour measures
- mental workload measures may offer a more cost-effective screening tool for the detection of unacceptable driver information systems
- visual behaviour measures were sensitive enough to differentiate between the congestion warning device and the in-car entertainment system which was significantly more demanding of the visual resources than normal driving.

It has identified restrictions in the application of visual demand metrics for the assessment of the safety of driver visual behaviour. The study highlighted the value of each calculated metric to provide insight into the differing aspects of the driver's interaction with advanced information system.

# Chapter 7

# Driving Simulation for the Evaluation of Information Systems

# Driving Simulation for the Evaluation of Information Systems




## 7.1. Chapter Summary

Visual demands are investigated in this Chapter by considering the relationship between the assessment environment (road or simulator) and its influence on driver visual scanning during information system use. It discusses the value of conducting trials in a driving simulator for the assessment of driver information systems[1]. Measures of driver visual behaviour, subjective mental workload and vehicle performance data were collected during the study. The results suggest that the mid-fidelity driving simulator sufficiently represented the driving task to be usable for the evaluation of the visual demands associated with advanced driver information systems. Although, this depends on the system under assessment and which aspects of performance are being tested.

## 7.2. Introduction

Evaluation of the impact of advanced information systems on the driver can be conducted in a variety of different settings and environments including: road trials, vehicle simulation or by using primary tracking tasks. Selection of the evaluation environment will have an impact in the reliability and validity of obtained experimental results. For example, road trials provide high ecological validity but low experimental control. In contrast, vehicle simulation provides good experimental control but its ecological validity remains questionable because it is uncertain how simulation influences driver visual behaviour. Experimental comparison of two environments would enable the suitability and/or limitations of simulation for the assessment of visual demand to be determined.

### 7.2.1. *Factors Affecting Road Trials*

In road trial based experimental work subjects interact with other road users in a manner consistent with everyday driving. This method retains high ecological validity (i.e., the driver is in control of a real vehicle, interacting in a meaningful way with other road users and immersed in a rich visual, auditory, and cultural environment). The benefits of *real* road trial based experimental work inevitably carry associated costs. Control over extraneous variables is limited as with any non-laboratory based experimental work. Some of the factors which may influence road trial work include: traffic density, weather variation and unexpected or unusual events.

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[1] The work is based on an experiment presented at Roads 96, the Australian Road Research Board and Transit New Zealand Conference, Christchurch, New Zealand (Lansdown & Galer Flyte, 1996)

Ethical and safety issues associated with road trials are a primary concern for the researcher. Subjects cannot be exposed to prototype information systems in road trials without very careful consideration of the risks they will impose. Typically, an experimenter would accompany a subject during trials and the vehicle would be fitted with dual controls, such that the experimenter can assume control of the vehicle, should that be necessary.

Off-road trials provide an opportunity for subjects to use a real vehicle during an experimental period. Commonly, these are conducted using a test track, disused airfield or private road. Although risks to the individuals are reduced (because of a lack of other vehicles and obstacles), the experimenter must clearly ensure that the subject's safety is paramount at all times. Off-road trials have high validity in terms of the vehicle, but low validity in terms of the driving environment.

The lack of meaningful interaction with other road users is perhaps one of the main limitations in the application of off-road trials for the evaluation of driver information systems. Use of an information system will be influenced by the driver's perception of the risk of attending to the system at a particular time. Consequently, if the risk element of the driving task cannot be replicated, the subjects' use of a system may be considered atypical.

### *7.2.2. Vehicle Simulation*

"The driving task simulator provides a convenient means of evaluating the visual demand of many information acquisition tasks." (Collins & McDonald, 1993). It enables the assessment of system concepts which may be unacceptable (from ethical or safety perspectives) to determine on the road. Driving simulators may be classified as high, mid and low fidelity. A high fidelity driving simulator would typically consist of a full moving motion base real vehicle, providing three translational and three rotational degrees of movement. Translational degrees of freedom provide lateral, longitudinal and vertical motion. The rotational degrees of freedom facilitate yaw, pitch and roll. The visual scene is often presented using video projected computer generated images. The user would interact with other virtual vehicles in a manner similar to the real road, but without the risk of collision associated with the real road.

Mid-fidelity simulation is considered to be either interactive or non-interactive and would often use a fixed base vehicle. Non-interactive mid-fidelity driving simulators are essentially a passive driving task. The subject sits in a vehicle *buck* and a video tape of a vehicle being driven would be projected to them. A rich visual environment is provided but no interaction with the roadway or events therein. Non-interactive simulators have been demonstrated to be valid research tools under some experimental conditions (i.e., where the quality of the image needs to be high, yet the control-display feedback is not critical, Wierwille & Fung, 1975). Interactive mid-fidelity simulation is typically computer generated. The level of detail of the visual scene would be low (i.e., simple polygon generated objects rather than texture mapped scenery characteristic of high fidelity systems). It may also provide some limited motion to enhance the simulation. It responds to the driver's control actions and provides approximations to visual, proprioceptive and auditory feedback.

Simulation provides a means to investigate issues which cannot safely be considered in a road trial. For example, sleep deprivation research. However, simulation is inevitably a degradation of the real driving task. Consequently, to a greater or lesser extent the value of simulation for the evaluation of driver information systems is reduced by the following.

**Vehicle Dynamics Model**

The dynamics model of a driving simulator controls the perception of how *real* the vehicle feels to control. It should consider the throttle, brake and clutch responses. The reaction of the vehicle to steering manoeuvres at both high and low speeds.

**Physical and Auditory Feedback**

If appropriate auditory feedback is not provided subjects may have great difficulty in maintaining a particular speed. Physical feedback can include such features as: the vehicle bonnet dipping down during a sharp braking action or a thump from the suspension when the vehicle mounts a curb. The feedback subjects receive from a vehicle simulator, even under optimal circumstances, is unlikely to be as realistic as that which they would experience in even an unfamiliar vehicle.

**Poor Visual Image**

Historically the computer processing power to generate realistic visual images of buildings, roadways and vehicles which interact with the driver and vehicle in a meaningful way, has been extremely expensive. Technology has improved such that computers are now able to generate other vehicles in a more realistic looking environment and provide a task of similar complexity to that of real driving at relatively low cost.

**Image Pixellation**

Many simulators employ video projection as a means to present the visual images of the traffic and roadway to the driver. Video projection technology is currently not sufficiently developed to present images which appear at high enough detail to be resolved at the correct visual angle from the driver's perspective. To illustrate, a subject must drive closer to a simulated road sign to resolve the detail than would be necessary in the real road because the sign is blurred in simulation at the visual angle in which it would be clear in the real world. Such deficiencies in the quality of visual simulation, coupled with the intrusion of additional apparatus (e.g., cameras), may threaten the validity of experimental findings from driving simulator research. Identifying the necessary balance in the levels and features of fidelity of a vehicle simulation is necessary in order to reliably obtain visual demand measurements that reflect real world behaviour (Fowkes, 1996).

### 7.2.3. *The Evaluation Process*

Effective evaluation of the visual demand of driver information systems, and assessment of their effect on driver behaviour requires consideration of the following factors: the evaluation environment, the evaluation protocol and the measures taken in the evaluation.

*The evaluation environment* refers to whether the system is assessed in a laboratory, such as in simulation trials, or in road trials. Selection of an appropriate evaluation environment requires the researcher to consider the relative merits of the available options. The principle advantages of road trials are the increased confidence that the data correspond to real phenomena. The ready availability of vehicles in which to conduct the tests (depending on the amount of instrumentation required) is also an issue. Simulation trials on the other hand, allow the researcher to control many more of the experimental variables, to ensure the safety of the subjects and the experimenters and also to conduct tests on systems which may only exist as design prototypes. In laboratory studies, the nature and fidelity of the simulation (whether part-task or full task), and its ability to replicate the essential features of the task or environment under test, are critical. Depending on the nature of the variables being studied it may not be essential to replicate the physical environment to the same degree of fidelity as the task environment. Hence it could be possible to conduct entirely satisfactory studies of driver response to certain aspects of driving using simple primary tracking tasks. The proximity of simulation to the reality of the road traffic environment and the driving task is entirely dependent on the purpose of the study.

*The evaluation protocol* is concerned with whether a system is evaluated against others (i.e., comparatively) or in isolation. The evaluation protocol influences the design of the experiments. Some of the studies assessing drivers' responses to in-vehicle systems have used comparative evaluation techniques (Fairclough & Parkes, 1990). The purpose of these studies is usually to assess how well drivers perform on various measures with System A compared with System B or C. The experimenters are concerned with the differences on these measures between the systems and not so much with the absolute performance of each system in terms of, for example, safety or ease of use. Single systems should be evaluated relative to driver visual and cognitive behaviour in normal driving. Absolute measures of the performance of driver information systems are more difficult to interpret. This is because the criteria are often assessed in terms of the system safety, ease of use under various conditions, usefulness or utility. Benchmarks to judge these criteria are not readily available.

The experimental design may also be further complicated when the nature of the system precludes certain types of design. For example, learning the experimental route would influence exact replication of experimental conditions when testing a route guidance system.

*The evaluation measures or metrics* employed can be associated with vehicle and driver or behavioural parameters. There are a large number of measures that can be taken in both laboratory simulation and road trials. These depend on the sophistication of the instrumentation of the simulator or the vehicle and include vehicle parameters such as vehicle speed and acceleration (Parkes, 1991), lateral position (Zwahlen, Adams & DeBald, 1988) and headway maintenance (Cavallo, Berthelon, & Mestre, 1996). Driver parameters such as visual behaviour include glance duration, glance allocation, glance frequency (e.g., Gioia & Morphew, 1986). Psycho-physiological indices include galvanic skin response, heart rate and heart rate variability, and eye blink rate (Delhomme & Malaterre, 1989; Fairclough, 1990; Helander, 1986; Thomas, 1989). Driver behaviour measures include steering wheel movements (Hara, Kamiya, Furuichi, & Yoshida, 1994), pedal actuations, and ecologically contextual measures such as critical incidents and accidents (Sivak, Post, Olson, & Donohue, 1981) as well as mental workload (Tijerina, Kantowitz, Kiger, & Rockwell, 1994).

Laboratory simulation has advantages when assessing driver information systems, in that the system prototypes can be evaluated early on in the design process and before fully functional systems have been built. This makes alterations to the appearance and performance of the systems much more easily achievable and at lower cost. It is also possible to assess systems where aspects of its safety may be considered without having to address ethical issues involving the unnecessary exposure to risk of both subjects and experimenters. However, the reliability and validity of the results obtained from simulation studies can be questioned when the fidelity and ecological validity of the simulation is restricted. Road trials enable the researcher to have confidence in the realism of the experimental environment but will be compromised in terms of the control over experimental variables. From a safety and design perspective there are strong demands for methods of evaluating systems that are valid and yet do not involve a safety risk.

### 7.2.4. *Aims*

The studies described in this Chapter had two aims:

- to quantify the applicability of a mid-fidelity driving simulator for the evaluation of driver information systems
- to determine the reliability of the results obtained from the empirical work presented in Chapter 6.

## 7.3. Method

Data presented in this Chapter refer to empirical results obtained from two experiments. The first was conducted on U.K. public roads and is discussed in detail in Chapter 6. The second was a replication of the first using a driving simulator. Attempts were made to duplicate the road trial in all practical respects in a simulator. This section will discuss the approach taken in the road and simulator trials, describe the simulator characteristics and highlight any relevant differences.

### 7.3.1. *Experimental Design*

A repeated measures design with three levels was employed: in-car entertainment system, congestion warning device and the control (where no additional driver information systems were used). All subjects drove the route three times, and the order of presentation was counter-balanced across conditions.

System use (congestion warning device or in-car entertainment system) was the independent variable. The dependent variables were the visual behaviour, subjective mental workload ratings, and the driver and vehicle performance data (in the simulation).

### 7.3.2. *Procedure*

The subjects were advised of the nature of the study, consent was obtained and they were shown a map of the experimental route. While stationary, a short training exercise was conducted to ensure the subjects could operate both the in-car entertainment system and the congestion warning device. They were shown how to perform each of the experimental tasks required of them and tested for proficiency until judged by the experimenter to be able to competently perform the tasks. The subjects were given navigational information by the experimenter and at pre-determined points on the route the experimenter asked the subject to either: obtain information from the congestion warning device, or perform an activity using the in-car entertainment system. During each experimental condition the subjects completed six tasks, two each at the three levels of task complexity, see Table 6 - 1. Drivers were instructed to perform information system related tasks only on straight sections of road with ample time to complete the task prior to the next junction. It was stressed by the experimenter that the tasks should be performed "in your own time" and only "when you are sure it is safe to do so".

**Road Trial Experiment**

Subjects drove the experimental vehicle for approximately fifteen minutes to familiarise themselves with its characteristics. Pre-test levels of subjective mental workload were assessed using adapted NASA R-TLX (Fairclough, 1991). The experimental route was approximately 21 km (13.1 mi) in length. It encompassed 10 km (6.2 mi) of motorway, 5.5 km (3.4 mi) rural and 5.5 km (3.4 mi) of urban driving. There were two roundabouts, five left and three right turns. A typical time for completion of the route was 19 minutes.

**Vehicle Simulator Experiment**

The experiment was conducted on an eight screen fixed base driving simulator. It presented a 360° visual scene with respect to the driver, see Figure 7 - 1. The visual scene was a computer generated environment which contained other vehicles, junctions and buildings. The simulator provided limited haptic feedback (e.g., the seat thumped when mounting a kerb). Driving sounds were also provided (e.g., engine and brake noise). Further information regarding the vehicle simulator is given in Appendix E. The simulated route included three roundabouts, six right and three left turns. It was approximately 11.2 km (7.0 mi) in length: 7.2 km (4.5 mi) of which was twin lane roads, 1.4 km (0.9 mi) rural and 2.6 km (1.62 mi) urban driving. Typical completion time for each condition was 18 minutes.

### 7.3.3. *Equipment and Apparatus*

The equipment common to both experiments is outlined below:

- a portable video recorder
- two monochrome video cameras (one recording the driver's face, the other the forward view)
- equipment to impose a time code on the video tapes
- video mixing equipment to combine the images from the two cameras and time codes
- two in-car entertainment systems. Positioned in similar locations in the road vehicle and simulator
- map based congestion warning system, see Chapter 6
- an instrumented vehicle (SAAB 9000i)
- a fixed base driving simulator (Time Warner, Model No. SV5000LE)

The position of the relevant apparatus in the simulator is shown in Figure 7 - 1, and for the road trial in Figure 6 - 2.

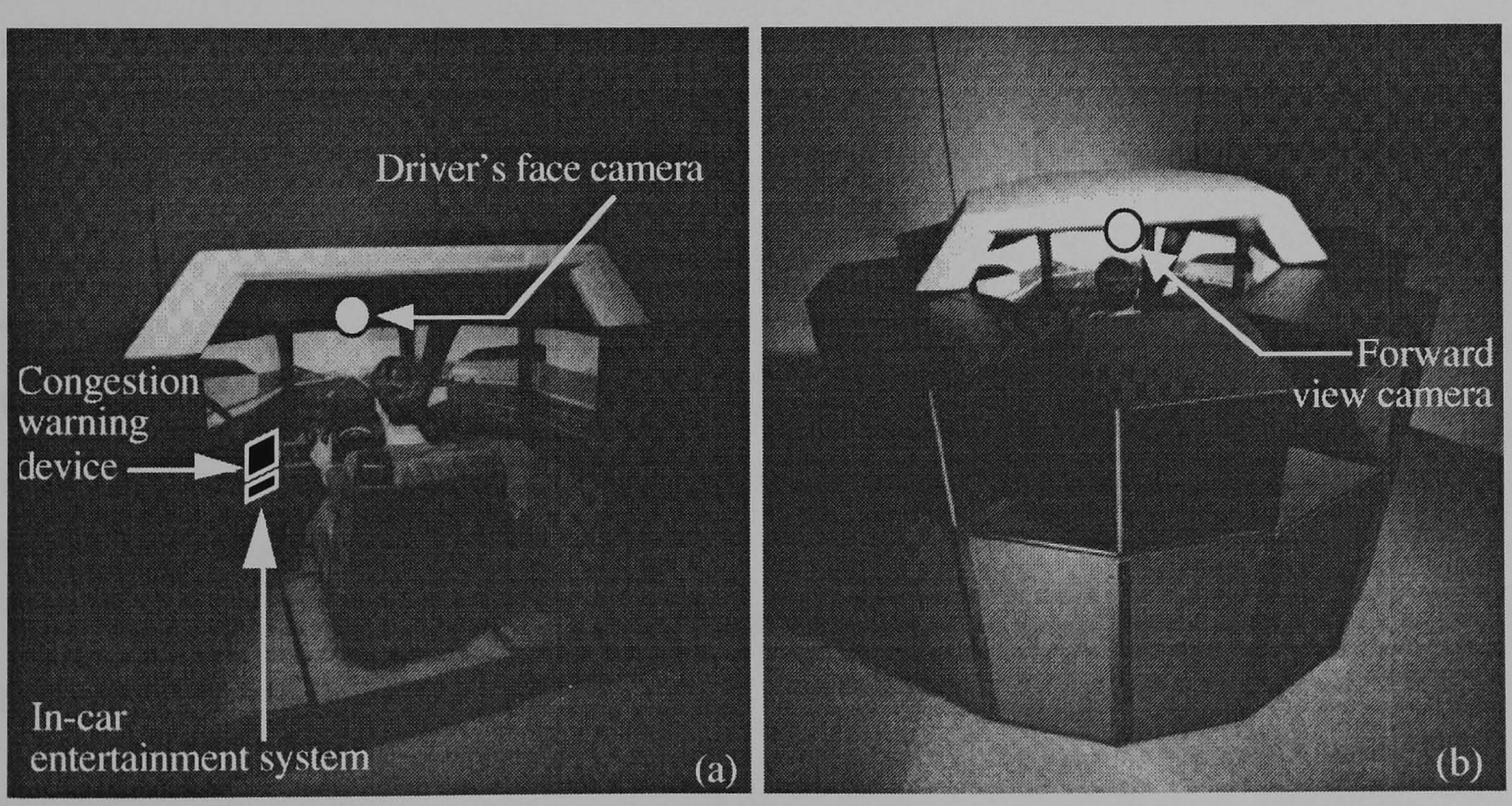



**Figure 7 - 1. The driving simulator: a) without rear view, and b) with rear view**

## 7.3.4. *Subjects*

Eighteen subjects took part in each experiment. All possessed full U.K. driving licenses (for more than two years) and had normal or corrected to normal vision. The age of the subjects in the road trial ranged from 21 years to 36 years, with a mean of 27 years, ten were male. In the simulator trial, the range was 22 years to 33 years, with a mean of 27 years, eleven were male.

## 7.3.5. *Data Capture Techniques*

**Video Tape Transcription**

Video tape records of the driver's face and forward view were analysed manually after the trial by subjective analysis. The glance frequencies and glance durations (minimum classification duration = 0.5 sec) were transcribed by hand. Visual behaviour was categorised into the following regions: driver's mirror (or ceiling of the vehicle), left region (window and mirror), right region (window and mirror), instrument panel (and/or glances into the vehicle) and the information system (congestion warning device or in-car entertainment system). Further detail regarding the method adopted to transcribe video tape records of the subjects' behaviour is published in (Lansdown & Fowkes, in press).

**Subjective Mental Workload**

Subjective mental workload measures were obtained after each condition using adapted NASA R-TLX (Fairclough, 1991).

**Vehicle Performance**

The simulator was configured to collect numerous driver and vehicle parameters. These included:

- time code (arbitrary interval scale)
- speed (mph)
- brake force applied (arbitrary interval scale)
- vehicle position in X, Y and Z axis

## 7.4. Results

Visual behaviour and subjective mental workload measures which were applied in both experiments are described. These are followed by driver and vehicle performance data which were collected from the driving simulator and the correlation of appropriate metrics.

### 7.4.1. *Driver Visual Behaviour*

**Glance Duration**

Differences in the duration of the subjects' glances to the information systems was significant in both experiments. Glance durations were identified as longest during the congestion warning device condition in both the road trial ($F(2,17) = 49.46$, $p < 0.0001$) and simulator ($F(2,17) = 32.75$, $p < 0.0001$), see Table 7 - 1. Glance duration results for the control condition were calculated by taking a mean of the glances to the other regions of the visual scene (i.e. glances to the left and right mirrors and windows, the driver mirror and instrument panel, over the whole experimental condition).

**Table 7 - 1. Glance duration (secs, SD in parenthesis)**

| | Road | Simulator |
|---|---|---|
| Control | 0.63 (0.06) | 0.58 (0.04) |
| In-car entertainment system | 0.88 (0.13) | 0.81 (0.21) |
| Congestion warning device | 1.07 (0.20) | 1.09 (0.34) |

**Glance Frequency per Minute**

The number of subjects' glances away from the forward scene per minute (gf/min) were highly significant in both the road trial ($F(2,17) = 49.34$, $p < 0.0001$) and the simulator experiment ($F(2,17) = 40.20$, $p < 0.0001$), see Table 7 - 2. Subjects' glances were most frequent during congestion warning device use in both experiments.

**Table 7 - 2. Glance frequency per minute (gf/min) away from the forward view (SD in parenthesis)**

| | Road | Simulator |
|---|---|---|
| Control | 2.02 (0.54) | 1.86 (0.60) |
| In-car entertainment system | 2.41 (0.52) | 2.08 (0.72) |
| Congestion warning device | 2.83 (0.61) | 2.50 (0.71) |

**Percentage Time Away from the Forward View**

The percentage of time the subjects spent looking away from the forward scene was significantly different across conditions in the road trial ($F(2,17) = 77.09$, $p < 0.0001$) and in the simulation ($F(2,17) = 71.32$, $p < 0.0001$), see Table 7 - 3. The pattern observed in the glance frequency and glance duration results was also seen in the percentage time away from the forward view. In both studies the time away from forward view was lowest in the controls, higher in the in-car entertainment conditions and highest in the congestion warning device conditions.

**Table 7 - 3. Percentage time away from the forward view (SD in parenthesis)**

| | Road (%) | Simulator (%) |
|---|---|---|
| Control | 10 (2.6) | 9 (2.9) |
| In-car entertainment system | 14 (3.2) | 11 (3.3) |
| Congestion warning device | 18 (3.6) | 15 (3.3) |

**Long Glances**

The distribution of long glances can be seen in Table 7 - 4. It can be seen that the proportion of long glances increases during in-car entertainment system use. The effect is more pronounced for congestion warning device use. The control condition is calculated from the subjects' glances to the driver mirror and instrument panel. The glances to the left and right regions were excluded because of a number of *long safe* glances which would confound the results (i.e., when the vehicle was stationary at a junction and in no additional danger as a consequence of extended glances away from the forward view).

**Table 7 - 4. Percentage of long duration glances**

| Time (secs) | Control (%) | | In-car entertainment system (%) | | Congestion warning device (%) | |
|---|---|---|---|---|---|---|
| | Road (n = 2244) | Simulation (n = 1543) | Road (n = 881) | Simulation (n = 516) | Road (n = 1686) | Simulation (n = 1350) |
| ≥ 1.0 | 3.88 | 6.03 | 58.12 | 43.80 | 68.68 | 58.22 |
| ≥ 1.5 | 1.02 | 0.39 | 11.92 | 8.53 | 24.61 | 23.33 |
| ≥ 2.0 | 0.58 | 0.26 | 4.65 | 4.65 | 12.10 | 16.22 |
| ≥ 2.5 | 0.36 | 0.13 | 0.57 | 2.52 | 2.19 | 7.19 |

### 7.4.2. *Subjective Mental Workload*

The overall imposed mental workload was shown to be significantly different between conditions (i.e., the congestion warning device, in-car entertainment system and normal driving). The same significant result was present in both the road trial ($F(2,17) = 29.29$, $p < 0.001$) and in the simulator experiment ($F(2,17) = 31.29$, $p < 0.0001$). These results can be seen in Table 7 - 5. This pattern of differences was consistently significant for the sub-scale workload elements: *Mental Demand*, *Mental Effort*, *Time Pressure*, *Distraction* and *Stress Level* for both the road and simulator experiments. The magnitude of the differences between the road and simulation was found not to be significant.

**Table 7 - 5. Mean mental workload (SD in parenthesis)**

| | Road | Simulator |
|---|---|---|
| Control | 24.0 (13.6) | 26.1 (17.4) |
| In-car entertainment system | 37.7 (18.6) | 34.8 (18.6) |
| Congestion warning device | 56.3 (18.7) | 51.6 (18.1) |

### 7.4.3. *Driving Performance*

In the simulator, driver and vehicle performance data were filtered to remove times when negotiating corners and when the simulated vehicle was stationary, as these would confound results. The regime adopted was to remove all data when the speed of the vehicle was 24.14 km (15 mph) or less. Mean speed was significantly different ($F(2,15) = 7.2$, $p < 0.0028$) between conditions. Mean braking effort ($F(2,15) = 3.49$, $p < 0.044$) and length of time the brakes were applied ($F(2,15) = 4.62$, $p < 0.018$) were also significantly different between conditions, see Table 7 - 6. Two subjects' data were lost as a result of equipment error.

**Table 7 - 6. Driver and vehicle performance (SD in parenthesis)**

| | Control | In-car entertainment system | Congestion warning device |
|---|---|---|---|
| Speed (km/h) | 63.79 (7.62) | 61.26 (10.41) | 57.53 (9.01) |
| Braking effort (arbitrary interval scale) | 7.28 (3.84) | 6.34 (3.65) | 5.46 (2.91) |
| Duration of brake use (arbitrary interval scale) | 53.00 (14.24) | 63.13 (17.67) | 62.93 (18.82) |

**Mean Time to Complete Route**

Average completion times for the two experiments were calculated and can be seen in Table 7 - 7. There were no significant differences for any of the experimental conditions.

**Table 7 - 7. Mean time to complete routes (mins : secs, SD in parenthesis)**

| | Road | Simulator |
|---|---|---|
| Control | 18:29 (0:59) | 17:16 (2:43) |
| In-car entertainment system | 18:33 (1:35) | 17:58 (4:10) |
| Congestion warning device | 19:10 (1:05) | 18:47 (3:58) |

**Correlation of Dependent Variables**

Correlations of the dependent variables for the road and simulation experiments (for the three conditions) were calculated. The results show that glance frequency, glance duration and subjective mental workload were found to be significantly correlated, as shown in Table 7 - 8.

**Table 7 - 8. Dependent variable correlations**

| Measure | Correlation |
|---|---|
| Glance frequency | r = 0.992* |
| Glance duration | r = 0.991* |
| Subjective mental workload | r = 0.996* |
| Percentage of time eyes away from the forward view | r = 0.982 |
| Total time to complete condition | r = 0.927 |

* *denotes significance at $p < 0.05$, $df = 1$, $r_{crit} = 0.988$, one tailed.*

## 7.5. Discussion

The results show that broadly the same distribution of visual behaviour and subjective mental workload was present in both the road and the simulator trials. Comparison of the three conditions: the control (normal driving), the in-car entertainment system and the congestion warning device provides information on the comparative visual and cognitive demands of the system under test, rather than its safety. The results demonstrate a clear distinction between drivers' visual behaviour under normal, increased and high visual demand scenarios, imposed by the use of conventional and advanced driver information systems.

### 7.5.1. *Visual Behaviour*

Glance duration, glance frequency and percentage time away from the forward view all presented the same significant trend. Both the in-car entertainment system and the congestion warning device were significantly more visually demanding than the control for the road trials and the simulation. In the simulation, the *number of glances* and *percentage time away from the forward view* was consistently lower than in the road trials, but not significantly so. Perhaps the relative simplicity of the simulated visual environment provided less visual distraction. It is possible that the subjects felt the potential consequences of extended glances away from the forward view to be less serious in the simulator. Indeed, the *observed long glances* would support this assumption. In the simulator sixteen percent of glances to the congestion warning device, were longer than two seconds. In the road trial twelve percent of glances were longer than two seconds.

### 7.5.2. *Mental Workload*

Imposed subjective mental workload was shown to be significantly greater when using either: the in-car entertainment system or congestion warning device. Adapted NASA R-TLX provides a quick and accurate manner to investigate the cognitive load imposed on the driver (Fairclough, 1991; Sawin & Scerbo, 1993). The simulator results differ from the road trial only in that the levels of mental workload were less, but not significantly so.

### 7.5.3. *Driver and Vehicle Performance Measures*

The driver and vehicle performance measures could unfortunately only be taken in the simulator. Therefore, no direct comparison can be made between the road and simulator experimental results. However, the driver performance is assumed to be similar in both environments based on visual behaviour and subjective mental workload data. The simulator may provide indications of the likely changes the introduction of an advanced driver information system would impose. For example, subjects' mean speed was recorded to be lower when using the congestion warning device. The drivers' braking behaviour was found to be contrary to expectations. It was considered that the introduction of a driver information system would result in less frequent and more harsh braking. However, drivers' use of the information systems resulted in more progressive and softer braking than during the control condition. It may have been that subjects were compensating for the additional imposed demand of the information systems by driving more slowly. Mean road speed in the driver information system conditions was lower. Higher speed in the control condition would also support the need for sharper and stronger braking. It was assumed that lane deviation would increase during driver information system use. Both position in lane and standard deviation of position in lane approached significance at the $p = 0.05$ level, but did not reach it. It is assumed that either, the quantity of normal driving between the interactions with the information systems may have reduced the sensitivity of the measure or there may not have been a very large effect on lane deviation.

### 7.5.4. *The Evaluation of Advanced Driver Information Systems*

The studies reported in this Chapter compare results of an evaluation of a congestion warning device with those from an in-car entertainment system and a control (no additional device). The trials were based on an instrumented car in a real traffic environment and a mid-fidelity simulator. The significance of this research is to assess the validity of mid-fidelity driving simulation for the evaluation of in-vehicle systems.

In terms of the *evaluation environment* this study has used a mid-fidelity simulator and an instrumented car. The programming facilities of the simulator enabled the road and traffic environment of the road trials to be reasonably replicated in terms of the driving task. The simulator was programmed to provide similar driving tasks to the road trials in terms of the number of junctions, straight sections and roundabouts requiring vehicle control manoeuvres and associated visual activity. The visual environment in the simulator trials did not replicate the richness of that of the real world public roads. However, visual scanning was shown to be primarily affected by performance of the task, and followed very similar patterns in both experimental environments. It can be seen from the results presented in this chapter that glance duration, glance frequency, percentage time per region and observed long glances were similar in the road trials and the simulator trials within conditions. In addition, the mean mental workload measures for the two experimental environments were also similar and discriminated between conditions. The findings indicate that the two experimental environments produced similar results in terms of the performance of the subjects in each condition.

*The experimental protocol* adopted in this study was such that the measures obtained for the congestion warning device (the system under evaluation) were compared with the same measures for the use of an in-car entertainment system (socially accepted as *safe*) and no system at all (the control). In this way the benchmark criteria for the assessment of the performance of the system were made comparative rather than absolute.

The comparison with a control (i.e., no additional device), provided information on whether or not the visual demand and mental workload were influenced by the introduction of a congestion warning device (the system under test). The comparison with the *accepted as safe* in-car entertainment system provided some indication of the extent of the influence of the systems on visual behaviour and subjective mental workload and its likely consequences in terms of safety. Nevertheless, the control and *accepted as safe* conditions and their physical implementation (i.e., exactly what sort of radio) must be carefully controlled. One in-car entertainment system is not necessarily functionally the same as another. It cannot be assumed that given different experimental equipment similar results would be obtained. The experimental protocol should also provide some comparison with what could be termed *normal* driving. It can be seen from the results that significant differences in visual behaviour and mental workload were obtained between experimental conditions, regardless of the environment in which the evaluations were conducted.

Considering the measures taken, a number of driver and behavioural parameters such as glance frequency, glance duration and mental workload, were measured and recorded in both the simulator and the road trials. It was also possible to programme the simulator such that additional measures of driver behaviour and vehicle parameters (e.g., mean speed and braking) could be recorded. It was not possible to measure these in the instrumented car used in the road trials. The fitting of miniature video cameras in the same positions relative to the driver, in both the car and the simulator provided recordings of visual behaviour that could be analysed in the same way. The adapted NASA R-TLX data could be gathered easily in both experimental environments. It is interesting to note that the mental workload measures provided results that corresponded well with the trends obtained from the visual behaviour data in both experimental environments and between conditions. It discriminated between the congestion warning device, the in-car entertainment system and the control in the same way as the visual behaviour data. However, visual behaviour measures provide information regarding extended glances away from the forward view (which have been argued to be most reflective of increased risk) that subjective mental workload data cannot provide. Thus, subjective mental workloads are valuable as a general indicator of increased demand from an information system, but are most suitably employed as an initial assessment tool or supplementary measure to visual behaviour metrics.

There has been much debate among researchers about the relative merits of conducting experiments in a simulated driving environment compared with the real road. However, there is surprisingly little evidence on the outcome of direct comparisons between the methods. The findings of this study address whether results obtained from a mid-fidelity simulator can be related to the findings from road trials. A relationship was found between the two evaluation environments. Visual behaviour and the supporting measures were similarly represented in both environments. However, it is not being suggested that simulation based experiments can substitute for road trials entirely. Much depends on the nature of the simulation and its fidelity in relation to the attributes of the system under test. The simulation environment provides the opportunity for greater control over experimental variables and the driving task experienced by the subjects. The visual demand of devices can be tested at an earlier stage of the development process than is possible when a fully functional product is required for road trials. The ethical concerns of exposing subjects and experimenters to potential risk from using untried and unproven systems are also eliminated. It is suggested that simulation trials are used as a screening and development tool prior to the assessment of visual demand on public roads. The early consideration of prototype devices will provide information on the performance of subjects with the devices without exposing them to risk. It will also enable aspects of the device or alternative design options to be assessed as prototypes prior to final manufacture. This provides the opportunity for systems that more closely meet user requirements to be evaluated, with the likelihood that fewer and less costly problems will be found.

It is unfortunate that the same subject group were not available for the simulation experiment as that used in the road trial. This may have had a confounding effect on results. The study was also restricted by the programming constraints of the vehicle simulator. Greater flexibility in the simulated environment would have allowed a closer representation of the route taken in the road trial. However, it is believed that the routes were long enough for the distribution of drivers' visual scanning to remain representative.

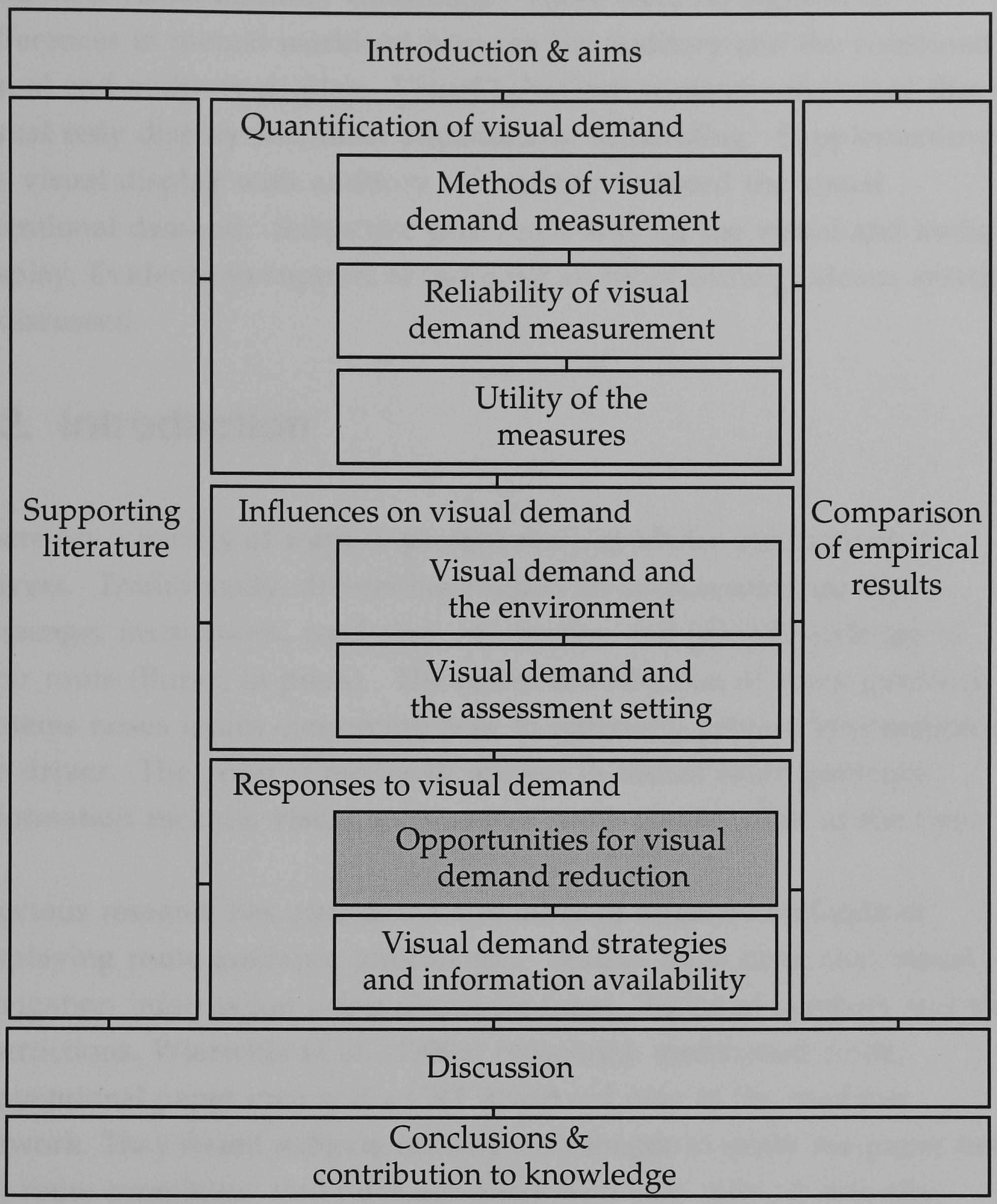
## 7.6. Chapter Conclusions

The results provide evidence that the simulator is appropriate to establish a driver information system may impose unreasonable visual demand or mental workload with respect to currently acceptable in-car entertainment systems or normal driving (without any system). It is stressed that a simulator would not be a suitable environment to determine that an advanced driver information system is *safe*. The mid-fidelity simulator provides a reasonably good representation of the driver's visual behaviour to filter out prototype systems which could impose clearly inappropriate visual demands. Driver information systems which can be demonstrated *not to be acceptable* should then be subject to further development prior to re-evaluation and progression to carefully controlled assessment on the road.

# Chapter 8

# Route Guidance Information: Verbal, Visual or Both?

# Route Guidance Information: Verbal, Visual or Both?




## 8.1. Chapter Summary

This Chapter explores opportunities to reduce visual demand with under-utilised driver resources. It describes a study which evaluates the effectiveness of presenting: visual, auditory, and a combination of visual and auditory information for route guidance. The research was conducted in a simulated driving environment. Driver visual behaviour, subjective mental workload and ratings of individual preferences were obtained. The results show that mean subjective mental workload for the visual only condition was significantly higher than that of the auditory and the combined visual-auditory conditions. There were no significant differences in mental workload between the auditory and the combined visual and auditory display. Visual behaviour measures indicated that the visual only display was most attentionally demanding. Supplementing the visual display with auditory information reduced the visual attentional demand. Subjective preference was for the visual and auditory display. Evidence in support of in-transit auditory route guidance systems is discussed.

## 8.2. Introduction

There are a variety of ways to present route guidance instructions to drivers. Traditionally, drivers have relied on such sources as: maps, passenger instructions, road sign information and prior knowledge of their route (Burns, in press). The recent introduction of route guidance systems raises issues concerning how to optimally present information to the driver. The popular modes to present in-transit route guidance information include: visual, auditory or some combination of the two.

Previous research has considered a number of different methods of displaying route guidance information. Studies have presented visual navigation information using electronic maps, direction symbols and text instructions. Wierwille et al. (1988a) compared: memorised route, conventional paper map and a CRT displayed map of the roadway network. They found subjects initially took longer to study the paper maps but route completion times did not differ with map type. It was also suggested that the CRT-map demanded more visual attention while driving than did the paper map. Drivers using the electronic map made glances of longer duration away from the roadway. Streeter, Vitello, & Wonsiewicz (1985) compared four different methods of navigation: verbal directions, customised route map, both verbal and customised route map, and conventional paper maps. The study concluded that route guidance systems should be voice oriented given their superiority over maps in terms of fewer navigation errors.

Fairclough et al. (1991) compared the effectiveness of two existing route guidance systems: TravelPilot (moving map display) and LISB/ALI-SCOUT (directional symbols and simultaneous verbal instructions). They found that 18% of the glances to the moving map display, and 7% to the directional symbol display, were "dangerously" long. It has been suggested that remembering or mentally re-orienting maps is difficult and conflicts with the spatial elements of the driving task (Wetherall, 1979). In another study, Burnett & Parkes (1993) made comparisons between the performance of a route guidance system displaying directional symbols with one that accompanied them with verbal instructions. Results showed that glances were more frequent and lasted longer for the display using visual direction symbols alone. Alm, Nilsson, Järmark, Savelid, & Hennings (1992) investigated the merits of supplementing left, right and straight ahead visual and verbal instructions with landmark information. The experiment established the addition of landmark cues improved subjects' confidence in navigation, reduced navigational errors and reduced subjective mental workload.

In review of the research, maps have consistently been shown to be troublesome for people to use while driving (Streeter et al., 1985). Consequently, for this study maps were disregarded as an option for in-transit displays. It can be noted that no comparisons have been made between auditory only and auditory & symbol formats. This research investigated the relative merits of: visual, auditory and a combination of the two mediums. No research has been found that explored these three conditions together, see Table 8 - 1.

### *8.2.1. Aims*

The work reported in this Chapter aimed to identify opportunities for reducing driver visual demand via information system design. Specifically, it planned to determine whether auditory information was sufficiently effective to support/replace visual displays of in-vehicle information.

**Table 8 - 1. Route guidance display research**

| Study | Auditory | Visual | | Auditory & Visual | |
|---|---|---|---|---|---|
| | Speech | Maps | Symbols | Speech & maps | Speech and symbols |
| Streeter et al. (1985) | ✔ | ✔ | - | ✔ | - |
| van Winsum (1987) | ✔ | ✔ | - | - | - |
| Wierwille et al. (1988a) | - | ✔ | - | - | - |
| Fairclough et al. (1991) | - | ✔ | - | - | ✔ |
| Alm et al. (1992) | - | - | - | - | ✔ |
| Burnett & Parkes (1993) | - | - | ✔ | - | ✔ |
| This study | ✔ | - | ✔ | - | ✔ |

## 8.3. Method

### *8.3.1. Experimental Design*

The study had a repeated measures design with four factors: visual, auditory, visual-auditory and car following navigational information. There were four different routes of approximately 8 km (5 mi) in length with an equal number of left and right turns (20 of each). The independent variable was the modality of navigational information. Dependent variables were visual behaviour, subjective mental workload and navigational errors. A typical time for completion of each route was fifteen minutes. Further information regarding methodological considerations is given in Appendix E.

### 8.3.2. *Procedure*

A description of the study was read to the subjects and consent obtained. Subjects were given a car following task to familiarise themselves with the simulator. During the trials the subjects drove each of the four routes. The experimenters recorded navigational errors and driving performance during the trials. Mental workload measures were obtained after each condition using adapted NASA R-TLX (Fairclough, 1991). At the end of the experiment a questionnaire was administered which established subjective preference for the route guidance conditions.

### 8.3.3. *Equipment and Apparatus*

The experiment was conducted on a five screen fixed base driving simulator. It presented a forward visual scene of approximately 200° with respect to the driver, see Figure 8 - 1. The specifications of the simulator are presented in Chapter 7.

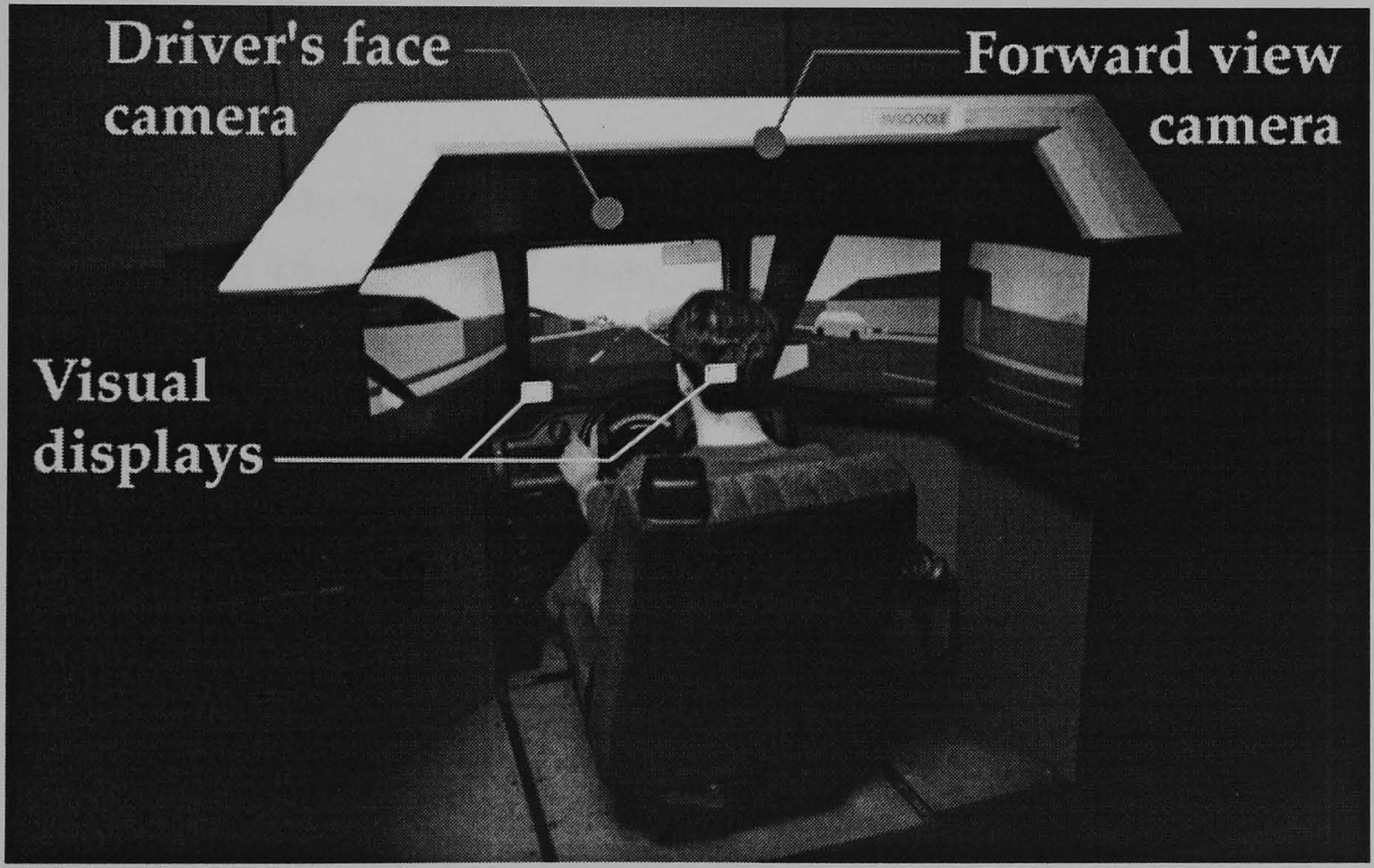



**Figure 8 - 1. Position of the experimental apparatus**

The presentation of the route guidance information was experimenter controlled. There were two direction symbols, left and right. The white opaque arrows were illuminated from behind and subtended a visual angle of 3°. They were positioned as shown in Figure 8 - 2. A recorded female voice was used to present the auditory information. The instructions were "next left" or "next right". In the combined condition the visual information was presented after the auditory. The loudspeaker used to present auditory information was positioned to the right of the subjects at approximately elbow height. All navigation instructions were presented at a fixed distance prior to the manoeuvre.

Two video cameras were used in the experiment. The driver's face was recorded with one and the forward view using the other. The images were synchronised in real time and a time signal imposed on the images.

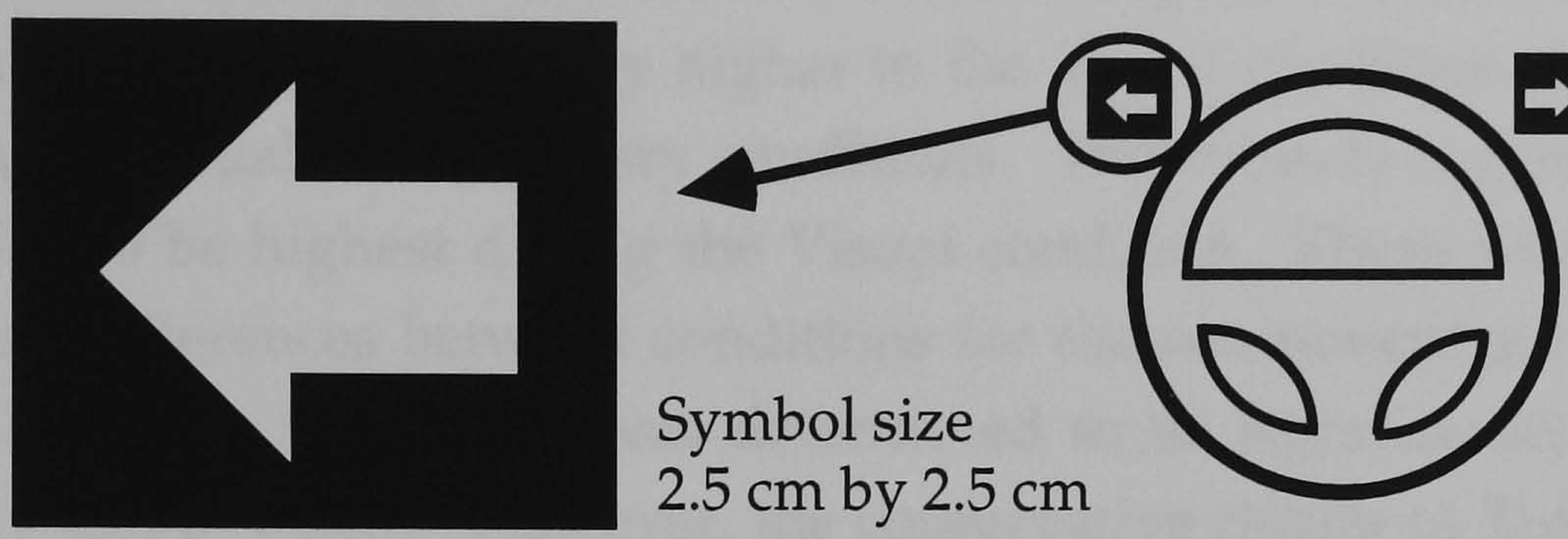



**Figure 8 - 2. Size and position of the visual displays in relation to the simulator steering wheel**

### 8.3.4. *Subjects*

Twenty one subjects took part in this experiment, 13 were male. Subjects' age ranged from 18 years to 37 years , with a mean of 25 years. All held full U.K. driving licences and had normal or corrected to normal vision. Two additional subjects were unable to complete the experiment because of feelings of nausea. All subjects were paid £15 for their participation.

## 8.4. Results

### 8.4.1. *Subjective Mental Workload*

The imposed mean mental workload was shown to be significantly different across methods of presentation of navigation information ($F_{(3,20)} = 9.24$, $p < 0.0001$), see Table 8 - 2. Tukey's HSD was used for post-hoc testing. Means with the same letter are not significantly different. For example, no significant difference was found in *Mental Demand* between: the *Control* and *Visual* (A), *Control* and *Auditory* (B) and *Auditory* and *Visual-Auditory* (C). Significant differences in *Mental Demand* were established between: the *Control* and *Visual-Auditory*, the *Visual* and *Auditory* conditions, and the *Visual* and *Visual-Auditory* conditions. The HSD results suggest that the mean mental workload was significantly lower for the auditory condition (33.9) and the visual-auditory condition (33.0) than the visual alone (46.3). This pattern of differences was significant for the component sub-scale *Mental Effort*. *Mental Demand* was reported to be significantly higher in the Visual condition than the Auditory or Visual and Auditory conditions. The subjects reported *Distraction* to be highest during the Visual condition. There were no significant differences between conditions for the component sub-scale *Physical Demand*. *Stress level* was determined to be significantly different ($F(3,20) = 2.9$, $p < 0.05$). However, the conservative nature of Tukey's HSD did not reveal the specific post-hoc effects.

**Table 8 - 2. Subjective mental workload and Tukey's HSD post-hoc comparisons* (1 - 100, SD in parenthesis)**

| | Control | Visual | Auditory | Visual-Auditory |
|---|---|---|---|---|
| Mental demand | 50.9 (25.3) A & B | 59.3 (26.2) A | 41.1 (21.7) B & C | 39.3 (21.3) C |
| Mental effort | 47.8 (23.6) A, B & C | 58.4 (20.0) A | 44.4 (19.2) B& C | 42.2 (16.8) C |
| Physical demand | 29.4 (18.9) | 32.8 (21.6) | 30.1 (20.3) | 27.0 (17.5) |
| Time pressure | 43.1 (23.7) A | 36.5 (23.3) A & B | 29.5 (23.5) A & B | 26.0 (20.5) B |
| Distraction | 33.9 (24.7) A | 48.7 (23.9) B | 25.8(17.0) A | 32.8 (21.6) A |
| Stress level | 37.3 (21.0) | 42.2 (23.8) | 32.6 (23.9) | 30.7 (19.0) |
| Mean Workload | 40.4 (16.6) A, B & C | 46.3 (17.5) A | 33.9 (16.6) B & C | 33.0 (15.1) C |

* *Means with the same letter are not significantly different* ($\alpha = 0.05$).

## 8.4.2. *Visual Behaviour*

**Glance Frequency per Minute**

The subjects' frequency of glances per minute (gf/min) to the driver mirror ($F (3,20) = 6.626$, $p < 0.001$) and route guidance systems ($F (2,20) = 41.628$, $p < 0.0001$) were highly significant across conditions, see Table 8 - 3. Glance frequency to other regions of the visual scene was not significantly different. Significantly fewer glances to the driver mirror occurred in the control.

The mean frequency of glances to the route guidance systems was significantly greater during presentation of the visual only display than either of the conditions where auditory information was available to the driver.

**Table 8 - 3. Mean glance frequency per minute (gf/min) and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control | Visual | Auditory | Visual-Auditory |
|---|---|---|---|---|
| Driver mirror | 1.19 (1.17) A | 1.95 (1.13) B | 2.03 (1.13) B | 1.82 (0.99) B |
| Right region | 4.95 (1.81) | 4.56 (1.11) | 5.14 (1.77) | 4.85 (1.48) |
| Left region | 3.58 (1.28) | 3.47 (1.07) | 3.77 (1.40) | 3.62 (1.45) |
| Instrument panel | 0.93 (0.94) | 0.73 (0.49) | 1.04 (0.88) | 0.90 (0.65) |
| Route guidance systems | - | 2.41 (1.55) A | 0.25 (0.38) B | 0.84 (0.46) B |

* *Means with the same letter are not significantly different* ($\underline{\alpha} = 0.05$).

**Glance Duration**

The duration of the subjects' glances to the left region were significantly different across conditions ($F (3,20) = 3.21$, $p < 0.05$), see Table 8 - 4. Subjects' (mean) glance durations to the left region were significantly shorter during the control than the auditory condition.

**Table 8 - 4. Mean glance duration and Tukey's HSD post-hoc comparisons* (secs, SD in parenthesis)**

| | Control | Visual | Auditory | Visual-Auditory |
|---|---|---|---|---|
| Driver mirror | 0.55 (0.06) | 0.59 (0.09) | 0.58 (0.10) | 0.62 (0.14) |
| Right region | 0.70 (0.12) | 0.73 (0.14) | 0.74 (0.14) | 0.74 (0.16) |
| Left region | 0.64 (0.08) | 0.69 (0.12) | 0.70 (0.10) | 0.69 (0.14) |
| | A | A & B | B | A & B |
| Instrument panel | 0.55 (0.08) | 0.56 (0.08) | 0.60 (0.22) | 0.56 (0.07) |
| Route guidance systems | | 0.54 (0.08) | 0.56 (0.22) | 0.53 (0.05) |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05).*

**Percentage Time per Region**

The percentage of time the subjects spent glancing to the driver mirror ($F (3,20) = 6.76$, $p < 0.0005$), route guidance system ($F (2,20) = 40.00$, $p < 0.0001$) and forward view ($F (3,20) = 6.64$, $p < 0.001$) were significantly different across conditions, see Table 8 - 5. The mean percentage of total time spent glancing to the driver mirror was significantly shorter in the Control than any of the other conditions. During the Control condition the total time (mean) allocated to forward view glances was significantly greater than the other conditions. The total mean time allocated to each of the route guidance applications was significantly different. The greatest total time was spent glancing to the Visual display (2.1%), followed by the Visual and Auditory (0.8%) with the Auditory presentation the lowest (0.1%).

**Table 8 - 5. Mean percentage time per region and Tukey's HSD post-hoc comparisons* (%, SD in parenthesis)**

| | Control | Visual | Auditory | Visual-Auditory |
|---|---|---|---|---|
| Driver mirror | 1.0 (1.0) A | 1.9 (0.9) B | 1.9 (1.0) B | 1.8 (1.1) B |
| Right region | 5.8 (2.1) | 5.6 (1.6) | 6.1 (2.1) | 5.8 (2.1) |
| Left region | 3.7 (1.3) | 4.0 (1.5) | 4.3 (1.7) | 4.1 (1.7) |
| Instrument panel | 0.9 (1.1) | 0.6 (0.6) | 1.0 (0.9) | 0.9 (0.8) |
| Route guidance systems | - | 2.1 (1.4) A | 0.1 (0.4) B | 0.8 (0.5) C |
| Forward view | 88.4 (2.8) A | 85.9 (3.8) B | 86.3 (3.9) B | 86.5 (3.7) B |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05).*

### 8.4.3. *Subjective Preferences*

The subjective order of preference for the presentation of route guidance information was: Visual-Auditory (9 subjects) followed by no difference between the Visual only and the Auditory only conditions (5 subjects each). Only 2 individuals reported that they would not want a route guidance system in their car. Both of these subjects were male.

### 8.4.4. *Driving and Navigation Performance Errors Rates*

A wrong turn was defined as a missed junction or an incorrect turning. In all conditions a total of thirty wrong turns were made, 80% of these navigational errors occurred with the visual only display. During the experiment application of the brakes which was sufficiently strong to produce simulated skidding occurred eighty five times, 44% of these were observed in the control condition.

## 8.5. Discussion

This study examined three different methods of presenting in-transit route guidance information: auditory, visual, and visual-auditory, with the aim of reducing visual demands on the driver. The experiment was conducted in a simulated driving environment. Subjective mental workload associated with the different display types was highest for the visual only condition. There was no significant difference in mean mental workload with the auditory display and the visual-auditory. The number of navigation errors was highest for the visual only condition and subjective preference was highest for the visual-auditory display. Total percentage time and glance frequency were highest in the visual only condition. It is argued these results support the preferred use of auditory and visual displays for route guidance systems as a potential mechanism to reduce driver visual demand.

### 8.5.1. *Visual Performance Measures*

The frequency of subjects' glances to the driver mirror was significantly lower during the car following task (the control) than any of the other conditions. The car following task may have led the subjects to reduce their routine non-essential visual checking manoeuvres (e.g., left and right glances), as a consequence of their passively following the lead vehicle. Additionally, the lack of a rear view during the experiment causes the simulator to display a virtual driver mirror, the quality and value of which remains questionable. Therefore, subjects may have disregarded the driver mirror as a worthwhile source of visual information.

Glances to the route guidance systems occurred most frequently during the visual only condition. Supplementing visual information with auditory significantly reduced the number of glances away from the forward view. The finding would suggest that visual demand may be usefully reduced by the additional support of auditory indicators. A reduction was observed in glance frequencies and percentage time allocated to the navigation systems when supplemented by auditory information. However, the navigation task in the experiment was a simple one and the benefits of supplementing visual displays with auditory messages would need to be further investigated with tasks that better reflect real world scenarios. The findings were supported by the percentage time allocation to the route guidance system which was also highest when presented visually. The auditory only information virtually eliminated the drivers' glances to the route guidance display. This would be expected because it was not functioning during the auditory only condition.

The percentage time allocated to driver mirror glances was lowest in the control condition. The finding is consistent with the low glance frequencies observed to the driver mirror. There were no significant differences between the total percentage visual allocation during the other conditions. The reduced allocation to the mirror provides further evidence that the drivers' visual checking was not representative of behaviour on public roads. No driving simulator currently exists that truly represents the driving task in all respects. Consequently, the findings of this study may be considered as representative of a vehicle negotiation task involving route guidance and therefore justify further replication on public roads. The results cannot be interpreted as equivalent to the complexities of route guidance in *real* roads.

Percentage time glancing to the forward view was highest during the control condition. The vehicle following task would have required the subjects to fixate to the forward view to obtain navigational information. Interestingly, in comparison with the visual conditions, the auditory only condition did not result in less percentage time from the forward view, as might be expected from the reduced need for visual information.

Mean glance duration to the left region of the visual scene was significantly different. The control condition was shown to have the lowest mean glance duration to the left region. The vehicle following task utilised in the control may have made the subjects feel that they were safe to emerge from junctions immediately after the lead vehicle and consequently did not carry out the normal level of *left* region visual checking.

The development of route guidance systems in automobiles has been shaped by available technologies (Owens, Helmers, & Sivak, 1993). The research assessing the implications of the introduction of navigation systems into vehicles has been restricted mainly to the assessment of existing systems. Such work can only identify the relative merits of the devices in question. This study has attempted to address the basic user requirements with less emphasis on the technologies required. It has been suggested that the driver obtains more than 90% of their information visually when driving (Hartmann, 1970; Sabey & Staughton, 1975). As a consequence the driver may experience unacceptably high demands on their visual resources even without the introduction of route guidance systems. For example, driving in heavy traffic while negotiating an unfamiliar and complex junction would be very demanding. Thus, presenting additional visual information to the driver may be problematic in that it could impose further strain on an already heavily loaded information channel. However, there are several benefits to the use of visual displays. For example, they have the potential advantages of: providing the driver with information on demand, compatibility of stimulus to response and rapid presentation of complex in-vehicle information.

Drivers over-dependence on visual information raises concerns about introducing additional visual inputs and highlights the need for alternative information channels (notwithstanding, systems, both existing and under development, are reliant on visual displays). The overall mental workload ratings and visual behaviour measures (glance frequency and total percentage allocation) suggest that the use of the visual only display imposed significantly greater attentional demand on the driver than when supported with an auditory component or auditory information alone. Additionally, the driver performance measures suggested that 80% of all wrong turns occurred in the visual only condition. It must be stated that the relative simplicity and conspicuity of the visual display could have enabled the subjects to detect and respond to the visual stimuli without using foveal vision. Therefore, they would not need to glance away from the forward view to attend to the display. Consequently, the findings are surprising in that the significant differences can still be found between conditions. Additionally, attempts were made to balance the auditory messages with the visual displays. A complex visual display and a simple auditory signal may have confounded comparison between metrics.

In existing systems the assumption has been that symbolic visual displays complemented with auditory information are the best way to present navigation information (e.g., systems such as Philips CARIN or Bosch TRAVELPILOT). The advantage of this strategy is that it may benefit the driver by employing the best features of both modalities. A potential disadvantage is that the information from the different modalities could compete for the driver's attention (Wickens, 1984). Mental workload, visual demand measures and performance data provide evidence for the superiority of a combined display format over a visual display alone, as has been shown previously by Alm et al. (1992). This raises the issue of whether visual information is essential to a route guidance system or can a speech only system adequately meet the user's needs. A speech only system may be favourable to a combined system because of the reduced interference with the visual-spatial components (Wickens, 1984) of driving. It could also be beneficial because information can be presented in an active and timely manner. The superiority of auditory over visual (map) route guidance was demonstrated in a study by van Winsum (1987) as cited in Schraagen (1993).

Low demands are placed on the driver's auditory system by the driving task (Leiser, 1993). Therefore, to exploit this neglected resource, it may be appropriate to present verbal route guidance information. Successful implementation of verbal navigation information would require that several issues be resolved. Potential concerns include: background noise, voice characteristics, message transience and information content. Future research should consider the questions regarding the use of a minimum instruction set for the driver. For example, are simple left-right commands enough to overcome system implementation and user interface issues? Previous research has shown that visual and verbal left, right and straight ahead instructions are insufficient to provide route guidance for complex roadways (i.e., those including roundabouts; Alm et al., 1992). The feasibility of an auditory system will be dependent on whether it can safely and efficiently guide drivers around complex road layouts.

## 8.6. Chapter Conclusions

This Chapter has considered opportunities to reduce visual demand. Findings support the feasibility of visual and verbal in-transit route guidance system as an example of an application in which visual demand may be moderated by exploiting under-used driver resources. Such systems may fulfil the functional requirements of route guidance systems without imposing unnecessary visual demands in a potentially heavily loaded driver. However, prior to the development of such a system there are several outlined research questions that must be addressed.

### *8.6.1. Acknowledgement*

Completion of the experimental work discussed in this chapter was assisted by Peter C. Burns[1].

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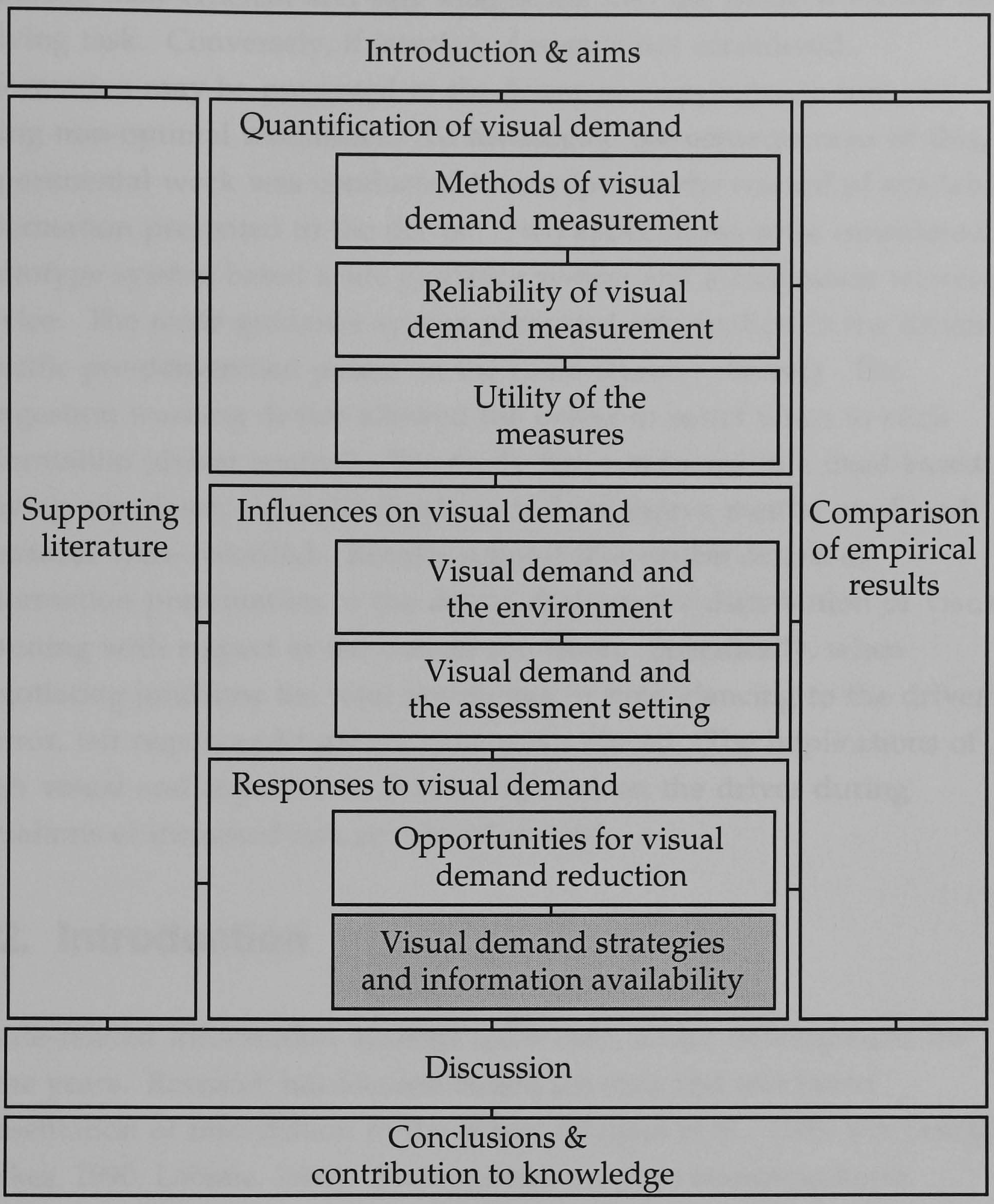
# Chapter 9

# Visual Behaviour and the Availability of Advanced Driver Information

# Visual Behaviour and the Availability of Advanced Driver Information




## 9.1. Chapter Summary

In Chapters 3, 4 and 6 methods for the measurement and interpretation of visual demand have been discussed. Empirical work in Chapters 5 and 7 describe the effect that environmental changes may have on visual demand and in Chapter 8 the opportunities for the reduction of unacceptable visual demand are considered. In this study, control over the availability of information from different systems on driver visual demand was explored[1].

The interface design of driver information systems is important in ensuring their efficient and safe integration into the modern vehicle and driving task. Conversely, if interface design is not considered, information may be presented to the driver at inappropriate times or using non-optimal modalities. To investigate the consequences of this, experimental work was conducted to manipulate the control of available information presented to the driver. Two applications were considered, a prototype symbol based route guidance system and a congestion warning device. The route guidance system presented information to the driver at specific pre-determined points on the route (system control). The congestion warning device allowed the driver to select when to elicit information (driver control). The study was conducted in a fixed-based driving simulator. Visual behaviour and subjective mental workload measures were recorded. Results suggest that *system control* of information presentation to the driver changes the distribution of visual scanning with respect to the control condition. Specifically, when negotiating junctions the total percentage of time glancing to the driver mirror, left region and forward view was reduced. The implications of high visual and cognitive demands imposed on the driver during situations of increased risk are also discussed.

## 9.2. Introduction

Route-related information systems have been under development for some years. Research has focused largely on map and text based presentation of information to the driver (Dingus et al., 1989; Fairclough & Parkes, 1990; Labiale, 1989). Such systems are now becoming more common in vehicles and have produced a wide variety of novel user interfaces. These systems aim to ease the flow of information to the driver and *reduce uncertainty* during information extraction (Rumar, 1988).

It has been suggested that the driving task is a predominantly visual one (Charman, 1986; Dewar & Ellis, 1994; Mourant et al., 1970; Rockwell, 1988;

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[1] The research described in this chapter was presented at the 1st International Conference on Traffic and Transport Psychology, Valencia, Spain (Lansdown, 1996)

Rumar, 1988). Spare visual capacity when driving has been investigated by several researchers (e.g., Hughes & Cole, 1986; Rockwell, 1988; Wierwille et al., 1988a). It has been established that under many scenarios the visual demands of the driving task remain within the capabilities of the driver (Rockwell, 1988; Wierwille et al., 1988). The distribution of visual scanning has been shown to change as a consequence of the task demands (Hughes & Cole, 1988), and some conventional in-vehicle tasks may demand a large amount of attention (Wierwille et al., 1988), see Chapter 2. Similarly, driver information system functions may also impose excessive visual demands (Fairclough & Parkes, 1990; Lansdown & Fowkes, in press; Wierwille et al., 1988). Models have been proposed (Wierwille, 1993b; Zwahlen et al., 1988, see figures 2 - 5 and 2 - 8 respectively) which illustrate that distraction from the primary driving task (i.e., safe maintenance of lateral and longitudinal vehicle control); must be equated by the driver against the potential value of attending to a distracter (e.g., a route guidance system). Fairclough & Parkes (1990) consider this when discussing experimental work stating:

> "[their finding] ...centres on the critical role of vision in the driving task and how visual resources are 'shared' between the drivers primary task of safely conducting the vehicle through the roadway environment and his secondary task of successful navigation", page 2.

In the models, visual attention is allocated to one of two states, *in-vehicle* or *on driving*. These are discussed in more detail in Chapter 2. To recap, during performance of an in-vehicle task the driver is presumed to require one or more glances to a display. Wierwille (1993a) and Zwahlen et al. (1988) present an interpretation in which the driver is reluctant to glance away from the forward view for extended periods (i.e., from 0.6 secs to 1.6 secs). Therefore, short glances occur repeatedly until the information is obtained. Zwahlen et al. (1988) goes further by relating this behaviour to the available road traffic information in working memory. It is suggested that the driver will continue to attend to an information system until a threshold is reached after which they become increasingly uncomfortable with glances away from the forward view. Wierwille (1993a) discusses this in terms of a *forward view uncertainty buildup*. Both models provide insight into the visual and information processing of the driver when extracting specific chunks of information. However, neither can be interpreted in the context of task performance which is more complex than a simple interaction with a system. For example, a route guidance system will require integration of several *chunks* of information with knowledge of the road network to usefully negotiate the roadway. Thus, it is the piecing together of these chunks of extracted data which remains unclear. Additionally, the influence of the specific road scenario is not considered (e.g., traffic density).

Wierwille (1993) demonstrated changes in the distribution of drivers' visual scanning when performing navigation tasks with different types of route information constantly available (i.e., driver control), see figures 2 -14 to 2 - 16. These results are considered in more detail in Chapter 2. Paper map use did not appear to reduce the drivers' normal checking of instruments and mirrors, but reduced the percentage of time glancing to the roadway centre. Glance probability to the instruments was reduced from 3% to 2%. Subjects' use of a computerised moving map was shown to demand radically more visual attention than the paper map, 33% and 7% respectively. The electronic map also shifted visual attention from the roadway (centre and off centre) while the other normal scanning behaviour was not stated to be significantly different. The subjects' probability of glancing to the instruments was reduced in the same manner as with the paper map (i.e., from 3% to 2%). Drivers' control over the interaction with the information systems enabled them to maintain visual scanning to regions of the environment other than the forward view. It is assumed that the forward view glances encompass a large proportion of non-driving relevant glances which can be reduced without compromising vehicle safety. Indeed some researchers have estimated spare driver visual capacity to be as high as 30% to 50% of total fixations (Hughes & Cole, 1986).

Fairclough & Parkes (1990) investigated drivers' visual behaviour while using a paper map and text instructions presented on computer (e.g., 'Turn Left: Colchester Road). The results supported Wierwille et al.'s (1988a) findings. Subjects were reported to spend 22.1% and 12.1% of the total driving time glancing to the paper map and text displays respectively, see Table 9 - 1. It can be seen that drivers were diverting visual attention from the forward view to the information system. Little change is evident in the distribution of visual scanning to the other regions of the environment. It should be noted that the percentage of visual allocation to the left and right regions was not stated in Fairclough & Parkes' (1990) study. Therefore, the values (0%-4.2%) have been calculated from available data. Additionally, the authors report that the control data do not provide a true control as the information was taken from different experimental work. The drivers were able to adapt their deployment of visual resources in anticipation of increased task demands, thus maintaining left and right visual checking. Wierwille et al. (1988b) reported that visual demands were seen to *double* when the information drivers were expecting was not available (system control). The specific nature of these shifts of visual attention will be influenced by the interface dialogue, timing of presentation, roadway context and system function.

**Table 9 - 1. Distribution of visual attention (paper map, text instructions, and control data from other experimental work; n = 10), adapted from Fairclough & Parkes (1990). * denotes calculation from available data**

| | Control | Paper Map | Text Instructions |
|---|---|---|---|
| Driver mirror | 2.3% | 1.7% | 2.3% |
| Right region | 0% - 4.2%* | 5.9% | 6.2% |
| Left region | 0% - 4.2%* | 3.0% | 3.1% |
| Instrument panel | 1.5% | 0.2% | 0.3% |
| Information system | - | 22.1% | 12.1% |
| Forward view | 92.0% | 67.1% | 76.0% |

Burnett & Joyner (1994) also suggested that the introduction of driver information systems affects the driver's distribution of visual scanning. They report reductions in the proportion of visual allocation to the forward view, mirrors and dashboard when using: a moving map route guidance system or a combination of paper map and route planning notes. Burnett & Joyner (1994) state that "The moving map based system was a self-paced system, which allowed drivers to fit their glance patterns to the demands of the primary task. This requires constant visual checking for new information and has been shown here and elsewhere to lead to large amounts of time spent with eyes off the road", page 158. All experimental conditions were self-paced and the locations and durations of visual allocation is not considered further in their study.

Driver information systems can be classified as those that *provide status information*, *recommend action* or actively *assume control* of the vehicle in some manner. This experiment considers the impact on visual behaviour of systems that *provide information* and *recommend action*. Systems which are essentially non-intrusive *information providers* include: in-car entertainment, congestion warning and route planning (list type instructions, either pre-written or computer presented) systems. Often, they rely on the driver's knowledge of the road network to utilise any potential benefits. In-vehicle information systems which *recommend a course of action* to the driver may include: seat belt warning and route guidance. Considering route guidance, typically pre-determined knowledge of the route is not required and the driver retains the option to disregard any advice. It is technically feasible now for some systems to actively *assume control* of some aspects of the driving task. For example, intelligent cruise control, blind spot and overtaking systems. Such devices would either be given control by the driver or would employ some type of monitor and assume control when its activation criterion are met.

*Continuous presentation* of information provides the driver with the opportunity to self-select when to attend to the display. *System control* of information forces the driver to make a decision to attend to the display when information is available or to risk losing the data. For example, a route guidance system may suggest a turning, but if the driver is negotiating complex traffic prior to the junction, the driver must decide to either attend to the display and risk a collision or concentrate on traffic and risk a wrong turn.

Who should control the flow of information to the driver? Flexible and multi-function information systems may contain elements of both *system* and *driver* control strategies. Consequently, without careful consideration of the users' needs, the use of such devices may prove complex and therefore hazardous for use in-vehicle.

### 9.2.1. *Aims*

This experimental work aimed to investigate changes in visual behaviour as a consequence of *system* or *driver* control of information presentation. It is hypothesised that *driver* control of information would impinge primarily on visual attention to the forward view. *System* control of information is predicted to intrude on visual scanning to the other regions of the visual scene in addition to the forward view. Visual scanning to these regions (e.g., driver mirror, left & right regions and instrument panel is suggested to decrease because the in-vehicle display is in competition with roadway information).

## 9.3. Method

### 9.3.1. *Experimental Design*

A repeated measures design was employed. In a mid-fidelity driving simulator subjects completed three matched & counterbalanced routes using either: a congestion warning device (driver control), route guidance system (system control) or a control (normal driving). All routes were 12 km (7.5 mi) long and took on average 14 mins 42 secs (SD = 3 mins 20 secs) to complete. Information system use was the independent variable. The dependent variables were: visual behaviour, vehicle performance data and subjective mental workload. Further information regarding methodological considerations is given in Appendix E.

### 9.3.2. *Procedure*

Subjects were required to perform a short familiarisation drive in the simulator prior to data recording. In the congestion warning device condition the subjects completed six tasks, two each at three levels of complexity, as described in Chapter 6. In the route guidance condition, subjects were instructed to follow the visual navigational instructions provided by the system. Navigational directions were given to the subjects by the experimenter during the non-route guidance conditions. The SSQ (simulator sickness questionnaire, Kennedy, Lane, Berbaum, & Lilienthal, 1993) was administered immediately before and after the experimental trials. The results of which are presented in Appendix D.

### 9.3.3. *Equipment and Apparatus*

The experiment was conducted in a driving simulator. Its specifications are described in Chapter 7. The position of the experimental apparatus is shown in Figure 9 - 1. A map based congestion warning device (driver control) and a prototype symbol based route guidance system (system control) were used in the experiment, see figure 9 - 2a and 9 - 2b. The congestion warning device presented information to the driver continuously, while the route guidance system displayed navigational information prior to junctions. The congestion warning device display was approximately 10 cm by 7 cm. The prototype route guidance system displayed single symbols on a display approximately 6 cm by 6 cm.

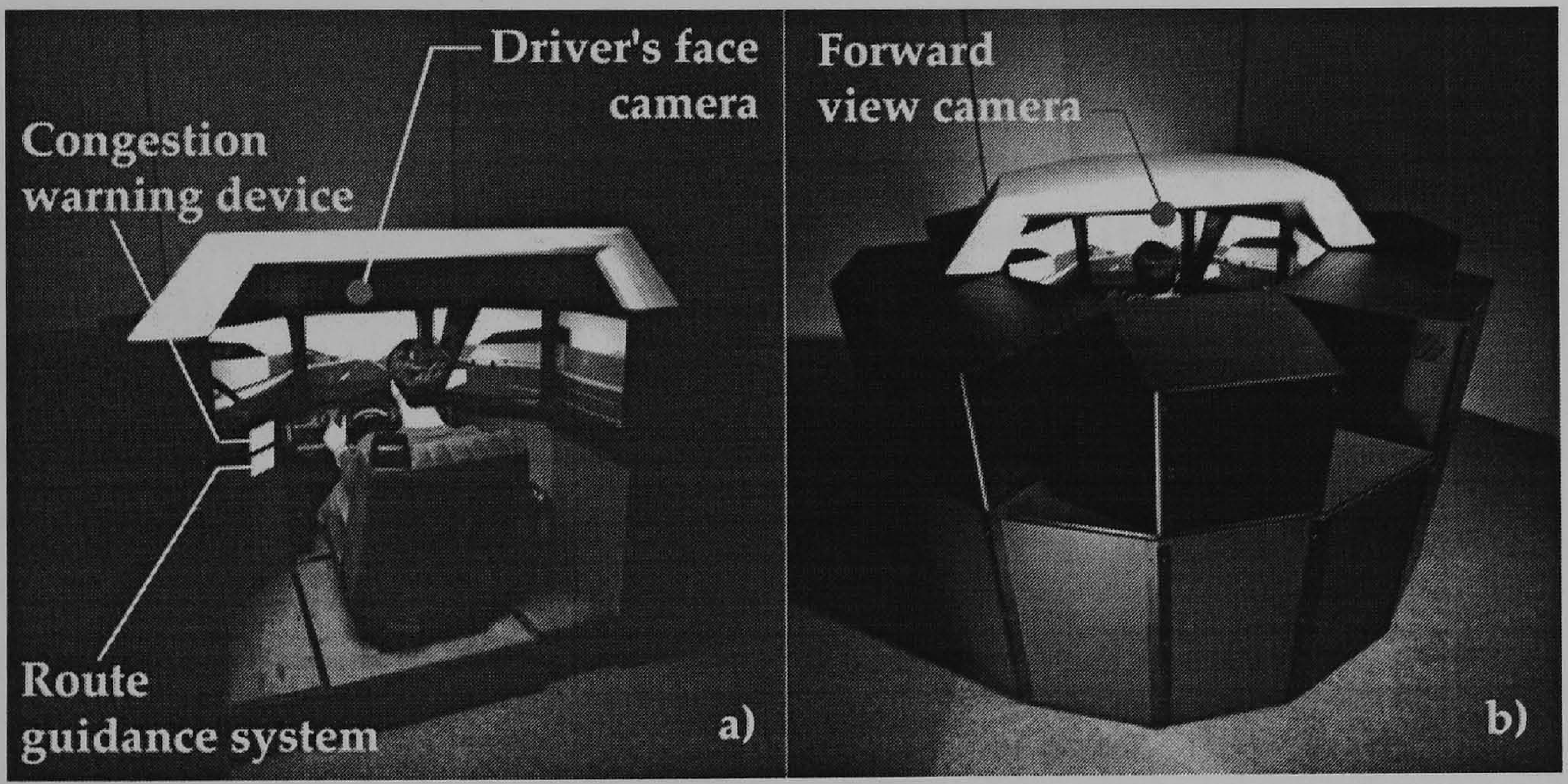



**Figure 9 - 1. Vehicle simulator: a) without rear views and b) with rear views**

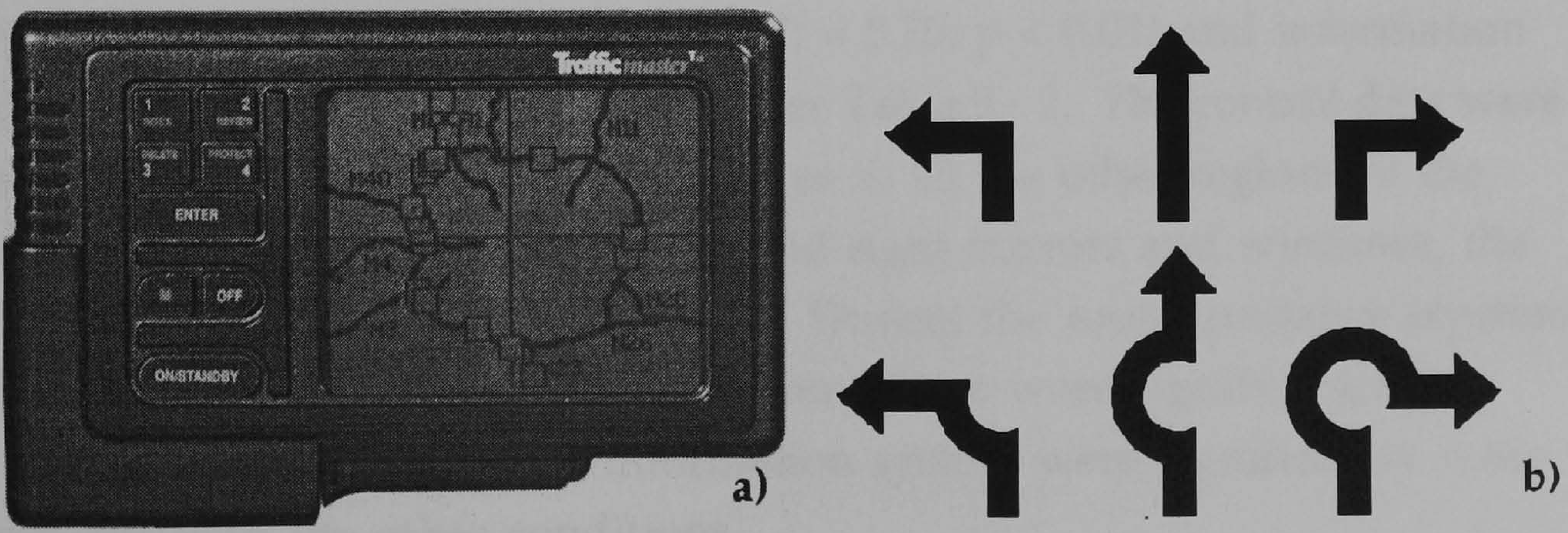



**Figure 9 - 2. Information systems: a) congestion warning device, and b) route guidance symbols**

### 9.3.4. *Subjects*

Eighteen subjects participated in the experiment, 11 of whom were male. Their ages ranged from 21 years to 45 years, with a mean of 25.6 years. All had greater than two years driving experience and normal (or corrected to normal) vision with respect to U.K. driving requirements. All subjects were paid £10 for their participation.

## 9.4. Results

### 9.4.2. *Glance Duration*

Data on the duration of glances to the driver mirror, left & right region and instrument panel during the control condition were averaged to provide a meaningful comparison with glances to the information systems in the other two conditions. The duration of subjects' glances to the information systems were significantly different ($F\ (2,17) = 102.28$, $p < 0.0001$). Post-hoc analysis (Tukey's HSD) revealed glance durations to the congestion warning device (driver control, mean = 0.96 secs) to be significantly longer than either to the route guidance system (system control, mean = 0.5 secs; $Q_{obs} = 17.82$, $p < 0.01$) or the control (mean = 0.54 secs; $Q_{obs} = 16.27$, $p < 0.01$). There were no significant differences between other regions of the visual scene.

### 9.4.3. *Glance Frequency per Minute*

The number of glances to the regions of the visual scene were significantly different for the driver mirror ($F\ (2,17) = 5.70$, $p < 0.01$) and information systems ($F\ (2,17) = 22.69$, $p < 0.0001$), see Table 9 - 2. The control data were calculated from the mean of the glances to all the other regions of the visual scene (i.e., glances to the left and right mirrors and windows, the driver mirror and instrument panel). During the route guidance (system control) condition, glances to the driver mirror were significantly less frequent, also glances to the information system were significantly more frequent than the other conditions.

**Table 9 - 2. Mean glance frequency per minute (gf/min) and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control | Route Guidance | Congestion Warning |
|---|---|---|---|
| Driver mirror | 2.54 (1.76) A | 1.73 (1.59) B | 2.16 (1.60) A |
| Right region | 2.76 (1.71) | 1.93 (1.47) | 2.43 (1.28) |
| Left region | 1.27 (0.79) | 0.84 (0.90) | 1.08 (0.97) |
| Instrument panel | 3.77 (1.84) | 4.99 (10.34) | 3.30 (2.20) |
| Information system | 2.58 (1.12) A | 11.81 (7.14) B | 4.75 (1.70) C |

* *Means with the same letter are not significantly different ($\alpha$ = 0.05). For example, glance frequency to the driver mirror was significantly lower during route guidance system use than either the congestion warning device or the control condition.*

## 9.4.4. *Percentage Time per Region*

Total *fixation time* in each region of the visual scene can be seen in Table 9 - 3. The distribution of visual behaviour to the driver mirror ($F(2,17) = 4.37, p < 0.05$), left region ($F(2,17) = 4.68, p < 0.05$), information system ($F(2,17) = 90.10, p < 0.0001$) and the forward view ($F(2,17) = 39.04, p < 0.0001$), were all significantly different. Percentage time per region to the driver mirror and left region was significantly lower during the route guidance condition. Information system percentage time per region was highest for the route guidance system, which was significantly greater than for the congestion warning device, which in turn, was significantly greater than for the control condition. Total percentage time per region to the forward view was significantly higher during the control condition.

## 9.4.5. *Subjective Mental Workload*

The subjective mental workload ratings (adapted R-TLX) can be seen in Table 9 - 6. One subject failed to complete the assessment scales and therefore the data were removed from the analysis. Mean mental workload was significantly different across the three conditions ($F(2,16) = 8.75, p < 0.001$). The component mental workload scores: *Mental Demand* ($F(2,16) = 6.76, p < 0.005$), *Mental Effort* ($F(2,16) = 9.08, p < 0.001$), *Time Pressure* ($F(2,16) = 3.51, p < 0.05$), *Distraction* ($F(2,16) = 4.47, p < 0.05$), and *Stress Level* ($F(2,16) = 7.13, p < 0.005$) were also significantly different. *Physical demand* was not significantly different across condition. *Mean*

*Mental Workload*, *Mental Demand* and *Mental Effort* were all significantly lower in the control than the congestion warning device (driver control), but not the route guidance system (system control).

**Table 9 - 3. Percentage time per region and Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control (%) | Route Guidance (%) | Congestion Warning (%) |
|---|---|---|---|
| Driver mirror | 2.3 (1.5) A | 1.8 (1.4) B | 2.0 (1.5) C |
| Right region | 2.5 (1.6) | 1.9 (1.3) | 2.3 (1.2) |
| Left region | 1.1 (0.7) A | 0.6 (0.4) B | 1.0 (0.9) C |
| Instrument panel | 3.3 (1.8) | 2.7 (1.4) | 2.9 (1.9) |
| Information system | 0.3 (0.5) A | 8.8 (3.1) B | 7.5 (2.9) C |
| Forward view | 90.4 (4.0) A | 84.1 (3.0) B | 84.4 (4.5) B |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

**Table 9 - 4. Subjective mental workload and Tukey's HSD post-hoc comparisons* (1 - 100, SD in parenthesis)**

| | Control | Route Guidance | Congestion Warning |
|---|---|---|---|
| Mental demand | 40.65 (26.95) A | 55.24 (23.49) B | 59.35 (19.87) B |
| Mental effort | 44.65 (30.31) A | 66.88 (18.85) B | 69.12 (21.36) B |
| Physical demand | 34.12 (28.06) | 33.59 (24.41) | 38.29 (23.88) |
| Time pressure | 25.71 (22.31) A | 35.65 (17.53) A & B | 40.06 (27.36) B |
| Distraction | 32.24 (27.21) A | 51.06 (20.86) A & B | 54.35 (24.74) B |
| Stress level | 30.23 (26.15) A | 41.77 (21.49) A & B | 52.24 (23.50) B |
| Mean mental workload | 34.60 (24.31) A | 47.36 (14.47) B | 52.24 (17.10) B |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

### *9.4.6. Vehicle and Driver Performance Measures*

The standard deviation of braking effort was significantly different across the three conditions (F (2,16) = 4.39, p < 0.05). Similarly, mean braking effort was also significantly different (F (2,16 = 3.42, p < 0.05), see Table 9 - 5. Lane position and standard deviations of lane position were not found to be significantly different. Significantly lower standard deviations were obtained during the congestion warning device condition (driver control) than the control or the route guidance system condition (system control). The same trend emerged for mean braking effort.

**Table 9 - 5. Driver and vehicle performance with Tukey's HSD post-hoc comparisons* (SD in parenthesis)**

| | Control | Route guidance | Congestion warning |
|---|---|---|---|
| Standard deviation of braking effort | 37.18 (10.8) A | 37.88 (8.97) A | 31.73 (8.75) B |
| Mean Braking effort (arbitrary interval scale) | 10.79 (6.6) A | 10.31 (4.55) A | 7.67 (4.12) B |

* *Means with the same letter are not significantly different ($\underline{\alpha}$ = 0.05).*

## 9.5. Discussion

The results demonstrate that the introduction of driver information systems imposed additional visual and cognitive demands. Driver fixations to the information systems showed that individual mean glance durations were significantly longer when using the congestion warning device (driver control) than when using the route guidance system (system control) or during the control. The drivers presumably found specific chunks of information more difficult to obtain from the congestion warning device than from the route guidance system. However, percentage dwell time (time per region) was significantly higher when using the route guidance system (8.8%) than either the congestion warning device (7.5%) or the control (0.3%). This can be explained by significantly greater numbers of glances to the route guidance system (11.81) with respect to the congestion warning device (4.75) and the control (2.58). Glance frequencies to the driver mirror were also significantly reduced when using the route guidance system. The drivers were apparently forced by the interface to adopt different strategies when using the devices; longer glances to the congestion warning device and shorter more frequent glances to the route guidance system with the consequent reduction in other visual scanning.

Distraction from the roadway may be a negative safety consequence of driver information system use. It is assumed that this could lead to an increased accident risk. The experimental findings suggest that the congestion warning device would impose a greater safety risk than the route guidance system because of the longer glance durations and therefore *individual maximum distractions* from the road. However, this view is simplistic as the context in which distractions may occur will influence the consequent danger. For example, a one second distraction is unlikely to pose the same safety risk on quiet straight roads as it would in a complex busy junction. Visual attention was diverted away from the forward view significantly more when using the congestion warning (84.4%) and route guidance systems (84.1%) than the control condition (90.4%). The percentage of dwell time to the driver mirror, left region and information system were all significantly greater when using the route guidance system and the congestion warning device than the control condition. Thus, both information systems introduced additional visual demands with respect to the control. The route guidance system reduced the total percentage of visual checking to regions of the scene (driver mirror, right & left regions, and instrument panel) significantly more than either the congestion warning device or the control condition. Clearly, visual sampling of these regions is important to maintain situational awareness of the immediate vehicle environment. Examination of video tape records revealed most checking of the driver mirror and left & right regions occurs at or when approaching junctions. The route guidance system disrupted visual checking at the time when the driver should be extracting information from the roadway.

A typical experimental condition of fifteen minutes generated a data file of approximately 18,000 items for speed, lane position, brake actuation and throttle actuation. Therefore, data reduction was required. Three regimes were adopted filtering on:

- cornering
- cornering and speed
- speed only.

Initial analysis using steering wheel movement (to remove the parts of the conditions where the subjects were negotiating corners) proved problematic because of erratic correcting motions used by some drivers to maintain lane position. Thus, these correcting movements were being filtered out of the data inappropriately. Steering filtering was supplemented by removal of vehicle manoeuvres when travelling at 15 mph or less. The aim was to remove driver actions when the vehicle was at or near to stationary, for example, at a crossroads. The data were filtered using speed alone which removed the confounding influence of steering on consideration of lane deviation.

The lane deviation measures showed no significant differences between conditions. It may have been that the experimental design was too crude to take account of the subtle effects of system use on lateral position in lane. "Thus in some situations, measurements of driver performance may show no effects of adding tasks, even though they are present (e.g., the elimination of reserve capacity)" (Green, 1994), page 7.

Both information systems imposed significantly greater *Mean Mental Workload* than the control. The same was true of the component workload sub-scales *Mental Demand* and *Mental Effort*. Subjects did not rate subjective mental workload from the *system* paced route guidance system to be greater than the *driver* paced congestion warning task. This was contrary to expectations. It would appear they were not aware of the changes in the distribution of visual scanning at junctions when using the route guidance system.

It is interesting to compare the experimental work conducted by Fairclough & Parkes (1990) and Wierwille (1993a) with the results from this study. It can be seen that the distribution of visual scanning was similar in these studies even though the specific experimental aims and designs were different, see Table 9 - 6. It may be that regardless of the particular feature under scrutiny by researchers, if it can be assumed that the driving task is valid and therefore comparable with driving on public roads; the drivers visual behaviour during a control condition will be broadly similar with other experimental work. Indeed, it could be argued that if visual behaviour is not similar to the empirically obtained distributions the task may not represent driving in a meaningful manner.

The systems employed in this experiment were selected as examples which were expected to require different information extraction strategies from the driver. However, it is possible that the demonstrated changes in driver visual and control behaviour were attributable to the applications (route guidance and congestion warning) and not to the interface required to utilise them. Further work could consider the same application and manipulate the interface. The fact remains though, that the systems did change the drivers' visual behaviour as a function of their use. Additionally, traffic density in the driving simulator was lower than on public roads, as a consequence of computer processing limitations. Thus, there may have been differences between the simulated driving task and the driving task on public roads. The validity of the simulator as a research tool to investigate visual demand is discussed in more detail in Chapter 7. The simulator does provide an opportunity to investigate issues which are ethically difficult to consider on public roads (i.e., where subjects and experimenters may be exposed to additional risk over and above their normal driving). The physical constraints within the facia of the vehicle simulator prevented positioning of the route guidance and congestion warning systems in exactly the same location. The congestion warning device was located immediately above the route guidance system. However, the difference in visual angle between a fixation from the focus of expansion to the route guidance system or congestion warning device was less than 5° visual angle, and therefore would be unlikely to have a large effect.

**Table 9 - 6. Comparison of control (normal driving) conditions for this experiment, Fairclough & Parkes (1990) and Wierwille (1993a)**

| | Fairclough & Parkes (1990) | Wierwille (1993a) | This experiment |
|---|---|---|---|
| Driver mirror | 2.3% | 0.7%** | 2.3% |
| Right region | 0% - 4.2%* | 0.7%** | 2.5% |
| Left region | 0% - 4.2%* | 0.7%** | 1.1% |
| Instrument panel | 1.5% | 3.0% | 3.3% |
| Forward view | 92.0% | 93.0%*** | 90.4% |

* *calculated from available data.*

** *calculated from the stated 0.2% of time glancing to the mirrors divided by the three regions. It should be noted that typically the proportion of time glancing to the driver mirror would be higher than the right and left driver mirrors.*

*** *sum of visual allocation to the roadway (centre and off-centre and signs / landmarks).*

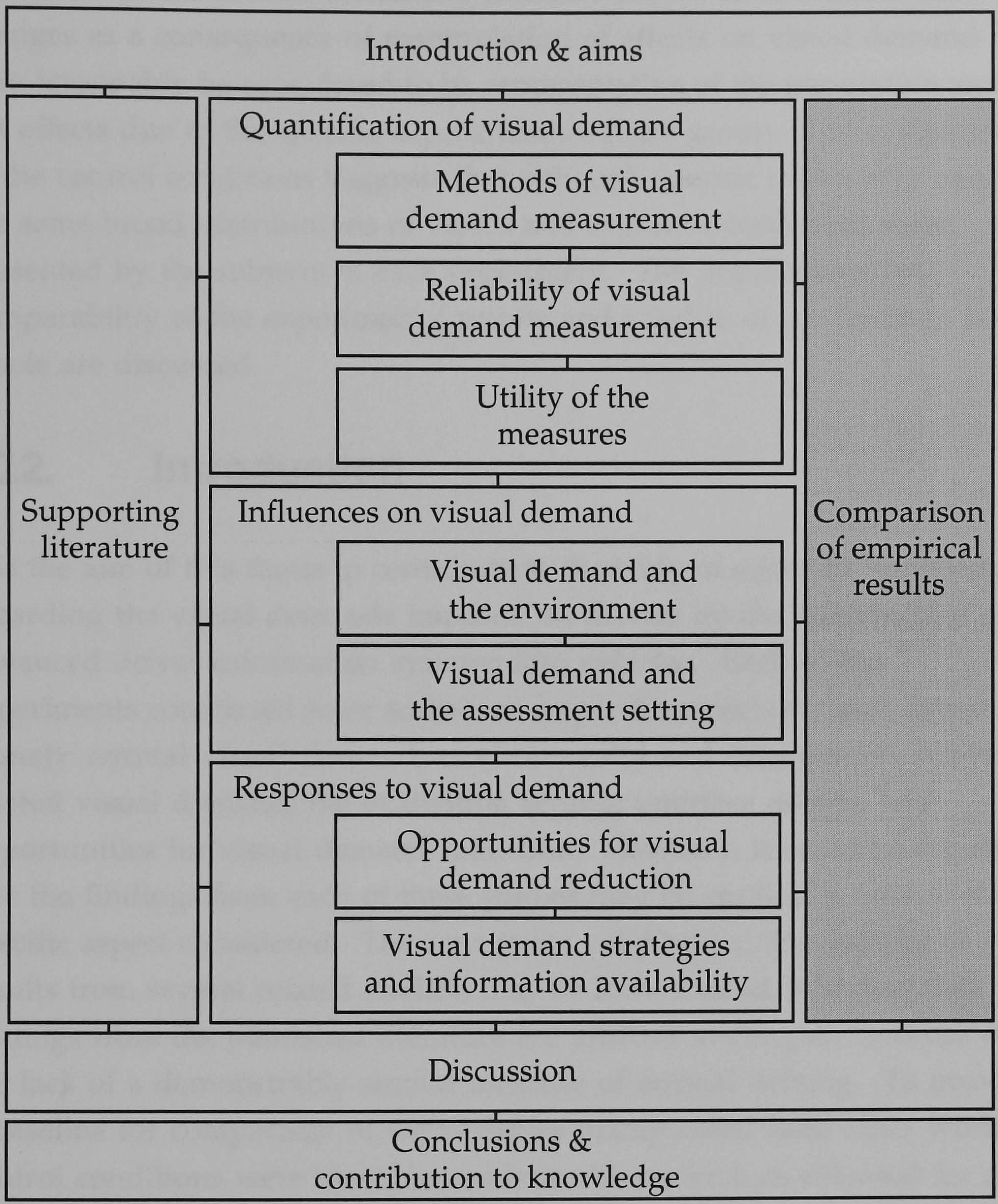
# 9.6. Chapter Conclusions

The experimental findings would suggest that the distribution of driver visual scanning is influenced by interface design and consequently, the availability of information to the driver. As stated by Wierwille (1993a) "...a device such as an in-car navigation system can profoundly affect the visual scan patterns of drivers", page 138. *System control* of information presentation has been shown to potentially lead to conflict between the visual demands of the roadway and the in-vehicle device. Design of driver information systems should support the availability of clear, simple information that enables the driver to *self-select* when to interact with such devices. It is hoped that this would facilitate interaction during periods when the driver has spare visual and attentional resources. The distribution of visual scanning and consequently the propensity for distraction from the roadway is influenced by the design of the in-vehicle interface.

# Chapter 10

# Comparison of the Control Conditions

# Comparison of the Control Conditions




## 10.1. Chapter Summary

The chapters in this thesis have aimed to address one or more specific issues associated with the measurement of driver visual demand, with reference to the introduction of driver information systems. The findings of each apply to the particular scenario considered. The generalisability of results to driver visual behaviour remains uncertain. This chapter considers the inter-relationships between the experimental work conducted in this thesis. It aims to support the generalisability of the findings by comparison of control conditions in each study. Data taken from the control conditions of the experiments are presented. If visual behaviour in the control conditions could be shown to be similar; the changes as a consequence of manipulation of effects on visual demand may reasonably be considered to be representative of the population and not effects due to the specific experiment's subject group. The comparison of the control conditions suggests that although specific differences exist, the same broad distributions of visual and cognitive behaviour were presented by the subjects in each experiment. The implications for comparability of the experimental results and validity of the findings as a whole are discussed.

## 10.2. Introduction

It is the aim of this thesis to contribute to the body of scientific knowledge regarding the visual demands imposed on drivers by the introduction of advanced driver information systems into vehicles. Each of the experiments conducted have addressed a specific aspect of visual demand, namely normal visual demand; environmental and information system related visual demand; the evaluation setting; interface design; and opportunities for visual demand reduction. However, it could be argued that the findings from each of these studies may be applicable only to the specific aspect considered. The concurrent validity (i.e., the validity of results from several related studies) may be low. Indeed, it is clear that findings from the published literature are difficult to compare because of the lack of a demonstrably similar measure of normal driving. To provide a baseline for comparison of the variables manipulated with other work, control conditions were identified early in the research as essential for all the experimental work. It is hoped that consistently presented *normative* or datum levels of visual and cognitive demand would enable comparison of the factors manipulated in each individual study.

### *10.2.1. Aims*

This chapter aims to determine the comparability of the results of each of the experimental studies undertaken. By presenting evidence that the results from the control conditions were similar, it sets out to support the generalisability of the research findings to the driving population as a whole.

## 10.3. Method

In this research experimental designs for each study were different. For this reason the control conditions are presented to enable some estimate to be made of how representative the driving conditions were, regardless of the manipulation of the independent variables for each experiment. The control conditions were conducted to be as close to the driving task as possible, given the experimental setting (e.g., road or simulator). The taxonomy for consideration of experimental data is shown in Table 10 - 1.

**Table 10 - 1. Notation for experimental work**

| | Experiment |
|---|---|
| Chapter 5 | Visual demand and the driving environment |
| Chapter 6 | Utility of metrics for the evaluation of driver information systems |
| Chapter 7 | Driving simulation for the evaluation of information systems |
| Chapter 8 | Route guidance information: verbal, visual or both? |
| Chapter 9 | Visual behaviour and the availability of advanced driver information |

A variety of experimental measures were employed in each of the studies. However, visual behaviour and subjective mental workload measures were used consistently in all experiments. Chapters 5 and 6 were conducted on public roads and Chapters 7, 8 and 9 in the driving simulator described in Chapter 7.

### *10.3.1. Considerations*

The structure of the dependent variables precludes statistical comparison of some data. For example, the total glance frequencies per condition recorded in each study cannot be compared as the duration of the experiments were different. Similarly, statistical correlation of visual behaviour measures was not possible as the summary data in each experiment were non-homogeneous within the metrics (i.e., the percentages of time per region is not the same order of magnitude as the glance duration data). Additionally, the subjects and numbers of subjects participating in each study were different and thus could not be matched to correlate the raw scores. Therefore, summary statistics are presented to provide comparison of the obtained results.

## 10.4. Results

### *10.4.1. Mean Glance Duration*

A comparison of mean glance duration for the control conditions in Table 10 - 2 is graphically presented in Figure 10 - 1. It can be seen that mean glance duration is similar in all regions. Chapter 5 presents longer glance durations. Table 10 - 3 shows that standard deviations were consistently greater in Chapter 5 than the other studies.

**Table 10 - 2. Mean glance duration (secs)**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5* | Chapter 6 | Chapter 7 | Chapter 8** | Chapter 9 | Mean |
| Driver mirror | 0.87 | 0.54 | 0.56 | 0.55 | 0.56 | 0.62 |
| Right region | 1.26 | 0.82 | 0.61 | 0.70 | 0.54 | 0.79 |
| Left region | 1.32 | 0.64 | 0.62 | 0.64 | 0.52 | 0.75 |
| Instrument panel | 0.98 | 0.53 | 0.53 | 0.55 | 0.46 | 0.61 |
| Overall mean | 1.11 | 0.61 | 0.57 | 0.61 | 0.52 | 0.68 |

* *Calculated from a mean of the rural, urban and motorway condition.*

** *No rear view was available in this experiment, a computer generated driver mirror was used.*

### *10.4.2. Glance Frequency per Minute*

Average glance frequency was highest to the driver mirror and right region and can be seen in Table 10 - 4 and Figure 10 - 2. The frequency of glances to the instrument panel can be seen to vary considerably across studies.

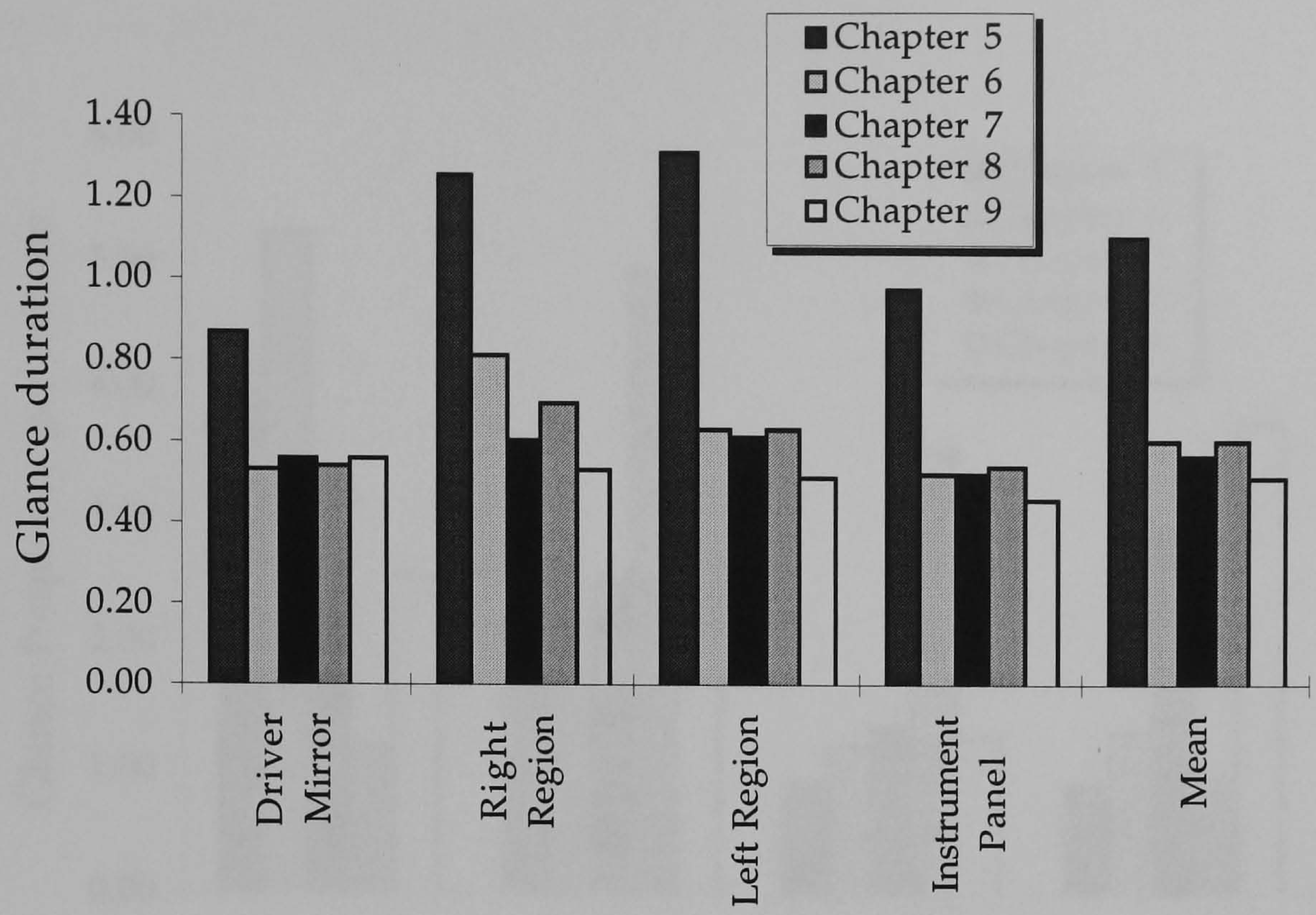



**Figure 10 - 1. Glance duration**

**Table 10 - 3. Standard deviation of glance duration**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5 | Chapter 6 | Chapter 7 | Chapter 8 | Chapter 9 | Mean |
| Driver mirror | 0.11 | 0.06 | 0.07 | 0.06 | 0.06 | 0.07 |
| Right region | 0.25 | 0.20 | 0.10 | 0.12 | 0.05 | 0.14 |
| Left region | 0.26 | 0.10 | 0.09 | 0.08 | 0.04 | 0.11 |
| Instrument panel | 0.36 | 0.06 | 0.04 | 0.08 | 0.17 | 0.14 |
| Overall mean | 0.25 | 0.05 | 0.04 | 0.09 | 0.04 | 0.09 |

**Table 10 - 4. Mean glance frequency per minute (gf/min)**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5* | Chapter 6 | Chapter 7 | Chapter 8** | Chapter 9 | Mean |
| Driver mirror | 4.02 | 5.26 | 2.44 | 1.19 | 2.54 | 3.09 |
| Right region | 2.84 | 2.14 | 2.49 | 4.95 | 2.76 | 3.04 |
| Left region | 0.92 | 1.21 | 1.34 | 3.58 | 1.27 | 1.66 |
| Instrument panel | 0.88 | 1.32 | 2.96 | 0.93 | 3.77 | 1.97 |

* *Calculated from a mean of the rural, urban and motorway condition.*

** *No rear view was available in this experiment, a computer generated driver mirror was used.*

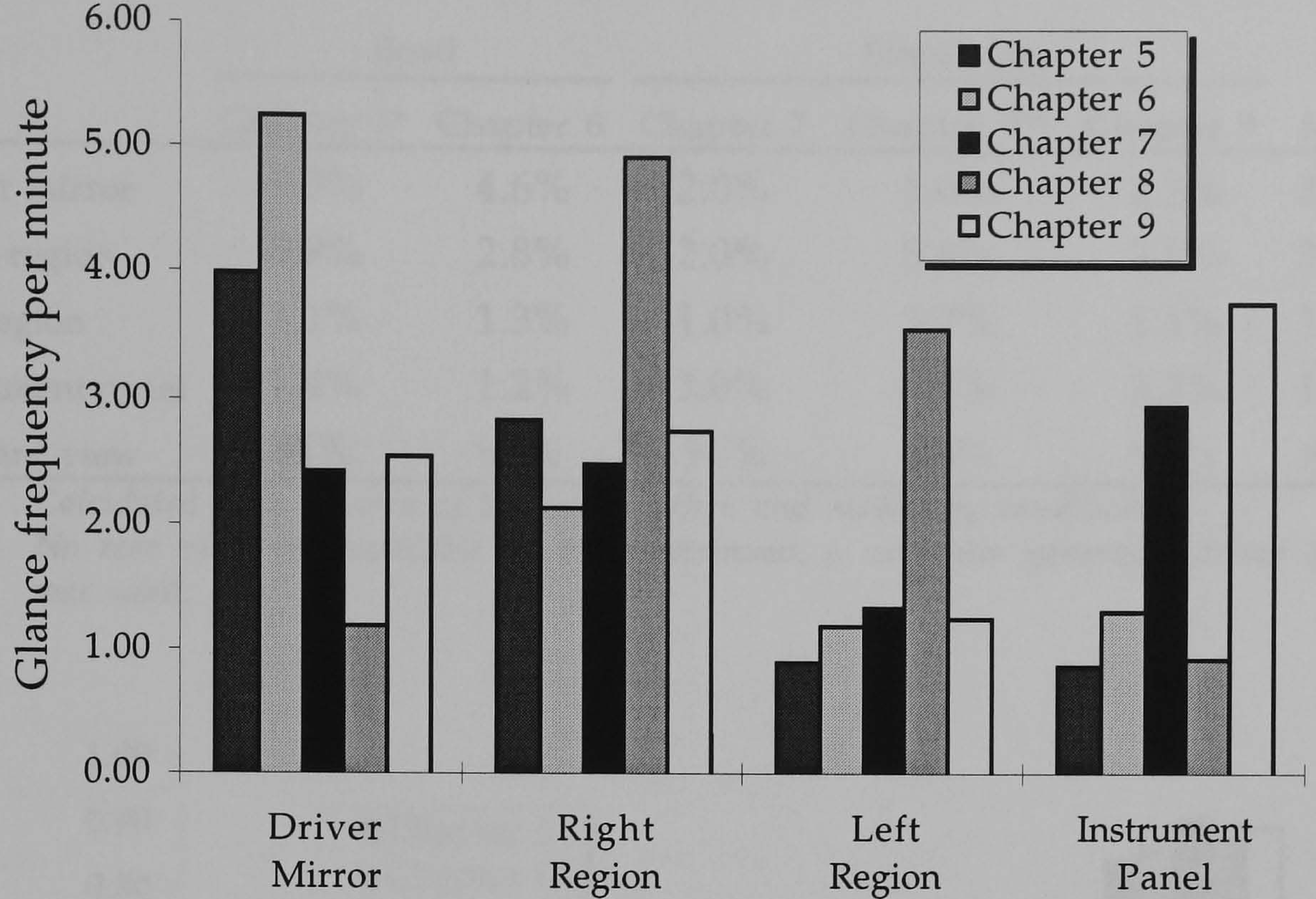



**Figure 10 - 2. Glance frequency per minute**

**Table 10 - 5. Standard deviation of glance frequency per minute**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5 | Chapter 6 | Chapter 7 | Chapter 8 | Chapter 9 | Mean |
| Driver mirror | 2.16 | 2.44 | 1.31 | 1.17 | 1.76 | 1.77 |
| Right region | 0.81 | 0.90 | 1.75 | 1.81 | 1.71 | 1.40 |
| Left region | 0.34 | 0.77 | 0.99 | 1.28 | 0.79 | 0.85 |
| Instrument panel | 0.56 | 0.86 | 2.96 | 0.94 | 1.84 | 1.43 |

### *10.4.3. Percentage Time per Region*

The percentage of total glance time in each identified region is shown in Table 10 - 6 and Figure 10 - 3. Subjects in Chapter 5 allocated more visual attention to the regions other than the forward view. Percentages of visual allocation tended to be longer to the driver mirror and right region than the left region and instrument panel.

**Table 10 - 6. Mean percentage time per region**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5* | Chapter 6 | Chapter 7 | Chapter 8** | Chapter 9 | Mean |
| Driver mirror | 5.9% | 4.6% | 2.0% | 1.0% | 2.3% | 3.2% |
| Right region | 5.9% | 2.8% | 2.0% | 5.8% | 2.5% | 3.8% |
| Left region | 2.1% | 1.3% | 1.0% | 3.7% | 1.1% | 1.8% |
| Instrument panel | 1.4% | 1.2% | 3.0% | 0.9% | 3.3% | 1.9% |
| Forward view | 85% | 90% | 91% | 88% | 90% | 89% |

* *Calculated from a mean of the rural, urban and motorway condition.*

** *No rear view was available in this experiment, a computer generated driver mirror was used.*

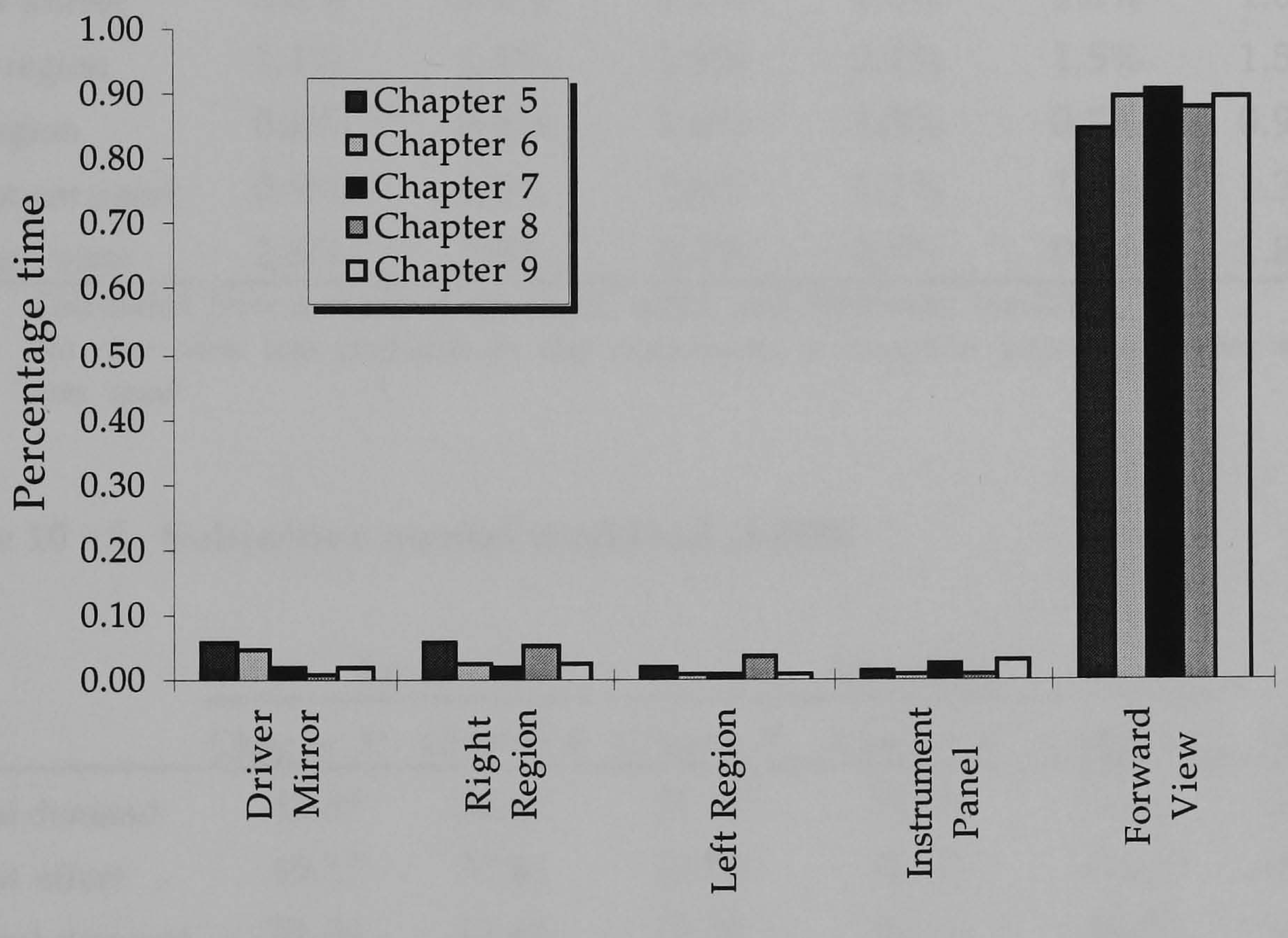



**Figure 10 - 3. Percentage time per region**

### 10.4.4. *Subjective Mental Workload*

The mean subjective mental workload results are presented in Table 10 - 8 and Figure 10 - 4. *Mental Demand* and *Mental Effort* sub-scales were reported by subjects to impose greater mental workload than *Physical*

*Effort, Time Pressure, Distraction and Stress Level.* Studies reported in chapters 5, 8 and 9 resulted in greater *Overall Mean* mental workload than Chapter 6 or 7. Standard deviations were calculated to be highest in Chapter 9, see Table 10 - 9. No clear differences were observed across component sub-scales.

**Table 10 - 7. Percentage time per region: standard deviation**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5 | Chapter 6 | Chapter 7 | Chapter 8 | Chapter 9 | Mean |
| Driver mirror | 2.2% | 2.2% | 1.1% | 1.0% | 1.5% | 1.6% |
| Right region | 1.1% | 1.1% | 1.8% | 2.1% | 1.5% | 1.5% |
| Left region | 0.6% | 0.8% | 1.0% | 1.3% | 0.7% | 0.9% |
| Instrument panel | 0.9% | 1.0% | 1.6% | 1.1% | 1.8% | 1.3% |
| Forward view | 2.6% | 2.6% | 3.0% | 2.8% | 0.4% | 1.8% |

* *Calculated from a mean of the rural, urban and motorway condition.*
** *No rear view was available in this experiment, a computer generated driver mirror was used.*

**Table 10 - 8. Subjective mental workload (1-100)**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5* | Chapter 6 | Chapter 7 | Chapter 8 | Chapter 9 | Mean |
| Mental demand | 45.87 | 32.61 | 31.88 | 52.25 | 40.65 | 40.65 |
| Mental effort | 49.17 | 32.61 | 32.88 | 48.83 | 44.65 | 41.63 |
| Physical demand | 31.04 | 17.61 | 22.00 | 29.13 | 34.12 | 26.78 |
| Time pressure | 27.42 | 19.22 | 16.35 | 41.70 | 25.71 | 26.08 |
| Distraction | 29.13 | 21.44 | 27.71 | 32.54 | 32.24 | 28.61 |
| Stress level | 29.87 | 20.44 | 26.00 | 36.25 | 30.24 | 28.56 |
| Overall mean | 35.42 | 24.00 | 26.10 | 40.12 | 34.60 | |

* *Calculated from a mean of the rural, urban and motorway condition.*

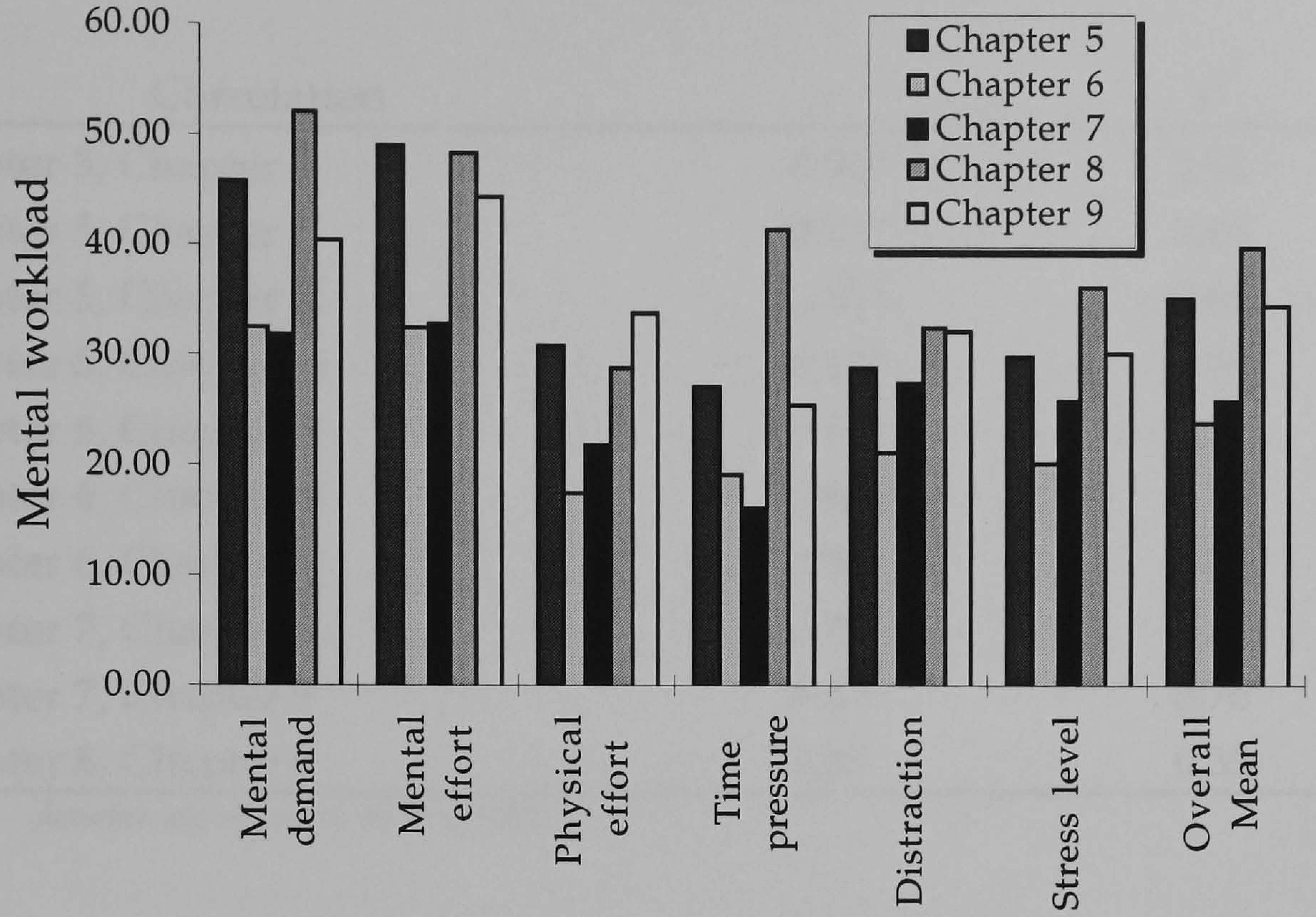



**Figure 10 - 4. Subjective mental workload**

**Table 10 - 9. Subjective mental workload (1-100): standard deviation**

| | Road | | Simulator | | | |
|---|---|---|---|---|---|---|
| | Chapter 5 | Chapter 6 | Chapter 7 | Chapter 8 | Chapter 9 | Mean |
| Mental demand | 21.29 | 17.35 | 29.12 | 25.76 | 26.95 | 24.09 |
| Mental effort | 20.91 | 19.78 | 23.63 | 24.41 | 30.31 | 23.81 |
| Physical demand | 15.81 | 13.2 | 19.07 | 17.97 | 28.06 | 18.82 |
| Time pressure | 12.89 | 15.07 | 12.3 | 23.65 | 22.31 | 17.24 |
| Distraction | 20.26 | 19.1 | 22.97 | 24.08 | 27.21 | 22.72 |
| Stress level | 15.20 | 15.57 | 20.54 | 20.76 | 26.15 | 19.64 |
| Overall mean | 13.15 | 13.63 | 17.35 | 16.88 | 24.32 | |

### *10.4.5. Correlation Matrix for Subjective Mental Workload Components*

Table 10 - 10 shows the correlation matrix for the subjective mental workload scores. The significance values have been obtained using Fisher's *Zr* transformation. It can be seen that only two correlations did not reach significance, the mental workloads imposed in chapters 7 and 8 and chapters 8 and 9.

**Table 10 - 10. Subjective mental workload correlations**

| Correlation | r | $r^2$ |
|---|---|---|
| Chapter 5, Chapter 6 | 0.96* | 0.92 |
| Chapter 5, Chapter 7 | 0.81* | 0.66 |
| Chapter 5, Chapter 8 | 0.81* | 0.65 |
| Chapter 5, Chapter 9 | 0.95* | 0.90 |
| Chapter 6, Chapter 7 | 0.84* | 0.70 |
| Chapter 6, Chapter 8 | 0.89* | 0.78 |
| Chapter 6, Chapter 9 | 0.87* | 0.76 |
| Chapter 7, Chapter 8 | 0.51 | 0.27 |
| Chapter 7, Chapter 9 | 0.87* | 0.76 |
| Chapter 8, Chapter 9 | 0.59 | 0.35 |

* *denotes significance at $p < 0.05$*

## 10.5. Discussion

This chapter investigated the degree of similarity of results between the control conditions for the studies described in the previous chapters (5 to 9). It was hoped that the concurrent validity could be demonstrated to be high. This would enable more meaningful comparison of the factors investigated in the individual studies as contributors to an understanding of the visual demands on the driver as a whole. Visual and cognitive behaviour (with some exceptions) can be seen to follow the same broad distributions.

### *10.5.1. Glance Duration*

Initial consideration of the mean glance duration data for the five studies may suggest little agreement between investigations. However, all Chapter 5 glance durations were longer during the control condition than any of the other studies. This was particularly interesting in that the video tape transcription method adopted in this *first* study was different to that employed during all the other experimental work. The video tape records were transcribed to a resolution of 0.05 secs, rather than 0.5 secs, in the subsequent studies. It was considered that the difference may have distorted the distribution of scores. Therefore, the data were filtered to reduce the resolution (to half a second) in line with the other studies. The manipulation of the data had essentially no effect on the mean scores and so is not included here. However, the analysis dismissed the concern that the data transcription method may have affected the obtained results.

The increased glance durations shown in Figure 10 - 1 may be attributable to the small sample and indeed this assumption is supported by the greater standard deviations for the Chapter 5 data. The subject group may have been insufficient to provide an accurate representation of the population they were drawn from. If the Chapter 5 data are excluded from the glance duration information, the mean score is 0.58 secs.

Standard deviations of glance duration were small, typically less than 0.2 seconds. Two scores of interest aside from the Chapter 5 data discussed above, were the Chapter 6 right region and Chapter 9 instrument panel glances. Right turn glances in the road experiment could have exhibited increased standard deviations as a consequence of extended *safe* glances while the vehicle was stationary at a junction. The relatively small number of right and left glances would be more prone to increased variance than for example, glances to the driver mirror which is frequently attended to by the driver. Additionally, in the U.K. right window glances are required for safe negotiation of both left and right turns, whereas left turns only require (while not recommended) right region glances. Therefore, if long glances were to occur they are likely to be more frequent to the right region.

A high standard deviation in the duration of glances to the instrument panel in Chapter 9 was found. The subjects may have been attending to the instrument panel to obtain speed information in the degraded visual environment of the simulator. On public roads the visual scene provides an enriched view from which optic flow (Gibson, 1979) information can be obtained. However, in the simulator the perception of objects moving across the retina would be reduced and the texture of surfaces was either absent or radically reduced with respect to public roadways and the objects one would expect to perceive. Large standard deviations have also been found by other researchers when considering glance duration data (e.g., Rockwell, 1988).

### 10.5.2. *Glance Frequency per Minute*

It is clear that during normal driving the frequency of glances to regions of the visual scene is different. The experimental results from all studies reported in this Chapter support this. Typically, driver mirror glances encompass the greatest number of individual glances. It is interesting to consider the glance frequencies to the instrument panel during the simulator experiments (chapters 7, 8 and 9). Instrument panel glance frequencies were higher than corresponding road trials (chapters 5 and 6) in two of the three simulator studies. The finding would support the assumption that in the degraded visual environment increased visual checking to the instrument panel (to control speed) is required by the drivers to compensate for reduced optic flow information.

### 10.5.3. *Percentage Glance Time per Region*

The relative distribution of visual attention can be seen to be similar for the control conditions in all the studies undertaken. It is particularly interesting that in the vehicle simulator drivers can be seen to continue to carry out visual checking manoeuvres even though it is clear that no personal risk will arise from the failure to observe or avoid an incident. Drivers may have been executing proceduralised visual checking routines identified as appropriate in a driving-like task (Anderson, 1987). It would be interesting to degrade the simulation to a point where the driver no longer feels such checking is worthwhile. This could determine which features and at what level of fidelity the driver decides the task represents driving and not object tracking. The road studies presented slightly different distributions of visual scanning to the simulator experiments. It can be seen that there was more frequent checking to the driver mirror in the road trials than the simulator studies. Consequently, the total time allocated to the forward view is reduced. However, the effect is small.

Standard deviations of the percentage of visual allocation per region tend to around 1%. This is small by comparison with the allocation to the forward view, but large in relation to the other regions: driver mirror, right and left regions and instrument panel. Perhaps the relative allocation of visual attention should be considered as a distribution and not in isolation from the other scores. For example, the percentage of glances to the forward view (80% to 90%) are of an order of magnitude greater than to the driver mirror (0% to 5%) or other regions. The variance in the standard deviations may also reflect differences between individual subjects scanning strategies.

### *10.5.4. Subjective Mental Workload*

It can be seen from the results that subjective mental workload ratings for the control conditions in each experiment were similar, especially for chapters 6 and 7. Chapter 7 was conducted to explore the reliability of recorded driver visual and cognitive behaviour. The experimental design was essentially the same as in Chapter 6. It is suggested that these subjective mental workload data present good evidence for the comparison of experimental findings between the studies described in this thesis. Table 10 - 10 presents correlation coefficients and $r^2$ values (reporting the variance attributable to the relationship between the variables). It can be seen that in only two correlations (Chapter 7, Chapter 8, and Chapter 8, Chapter 9) were significantly high correlations not achieved. Subjects reported similar levels of subjective mental workload even though the control conditions were taken from different experiments and thus only Chapter 6 and Chapter 7 provide truly comparable controls.

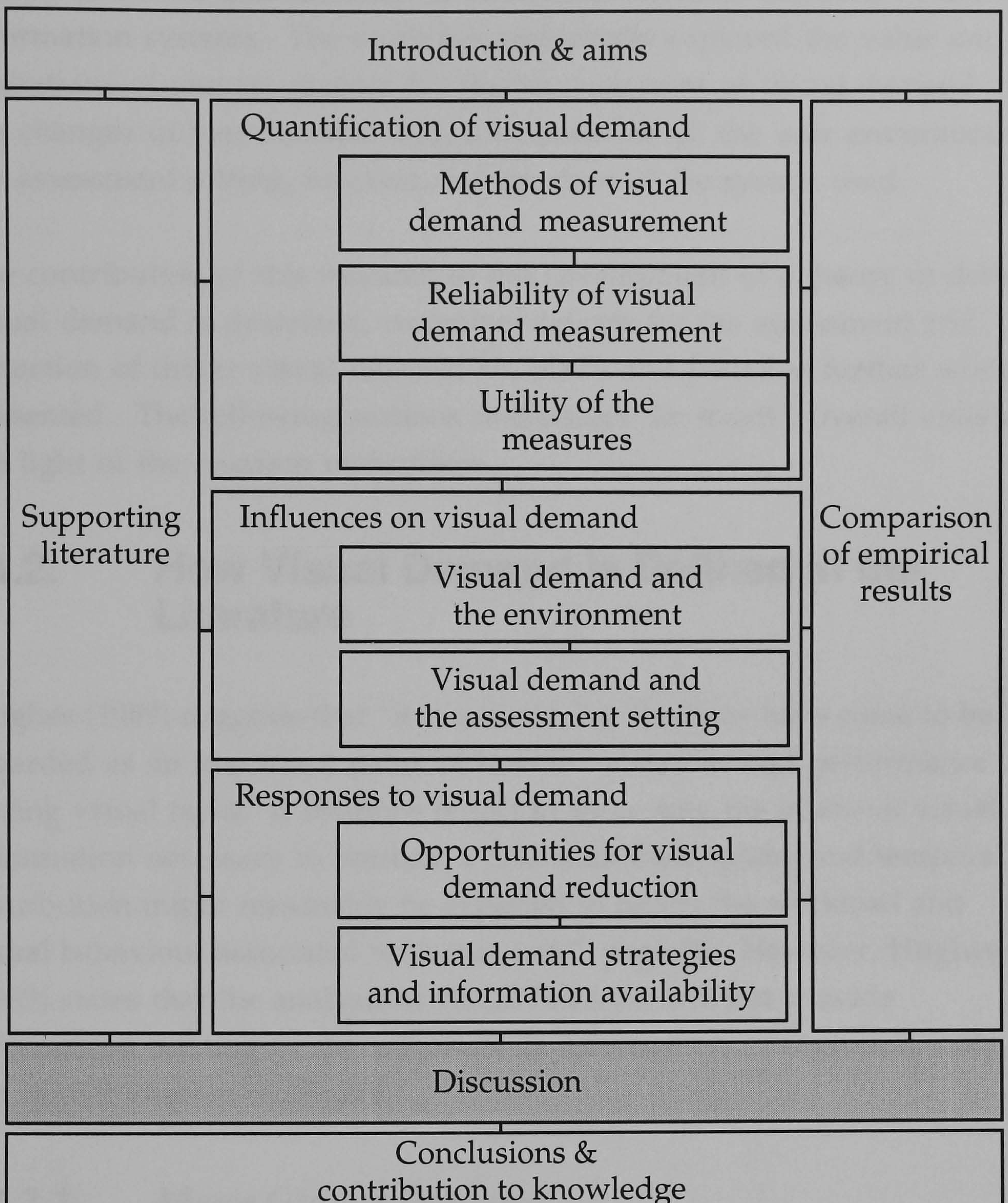
The mental workload standard deviation scores were large and provide a caveat for the application of adapted NASA R-TLX (Fairclough, 1991). The high inter-subject variability, while consistent, reduces the power of any conclusions drawn from trends in experimental work.

## 10.6. Chapter Conclusions

The comparisons developed in this chapter support the reliability of findings of each experiment and contribute to the development of an understanding of the features and processes of drivers' visual demand during use of information systems. It suggests that the results of each experiment may be generalised to the driving population on the grounds that the control conditions are comparable and representative of real driving.

# Chapter 11

# Discussion




## 11.1. Chapter Summary

This research has investigated visual demand and how it is affected by the introduction of advanced driver information systems. In this chapter the aims of the project are discussed, other relevant issues considered and a model of driver visual demand proposed.

The research in this thesis has investigated how visual demand is quantified in the literature. It has also considered the reliability of methods adopted for the analysis of driver visual behaviour. Measurement was taken of the visual activity normally undertaken by drivers to enable quantification of additional demands imposed by driver information systems. The work has empirically explored the value and limitations of various metrics for the measurement of visual demand and the changes in that demand with manipulation of: the user environment, the assessment setting, function and interface of the system used.

The contribution of this research to the development of a theory of driver visual demand is described, recommendations for the assessment and reduction of driver visual demand are made and potential further work presented. The following sections re-consider the thesis's overall aims in the light of the research undertaken.

## 11.2. How Visual Demand is Defined in the Literature

Hughes (1989) suggests that "it is natural that fixations have come to be regarded as an important index of human behaviour and performance during visual tasks. If fixations reflect in some way the intake of visual information necessary to perform a task then their spatial and temporal distribution might reasonably be expected to reflect the workload and visual behaviour associated with that task", page 98. However, Hughes (1989) states that the analysis of visual fixations will not provide information relating to the relevance of information in cognition, only the spatial location of targets.

### *11.2.1. Mean Glance Duration*

Glance duration reflects the total single glance time the driver is prepared to accept away from the forward view. It may be influenced by the quality of the target interface (Stevens & Martell, 1993), the complexity of the environment (Wierwille et al., 1988) and the available attentional resource (Wickens, 1984). Cohen (1981) presents data which suggests that drivers' mean glance duration in road trials are not replicated in the laboratory. In the research, a static slide presentation was used over a five second period as a comparator with a road scenario of similar duration. It is not reported in the paper which of the specified target regions the mean glance durations data relate to. As has been demonstrated by Wierwille et al., (1988b), changes in the duration of glances are dependent on the region of the visual scene in question. For example, as the mental workload increases, the mean duration of glances to information systems has been shown to decrease, while the mean glance duration to the forward view increases. Work by Hughes & Cole (1988) presents data supporting the use of laboratory studies for the investigation of driver visual behaviour. Data collected provide "some hope that glance durations are a reasonably consistent measure of driver 'in-car' visual performance" (Rockwell, 1988), page 323. It is suggested that the *in-car* systems which drivers use impact glance durations less than the demands of driving. Rockwell (1988) suggests that poor display/control design is more likely to lead to an increase in glance frequency than glance duration.

Driver glance durations have been presented for performance in both individual tasks (e.g., changing a cassette; Dingus et al., 1989) and throughout an entire experimental condition (e.g., when comparing different route guidance systems, Fairclough & Parkes, 1990). Both approaches have specific limitations. For example, the start and stop definitions for *task glance duration* are rarely reported in the literature. Therefore, valid comparison of reported results is difficult. Although, glance durations over *entire experimental conditions* are useful for comparison between conditions, they remain limited for comparison across studies.

### *11.2.2. Extended Glance Duration*

Mean glance duration may in fact be a poor reflection of drivers' visual demand. It is likely that the distribution of glance duration scores will be positively skewed with the corresponding impact on the use of the mean as a measure of central tendency. Two issues arise from the potentially non-normally distributed glance durations. First, the median may provide a more meaningful reflection of central tendency, as it is less sensitive to extreme scores. Second, use of the mean requires approximately 50% of the distribution be of a longer duration. Therefore, its value as an indicator of deviations from the forward view, and consequently reduced reaction time to a potential incident is reduced. Perhaps use of the mean should be supplemented by a measure reflective of the extremes of the distribution (e.g., the 90th percentile), in addition to the standard deviations. Such data has been reported (Rockwell, 1972; Tijerina, Kiger, Rockwell, & Wierwille, 1995), but is infrequently presented in the published literature.

### 11.2.3. *Maximum Glance Duration*

It has been argued that road or simulator based experimental evaluation of advanced driver information systems may be unnecessary in some circumstances (Parkes, 1995). It was suggested that a simple *maximum glance duration* criterion could be sufficient to establish unacceptability of a information system. The subject would be presented with the information system and required to perform a task within a pre-determined duration. If the visual demand imposed by the system is found to be greater than the criterion the system would be deemed unacceptable for use on public roads. Such a *criterion based* approach could provide a cheap alternative to road or simulator experimental work. The protocol cannot however, consider systems that require interaction with the roadway network to determine their successful use (e.g., a route guidance system). Furthermore, maximum glance duration evaluations could only consider the ease with which information can be extracted from the human computer interface.

### 11.2.4. *Glance Frequency*

While it is difficult to infer a relationship between high glance frequencies and safety (i.e., frequent glances away from the forward view may not necessarily result in an accident). It is likely that excessive glances to a driver information system will be indicative of a poorly designed interface. Such measures of glance frequency should be considered within the context of the task of interest. Consider a situation where the driver looks to a new route guidance system. Fifteen glances may not be a cause for concern if this occurs during a two hour drive. However, the same fifteen fixations during a one minute period presents a different perspective on the usability of such a device. It is therefore important to specify the experimental context in which glance frequency is recorded. In this thesis all glance frequency results have been presented as glance frequency per minute (gf/min) to enable comparison with other research.

### 11.2.5. *Task Glance Frequency*

A distinction may be made in visual behaviour measurement regarding the entire experimental condition or the specific task to be performed. For example, adjustment of the air conditioning temperature would constitute individual task performance (e.g., Dingus et al., 1989), whereas, use of the in-vehicle air conditioning unit throughout an experimental drive would be considered as use during the entire experimental condition (e.g., Fairclough & Parkes, 1990; Lansdown & Fowkes, 1995). Researchers have reported visual behaviour using both approaches. A task focused assessment is useful to consider individual features of the interface, but the context within which they are performed is lost. In contrast, measurement of glance frequency throughout the experimental condition provides only a general indication of the change in glance frequency per condition.

It is argued that consideration of the experimental condition provides a richer picture of the integration of specific in-vehicle tasks by considering them as part of the broader activity of driving, rather than a task based approach. Empirically, such a strategy will inevitably dilute any affects attributable to performance of a particular task. However, if significant differences can be achieved by consideration of the whole activity (which is presumably how both conventional and new advanced information systems will be utilised), such effects would certainly be present when performing the activity in isolation.

### 11.2.6. *Total Visual Allocation and Time Away from the Forward Scene*

It has been stated that the introduction of advanced driver information systems imposes a visual competitor for the driver's attention. Thus, as has been demonstrated in this document and in the published research, use of a visually-based information system reduces the number and duration of visual checking glances to the forward view and driver mirrors. The reduction in forward view checking, and of the other regions of the visual scene to a lesser extent (although arguably more importantly), may reduce the reaction time to a potential hazardous incident. Time away from the forward scene provides a measure reflecting the visual impact of an information system with reference to the driver's primary information source. Between 62% and 92% of visual allocation has been recorded to the forward scene Wierwille (1993a) and Fairclough & Parkes (1990) respectively. Forward scene deviations are problematic in that they cannot differentiate between safe and unsafe interactions with the information system. Therefore, extended times spent glancing away from the forward view cannot be simply interpreted as imposing high visual demand. The drivers may have rationally evaluated the traffic environment and attended to the information system and other identified regions at times when risk of non-forward scene glances was minimal. Consequently, measurement of driver visual demand must encompass more than any single measure to establish the driver's strategy for visual sampling.

### *11.2.7. Mental Workload and Visual Behaviour Measures*

Subjective mental workload assessment techniques have been shown in Chapters 5, 6, 7 and 8 to reflect visual behaviour metrics closely. In visual demand research techniques like the adapted NASA R-TLX (Fairclough, 1991) may be utilised to provide a reliability check for obtained visual measures. Further investigation of the reliability and validity of the relationship of such methods as an index of visual demand may offer the possibility of recording and using results from subjective mental workload alone. Certainly, the results presented here suggest suitability as a screening tool prior to recording of direct visual metrics. For example, it is argued that a prototype system presenting very high subjective mental workload would be unsuitable for use on the road. However, low subjective mental workload ratings would provide some confidence that the investment in visual behaviour assessment would be worthwhile.

### *11.2.8. Interactions Between Metrics*

The driving task has been interpreted as a multi-levelled one (Janssen et al., 1993; Michon, Smiley, & Aasman, 1990; Parkes, 1991). Changes in visual demand from the introduction of driver information systems into vehicles should entail a multi-faceted assessment strategy (Parkes, 1991). A single metric will only reflect one or more levels of the task (e.g., lane deviation implies a loss of vehicle control, but nothing can be concluded about navigational decisions that may occur at a more strategic level).

Comparisons can be made between visual behaviour measures which offer the opportunity to address different conceptual levels of the driving task. This approach has been tentatively proposed by Zwahlen et al. (1988), as described in Chapter 2. The approach provides a richer picture of the drivers' interaction with information systems because the relationship between glance duration and frequency can be visualised. The design guide was used to evaluate the congestion warning system (used in Chapters 6, 7 and 9, Stevens & Martell, 1993). The research differentiated between tasks which imposed excessive glance durations or frequencies, see Figure 11 - 1. Four tasks were evaluated. Roadsign identification [R], quiescent congestion warning device [Q] and beeping congestion warning device [B] can all be seen within the acceptable region of Figure 11 - 1. Detailed congestion warning device information [D] falls within the grey area between an acceptable and unacceptable visual task demand. Many individual performances (shown as small black squares) were observed in the unacceptable region. Experimental work described in chapters 6, 7 and 9 is in agreement with these findings (i.e., some congestion warning device tasks impose excessive visual demand on the driver).

A similar approach was advocated by Fairclough, Ashby, & Parkes (1991). A cumulative frequency distribution was used to evaluate the comparative demands of two systems in terms of the proportion of glances over a pre-determined criterion, see Figure 11 - 2. For example, (a) indicates that 50% of glances to both map (TravelPilot) and symbol (LISB) based systems were 1 second or less. In position (b), 82% of glances were within the (grey, nominally acceptable) 2 second limit for the map-based information system. Use of the symbol-based system (c) resulted in 93% of glances within the grey region.

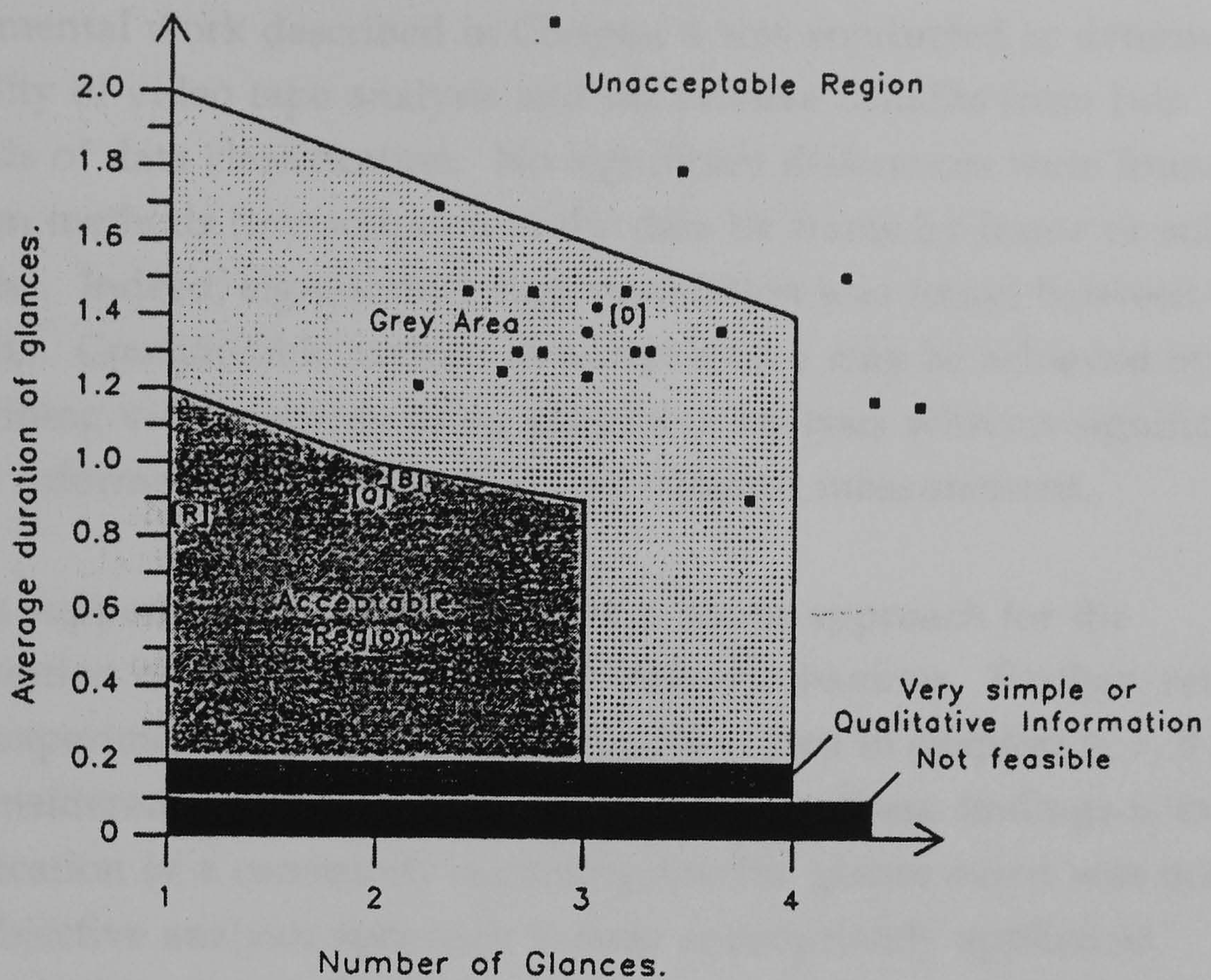



**Figure 11 - 1. Example graph illustrating the performance of several in-vehicle tasks using Zwahlen et al.'s design guide, from Stevens (1992)**

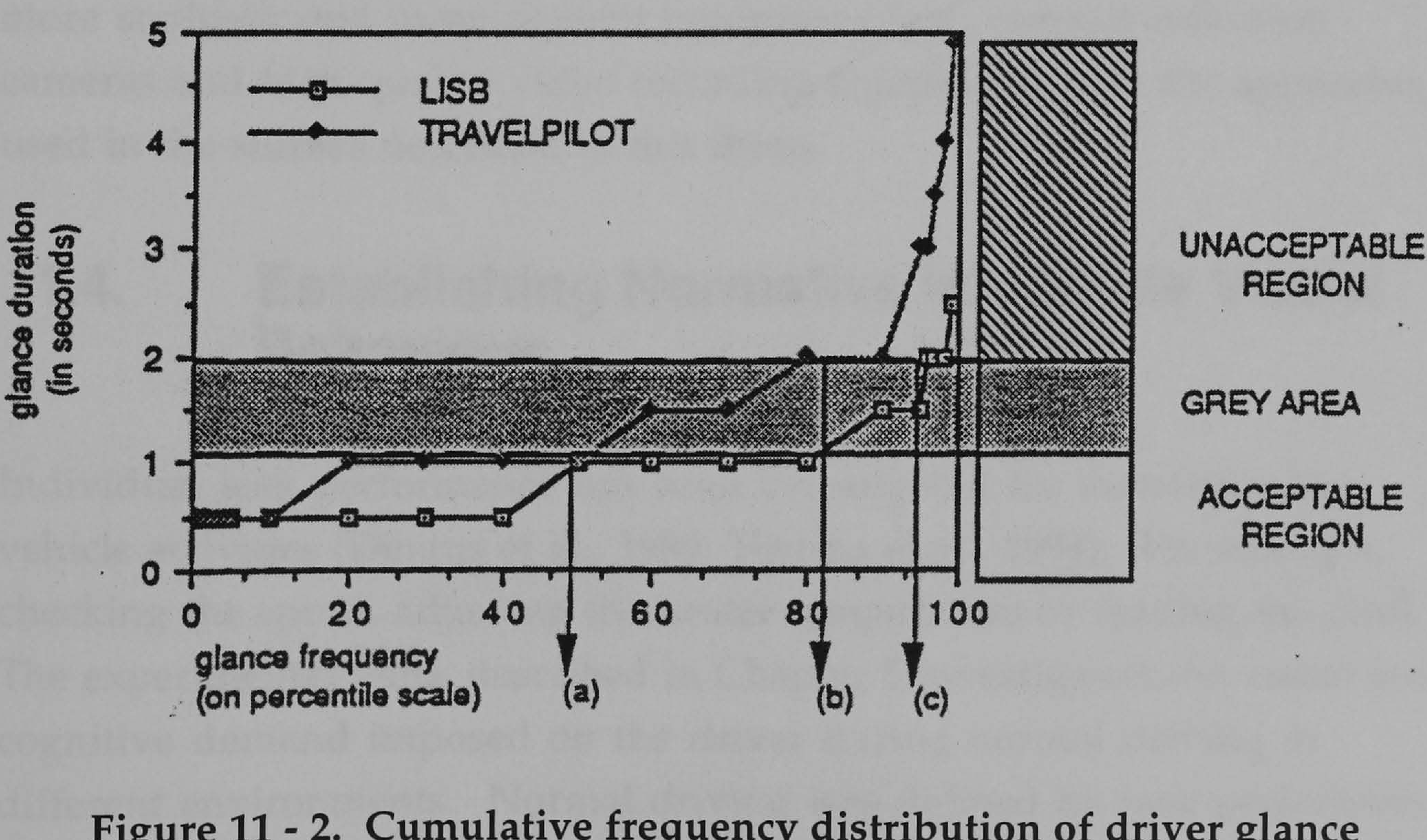



**Figure 11 - 2. Cumulative frequency distribution of driver glance behaviour, from Fairclough et al. (1991)**

## 11.3. Reliability of Video Tape Transcription

Experimental work described in Chapter 4 was conducted to determine the reliability of video tape analysis and the relative benefits from two methods of data classification. No significant differences were found between methods (transcription of the data by frame by frame or subjective analysis). Indeed, significantly high correlation was found between both methods. Considerable savings in analysis time may be achieved by transcribing video records using subjective analysis without significant loss of information for driving visual demand measurement.

Results support the use of a subjective analysis approach for the transcription of video tape records of driver behaviour. Further, reliability of the experimental results from studies described in chapters 6, 7, 8 and 9 was considered by the investigation. A caveat to these findings is that the identification of a commonly occurring specific glance event was poor. The subjective analysis approach is most appropriately applied to determine the general distribution of visual behaviour. It is valid for identification of broad differences between glance durations (e.g., a one second glance or a three second glance), but would be completely inappropriate for the investigation of individual fixations (e.g., 100 ms or 300 ms glance durations). Analysis of specific fixation durations requires more sophisticated measurement equipment (e.g., corneal reflection cameras and high quality video recording equipment) than the apparatus used in the studies described in this thesis.

## 11.4. Establishing Normative In-vehicle Visual Behaviour

Individual task performance has been investigated for numerous in-vehicle activities (Dingus et al., 1989; Tijerina et al., 1994). For example, checking the speed, adjusting the heater temperature or reading the clock. The experimental work described in Chapter 5 investigated the visual and cognitive demand imposed on the driver during normal driving in different environments. Normal driving was defined by task performance without the introduction of advanced vehicle information systems. Three driving environments were considered: urban, rural and motorway. The experiment established that road type does affect the nature of the allocation of visual and cognitive resources.

Normative levels of visual and cognitive demand for the urban, rural and motorway driving environments were established. Urban driving was found to be more visually demanding than either motorway or rural roads. This result was supported by the subjective ratings of mental workload. Most notably, in all three road environments drivers exhibited spare visual capacity, as has been previously demonstrated by other researchers (Hughes & Cole, 1986; Mourant et al., 1970; Rockwell, 1972; Rockwell, 1988).

Visual demand imposed on the driver has been shown to vary as a function of the complexity of the driving environment they negotiate. The findings highlight the need to quantify test routes adopted in experimental work. Different visual demands inherent in the roadway environments may confound data interpretation. It would be interesting to explore the visual demands at accident *blackspots*. Identification of regions with high environmental visual demand may provide opportunities to reduce attentional loads and decrease accidents. In-vehicle systems could consider the visual demand associated with particular road types (e.g., urban driving, see Chapter 5) with the result that excessively complex information is not presented to the driver during such situations.

Investigation was made into the normal environmental variance and the visual demands imposed on the driver. By comparing the distribution and quantity of visual and cognitive resources in such situations, the impact of the addition of advanced driver information systems may be better considered.

## 11.5. Sensitivity of Visual and Mental Workload Measures

This research has measured the impact the introduction of certain types of in-vehicle information systems namely, congestion warning, in-car entertainment and route guidance on driver visual behaviour. It is important to note that the systems were used as examples of in-vehicle technology which would influence driver visual behaviour, and not as systems which were under evaluation. Thus, the results from this experimental work may only be reflective of systems which utilise similar interfaces. However, on the basis of the literature review and obtained empirical data, it is suggested that the observed visual scanning strategies are reflective of the demands of commonly used in-vehicle interfaces. For example, the congestion warning device was representative of a visually complex display, typically requiring infrequent but extended glance durations. The route guidance application (employed in Chapter 9) was a simple symbolic display where the task required subjects to make frequent but brief glances.

The experimental work has demonstrated the sensitivity of metrics of visual behaviour for the determination of visual demand imposed over and above that which can reasonably be expected from the typical driving task. In Chapter 6, a congestion warning device was compared to an in-car entertainment system and to driving with no additional information extraction task. The results show that congestion warning device use results in frequent and extended glances to the system to the detriment of roadway visual scanning. The measures employed were sensitive enough to differentiate significantly between the three conditions. The in-car entertainment system was included in the analysis to provide a comparison with an in-vehicle information extraction task which is currently presumed to be reasonable. The assumption is made because no legislation is currently required (in the U.K.) prior to the introduction of an in-car entertainment system into a vehicle.

There were some user-interface problems identified with the congestion warning device, although the aim of the experiment was not to evaluate the system. Problems identified included: flashing symbols, which unfortunately oscillated at approximately the frequency that the drivers were prepared to make repeated glances to the system, and inconsistent relationships between the controls and displays when zooming the LCD route map in and out.

The prototype route guidance system investigation reported in Chapter 9 was used to explore how restrictions on the availability of information to the driver may change the nature of visual scanning. The system was compared with the congestion warning device. The experiment demonstrated changes in the distribution of driver visual scanning as a result of the experimental manipulation of the interface. Thus, not only will information systems impose a visual demand on the driver's attentional resources, but the nature of these demands will be a function of the interface design. Information should be available to the driver continuously (whenever possible) to enable them to employ effective strategies for use of in-vehicle systems.

It is clear that some information systems will impose unreasonable demands on drivers' visual attentional resources without human factors input during their design. A strategy for the development and assessment of such devices is required. However, the literature in this domain remains scarce and comparison between studies is difficult (see Chapters 2 and 10.

## 11.6. Assessment Settings for Visual Demand Measurement

Selection of the assessment setting for driver visual behaviour research will inevitably require compromise. The research must consider the relative merits of the available options. For example, the ecological validity of a road trial with the experimental control offered in a laboratory setting. The benefits and limitations of experimental work in different driving environments on the visual behaviour of the driver are discussed below.

Gstalter & Fastenmeier (1991) argue that evaluation of route navigation systems (and presumably other driver information systems) can only be achieved by varying the test route such that the drivers are kept at near maximal workload. They state that "... a population of experts will not reveal costs of navigation systems in the sense of visual costs, attention errors and so on...", page 20. They do, however, suggest that experts can provide solid and neutral judgements regarding the costs and benefits of navigation systems. They propose that field trial subject groups should be composed of novice and elderly (or worst case) drivers. Gstalter & Fastenmeier (1991) expect that the costs, benefits and risks associated with navigation systems are most distinct when utilising subjects drawn from these populations.

Subject stratification and selection is particularly important when conducting automotive human factors research. Many researchers have reported evidence of significantly different visual behaviour in novice and expert drivers (Duncan et al., 1991; Masuda, Nagata, Kuriyama, & Sato, 1990; Mourant & Rockwell, 1972; Nagata & Kuriyama, 1982). Age related decreases in information processing are well reported also, the interested reader is referred to (Clancy & Hoyer, 1994; Fisk & Rogers, 1991; Morrow, Leirer, & Altieri, 1992).

Assessment of information systems may be performed in several environments. These include: vehicle and/or task simulation, field trial or private test tracks and road trials (public or private). Selection of an assessment environment will inevitably be a compromise of many issues, including: experimental hypotheses, available time, funding and development stage in the design process. For example, real road trials would be inappropriate at the concept stage of product development. Ecological validity is the degree to which a task truly represents that which it is intended to. Assessment environments may be viewed as a range with low fidelity simulations (e.g., primary tracking tasks or part functional prototypes) at one end, and public road trials at the other, see Figure 11 - 3.

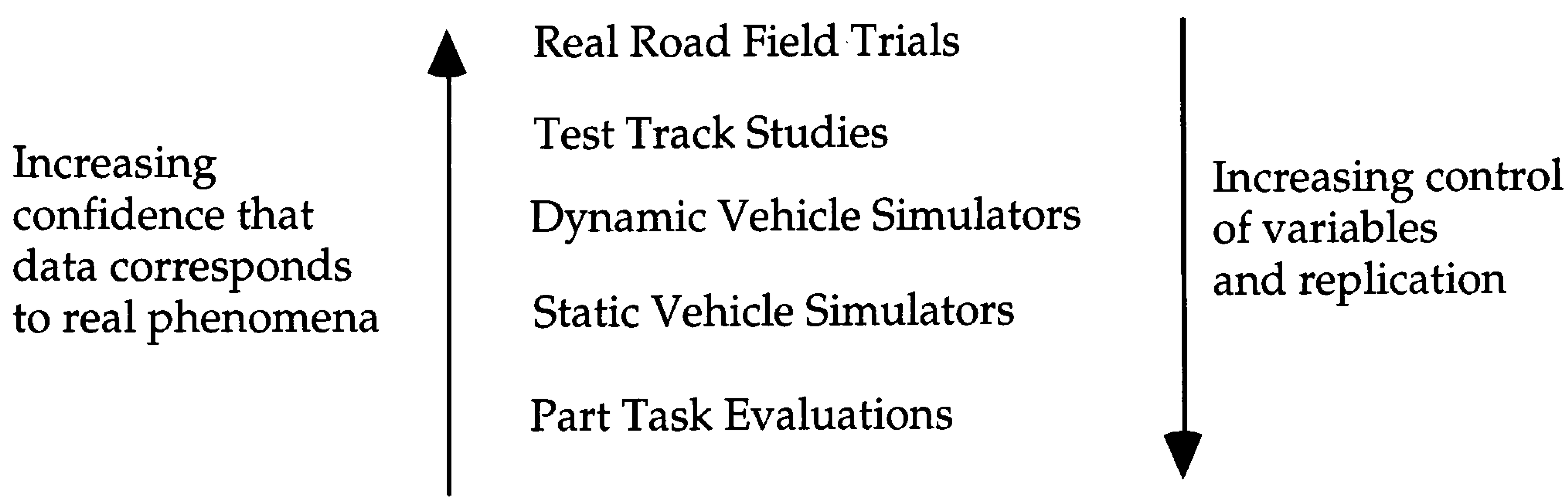



**Figure 11 - 3. The relationship between data capture environments, from Parkes (1991)**

The most realistic method of assessment is likely to be a multi-stage process involving simulator, field and road trials. It has been said that: "The single most important method for studies involving the development and testing of safety systems for vehicles, such as IVHS [intelligent vehicle highway systems], is simulation" (Hancock & Parasuraman, 1992), page 190. However, measures of lane deviation have been shown to be lower in a driving simulator than in comparable tasks on the road (Guyard & Boulanger, 1992). Therefore, one could conclude as did Noy & Zaidel (1991) "Laboratory techniques such as simulation can effectively isolate important perceptual/mediational mechanisms; however, there continues to be uncertainty about the generalisability of laboratory results to 'the real world' ", page 1484.

It is considered that assessment of the visual impact of driver information systems would be most efficiently determined by the employment of a multi-levelled battery of assessment methods to optimise the probability of a safe and suitably designed information system. For example, when the system in question is still early in the design process (when changes are consequently cheap and easy to make) user clinics may be most valuable. Development of the safe interaction and sophistication of the device would lead to a corresponding increase in the fidelity and therefore ecological validity of the evaluation method. Thus, the best compromise between professional, ethical, and economic considerations can be reached.

The experimenter's primary concern should be the validity of the study design. This will be strongly influenced by the safety of subjects assisting them. Therefore, an appropriate strategy for the selection of an evaluation environment should be one that provides maximum ecological validity while minimising the risk to subject and experimenter. A driver information system which is safe on the road will be safe in a simulator, whereas the opposite will not necessarily be true. Thus, any investigation should ensure that the system under test is safe prior to deployment on public roads.

### *11.6.1. Field Trials*

Field trials represent a mid-way point in terms of confidence in the validity of visual behaviour during use of a system. Such research would typically take place on a test track, disused airfield or private road. The experimenter must nevertheless ensure that the subject's safety is paramount at all times. The findings of such work gain ecological validity over the simulator experiment, but can still not easily be generalised to the real road environment, a notable example being the study reported by Zwahlen et al., (1988), see Chapter 2. Use of a real vehicle in a field trial does not enable the complex interaction with other road users to be considered. However, it does provide realistic control and display compatibility and a rich visual environment.

### *11.6.2. Road Trials*

While the road trial represents the real task in all respects, the experiences of individual subjects may be extremely variable in terms of traffic volumes and specific roadway events (e.g., unpredictable road users, weather, congestion, etc.). Control of these and other confounding variables is discussed in detail by Gstalter & Fastenmeier (1991). Some researchers, notably Zaidel (1991) argue that an evaluation framework for driver information systems will only be valid if conducted in the "real traffic environment" because of the richness of the cues that it provides.

Road trial experimental work will be affected by external influences. Busy traffic periods may present the experimenter with unacceptable variance between subjects in terms of the density of vehicles (e.g., during *rush* hour driving). High traffic volume periods should be avoided if at all possible. A caveat to this, of course, is when the specific aim of the experimental work is to consider scenarios of high traffic density (e.g., gap acceptance research). Routes should be balanced during conditions as far as possible to control for the number and type of junctions and overall duration of driven road. During repeated measures studies, the same route can be employed for each. However, some experimental designs are confounded unless different routes are introduced across conditions (e.g., during route guidance research where the subjects gain the opportunity to negotiate the roadway from memory rather than using the information system).

### *11.6.3. Simulation*

There are a variety of simulators available to the researcher. Selection of the appropriate device would depend on:

- required fidelity
- cost
- nature of the study
- interaction with the simulation

Interactive driving simulators provide the researcher with some form of primary task feedback. The level of information gained will depend on the fidelity of the facility. Feedback may reasonably take the form of lane deviations, braking, pressure on steering wheel, speed, etc. The study of subjects' performance in a driving task has been stated (Nilsson, 1993) to require a simulator which meets the following criterion:

- it must run in real time
- the vehicle model must at least consider, the engine, brakes, transmission, steering system and suspension
- the model must represent vehicle ride and handling characteristics. For example, under and oversteer, front and rear wheel drive
- road surfaces should be represented (e.g., slippery conditions)
- the visual display should be preferably colour and have a wide visual angle
- the image detail should be sufficiently high to appear realistic
- simulation of inertial forced requires a moving base
- control-display time lags must by short in comparison with road vehicles (100 ms - 250 ms).

The simulator used in this research complies with most of the above requirements. It's representation of different road surfaces was poor with respect to the quality of the control and display feedback. However, all experimental work was conducted under the equivalent of ideal weather conditions, where hazardous road surfaces would not be expected to be a problem. The level of visual detail in the 360° colour display was low in comparison with the public road, but investigation of experimental data presented in chapters 6 and 7 suggests that the detail was sufficient to elicit equivalent distributions of visual behaviour in the simulator as on the road. The simulator did not have a motion base, however, limited physical feedback was provided in the form of seat motion during collision with objects (e.g., the curb). The time delay between control and display feedback was unknown, but could have been improved as some subjects reported symptoms associated with simulator sickness, see Appendix D.

The experimental evidence reported in Chapter 7 compares results from the same experimental design in both road and simulator settings. The results suggest that use of a mid-fidelity driving simulator provides the driver with sufficient cues to elicit similar distributions of visual behaviour (e.g., total dwell time per region, glance durations and glance frequencies), although, the richness of the visual scene (visual information per unit time) was lower in the simulator than the road trials.

### *11.6.4. Alternatives to Road and Simulator Experiments*

Visual demand research has been conducted in different environments along a continuum, with public roads at one end and a simple primary tracking task at the other. Experimental work reported in Chapters 6, 7 and 10 considered the sensitivity of visual demand metrics to the introduction of driver information systems and the comparability of results obtained from the road trial and the simulated driving scenario. However, using road or simulator trials may not necessarily be the best approach for the exploration of driver visual behaviour with reference to information systems. The imposed visual demand of an interface may be assessed by measuring the maximum glance durations required to extract information. Such assessments can be performed using, for example, a tachistoscope. Potentially, a concurrently performed tracking task could be used to increase the validity of a maximum glance duration assessment. The drivers' primary task is the lateral and longitudinal control of the vehicle with the aim of avoiding obstacles (Fairclough & Parkes, 1990). This tracking task may be represented by many sensory-motor co-ordination tests (e.g., using a mouse to maintain cursor position in a moving path presented on a computer screen (Fairclough & Ward, 1996)). Use of primary tracking tasks suffer from the limitation that visual scanning to the driver mirrors will not be observed.

Measurement of driver visual demand is complicated by the practicalities of experimental research, particularly when using driver information systems. Economically, a trade-off must be made between the quantity of data collected per condition and the validity of the experimental task. Thus, investigators are challenged with balancing the provision of a realistic scenario for system use, within which the costs are reasonable to obtain useable results from the experimental design. This section has discussed some of the different experimental settings for the assessment of driver visual demand. Relevant literature regarding the assessment settings has been identified and empirical work has been conducted to support the use of driving simulation as an appropriate medium for the investigation of visual behaviour.

## 11.7. Opportunities for the Reduction of Visual Demand

Information systems will inevitably be produced that impose unacceptable visual demands for in-vehicle use. Therefore, it is important to consider opportunities for the reduction of visual demand under such circumstances. Several approaches may be used to reduce visual demands including: improved interface design, positioning in the vehicle and restrictions on information availability while in-transit.

### *11.7.1. Interface Design and Visual Demand*

Driver information systems may present data using non-visual modalities (e.g., using tactile or auditory displays). Streeter et al. (1985) concluded that route guidance systems should be speech-oriented given their superiority over maps in terms of reduced errors. The superiority of verbally presented route guidance over conventional maps has previously been demonstrated (van Winsum, 1987). A key concern in the development of information system interfaces is that they should not overload the driver. Verwey, (1993) suggests that the solution is simple. It is advocated that "a system should be developed which schedules information presentation while taking the driver's capacities and limitations into account", page 235. Thus, a *dialogue controller* would consider the perceptual loading on the driver and adapt the syntax and modality of presented information, see

Figure 11 - 4. Thus, under visually demanding circumstances the information system may reduce visual demand while supplementing information using auditory signals.

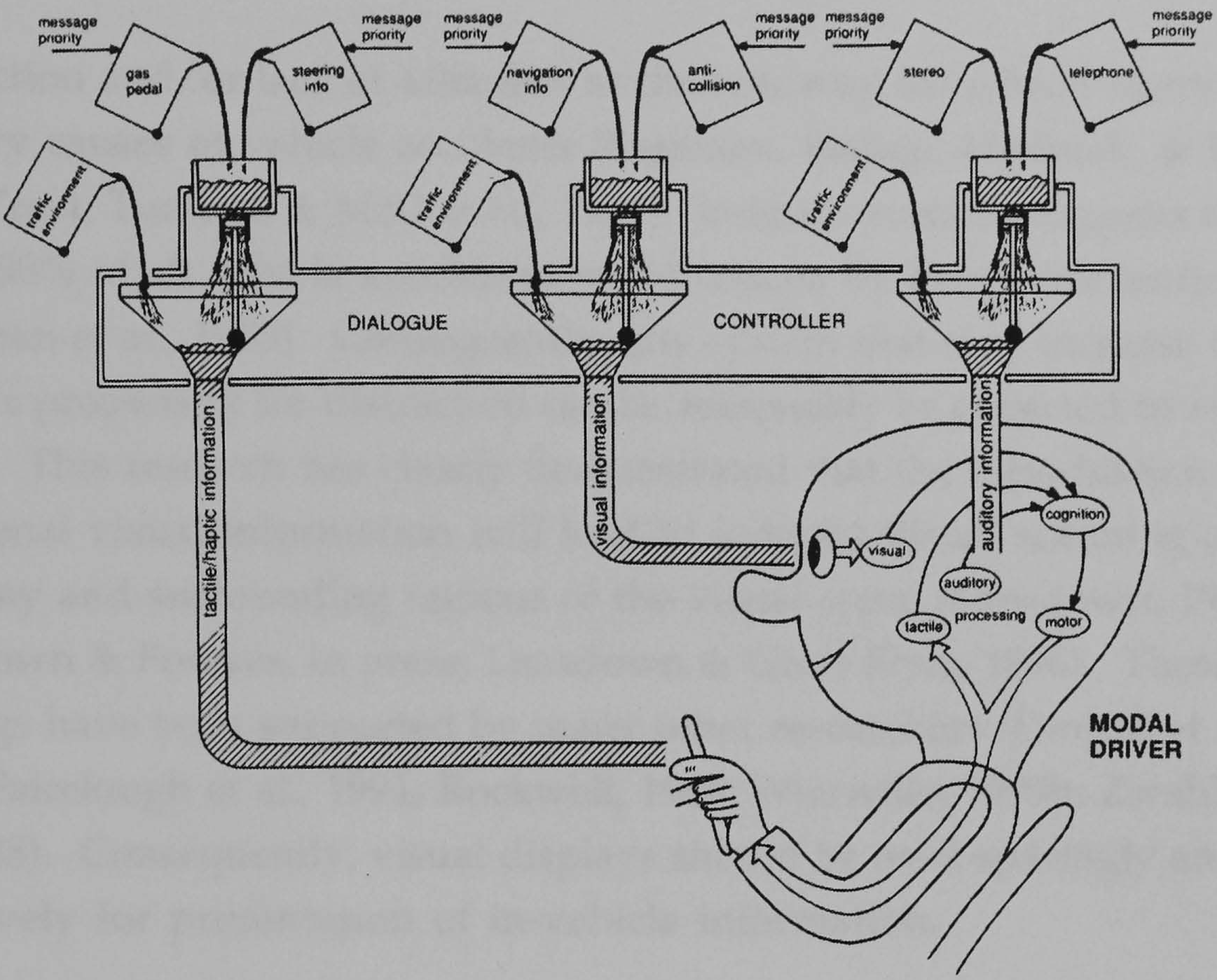



**Figure 11 - 4. Dialogue control and presentation of information to the driver, from Verwey (1993)**

Many existing advanced driver information systems concepts currently employ visual displays. While these may prove valuable for confirmation of in-vehicle information, their use should be carefully considered. For example, a visual display could be used to support a predominantly auditory information system. Chapter 8 considered the opportunities for the reduction of driver visual demand by presenting subjects with visual navigational information and supplementing this with speech or auditory signals alone. Visual behaviour measures indicated that the visual information only condition was the most demanding on the subjects. Supplementing the visual information with auditory information reduced the visual demand. The dual visual and auditory presentation was also the subjectively preferred. When information is continuously available to the driver, this has been shown to reduce visual scanning of the forward view (Dingus et al., 1989; Fairclough et al., 1991). If information access is restricted (e.g., route guidance data that is only available prior to a junction), this has been shown to reduce *normal* visual scanning to other regions of the visual scene, most notably the left and right regions, in addition to the forward view (see Chapter 9).

Distraction and/or lack of attention to the roadway have been identified as primary causes of vehicle accidents (Sussman, Bishop, Madnick, & Walter, 1985; Treat, Tumbas, & McDonald, 1979). Indeed, research suggests that 30% - 50% of all vehicle accidents are influenced by driver inattention (Sussman et al., 1985). Consequently, any system that may increase the driver's propensity for distraction can be reasonably be expected to reduce safety. This research has clearly demonstrated that the introduction of additional visual information will lead to reduced visual scanning of the roadway and surrounding regions of the visual scene (Lansdown, 1996; Lansdown & Fowkes, in press; Lansdown & Galer Flyte, 1996). These findings have been supported by many other researchers (Dingus et al., 1989; Fairclough et al., 1991; Rockwell, 1988; Wierwille, 1993b; Zwahlen et al., 1988). Consequently, visual displays should be used sparingly and selectively for presentation of in-vehicle information.

Human computer interaction (HCI) guidelines and standards can apply to the development of in-vehicle systems. ICE (1993) produced a code of best practice for the design of in-vehicle systems which reviews many of the applicable HCI guidelines, providing assistance such as: displayed text should be brief, clear and large enough to be easily resolved from the driver's position.

Driver skill acquisition may be sub-divided into safe vehicle control and use of the in-vehicle information systems. Further, the development of vehicle control skill requires demonstrable task performance to the legally pre-determined level. It is apparent that there is subsequent improvement in performance after successful fulfilment of the legal criterion. Information system developers must assume that all users will initially be unfamiliar with the systems and may also be novice drivers. Therefore, system design should immediately facilitate safe and efficient use by the novice, and consequently it is suggested that systems that are easy for novices to use will impose less demand on skilled drivers. Although, it is conceivable such operating systems may *annoy* experts and thereby increase overall visual demand.

When the display is too complex it may be easily improved by:

- reducing in the number of bits of information presented per unit time on the display
- restricting access to the complex information while the vehicle is in motion.
- consideration of alternative methods for information presentation (e.g., symbols rather than text, and text rather than maps)
- determining whether the modality of presentation is optimal for the data presented (e.g., visual and spatial, verbal and auditory, Wickens, 1984).

Such measures are not the only way to improve the interface design of in-vehicle systems. However, they may be appropriately applied to optimise interactions with acceptable systems. The integration of available driver information sources is not currently considered in existing systems. It seems likely that future integrated devices will contain the functionality of dialogue control to facilitate flexible and appropriate presentation of information to the driver. The flexibility of information presentation in such systems will potentially complicate assessment of their interface and usability.

### *11.7.2. Location in the Vehicle*

The location of an information system within the vehicle will influence the visual demand it imposes on the driver. The greater the eccentricity from the focus of expansion the longer it will take the eyes to move from the forward view to the display (transition time). A survey of congestion warning device users (Stevens & Martell, 1993) revealed that 60% placed the system in a central position level with the instruments; 20% located it in the glove compartment; 4% below the glove compartment; 9% in a central position at mid height and 7% in a central location but approximately level with the gear stick. The device was not manufacturer installed and the users were consequently free to position it anywhere in the vehicle. Thus, it could be argued that 31% of users were positioning the device in a non-optimal location requiring excessive deviations from the forward view to attend to the display. It is proposed that the reduced visual demand due to good positioning of such devices be assessed against the frequency with which the system would be used and the complexity of the information presented.

It would seem that head up displays (HUDs) offer the ideal solution for the presentation of information at the focus of expansion. However, methodologically, direct driver observation cannot differentiate between attentional allocation to the forward scene or to a head up display. Consequently, this research has not considered head up displays and the findings are not applicable to such devices.

This section discussed the research undertaken to facilitate a reduction in driver visual demand. It encompasses both the experimental work undertaken to explore the opportunities for visual demand reduction via auditory presentation of information and the supporting literature regarding interface design and the implementation of systems into the vehicle.

## 11.8. Information Availability and Visual Demand

The experiment described in Chapter 9 concentrated on observable changes in driver visual scanning as a consequence of the availability of in-vehicle information. Previous researchers have demonstrated changes in the relative allocation of fixations to the regions of the visual scene as a consequence of the introduction of advanced driver information systems (Fairclough & Parkes, 1990; Wierwille, 1993a). In the experiment, control over the availability of information was either with the driver or the information system. When the information system restricted the timing of the availability of information to the driver a conflict was observed between the driver's needs to obtain roadway or route guidance information. The findings suggest that whenever possible the driver should be able to select when to extract information from an in-vehicle device.

The introduction of driver information systems typically reduces the driver's total percentage dwell time to the forward view. Visual checking to the mirrors and over-shoulder remains largely unchanged by the visual demands of the task (Fairclough & Parkes, 1990; Wierwille, 1993a). However, in Chapter 9 drivers reduced the mirror checking as well as forward view percentage dwell times. The interface demanded the driver's visual attention at specific points (data was purposely presented immediately prior to junctions to encourage the conflict) when the safe deployment of visual scanning would be to the road junction and not to the in-vehicle device. Shifts in drivers' visual allocation are more subtle than simple reductions in forward view scanning when the availability of information is restricted. Visual demand cannot be considered as a simple equation of observable visual behaviour (e.g., glance duration or glance frequency per minute), but should also consider the context in which the activity occurs.

## 11.9. Safe Visual Behaviour and In-Vehicle Systems

The quantification of *safe* visual demand has been the subject of much debate in the visual demand literature. Many researchers (as highlighted in Chapters 2 and 3) have proposed design guides, models and equations to quantify driver visual demand. Some of these are based on calculations from recordings of the driver's eyes (e.g., glance frequency or duration), others are based on measures that are dependent on visual behaviour (e.g., lane position or steering wheel corrections), or measures that infer a high cognitive demand from psycho-physiological or subjective metrics. However, there is currently no consensus on the calculation of what constitutes safe visual demand. Currently, it is considered that such a judgement may only be formed on the basis of a informed knowledge of the research area and thorough evaluation of the effects of a prototype system on the driver. However, as described in Chapter 2, there are numerous guidelines on acceptable limits for the distraction information systems may impose. Research described in this thesis has highlighted the limitations of forming judgements regarding visual behaviour without taking account of the broader driving environment.

## 11.10. Ethical Considerations

While experimental work on public roads retains high ecological validity, such research inevitably exposes subjects to increased risk to their personal safety. Therefore, prior to such research preparations must be made to ensure that hazards are kept to an absolute minimum. For example, provision of a dual-control vehicle, careful selection of incidents where the driver must interact with prototype systems and confidence that the subjects are able to competently operate the prototype device prior to the experimental trial.

Removing the subject from public roads to a driving simulator eliminates any serious risk of injury. However, the different environment presents its own ethical considerations, most notably simulator nausea. Motion sickness has been defined as "a general term for the constellation of symptoms and signs, generally adverse, caused by exposure to abrupt, periodic, or unnatural accelerations" (Kennedy & Frank, 1986). Sickness has been reported in situations where there are no accelerations, only the perception of motion (Crampton & Young, 1953; Dichgans & Brant, 1973). Symptoms may include: pallor, sweating, salivation, vomiting, general discomfort, headache, stomach awareness, disorientation and desire for fresh air (Kennedy & Frank, 1986). The phenomenon may be caused by fear or anxiety, imbalance in autonomic nervous activity, engorgement or anaemia of the brain, toxic reaction or perceptual conflict (Kennedy & Frank, 1986). The interested reader is directed to the review articles by Chinn & Smith, (1955); McNally & Stuart (1942); Money (1970); Reason & Brand (1975) and Tyler & Bard (1949).

Experimenters must be sensitive to the other considerations in vehicle human factors work. For example, the duration of experimental trials (particularly with those that may be prone to tiredness), eye strain from prolonged use of apparatus and the individual's awareness of their rights as a subject. The British Psychological Society provide ethical guidelines for investigations on human subjects (BPS, 1990) which have been applied throughout this research.

## 11.11. Visual Demand: Towards a Theory

This section provides a model of driver visual demand with respect to task performance. It builds on Wierwille's (1993a) in-vehicle visual sampling model to encompass the broader concerns of in-vehicle task performance.

Three concepts are proposed, a *visual demand model*, *consequence assessor* and *driver visual demand task performance* model (considering both the visual demand model and consequence assessor).

Weirwille's model on in-vehicle visual sampling is based on experimental work by Rockwell (1988), Bhise, Forbes, & Faber (1986) and Dingus et al. (1989), see Chapter 2. The driver is assumed to attempt to chunk data during information gathering. Information which can be chunked in less than 1 second is obtained. More complex data leads to an increasing buildup of uncertainty regarding the forward view, as suggested by Zwahlen et al. (1988). If information can be chunked in approximately 1.5 seconds, this occurs and the fixation returns to the forward scene. Data requiring a longer glance is obtained by successive glances, subject to *buildup of uncertainty*. Wierwille's (1993a) model does not accommodate long duration glances (i.e., greater than 1.5 seconds). Many researchers have presented data reporting large numbers of these extended glances while using advanced driver information systems (Dingus et al., 1989; Fairclough et al., 1991; Lansdown, 1996; Lansdown & Fowkes, in press; Wierwille et al., 1988). A model must clearly take account of this aspect of driver visual sampling, particularly, as Wierwille indicates, longer glances will result in increased *buildup of uncertainty* regarding the forward view.

The model provides a valuable conceptual framework to consider visual activity during the performance of in-vehicle tasks. However, it does not consider the influence of external events. The specification of 1 second and 1.5 second glance durations is misleading as the context of the glance will affect the rate of buildup of uncertainty. For example, motorway driving with low traffic volumes poses a lower *contextual risk* than rush hour suburban traffic.

An adaptation of the (Wierwille, 1993a) model is shown in Figure 11 - 5. The consequence assessment module is included to represent the drivers' mediation as to what are un/acceptable glance durations.

It is clear that visual information presentation is only one of many information sources that are available to the driver. The in-vehicle task performance model shown in Figure 11 - 6. illustrates several of these available information sources (e.g., auditory, proprioceptive, and/or climatic feedback). The model integrates Wierwille's (1993a) in-vehicle model with the proposed consequence assessment module and visual demand model.

In-vehicle task performance is represented in Figure 11 - 6. At any given time the driver will be receiving information from one or more of the available modalities. During task performance, extraction of visual information will be a function of the in-vehicle visual sampling model proposed by Wierwille (1993a) and consequence assessment module. Visual information extraction will be moderated by the visual demand model to tune the duration of glances prior to unacceptable buildup of uncertainty regarding the forward view. Driver visual sampling will proceed through the adapted Wierwille model for each chunk of extracted information, successful or not. The visual information is combined with other sensory modalities and control actuation performed. The cycle is repeated until the task is complete.

The model has many shortcomings, but is presented in response to the deterministic approach presented by Wierwille (1993b). In particular, while the model focuses on visual function in task performance, the integration of other modalities is neither comprehensive nor diagnostic. The model cannot currently meaningfully represent different extraction strategies adopted by the driver. For example, high frequency, low duration or low frequency, long duration glances, as observed during route guidance and congestion warning system use respectively (in Chapter 9). Similarly, complex interaction between these two different strategies is also not represented adequately. Initial long glances followed by frequent short glances, as though the subject were first assessing the difficulty of information extraction from a system are not accounted for in this model.

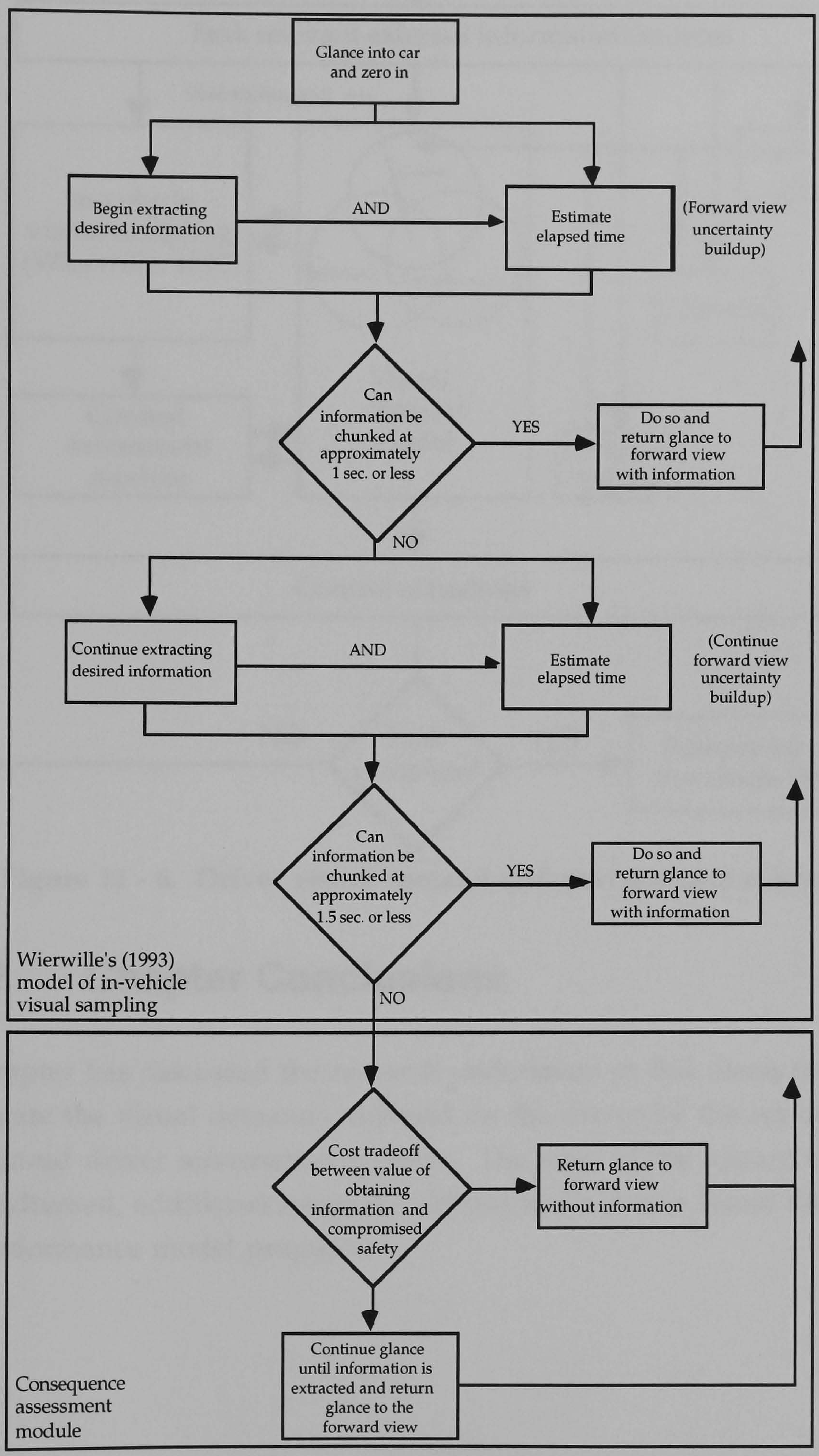



**Figure 11 - 5. Consequence assessment and in-vehicle visual sampling**

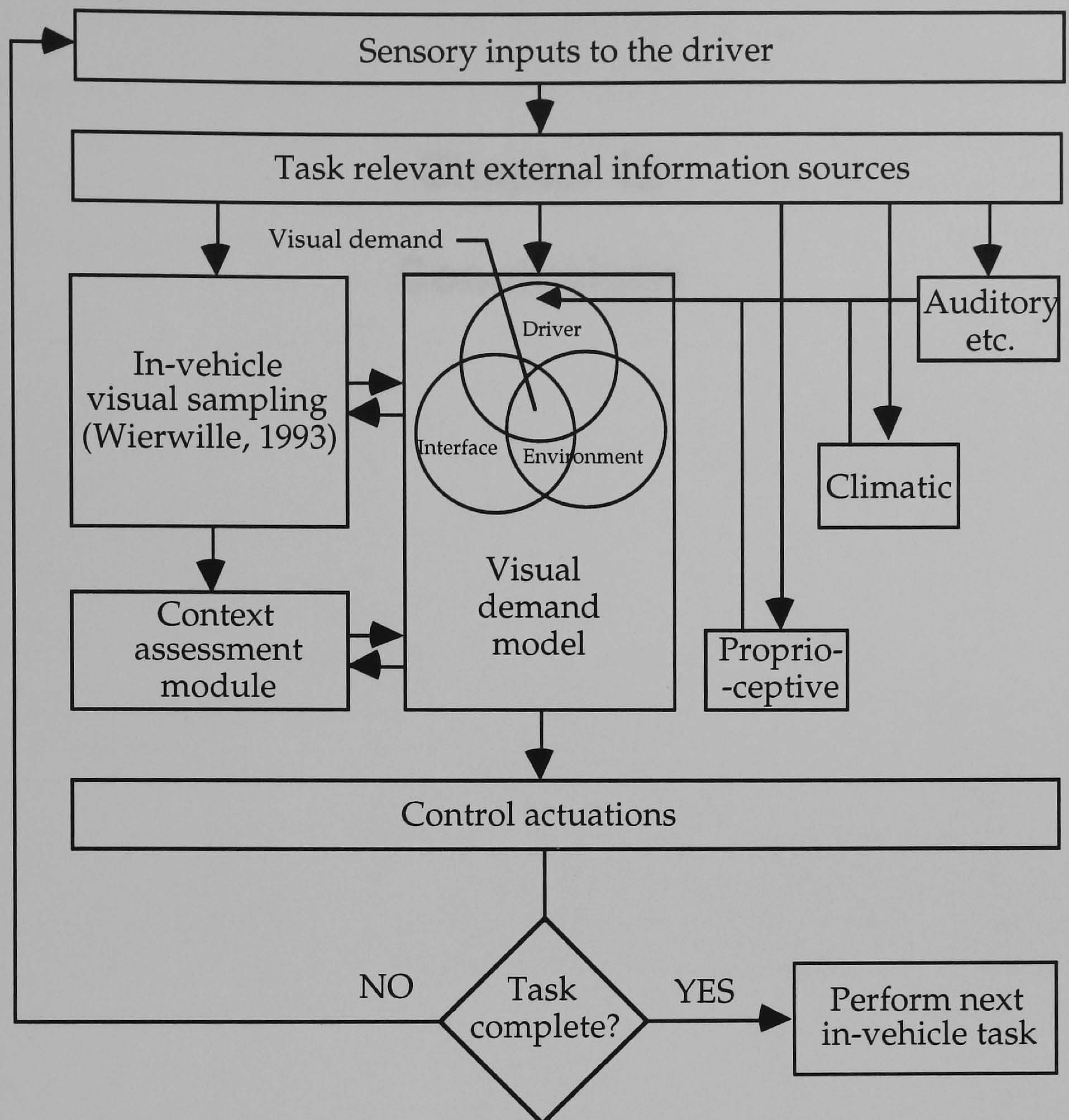


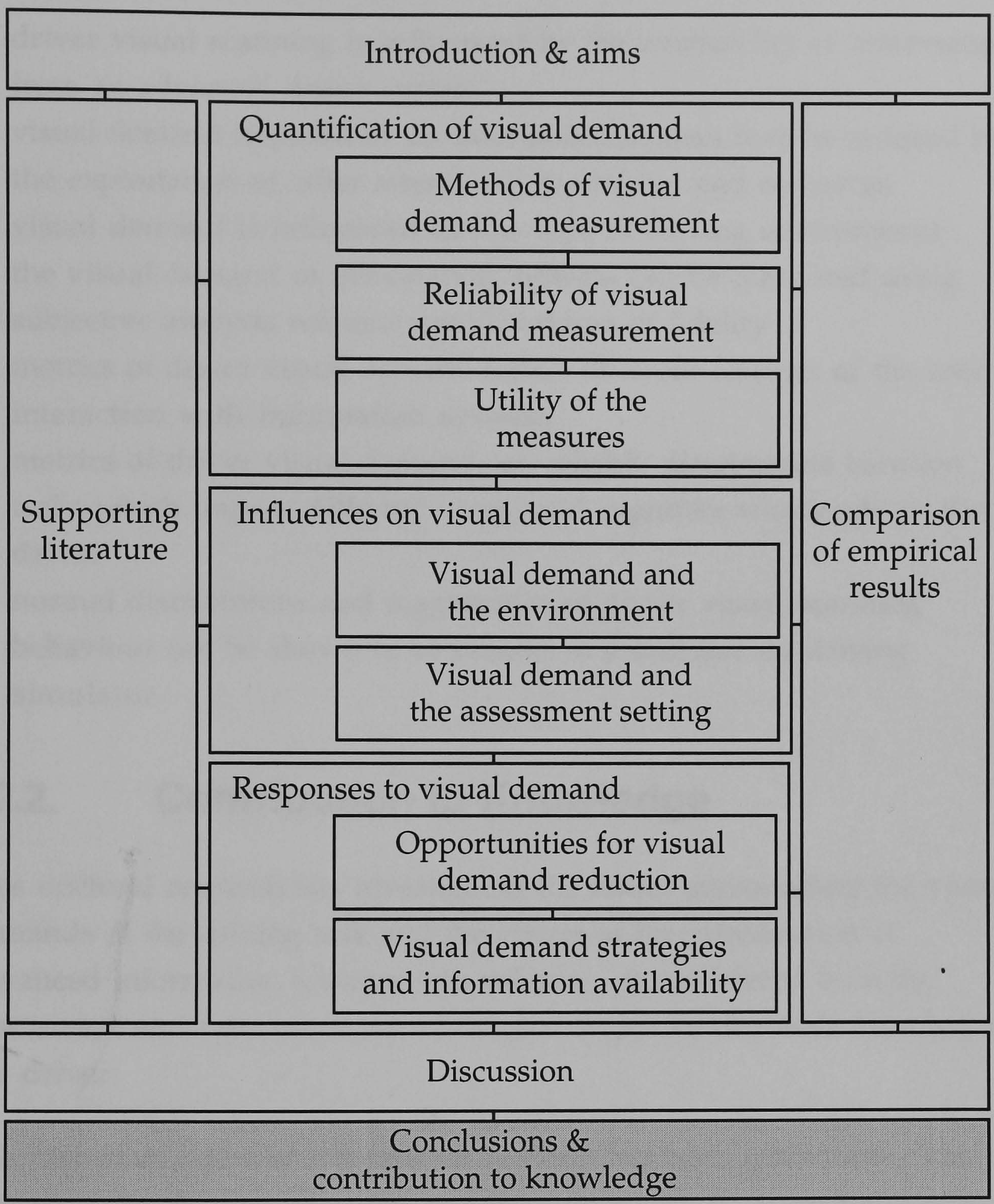

**Figure 11 - 6. Driver visual demand task performance model**

## 11.12. Chapter Conclusions

This chapter has discussed the research undertaken in this thesis to investigate the visual demands imposed on the driver by the introduction of advanced driver information systems. The aims of the research have been addressed, additional issues considered and a driver visual demand task performance model proposed.

# Chapter 12

# Conclusions




## 12.1. Final Conclusions

This thesis describes research undertaken to investigate the visual demands imposed on the driver by the introduction of advanced information systems. A review of the literature was conducted and a series of experimental studies performed. The main conclusions of the research were:

- driver visual scanning is influenced by the availability of information from an advanced driver system
- visual demand imposed by an information system may be reduced by the exploitation of other attentional modalities and resources
- visual demand is influenced by the type of driving environment
- the visual demand of information systems can be measured using subjective analysis without significant loss of fidelity
- metrics of driver visual demand reflect different features of the user's interaction with information systems
- metrics of driver visual demand can reliably discriminate between tasks which impose different visual and cognitive workloads on the driver
- normal distributions and magnitudes of driver visual scanning behaviour can be shown to be present in a mid-fidelity driving simulator.

## 12.2. Contribution to Knowledge

This doctoral research has investigated the issues surrounding the visual demands of the driving task and the effects of the introduction of advanced information systems into vehicles. It considered both the assessment and features of the visual and cognitive demands imposed on the driver.

The impact of different information systems has been quantified. The nature of the changes in driver visual scanning has been explored when using and not using advanced information systems. For example, route guidance applications in some circumstances may result in a reduction of typical visual scanning when approaching junctions, with possible effects on safety. Driver information system interfaces should provide opportunities to obtain information as and when required, thereby supporting the drivers ability to schedule in-vehicle tasks. Driver selection of the timing of information extraction from both the in-vehicle displays and the external roadway enables the driver to better compensate for the unpredictable variance in roadway visual demand (as demonstrated in Chapter 5).

The research has explored the value of available metrics for the evaluation of driver information systems. It has considered the potential opportunities for reducing visual demand through user-centred design and the factors responsible for increased visual demand during the driving task.

## 12.3. Further Research

The following list represents some of the issues which are intended for further consideration and possible experimental investigation.

- Given that all forms of simulation degrade the driving task. To what degree, and with which constraints can vehicle use be accurately represented (e.g., using simple primary tracking tasks)?

- Although drivers present a variety of visual behaviour when approaching junctions, there are a number of common features which many exhibit. To illustrate, one of the routines drivers were observed to perform was a *driver mirror, left, right, left and emerge* cycle. The duration of glances to the different regions of the visual scene may vary considerably (depending on the traffic density), but the general distribution of behaviour appears repeatedly. Further consideration of experimental data would be worthwhile to develop a taxonomy of junction strategies.

- Drivers were observed to attend to their instruments (most notably, the speedometer) extremely rarely with respect to the other regions of the visual scene. Further work could consider the cues, both available and utilised by the driver, to maintain pre-determined speed.

- Experienced drivers by definition have achieved a level of skill that enables them to concentrate on the external features of the driving task and perform vehicle control tasks without conscious activity (Masuda et al., 1990; Mourant & Rockwell, 1972; Nagata & Kuriyama, 1982). How does skill acquisition in driving effect the deployment of visual attention?

- There has been much debate in the literature regarding acceptable glance durations and frequencies during use of in-vehicle systems. What is the value of a simple screening tool for the removal of information systems which are clearly unsuitable for use in vehicles? For example, if users cannot extract required information from a prototype system within a specified duration, the device could be deemed unsuitable for use in vehicles in transit.

- Road sign information is currently presented in numerous positions with respect to the driver's field of view, typically appearing at the focus of expansion and following a path of increasing eccentricity until it is no longer visible. Presentation of roadway information in the vehicle could provide the driver with early warning of roadway information, in a consistent location and could be displayed using signage familiar to the driver (e.g., during foreign travel). In-vehicle presentation of information must be assessed to determine any potential conflict between, for example, urgent hazard warning and junction navigation information.

- The positioning of information systems in primary locations may be reasonably assumed to reduce the time required for information extraction. However, increasing the eccentricity of information system location could present increased transition times within any given glance. It would be valuable to quantify the transitional overhead for different display and control complexities and locations within the vehicle. Consequently, the relationship between system interaction and location could be determined.

- Consideration of the possibilities for automation of the video tape transcription of driver visual behaviour. Integration of eye-mark cameras with a driving simulator would provide the opportunity to explore the dynamically changing visual scene. It would enable glances to the roadway to be automatically determined even when the simulated vehicle negotiates a junction and the position of the road changes with respect to the forward view.

- Human factors guidelines for the development of prototypes for driver information systems were proposed by Bouis, Geiser, Haller, & Heintz (1985), they included:

    - menu depth: which should not be more than 2 levels
    - position: centrally
    - interface: standard

  Such guidelines could be explored to determine their limitations and the additional potential for the reduction of visual demand.

- Experimental work conducted in this research was undertaken during daylight hours. Accident statistics show that night-time driving is more hazardous per km than daytime driving. The attentional demand of night-time driving could be compared to day time driving to determine shifts in the magnitude and distribution of visual scanning at different times of the day. Similarly, such investigations could be extended to include visual demands associated with different weather conditions (e.g., fog, rain and snow).

- The research reported in Chapter 9 would benefit from replication with an adjustment to the experimental design. It would be preferable to use an information system with the same function (e.g., route guidance) and manipulate the interface (i.e., the availability of information to the driver).

- The range of information systems considered in the research could be extended. Congestion warning (map), route guidance (symbols) and conventional in-car entertainment system applications were employed. Knowledge about the impact on visual demand of other driver information systems would be valuable, to strengthen findings regarding driver visual demand and the use of advanced in-vehicle information devices.

# References

# References

Alm, H., Nilsson, L., Järmark, S., Savelid, J., & Hennings, U. (1992). The Effects of Landmark Presentation on Driver Performance and Uncertainty in a Navigation Task. A Field Study, VTI MEDDELANDE 692A. Swedish Road and Traffic Research Institute.

Anderson, J. R. (1987). Skill Acquisition: Compilations of Weak Method Problem Solutions. Psychological Review, 94, pp. 192-210.

Antin, J. F., Dingus, T. A., Hulse, M. C., & Wierwille, W. W. (1988). The Effects of Spatial Ability on Automotive Navigation. In: Trends in Ergonomics/Human Factors V.

Bainbridge, L. (1991). Verbal Protocol Analysis. In: Evaluation of Human Work. Taylor and Francis Ltd.

Beyreuther, G., & Laidebeur, A. (1989). RTI, State of the Art Review, DRIVE Project V1017 (BERTIE). Changes in Driver Behaviour Due to the Introduction of RTI Systems, No. 28.

Bhise, V. D. (1971). Relationship of Eye Movements to Conceptual Capabilities to Visual Information Acquisition in Automobiles. Ph.D. thesis (on micro-fiche), Ohio State University.

Bhise, V. D., Forbes, L. M., & Faber, E. I. (1986). Driver Behavioural Data and Considerations in Evaluating In-Vehicle Controls and Displays. In: Transportation Research Board 65th Annual Meeting, Washington, D. C.

Biederman (1972). Science, pp. 77-80.

Bouis, D., Geiser, G., Haller, R., & Heintz, F. (1985). Comparison of Conventional and Dialogue-Oriented Concepts for the Use of Vehicle Information Systems. In: G. Mancini, G. Johannsen, & L. Martensson (Eds.), IFAC Analysis, Design and Evaluation of Man-Machine Systems.

Boyce, P. R. (1981). Driving. In: Human Factors in Lighting, pp. 170-203.

BPS (1990). British Psychological Society Ethical Principles. The Psychologist, June.

Broadbent, D. E. (1958). Perception and Communication. Oxford, Pergammon.

Brookhuis, K. A., Schrievers, G., Tarriere, C., Petit, C., & Chaput, D. (1991). Monitoring Driver Status Through In-Vehicle Parameters. In: DRIVE, 1991. Advanced telematics in road transport. Brussels, February 4-6, pp. 1516-1525. Elsevier.

Brown, I. D., & Poulton, E. C. (1961). Measuring the Spare 'Mental Capacity' of Car Drivers by a Subsidiary Auditory Task. Ergonomics, 21, pp. 221-4.

Burnett, G. E., & Joyner, S. M. (1994). An Assessment of Route Guidance Systems and their Implications for Driver Safety. In: Proceedings of the 12th Triennial Congress of the International Ergonomics Association, Toronto, Canada, vol. 4, pp. 156-158. Human Factors Association of Canada.

Burnett, G. E., & Parkes, A. M. (1993). The Benefits of "Pre-Information" in Route Guidance Systems Design for Vehicles. In: E. J. Lovesey (Ed.), Contemporary Ergonomics: Proceedings of the Ergonomics Society Annual Conference, Taylor & Francis: London.

Burns, P. C. (in press). Driver Navigational Strategies and Information Needs. In: International Ergonomics Association, 13th Triennial Conference. Tampere, Finland, 29th June - 4th July.

Byers, J. C., Bittner, A. C., & Hill, S. G. (1989). Traditional and Raw Task Load Index (TLX) Correlations: Are Paired Comparisons Necessary? In: Advances in Industrial Ergonomics and Safety I, pp. 481-485.

Carr, D., Jackson, T. W., Madden, D. J., & Cohen, H. J. (1992). The Effect of Age on Driving Skills. Journal of the American Geriatrics Society, 40, pp. 576-573.

Carr, K. T. (1988). Survey of Eye Movement Measuring Equipment, Applied Vision Association.

Cavallo, V., Berthelon, C., & Mestre, D. (1996). Environmental Cues in Time to Collision Judgements. In: International Conference on Traffic & Transport Psychology, Valencia, Spain, pp. 97-101.

Charman, W. N. (1986). Vision and Driving. Optician, September 19th & 26th, pp. 15-20 & pp. 27-32.

Chinn, H. I., & Smith, P. K. (1955). Motion Sickness. Pharmacological Reviews, 7, pp. 33-82, as cited in Kennedy and Frank (1986).

Clancy, S. N., & Hoyer, W. J. (1994). Age and Skill in Visual Search. Developmental Psychology, 30, pp. 545-552.

Cohen, A. S. (1981). Car Drivers' Pattern of Eye Fixations on the Road and in the Laboratory. Perceptual and Motor Skills, 52, pp. 515-522.

Cole, B. L., & Hughes, P. K. (1984). A Field Trial of Attention and Search Conspicuity. Human Factors, 26, pp. 299-313.

Cole, B. L., & Hughes, P. K. (1988). Drivers Don't Search: They Just Notice. In: D. Brogan (Ed.), Visual Search. Taylor and Francis.

Cole, B. L., & Jenkins, S. E. (1980). The Nature and Measurement of Conspicuity. In: 10th Biennial Conference of the Australian Road Research Board, Melbourne, Australia, pp. 99-107.

Collins, J. J., & McDonald, M. (1993). Task Simulator for Evaluating Driver Information Acquisition. In: A. G. Gale, I. D. Brown, C. M. Haslegrave, H. W. Kruysse, & S. P. Taylor (Eds.), Fourth International Conference on Vision in Vehicles, University of Glasgow, Scotland, pp. 141-148. Elsevier Science, North-Holland.

Connoly, P. L. (1968). Visual Considerations: Man, the Vehicle, and the Highway. Highway Research News, 30, pp. 71-74, as cited in Mourant, Rockwell and Rackoff (1970).

Cooper, G. E., & Harper, R. P. (1969). The Use of Pilot Ratings in the Evaluation of Aircraft Handling Qualities, No. NASA TN-D-5153. NASA Ames Research Center.

Crampton, D. H., & Young, F. A. (1953). The Differential Effect of Rotary Visual Field on Susceptible and Non-Susceptibles to Motion Sickness. Journal of Comparative and Physiological Psychology, 46 (6), pp. 451-453, as cited in Kennedy and Frank (1986).

DEFSTAN (1986). Human Factors for Designers of Equipment, Part 6, Vision and Lighting, Interim Defence Standard, No. 00-25 (Part 6)/ Issue 1. Ministry of Defence.

Delhomme, P., & Malaterre, G. (1989). Bibliographic Analysis of Investigation Methods in Driver Behaviour, DRIVE Project V1040, No. 3.2. INRETS, Paris, France.

Dewar, R., & Ellis, J. (1994). The Design and Evaluation of Traffic Signs. In: 12th Triennial Congress on the International Ergonomics Association, Toronto, Canada, August 15-19, vol. 4: Ergonomics and Design, pp. 221-223.

Dichgans, J., & Brant, T. (1973). Optokinetic Motion Sickness as Pseudo-Coriolis Effects Induced by Moving Visual Stimuli. Acta Otolaryngologia, 76, pp. 339-348.

Dingus, T. A., Antin, J. A., Hulse, M. C., & Wierwille, W. W. (1989). Attentional Demand Requirements of an Automobile Moving -Map Navigation System. Transportation Research (a), 23 (4), pp. 301-315.

DoT (1992). National Travel Survey: 1989/91, Department of Transport, Transport Statistics Report. London: HMSO.

Duncan, J. D., Williams, P., & Brown, I. (1991). Components of Driving Skill: Experience Does Not Mean Expertise. Ergonomics, 34 (7), pp. 919-937.

Engel (1977). Vision Research, 17, pp. 95-108, as cited in Theeuwes and Hagenzieker (1993).

Ericson, A., & Simon, H. A. (1993). Protocol Analysis: Verbal Reports as Data. MIT Press/Bradford Books.

Evans, D. W., & Ginsburg, A. P. (1985). Contrast Sensitivity Predicts Age-Related Differences in Highway-Sign Discriminability. Human Factors, 27 (6), pp. 637-642.

Evans, L. (1994). The Older Driver Problem: an Epidemiological Overview. In: 14th Enhanced Safety of Vehicles Conference, Munich, Germany, May.

Faber, E., & Gallagher, V. (1972). Attentional Demand as a Measure of the Influence of Visibility Conditions on Driving Task Difficulty. Highway Research Record, 414, pp. 1-5, as cited in Wierwille et al., 1988b.

Fairclough, S. H. (1990). A Review of Psychophysiological Measurement of Driver Mental Workload, DRIVE Project V1017 (BERTIE), No. 22. HUSAT Research Institute, Loughborough, U.K.

Fairclough, S. H. (1991). Adapting the TLX to Assess Driver Mental Workload, DRIVE Project V1017 (BERTIE), No. 71. HUSAT Research Institute, Loughborough, U.K.

Fairclough, S. H., Ashby, M. C., & Parkes, A. M. (1991). In-Vehicle Displays, Visual Workload and Usability Evaluation. In: A. G. Gale, I. D. Brown, C. M. Haslegrave, H. W. Kruysse, & S. P. Taylor (Eds.), Fourth International Conference on Vision in Vehicles, University of Glasgow, Scotland. Elsevier Science, North-Holland.

Fairclough, S. H., Hirst, S. J., & Richardson, J. (1994). Critical Indicators of Driver Impairment. In: Proceedings of the 12th Triennial Congress of the International Ergonomics Association Toronto, Canada, 4, pp. 236-239. Human Factors Association of Canada.

Fairclough, S. H., & Parkes, A. M. (1990). Driver's Visual Behaviour and In-Vehicle Information, DRIVE Project V1017 (BERTIE), No. 29. HUSAT Research Institute, Loughborough, U.K.

Fairclough, S. H., & Parkes, A. M. (1991). Comparative Merits of Psycho-Physiological and Subjective Measures of Driver Effort. In: E. J. Lovesey (Ed.), Contemporary Ergonomics: Proceedings of the Ergonomics Society Annual Conference, pp. 394-399. Taylor & Francis: London.

Fairclough, S. H., & Ward, N. J. (1996). A Protocol for the Assessment of Subjective Sleepiness. In: International Conference on Traffic & Transport Psychology, Valencia, Spain, pp. 41-44.

Fisher, A. J. (1977). Road Lighting as an Accident Countermeasure. Australian Road Research, 7 (3).

Fisk, A. D., & Rogers, W. A. (1991). Towards an Understanding of Age-Related Memory and Visual Search Effects: Why Older Adults are Deficient in Automatic Process Development. Journal of Experimental Psychology: General, 120, pp. 131-149.

Fowkes, M. (1996). Personal Communication.

Fowkes, M., & Lansdown, T. C. (in press). The Development of a Standardised Method for Driver Visual Demand. In: A. G. Gale (Ed.), Sixth International Conference on Vision in Vehicles, University of Derby, U.K., 13-16th September, 1995 Elsevier Science, North-Holland.

Galer, M. D. (1993). Personal Communication.

Gibson, C. P. (1980). Binocular Disparity and Head-Up Displays. Human Factors, 22 (4), pp. 435-444.

Gibson, J. J. (1979). The Ecological Approach to Visual Perception. Houghton Mifflin Co., Boston.

Gioia, A. J., & Morphew, C. E. (1986). Evaluation of Driver Vision, Safety Seminar, General Motors.

Godthelp, H. (1986). Vehicle Control During Curve Driving. Human Factors, 28 (2), pp. 211-221.

Gordon, D. A. (1966). Perceptual Basis of Vehicular Guidance. Public Roads, 34, pp. 53-68.

Green, P. (1994). Measures and Methods Used to Assess the Safety and Usability of Driver Information System, Technical Report, No. UMTRI-93-12. University of Michigan Transport Research Institute, U.S.A.

Grubb, M. G. (1986). Driver Behaviour at Intersections: an Analysis of Accident Related Variables. In: Proceedings of the Human Factors Society, 30th Annual Meeting, vol. 1, pp. 251-255.

Gstalter, H., & Fastenmeier, W. (1991). Components of Test Routes for the Evaluation of In-Car Navigation Systems, DRIVE Project V1017 (BERTIE) Changes in Driver Behaviour Due to the Introduction of RTI Systems, No. 69. Forschungsgruppe, München.

Guyard, I., & Boulanger, O. (1992). The driving simulator as a means to assist human engineering in the design of car interiors. SAE paper 925178, pp. 87-94.

Hagenzieker, M. P. (1990). Visual Perception and Daytime Running Lights (DRL): A Literature Study, No. R-90-43. SWOV Institute for Road Safety Research, The Netherlands.

Hale, A. R., Stoop, J., & Hommels, J. (1990). Human Error Models as Predictors of Accident Scenarios for Designers in Road Transport Systems. Ergonomics, 33, pp. 1377-1388.

Hancock, P. A., & Parasuraman, R. (1992). Human Factors and Safety in the Design of Intelligent Vehicle-Highway Systems (IVHS). Journal of Safety Research, 23, pp. 181-198.

Hancock, P. A., Wulf, G., Thom, D., & Fassnacht, P. (1990). Driver Workload during Differing Manoeuvres. Accident Analysis and Prevention, 22 (3), pp. 281-290.

Hara, T., Kamiya, K., Furuichi, T., & Yoshida, H. (1994). Study on Active Safety Using Simulator: "Driver's Steering Quality in Monotonous Driving". In: Proceedings of the Fourteenth International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In: Hancock & Meshkati (Eds.), Human Mental Workload, pp. 139-183. Elsevier Science, North Holland.

Hartmann, E. (1970). Driver Vision Requirements. In: International Automobile Safety Conference Compendium. New York: SAE, Inc.

Helander, M. (1986). Drivers Reactions to Road Conditions: a Psycho-Physiological Approach. Chalmers University of Technology.

Hill, S. G., Iavecchia, H. P., Byers, J. C., Bittner, A. C., Zaklad, A. L., & Christ, R. E. (1992). Comparison of Four Subjective Workload Rating Scales. Human Factors, 34 (4), pp. 429-439.

Hills, B. L. (1980). Vision, Visibility and Perception in Driving. Perception, 9, pp. 183.

Hughes, P. K. (1988). Eye Movement Behaviour as an Index of Attention and Search in a Complex Visual Environment. Unpublished Ph.D. thesis, as cited in Hughes (1989), University of Melbourne, Australia.

Hughes, P. K. (1989). Operator Eye Movement Behaviour and Visual Workload in Aircraft and Vehicles. In: 25th Annual Conference of the Ergonomics Society of Australia: Ergonomics, Technology and Productivity, The Australian Academy of Science, Canberra, 26-29 November, pp. 97-105.

Hughes, P. K., & Cole, B. L. (1986). What Attracts Attention when Driving? Ergonomics, 29 (3), pp. 377-391.

Hughes, P. K., & Cole, B. L. (1988). The Effect of Attentional Demand on Eye Movement Behaviour when Driving. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), Second International Conference on Vision in Vehicles, Nottingham, U.K., 14-17 September, 1987. Elsevier Science, North-Holland.

ICE (1993). The Design of In-Vehicle Information Systems: Code of Practice and Design Guidelines. Prepared for the Department of Transport. ICE Ergonomics Draft Report.

ISO (1996). Draft Visual Demand Measurement Method, Proposed ISO standard. Internal Committee Discussion Draft, August.

Janssen, W. H., Alm, H., Michon, J. A., & Smiley, A. (1993). Driver Support. In: Generic Intelligent Driver Support, pp. 53-66. Chapter 4: Taylor & Francis, London.

Johnson, C. A., & Keltner, J. L. (1983). The Incidence of Visual Field Loss in 20,000 Eyes and it's Relationship to Driving Performance. Archives of Ophthalmology, 101, pp. 371-375.

Johnson, W. A., & Dark, V. J. (1986). Selective Attention. Annual Review of Psychology, 37, pp. 43-75, as cited in Hughes & Cole (1986).

Jordan, P. W., & Johnson, G. I. (1985). Exploring Mental Workload via TLX: The Case of Operating a Car Stereo Whilst Driving. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), International Conference on Vision in Vehicles, Nottingham, U.K. Elsevier Science, North-Holland.

Kennedy, R. S., & Frank, L. H. (1986). Review of Motion Sickness with Special Reference to Simulator Sickness. Transportation Research Record, 1059, pp. 75-80.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). A Simulator Sickness Questionnaire (SSQ): An Enhanced Method for Quantifying Simulator Sickness. International Journal of Aviation Psychology, 3, pp. 203-220.

Kramer, U. (1991). Physiological Metrics of Mental Workload: A Review of the Recent Progress. In: D. L. Damos (Ed.), Multiple Task Performance, pp. 279-328. Taylor & Francis, London.

Kramer, U., & Neculau, M. (1986). Drivers Display, Eye-Movements and Steering Behaviour: the Visual Basis of Car Driving. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), International Conference on Vision in Vehicles, Nottingham, U.K., pp. 185-194. Elsevier Science, North-Holland.

Labiale, G. (1989). Influence of In-Car Navigation Map Displays on Drivers' Performances. SAE paper 891683, pp. 1281-1288.

Lansdown, T. C. (1996). How is Visual Behaviour Affected by Changes in the Availability of Advanced Driver Information? In: International Conference on Traffic & Transport Psychology, Valencia, Spain, pp. 161-166.

Lansdown, T. C., & Fowkes, M. (in press). An Investigation into the Utility of Various Metrics for the Evaluation of Driver Information Systems. In: A. G. Gale (Ed.), Sixth International Conference on Vision in Vehicles, University of Derby, U.K., 13-16 September, 1995. Elsevier Science, North Holland.

Lansdown, T. C., & Galer Flyte, M. D. (1996). Evaluating In-Vehicle Information System: A Comparison of Road and Simulator Based Experiments. In: Roads 96, Australian Road Research Board and Transit New Zealand, Christchurch, New Zealand, 2-6th September, vol. 7.

Lashley, K. S. (1954). Dynamic Processes in Perception. In: A. F. Bremer & H. H. Jasper (Eds.), Brain Mechanisms and Consciousness. Springfield, Ill.

Laya, O., & Carter, C. J. (in press). Drivers' visual search in a field situation and in a driving simulator. In: A. G. Gale (Ed.), Sixth International Conference on Vision in Vehicles, University of Derby, U.K., 13-16 September, 1995. Elsevier Science, North Holland.

Leibowitz, H. W., Owens, D. A., & Post, R. B. (1982). Nighttime Driving and Visual Degradation. SAE paper 820414.

Leister, R. (1993). Driver-Vehicle Interface: Dialogue Design for Voice Input. In: A. M. Parkes & S. Franzén (Eds.), Driving Future Vehicles, pp. 275-293. Taylor and Francis.

Luckiesh, M., & Moss, F. K. (1934). The New Science of Seeing. Cleveland: General Electric Co., as cited in Matanzo and Rockwell (1967).

Lynch, K., & Rivkin, M. (1959). A Walk Around the Block. Landscape, 8, pp. 24-34, as cited in Hughes and Cole (1986).

Machworth, N. H., & Morandi, A. J. (1967). The Gaze Selects In-formative Details within Pictures. Perception and Psychophysics, 2 (11).

Masuda, K., Nagata, M., Kuriyama, H., & Sato, T. B. (1990). Visual Behaviour of Novice Drivers in Obstacle Negotiation under Alcohol-Dosed Conditions. SAE paper 900140.

Matanzo, J. R. F., & Rockwell, T. H. (1967). Driver Performance under Nighttime Conditions of Visual Degradation. Human Factors, 9 (5), pp. 427-432.

McNally, W. J., & Stuart, E. A. (1942). Physiology of the Labyrinth Reviewed in Relation to Seasickness and Other Forms of Motion Sickness. War Medicine, 2, pp. 683-771, as cited in Kennedy and Frank (1986).

Michon, J. A., Smiley, A., & Aasman, J. (1990). Errors and Driver Support Systems. Ergonomics, 33 (10/11), pp. 1215-1229.

Money, K. E. (1970). Motion Sickness. Physiological Reviews, 50 (1), pp. 1-39, as cited in Kennedy and Frank (1986).

Moray, N. (1981). The Role of Attention in the Detection of Errors in Man-Machine Systems. In: J. Rasmussen & W. Rouse (Eds.), Human Detection and Diagnosis of Failures. Plenium, New York, as cited in Wierwille (1993a).

Mori, M., & Abdel-Halim, M. H. (1981). Road Sign Recognition and Non-Recognition. Accident Analysis and Prevention, 13, pp. 101-115.

Morrow, D. G., Leirer, V., & Altieri, P. (1992). Aging, Expertise, and Narrative Processing. Psychology and Aging, 7, pp. 376-388.

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of Visual Search by Novice and Experienced Drivers. Human Factors, 14 (4), pp. 325-335.

Mourant, R. R., Rockwell, T. H., & Rackoff, N. J. (1970). Driver's Eye Movements and Visual Workload. Highway Research Record, 292, pp. 1-10.

Moussa-Hamouda, E., & Howard, J. M. (1977). Human Factors Requirements for Fingertip Reach Controls, Technical report No. DOT-HS-803-267. U.S. Department of Transportation, Washington D.C., as cited in Wierwille (1993b).

Muira, T. (1986). Coping with Situational Demands: a Study of Eye Movements and Peripheral Vision Performance. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), International Conference on Vision in Vehicles, Nottingham, U.K., 9-13 September, pp. 205-216. Elsevier Science, North-Holland.

Nagata, M., & Kuriyama, H. (1982). Visual Behaviour of Novices and Experienced Drivers. SAE paper 820415.

Nilsson, L. (1993). Contributions and Limitations of Simulator Studies to Driver Behaviour Research. In: A. M. Parkes & S. Franzén (Eds.), Driving Future Vehicles, pp. 401-407. Taylor and Francis.

Norman, O. K. (1944). Studies of Motor Vehicle Operations on Lighted and Unlighted Rural Highways in New Jersey. Proceedings Highway Research Board, 24, pp. 513-534, as cited in Matanzo and Rockwell (1967).

Noy, Y. I. (1990). Selective Attention with Auxillary Automotive Displays. In: Proceedings of the Human Factors Society, 34th Annual Meeting, pp. 1533-1537.

Noy, Y. I., & Zaidel, D. (1991). Methodological Framework for Evaluating the Ergonomics of Advanced Driver Information Systems. In: Proceedings of the 11th Congress of the International Ergonomics Association, Paris, France.

Owens, D. A., Helmers, G., & Sivak, M. (1993). Intelligent Vehicle Highway Systems: a Call for User-Centred Design. Ergonomics, 36 (4), pp. 363-369.

Parkes, A. M. (1991). Data Capture Techniques for RTI Usability Evaluation, DRIVE Project V 1017 (BERTIE), HUSAT Research Institute, Loughborough, U.K.

Parkes, A. M. (1995). Personal Communication.

Peacock, B., & Karowowski, W. (1993). Automotive Ergonomics. Taylor and Francis Ltd.

Pfeifer, M. R., & Tomaske, W. (1986). The Influence of Peripheral Visual Signals on Human Reaction Time. In: Human Decision Making and Manual Control. Elsevier Science, North Holland.

Rasmussen, J. (1983). Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models. Transactions on Systems, Man, and Cybernetics, smc-13 (3, May/June), pp. 257-266.

Rasmussen, J. (1986). Information Processing and Human-Machine Interaction. Elsevier Science, North Holland.

Reason, J. T., & Brand, J. J. (1975). Motion Sickness. Academic Press, New York, as cited in Kennedy and Frank (1986).

Reid, G. B., Shingledecker, C. A., & Eggemeier, F. T. (1981). Application and Conjoint Measurement to Workload Scale Development. In: Proceedings of the Human Factors Society, 25th Annual Meeting, pp. 522-525. Santa Monica, CA: Human Factors Society.

Renge, K. (1980). The Effects of Driving Experience on a Driver's Visual Attention. An Analysis of Objects Looked at: Using the 'Verbal Report' Method. International Association of Traffic Safety Sciences Research, 4, pp. 95-106, as cited in Hughes and Cole (1986).

Rockwell, R. H. (1972). Eye Movement Analysis of Visual Information Acquisition in Driving. Australian Road Research Board Proceedings, 6 (3), pp. 316-331.

Rockwell, T. H. (1988). Spare Visual Capacity in Driving-Revisited. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), Second International Conference on Vision in Vehicles, Nottingham, U.K., 14-17 September, 1987, pp. 317-324. Elsevier Science, North Holland.

Rumar, K. (1988). In-Vehicle Information Systems. International Journal of Vehicle Design, 9 (4/5), pp. 548-557.

Sabey, B. E., & Staughton, G. C. (1975). Interacting Roles of Road Environment, Vehicle and Road User in Accidents. In: Proceedings of the 5th International Conference of the Association for Accident and Traffic Medicine, London.

Sawin, D. A., & Scerbo, M. W. (1993). Vigilance: Where Has All the Workload Gone? In: Proceedings of the Human Factors and Ergonomics Society, 37th Annual Meeting, pp. 1383-1387.

Schlegel, R. E. (1993). Driver Mental Workload. In: B. Peacock & W. Karowowski (Eds.), Automotive Ergonomics, pp. 359-382. Taylor & Francis.

Schraagen, J. M. C. (1993). Information presentation in in-car navigation systems. In: A. M. Parkes & S. Franzen (Eds.), Driving Future Vehicles, pp. 171-185. London: Taylor & Francis.

Sciafa, C. T., Kline, D. W., & Lyman, B. J. (1987). Age Differences in Target Identification as a Function of Retinal Location and Noise Level: Examination of the Useful Field of View. Psychology and Ageing, 2.

Senders, J. W., Kristofferson, A. B., Levision, W., Dietrich, C. W., & Ward, J. L. (1966). An Investigation of Driver Information Processing, No. 1335. U.S. Department of Commerce, as cited in Wierwille et al. (1988b).

Senders, J. W., Kristofferson, A. B., Levision, W., Dietrich, C. W., & Ward, J. L. (1967). The Attentional Demand of Automobile Driving. Highway Research Record, 195, pp. 13-15.

Sheridan, T. B., Meyer, E., Roy, S. H., Decker, K. S., Yanagishima, T., & Kishi, Y. (1991). Physiological and Psychological Evaluations of Driver Fatigue during Long Term Driving. SAE paper 910116.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and Automatic Human Information Processing: II. Perceptual Learning, Automatic Attending and a General Theory. Psychological Review, 84, pp. 127-190.

Shinar, D., & Schieber, F. (1991). Visual Requirements for Safety and Mobility of Older Drivers. Human Factors, 33 (5), pp. 507-519.

Sivak, M., Flannagan, M., Ensing, M., & Simmonds, C. J. (1991). Discomfort Glare is Task Dependent. International Journal of Vehicle Design, 12 (2), pp. 152-159.

Sivak, M., Post, D. V., Olson, P. L., & Donohue, R. J. (1981). Driver Response to High-Mounted Brake Lights in Actual Traffic. Human Factors, 23 (2), pp. 231-235.

Skrene, P. (1976). The Cost Effectiveness of Upgrading Urban Street Lighting. M. Eng., School of Transportation and Traffic, University of New South Wales, Australia.

Spijkers, W. (1992). Distribution of Eye-Fixations During Driving. Journal of the International Association of Traffic & Safety Sciences, 16 (1), pp. 27-34.

Stevens, A. (1992). Assessment of the TrafficMaster Driver Information System: Summary and Discussion of Traffic and Safety Implications, Working Paper, WP/TO/108. Transport Research Laboratory.

Stevens, A., & Martell, D. K. (1993). Development and Evaluation of the TrafficMaster Driver Information System. In: IEEE-IEE Vehicle Navigation & Information Systems Conference, Ottowa, VNIS, pp. 251-258.

Streeter, L. A., Vitello, D., & Wonsiewicz, S. A. (1985). How to Tell People Where to Go: Comparing Navigational Aids. International Journal of Man-Machine Studies, 22, pp. 549-562.

Sussman, E. D., Bishop, H., Madnick, B., & Walter, R. (1985). Driver Inattention and Highway Safety. Transportation Research Record, 1047, pp. 40-8, as cited in Verwey (1993).

Suzuki, T., Nakamura, Y., & Ogasawara, T. (1966). Intrinsic Properties of Driver Attentiveness. The Expressway and the Automobile, 9, pp. 24-29, as cited in Renge (1980).

Szlyk, J. P., Brigell, M., & Seiple, W. (1993). Effects of Age and Hemianopic Visual Field Loss on Driving. Optometry and Visual Science, 70 (12), pp. 1031-1037.

Tanner, J. (1958). Reduction of Accidents by Improved Street Lighting. Light and Lighting, 51 (11).

Theeuwes, J., & Hagenzieker, P. (1993). Visual search of Traffic Scenes: on the Effect of Location Expectations. In: A. G. Gale, I. D. Brown, C. M. Haslegrave, H. W. Kruysse, & S. P. Taylor (Eds.), Fourth International Conference on Vision in Vehicles, University of Glasgow, Scotland, pp. 149-158. Elsevier Science, North-Holland.

Thomas, D. B. (1989). Monitoring Driver Status: the State of the Art, DRIVE Project V1004. Technischer Uberwachungs-verin Rheinland e.v. FRG.

Tijerina, L., Kantowitz, B., Kiger, S. M., & Rockwell, T. H. (1994). Driver Workload Assessment of In-Cab High Technology Devices. In: Proceedings of the Fourteenth International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, May 23-26.

Tijerina, L., Kiger, S., Rockwell, T. H., & Wierwille, W. W. (1995). NHTSA Heavy Vehicle Driver Workload Assessment Final Report Supplement - Task 5: Heavy Vehicle Driver Workload Assessment Protocol (Appendix A, pp. A-1 through A-19)., (Contract No. DTNH22-91-C-07003).Columbus, OH: Battelle.

Tinker, M. A. (1935). Cautions Concerning Illumination Intensities for Reading. American Journal of Optomology, 12, pp. 43-51, as cited in Matanzo and Rockwell (1967).

Treat, J. R., Tumbas, N. S., & McDonald, S. T. (1979). Tri-Level Study of the Causes of Traffic Accidents: Final Report, Final Report (vol. 1 and 2), No. U.S. DOT HS-805-086 (NTIS PB 80-121064), as cited in Verwey (1993).

Tyler, D. B., & Bard, P. (1949). Motion Sickness. Physiological Reviews, 29, pp. 311-369, as cited in Kennedy and Frank (1986).

van Winsum, W. (1987). De Mentale be Lasting van hut Navigeren in het verkeer, Rapport Verkeerskundig Studiecentrum, No. VK 87-30, as cited in Schraagen (1993).

Verwey, W. B. (1993). How Can We Prevent Overload of the Driver? In: B. Peacock & W. Karowowski (Eds.), Automotive Ergonomics, pp. 235-244. Taylor and Francis.

Viano, D., Davis, R. F., LeFevre, R. L., & Scherba, M. C. (1991). Opportunities in Automotive Safety: A Public Health Perspective. In: ESV Conference.

Vidulich, M. A., & Tsang, P. S. (1987). Absolute Magnitude Estimation and Relative Judgement Approaches to Subjective Workload Assessment. In: Proceedings of the Human Factors Society, 31st Annual Meeting, pp. 1057-1061. Santa Monica, CA: Human Factors Society.

Voss, J. F. (1955). Effect of Target Brightness and Target Speed Upon Tracking Proficiency. Journal of Experimental Psychology, 49, pp. 237-243, as cited in Matanzo and Rockwell (1967).

Wall, J. G. (1992). Vehicle Safety - What are the Needs? SAE paper 925201, pp. 9-19.

Ward, N., Fletcher, W. S., & Hirst, S. J. (1993). Strategic Study: Motorist Information Needs and System Design Issues, BRIMMI, CED3: Collision Avoidance, 3.7. HUSAT Research Institute, Loughborough, U.K.

Wetherall, A. (1979). Short Term Memory for Verbal and Graphic Route Information. In: Proceedings of the Human Factors Society, 23rd Annual Meeting, Human Factors Society, Santa Monica, CA, pp. 464-468.

Wickens, C. D. (1984). Engineering Psychology and Human Performance. (2nd ed.) Harper Collins.

Wierwille, W. W. (1987). Can Dash Instrumentation Visual Attentional Demand be Predicted using the Design Driver Concept? Transportation Research Board Annual Meeting, as cited in Wierwille (1993a).

Wierwille, W. W. (1993a). Demands on Driver Resources Associated with Introducing Advanced Technology into the Vehicle. Transportation Research (c), 1 (2), pp. 133-142.

Wierwille, W. W. (1993b). Visual and Manual Demands of In-Car Controls and Displays. In: B. Peacock & W. Karowowski (Eds.), Automotive Ergonomics, pp. 299-320. Taylor and Francis.

Wierwille, W. W., & Casali, J. G. (1983). A Validated Rating Scale for Global Mental Workload Measurement Applications. In: Proceedings of the Human Factors Society, 27th Annual Meeting, vol. 1.

Wierwille, W. W., & Eggemeier, F. T. (1993). Recommendations for Mental Workload Measurement in a Test and Evaluation Environment. Human Factors, 35 (2), pp. 263-281.

Wierwille, W. W., & Fung, P. (1975). Comparison of Computer-Generated and Simulated Motion Picture Displays in a Driving Simulation. Human Factors, 17 (6), pp. 577-590.

Wierwille, W. W., & Gutmann, J. C. (1978). Comparison of Secondary and Primary Task Measures as a Function of Simulated Vehicle Dynamics and Driving Conditions. Human Factors, 20, pp. 233-44.

Wierwille, W. W., Hulse, M. C., Antin, J. F., & Dingus, T. A. (1988a). Visual Attentional Demand of an In-Car Navigation Display System. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), Second International Conference on Vision in Vehicles, Nottingham, U.K., 14-17 September 1987, pp. 307-316. Elsevier Science, North Holland.

Wierwille, W. W., Hulse, M. C., Fischer, T. J., & Dingus, T. A. (1988b). Strategic Use of Visual Resources by the Driver While Navigating with an In-Car Navigation Display System. SAE paper 885180, vol. 2, pp. 661-675.

Wilde, G. J. S. (1994). Target Risk. Dealing with the Danger of Death, Disease and Damage in Everyday Decisions. PDE Publications and Castor & Columbia.

Yarbus, A. L. (1967). Eye Movements and Vision.

Zaidel, D. M. (1991). Specification of a Methodology for Investigating the Human Factors of Advanced Driver Information Systems, University of Toronto, Department of Industrial Engineering.

Zimmer, A. (1990). Driver Information Needs - Revised Version, DRIVE Project V1017 (BERTIE), No. 25.

Zwahlen, H. T., Adams, C. C., & DeBald, D. P. (1988). Safety Aspects of CRT Touch Panel Controls on Automobiles. In: A. G. Gale, M. H. Freeman, C. M. Haslegrave, P. Smith, & S. P. Taylor (Eds.), Second International Conference on Vision in Vehicles, Nottingham, U.K., 14-17 September 1987, pp. 335-344. Elsevier Science, North Holland.

# Appendix A

## Chapter 4 Data Forms & Instructions

# Appendix A. Chapter 4 Data Forms & Instructions

## Study Description Presented to the Subjects

Please read thoroughly, if anything is unclear ask the experimenter.

I am interested in people's ability to extract information about driver's visual behaviour.

You will be analysing some video tape of a driving sequence. Please feel free to rewind or forward wind the tape to review the data. Ask the experimenter to explain how the video recorder works.

I would like you to record (on the sheet provided):

a) **when** the driver looks away from the forward view;
b) **where** the driver looks;
c) **how long** the driver looks away.

The experimenter will inform you when to stop (it should take about an hour).

**Tips:**

- use the time signal on the screen **not** the video recorder counter;
- the forward view usually encompasses the windscreen (except when turning corners);
- the right region encompasses the right mirror and glances between the right 'a' and 'b' posts;
- the left region encompasses the left mirror and glances between the left 'a' and 'b' posts;
- the 'into vehicle' region considers glances to the instrument panel or interior of the vehicle.
- estimate how long the driver looks away to the nearest tenth of a second, e.g. 1.4 seconds.

| Number of frames on video | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| Equivalent time (seconds) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |

**Example**

When the driver looks away from the forward view, insert the 'on screen' time here

Insert the amount of time the driver looks, in the appropriate column

Please write any comments which you feel are appropriate in here

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| Clock Time | Driver mirror | Right region | Left region | Into Car | Notes |
|---|---|---|---|---|---|
| 54:51 | 0.6 | | | | |
| 54:52 | | 0.6 | | | |
| 54:56 | ? | ? | ? | ? | |
| etc.. | | | | 1.5 | looks at the instruments |

## Study Description Presented to the Subjects

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Please read thoroughly, if anything is unclear ask the experimenter.

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I am interested in people's ability to extract information about driver's visual behaviour.

You will be analysing some video tape of a driving sequence. Please feel free to rewind or forward wind the tape to review the data. Ask the experimenter to explain how the video recorder works.

I would like you to record (on the sheet provided):

a) **when** the driver looks away from the forward view;
b) **where** the driver looks;
c) **how long** the driver looks away.

The experimenter will inform you when to stop (it should take about 30 minutes).

---

### Tips:

- use the time signal on the screen **not** the video recorder counter;
- the forward view usually encompasses the windscreen (except when turning corners);
- the right region encompasses the right mirror and glances between the right 'a' and 'b' posts;
- the left region encompasses the left mirror and glances between the left 'a' and 'b' posts;
- the 'into vehicle' region considers glances to the instrument panel or interior of the vehicle.
- estimate how long the driver looks away in half second intervals, e.g. 3.5 seconds.

### Example

| When the driver looks away from the forward view, insert the 'on screen' time here | Insert the amount of time the driver looks, in the appropriate column | | | | Please write any comments which you feel are appropriate in here |
|---|---|---|---|---|---|
| Í | Í | Í | Í | Í | Í |

| Clock Time | Driver mirror | Right region | Left region | Into Car | Notes |
|---|---|---|---|---|---|
| 54:51 | 0.5 | | | | |
| 54:52 | | 0.5 | | | |
| 54:56 | ? | ? | ? | ? | |
| etc.. | | | | 1.5 | looks at the instruments |

## Pre-experimental Checklist and Instructions

Is the tape at the right place, 54:45?
Is the remote control handy?
Is the subject comfortable?
Have you got their demographics?

**Subject Instructions**
Please use the jog/shuttle control to wind the video tape backward and forwards as necessary, and the pause to start and stop the tape. Additionally, the jog/shuttle button (show them) should pressed so that the red light to the right remains on, it makes the shuttle easier to use!

This is the timer and as you can see it is in minutes and seconds (point to it). Put the time here, for example at this point (54:51) the driver can be seen to look away from the forward scene and at the driver mirror. You should then (either):

a) move the shuttle backward or forward and count the number of frames until the driver looks back to the forward scene

b) move the shuttle backward or forward and estimate to the nearest half second the time until the driver looks back to the forward scene

and write it here (point).

Similarly, here (54:52) the driver looks at the right mirror so we write down in the *clock time* column, the on screen time and work out the duration as above (i.e., count with them and show where to write).

So, where does the driver look at this point (54:56) and for how long?

It is interesting to note that as the driver goes round the corner he is still looking at the forward scene.

When the driver looks away from the forward view, insert the 'on screen' time here

Insert the amount of time the driver looks in the appropriate column

Please write any comments which you feel are appropriate in here

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| Clock Time | Driver mirror | Right region | Left region | Into Car | Notes |
|---|---|---|---|---|---|
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# Appendix B

# Subject Consent and Payment Forms

# Appendix B. Subject Consent and Payment Forms

*Loughborough University of Technology*

Department of Aeronautical & Automotive Engineering & Transport Studies

**Subject Consent Form**

The experimenter has read the outline of this investigation and I understand what will be required of me. I have had the opportunity to ask for further information and for clarification of the demands of each of the procedures. I am aware that I have the right to withdraw from the study at any time, with no obligation to give reasons for my decision.

I agree to take part in this investigation into the visual demands associated with (**insert study description**).

Signed:

Date:

Witnessed by:

.......... Cut Here ✂ ..........

**Subject Payment Form**

I ........................................................................ (please print your name)

accept payment of ........................ pounds for participation in

experimental work.

Address: ........................................................................

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Signed: ............................................................

Date: ........................................

# Appendix C

# Chapter 5 Subject Instructions & Adapted R-TLX Forms

# Appendix C. Chapter 5 Subject Instructions & Adapted R-TLX Forms

**Study Description Presented to the Subjects**

I am interested in observing what people attend to when they drive in different traffic environments.

I will give you directions to follow in driving a set route. The route encompasses a range of roads and junctions. It takes approximately 45 mins to complete.

You are not obligated to comply with my instructions if you feel they are unsafe at that moment. Your safety is paramount. Only comply with my requests when you feel it is safe to do so. You may reject any request outright.

Adapted NASA-R-TLX Rating Scale

**Please read the following instructions carefully**

Driving is a very complex skill which most of us take for granted. Imagine all the different components and pieces of behaviour which are involved in successfully controlling the vehicle through the traffic environment. For instance, one has to look-out for pedestrians, judge distance and speed in relation to other vehicles, control position on the road via the steering wheel while simultaneously attending to gear changes and pedal controls. In other words, driving demands the human to perform a number of tasks at once.

Fortunately an experienced driver learns how to bring together these skills and perform them in a manner which demands little conscious control. This comes with practice and experience on the road. Most of us can remember those days as learner drivers when we were forced to remember each skill in turn and there always seemed to be too much to be done to too little time.

The following breaks down the driving task into six distinctive components. Please read through the descriptions of each factor and inform the experimenter when you have finished.

**1. Mental Demand**
This factor refers to any mental demands **placed on you** by the driving task, e.g. in planning, thinking, deciding, remembering, looking or searching. Was the driving task mentally easy or demanding?

**2. Mental Effort**
This factor refers to the mental effort **required by you** to maintain a safe level of driving. During the course of the journey how much concentration was required?

**3. Physical Demand**
This factor refers to any **physical activity** you have just experienced while driving, e.g. operating the car's controls and displays, etc.

**4. Time Pressure**
This factor refers to how **hurried or harassed** you felt while driving, e.g. due to the presence of other vehicles, traffic flow, etc.

**5. Distraction**
This factor refers to the extent to which you felt **distracted** from the driving task. Safe driving requires you to demonstrate a reasonable amount of vigilance to the events outside the vehicle. Information both inside and outside the car (visual and/or auditory) has the potential to distract you from the driving task.

**6. Stress Level**
Ideally you should feel relaxed and unworried while driving. However, circumstances may cause you to feel stressed, i.e. annoyed, frustrated, worried and/or irritated. This factor refers to how **relaxed or stressed** you felt while driving.

Please place a mark through each line to show the amount that each factor applied to YOU.

---

**For example**, if you felt that your response was high, you would place a cross as shown below.

Example — Low ———————— High (X)

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Mental Demand — Low ———————— High

Mental Effort — Low ———————— High

Physical Demand — Low ———————— High

Time Pressure — Low ———————— High

Distraction — Low ———————— High

Stress Level — Low ———————— High

# Appendix D

## Symptoms Checklist

## Introduction

The symptoms checklist (Kennedy, Lane, Berbaum, & Lilienthal, 1993) administered to subjects in Chapter 9 investigated any detrimental affects from use of the simulator. The checklist consisted of thirteen rating scale questions concerning: general discomfort, fatigue, boredom, drowsiness, headache (severity and location), eye strain, difficulty focusing, sweating, claustrophobia, disorientation, nausea and difficulty concentrating. Additionally, ten forced choice (yes/no) questions considered presence of: dizziness, vertigo, visual flashbacks, blurred vision, faintness, stomach awareness confusion, vomiting, exhilaration and other symptoms.

## Results

The following rating scale questions (50%) resulted in reports of greater than slight symptoms during post experimental inquiry, see Table D - 1. None of the subjects reported severe symptoms. Forced choice (yes/no) questions for the pre and post-trial, can be see in Table D - 2. Dizziness, visual flashbacks, blurred vision, confusion and other symptoms were shown to increase to a small degree. Contrary to expectations stomach awareness was reported to decrease.

**Table D - 1. Percentage of subjects' symptoms ratings (pre and post-trial)**

| Symptom | None | | Slight | | Moderate | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post |
| General discomfort | 83% | 39% | 17% | 56% | 0% | 6% |
| Fatigue | 44% | 17% | 56% | 61% | 0% | 22% |
| Boredom | 100% | 61% | 0% | 39% | 0% | 6% |
| Drowsiness | 72% | 56% | 22% | 22% | 6% | 22% |
| Headache | 83% | 56% | 17% | 39% | 0% | 6% |
| Difficulty concentrating | 78% | 56% | 22% | 39% | 0% | 6% |

**Table D - 2. Percentage of subjects' reporting symptoms (pre and post-trial)**

| Symptom | Pre-trial | Post-trial |
|---|---|---|
| Dizziness | 0% | 17% |
| Vertigo | 0% | 0% |
| Visual flashbacks | 0% | 6% |
| Blurred vision | 0% | 11% |
| Faintness | 0% | 0% |
| Stomach awareness | 11% | 6% |
| Confusion | 0% | 6% |
| Vomiting | 0% | 0% |
| Exhilaration | 0% | 0% |
| Other symptoms | 6%* | 6%* |

* *one subject reported "feeling fluey"*

## Discussion

The symptoms checklist administered to the subjects was employed to ensure the study was not imposing undue distress. Rating scale questions indicate that general use of the simulator increased the severity of the reported symptoms. However, the increases were not great and no subject indicated severe symptoms in any of the questions. It should also be noted that several subjects stated slight symptoms prior to the experimental trial, yet considered themselves able to participate in the trial. The pre-experimental protocol specifically states that the subjects are free to withdraw from the trials at any time, see Appendix B - 1. Subjects indicated an increase in the following symptoms during the experiment: dizziness, visual flashbacks, blurred vision, confusion and other symptoms ("feeling fluey"). However, these effects were small, except for dizziness which increased from 0% of subjects to 17%. Stomach awareness was reported to decrease. The simulator imposed some discomfort on the subjects. It is uncertain which perceptual features were inappropriately represented by the device, but the fidelity was not sufficient to overcome the mismatch between the subjects expectations of driving feedback and the sensations which they experienced.

# Appendix E

# Methodological Considerations

# Appendix E. Methodological Considerations

## Introduction

This appendix discusses the rationale behind decisions made during the planning of empirical work for this thesis. First, it considers general issues relating to all studies and continues by describing salient points relevant to each specific experiment.

## General Issues

Subject selection for all studies (with the exception of work described in Chapter 4) was carefully considered so as to reduce the confounding effects that may be attributable to variable driving experience or poor visual function. Subjects with less than two years regular driving experience or those who were over 60 years of age were excluded from the studies. Similarly, any drivers without *normal* vision, or spectacles to correct their vision to normal were also excluded from the subject pool. The rationale behind selection of drivers who could be deemed not to be complete novices and who were without significant visual defect was to enable experimental findings to be generalisable to the broadest range of the driving population. Inclusion of elderly drivers would be an interesting area of further research but was outside the remit of this thesis. Novices drivers and their acquisition of visual scanning strategies has also been identified as an area of additional study. The legal requirement in the U.K. to read a number plate at 20.5m defines clearly the need to exclude drivers who do not reach this criterion and this has been applied throughout subject selection.

The number of people of each sex was balanced as far as possible to reduce any confounding effect. Although, few studies (e.g., Rockwell, 1988) have reported significant differences between male and female visual behaviour.

All experimental work was conducted during daylight hours. Changes in visual ability as a consequence of scotopic light levels are well reported and thus may have confounded results of the road trials had the time of day not been controlled. Additionally, the vehicle simulator could not represent the night-time light levels with sufficient fidelity to represent this driving to a degree where generalisations about such an environment could be made.

The duration of experimental trials was determined by the need to avoid subject fatigue and the requisite number of conditions. The trials needed, however, to be of sufficient length to enable subjects to interact with the information systems (or control) for long enough to be representative of task performance.

Statistical methods and subsequent analysis of data in this thesis were selected with the rationale to optimise the power of the tests with respect to the experimental design and subject numbers. Therefore, to establish significant differences between repeated measures conditions, with more that two comparison groups, using ratio data, one way repeated measures analysis of variance was the most powerful and valid test to employ. Tukey's honestly significant difference (HSD) was selected as the post-hoc test for contrasts because of its greater power for comparisons between simple means, than for example, Scheffé's method. Additionally, the nature of Tukey's HSD means that the likelihood of Type I errors, regardless of the number of comparisons made, does not exceed the chosen significance level.

## Chapter 4

Subject selection in this study was different from the other experiments in that the participants were considering video tape data and not participating in any experimental manipulation of their driving behaviour. Therefore, the criterion adopted in recruitment of subjects was that they have normal or corrected to normal visual function. Thus, it can be stated that they were able to discriminate the detail of the video image they were requested to transcribe.

During each condition subjects were able to review the sample video tape as often as required to confirm their judgements regarding the duration and frequency of glances. The video tape sample contained a time code which was always displayed on screen enabling them to determine the start and stop points for each visual event, see Figure 5 - 3.

## Chapter 5

The experimental route was approximately 14 miles in length, with 6.2 miles of rural driving, 5.6 miles of motorway and 2.2 miles of urban roads. It was selected to balance the time period between the rural, urban and motorway driving and the number of right and left turns where possible. Subjects were shown a map of the route and questioned regarding their familiarity prior to the experimental condition. On a five point scale (very unfamiliar, unfamiliar, neutral, familiar, very familiar) no subject reported extremes of either very unfamiliar or very familiar with the route. The experimental design could have been improved by investigating the subject's familiarity with each specific road type.

## Chapter 6

Additional details regarding the experimental systems were as follows. The in-car entertainment system consisted of a radio and cassette tape player. It had a simple visual display. The congestion warning device presented information to the driver via a complex map-based display. The tasks the subjects were requested to perform were balanced in terms of the minimum number of required interactions with the controls and displays and subjects were instructed to verbally respond to the tasks. The complexity of the in-car entertainment system and congestion warning device tasks was defined to be similar and thus the differences in visual behaviour attributable to differences in the complexity of the visual displays. Subjects were unaware that task performance was not recorded. Task performance was contrived to instigate interaction with the information systems. However, the frequency of tasks (six per condition), was not felt to be sufficient to make inferences regarding successful performance and was therefore not recorded.

## Chapter 7

The driving simulator used in this thesis was a model SV5000LE produced by Time Warner Interactive. The eight CRT visual displays presented 360° computer generated colour images of the other vehicles and virtual environment. The simulated roadway included open field, residential and business areas with single and dual carriageway roads. Handling characteristics of the simulator could be controlled to represent different vehicles. In this thesis, the vehicle model selected was a small front wheel drive family car with an automatic transmission. Speed, distance and indicator state (on/off) were available displays in the facia.

## Chapter 8

In control conditions in the previous studies navigational information was provided to the subjects as and when required. The rationale was to support the driver as much as possible, such that minimal additional load was imposed by the navigation task. The control condition in this study was selected as a car following task because this study was specifically manipulating navigational performance. Therefore, car following was introduced to attempt to provide navigational information in as naturalistic a manner as possible. Similarly, four matched counterbalanced routes were required because of the problems with subjects remembering routes in the repeated measures design, which are inherent in investigations into navigational behaviour.

The relatively simple visual symbols were selected to enable a comparison with the comparatively straightforward auditory information presented. More complex information was avoided because of the potential to confound results by using different quantities of information in each modality.

Technical difficulties precluded the use of the three rear-view screens in the experiment.

## Chapter 9

The congestion warning device tasks conducted in this study were presented to the subjects at points in the experimental conditions where they could self-select when to interact with the information system. This presentation was in contrast to the route guidance information which was only available immediately prior (approximately 250m) to junction negotiation. Thus, when using the route guidance system subjects were forced to either change visual scanning or attend to the in-vehicle display.