The Effects of Visual Clutter on Driving Performance

Jessica Edquist, BSc, Grad Dip Psych.

Accident Research Centre

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Abstract

Driving a motor vehicle is a complex activity, and errors in performing the driving task can result in crashes which cause property damage, injuries, and sometimes death. It is important that the road environment supports drivers in safe performance of the driving task. At present, increasing amounts of visual information from sources such as roadside advertising create visual clutter in the road environment. There has been little research on the effect of this visual clutter on driving performance, particularly for vulnerable groups such as novice and older drivers. The present work aims to fill this gap.

Literature from a variety of relevant disciplines was surveyed and integrated, and a model of the mechanisms by which visual clutter could affect performance of the driving task was developed. To determine potential sources of clutter, focus groups with drivers were held and two studies involving subjective ratings of visual clutter in photographs and video clips of road environments were carried out. This resulted in a taxonomy of visual clutter in the road environment: 'situational clutter', including vehicles and other road users with whom drivers interact; 'designed clutter', including road signs, signals, and markings used by traffic authorities to communicate with users; and 'built clutter', including roadside development and any signage not originating from a road authority. The taxonomy of visual clutter was tested using the change detection paradigm. Drivers were slower to detect changes in photographs of road scenes with high levels of visual clutter than with low levels, and slower for road scenes including advertising billboards than road scenes without billboards. Finally, the effects of billboard presence and lead vehicles on vehicle control, eye movements and responses to traffic signs and signals were tested using a driving simulator. The number of vehicles included appeared to be insufficient to create situational clutter. However billboards had significant effects on driver speed (slower), ability to follow directions on road signs (slower with more errors), and eye movements (increased amount of time fixating on roadsides at the expense of scanning the road ahead). Older drivers were particularly affected by visual clutter in both the change detection and simulated driving tasks.

Results are discussed in terms of implications for future research and for road safety practitioners. Visual clutter can affect driver workload as well as purely visual aspects of the driving task (such as hazard perception and search for road signs). When driver workload is increased past a certain point other driving tasks will also be performed less well (such as speed maintenance). Advertising billboards in particular cause visual distraction, and should be considered at a similar level of potential danger as visual distraction from in-vehicle devices. The consequences of roadside visual clutter are more severe for the growing demographic of older drivers. Currently, road environments do not support drivers (particularly older drivers) as well as they could. Based on the results, guidance is given for road authorities to improve this status when designing and location road signage and approving roadside advertising.

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other institution.

To the best of the candidate's knowledge, the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signed:………………………………………………..

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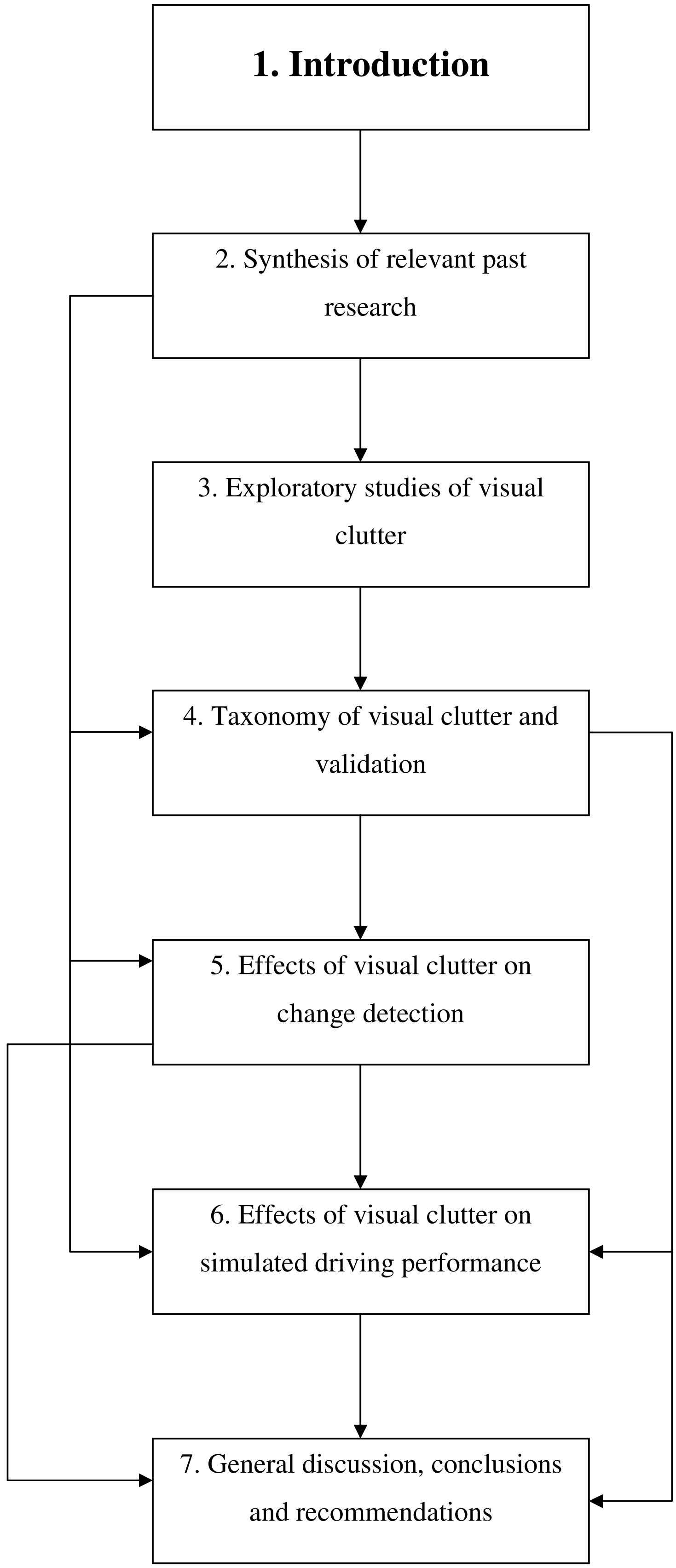
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Chapter One

Introduction

Problem statement

Road safety is a worldwide public health problem. Unlike other leading causes of death, traffic accidents cause death and injuries in young people as well as people approaching their expected lifespan. Crashes are therefore a huge contributor to years of life lost, particularly when quality of life is taken into account. Crashes also lead to property damage, as well as costs from indirect effects such as congestion. A great deal of research effort is therefore focussed on investigating how the driving task is carried out, and what factors can impair driving performance.

Driving a motor vehicle on a typical major road is a complex activity. It involves processing large amounts of (mostly) visual information, perceiving a constantly changing environment, and making decisions at speed. The amount of visual information in road environments is increasing, due to higher traffic density, more complex traffic management systems, increased commercial roadside development, and increasing pressure on road authorities to permit advertising next to major roads.

With this increasing amount of visual information, the road environment is increasingly prone to 'visual clutter'. There has been little research into how and to what extent visual clutter can compromise driver safety. Because of the lack of recent relevant research, road authorities develop their guidelines around the visual appearance of the road and roadside environment based on engineering judgement, conventions and international standards. Recently, these guidelines are being challenged; in the area of roadside advertising, road authorities have been asked to provide evidence to defend their assumption that additional visual stimuli could impair driving performance.

Aim

The principal aim is to ascertain what effect visually cluttered environments have on driving performance. To achieve this aim, it is necessary to first determine what visual clutter is, i.e. what are the sources of visual clutter in the road environment? The pathways by which visual clutter might affect driving performance can then be investigated. Finally, the thesis aims to carry out experiments simulating driving performance to confirm the hypothesised effects of visual clutter on driving.

As the literature suggests that certain drivers may be more vulnerable to the effects of visual clutter, a subsidiary aim is to explore the differential effects of clutter on young novice drivers and elderly drivers as compared to fully licensed young-middle aged drivers.

Scope

A visually cluttered environment is defined in this thesis as an environment with visual characteristics that have the potential to impair performance of the driving task. The use of this definition incorporates the concept that performance depends on an interaction between the individual, the task, and the environment. Therefore effects of visual clutter on perception are not examined in isolation, but are situated in the context of the driving task.

The experimental work focuses on road scenes during the day. Daylight provides the simplest setting to explore the fundamentals of visual clutter. Issues around night vision and artificial light sources are outside the scope of this current research. The research is primarily focussed on car drivers as these are the major form of road transport. Many of the issues raised will also be pertinent to other forms of transport such as trucks and bicycles; however these modes have additional specific issues which will not be dealt with as part of this thesis. Finally, the experimental work concentrates on the visual and cognitive antecedents to specific behaviours, rather than investigating crashes or crash statistics.

Project background

The present thesis is part of an ARC Linkage Grant, with the Department of Main Roads, Queensland as the industry partner. The project was initially conceived as a study of the effects of billboards and other visual sources of information in the road environment on driver performance. This topic was not only of great practical interest to the industry partner, but of academic interest as these effects are under-researched and not well understood. While it would have been possible to look at this topic purely from the point of view of the visual distraction such objects may create, the author wished to situate the potential effects within a broader theoretical framework. The thesis therefore examines both the issues of distraction from specific types of information, and overload from too much information.

Overview

Four experimental chapters are presented, building from subjective studies of visual clutter to a complex driving simulator experiment. Each chapter is self-contained, but relevant literature is primarily contained in the review at the beginning and the final discussion and conclusions chapter.

Chapter Two reviews the background literature on what visual clutter is and how it might impair driving performance. Literature from many domains is surveyed and integrated, and a model of potential effects on driving performance is presented.

Chapter Three explains the initial exploratory studies to operationally define visual clutter. These included focus group discussions with drivers, and a study in which drivers rated the level of visual clutter in photographs of road scenes.

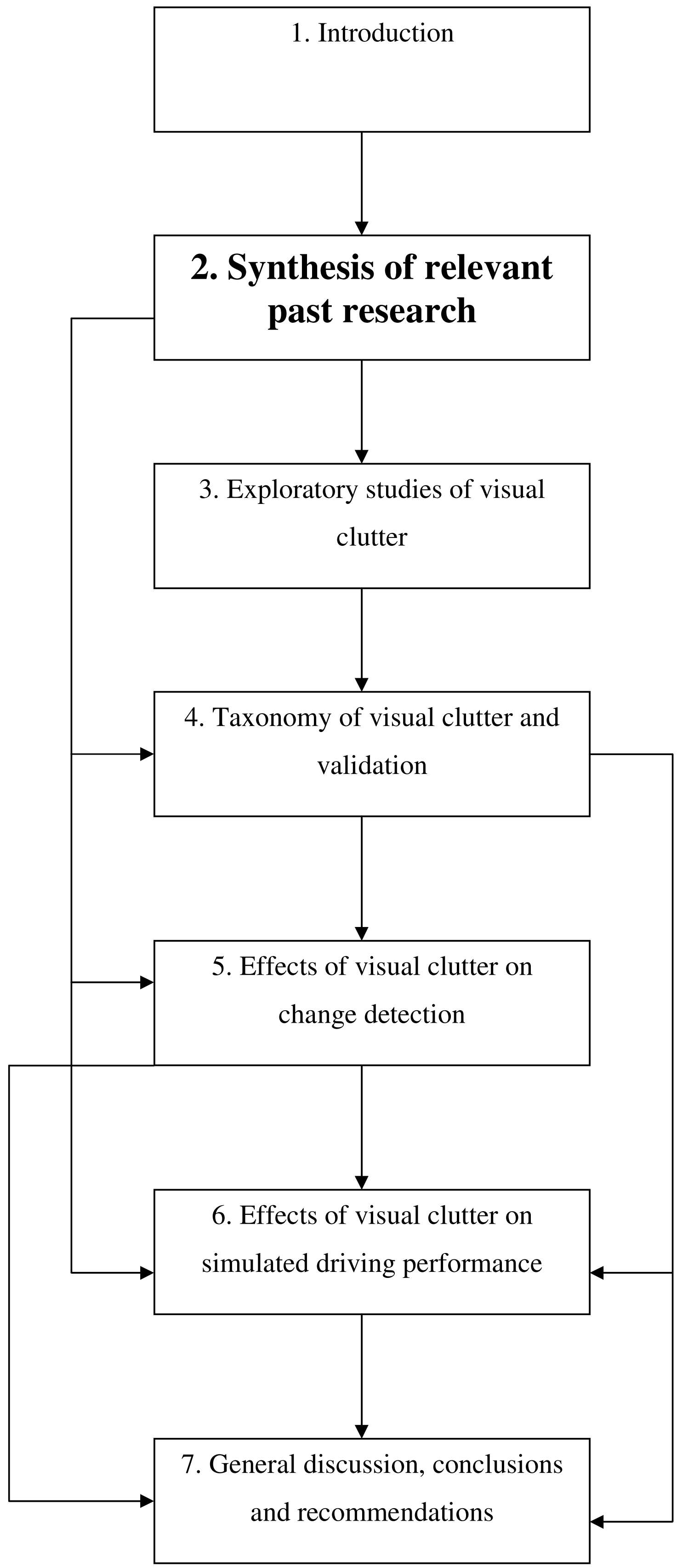
Chapter Four explains the taxonomy of visual clutter developed from the initial studies, and describes the experimental validation of the taxonomy. The taxonomy was initially validated by reanalysing the ratings from the photograph study. After positive results, a new study using video clips was designed to determine the contributions of each type of visual clutter and examine whether ratings were similar when dynamic stimuli (video clips) were used instead of static stimuli (photographs).

Chapter Five describes an experiment investigating the results of visual clutter on change detection, which is an important component of driving performance. This study also specifically investigated the effect of roadside billboards on change detection (and, by extension, situation awareness/hazard perception and visual search).

Chapter Six describes an experiment investigating the effects of a certain type of visual clutter in the roadside environment on performance in a driving simulator, with a specific focus on the effects of roadside advertising. The tasks investigated included vehicle control, stopping at signals, and following road signs, with and without the presence of lead vehicles. Eye movements were also recorded and visual behaviour examined.

Chapter Seven discusses the results of the research, limitations and where further research is necessary. The results are linked to existing theory, and implications for road safety practitioners are discussed.

The flowchart at the start of each chapter explains the links between chapters and highlights the current chapter.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Chapter Two

Synthesis of relevant past research

The aim of this chapter is to bring together relevant information from many different theoretical perspectives - basic vision research, experimental cognitive psychology, ergonomics, and specific research on the activity of driving - in order to comprehend the potential effects of visually cluttered environments on driving performance.

The potentially relevant literature is enormous. Obviously this single chapter cannot cover every aspect of seeing and driving. Therefore the literature review focussed on specific areas which were thought likely to contain relevant findings: driver distraction and the associated issue of mental workload; visual search and selective attention; and the small number of studies which have specifically investigated 'visual clutter'.

It is necessary to start with an understanding of the driving task itself. Deconstructing the driving task into component subtasks allows the examination of how the visual environment can affect driving performance. Particular attention is given to examining the task of collecting information from the visual environment. Factors which might moderate the effect of visual clutter on different individuals or for one individual in different situations are reviewed. This chapter also reviews how previous researchers have attempted to measure visual clutter. The knowledge gained from this review of the literature is integrated into a model of how visual clutter might affect driving performance. The chapter concludes with the identification of gaps in the literature and describes how the present thesis aims to address those gaps.

Information processing

The driving task: the driver as an information processor

From one theoretical perspective, driving can be understood as fundamentally an information processing task: in order to achieve certain goals, the driver gathers information from the environment, interprets it, makes decisions, and carries out actions (Senders, Kristofferson, Levison, Dietrich, & Ward, 1967). This process is not carried out once per journey but continually: there is continuous interaction between the driver and the environment (including the vehicle) as the driver monitors the results of previous actions and gathers new information as the vehicle moves through the road environment (Sheridan, 2004). The process occurs on many levels; even the task of gaining information requires the driver to make decisions about what to attend to and when (Wickens, 1987).

To successfully perform the driving task, the driver must be able to select necessary information and process it in time to make the appropriate decision and execute the required action. Anything that interferes with the selection of relevant information and/or the speed of information processing will therefore impair driving performance.

A hierarchy of driving tasks

Allen, Lunenfeld and Alexander (1971) and many authors subsequently (e.g. van der Molen & Botticher, 1988), proposed that driving tasks can be categorised into three levels. The highest level is the *strategic* level, and includes decisions about where and when to drive, and which routes to take. These decisions can be made in advance of the journey, as well as during the journey. The second level is referred to as the *tactical* or *manoeuvring* level, and includes decisions such as whether to overtake a leading vehicle. The lowest level is *operational* or *vehicle control*, and involves very short time-frame decisions such as whether to brake or accelerate to maintain vehicle speed. This lowest level is often modelled as a closed-loop servomechanism control system: the driver tries to minimise the difference between reference inputs (e.g. the appropriate position within the lane) and the output or results of their actions (Flach, 1999).

An alternative way to look at decision-making in driving uses Rasmussen's (1987) three levels of performance. He defines skill-based behaviour as automated patterns of behaviour occurring without conscious control; rule-based behaviour as the (not necessarily explicit) recognition of a situation and application of a stored rule; and knowledge-based behaviour as the testing of plans to achieve a goal against a mental model of the system. Each type of behaviour will result in different types of errors. Ranney (1994) noted that when these three types of behaviour are crossed with the three levels of driving tasks, there are nine possible states for a driver controlling a vehicle. However, for experienced drivers in normal situations, strategic decisions will be knowledge-based, tactical decisions will be rule-based, and control decisions will be skill-based. This alternate way of looking at the pathway from input to response emphasises that different task performance levels require different levels of cognitive processing, which (as will become clear later) has implications for the likely level of disturbance from visual clutter.

The results of actions at each of the three task levels can affect decisions at the other levels. For example, if a drivers' normal route is blocked or the signage obscured, the driver will not be able to turn (a tactical manoeuvre) at the planned location (and therefore will have to change their strategic level route plan). Drivers who decide to overtake a leading vehicle will have to perform the appropriate control actions in order to get into the correct position. Drivers who have difficulty braking on wet roads may make a strategic decision not to drive when it is raining. Thus while visual clutter may primarily affect one level of driving tasks, there may be flow-on effects to the other levels.

Decisions at each level require information from different sources (Ranney, 1994). The strategic level requires information about likely conditions on the routes and at the times being considered. Manoeuvring requires information about the position of other vehicles, as well as information as to what actions the driver is permitted to take, for example no overtaking/no entry/no right turn (at certain times)/no parking/etcetera. Vehicle control is concerned with maintaining appropriate lateral and longitudinal position relative to the road and other vehicles; the information required comes from the lane markings, the relative size and movement of other vehicles, and the speedometer. Visual clutter is most likely to affect decisions made at the level of manoeuvring, although it may also affect the other levels. The section on visual information gathering explains how tasks at each level are likely to be affected.

Situation awareness

Some tasks cut across all three levels of the driving task hierarchy. One such is the perceptual and cognitive task of maintaining appropriate situation awareness. Endsley (1995) uses the term 'situation awareness' (SA) to refer to how well the driver (or pilot, or other operator) has gathered and interpreted information about the environment. SA has three levels of complexity, with higher levels building upon lower levels. Level 1 involves being aware of surrounding vehicles/obstacles. Level 2 involves integrating and interpreting this information with regard to the driver's goals. Level 3 involves predicting likely future actions by other agents (road users) and what the situation might become.

This awareness feeds back into the driver's decision making. Novice drivers are less able to maintain SA than experienced drivers (Kass, Cole, & Stanny, 2007); this may be because novices are less skilled in extracting relevant information, or because they have more demands on working memory from the other driving subtasks. Because it relies upon cognitive processing, distraction impairs SA in both experienced drivers (Groeger, Whelan, Senserrick, & Triggs, 2002) and learner drivers (Whelan, Senserrick, Groeger, Triggs, & Hosking, 2004). Situation awareness also depends on the degree of engagement with the task. Gugerty (1997) found that drivers who have active control of a simulated driving task remembered the locations of potentially hazardous cars more accurately than when they viewed driving scenes in a passenger mode. Interestingly, the drivers' overall recall performance was lower than when they were passively watching (probably because of the higher task demand – see below) but they were better able to select which vehicles needed to be closely monitored. Because situation awareness relies on the ability to select relevant information under conditions which may involve high workload, it is likely to be affected by visual clutter.

Automaticity, schemata and expectancies

Another important concept in driving research is Schneider and Shiffrin's (1977) concept of automaticity. Automatic processing is conceived as fast, effortless, and not limited by capacity, compared with controlled processing which is described as slow, effortful, and capacity limited. Thus defined, automatic processing develops with consistent mapping between a stimulus and a response (similar to Rasmussen's skill-based processing) – for example, after multiple experiences of having to stop at a red light, drivers will automatically brake when they see a red light. (Note that an alternate definition of automaticity holds that automatic processes are inbuilt into the human perceptual system, therefore processes such as turning a wheel or pushing a pedal in response to a stimulus can never be truly 'automatic'.)

Some researchers doubt whether there is ever enough consistency in driving experiences to develop true automaticity; Groeger and Clegg (1997) note that the well-practiced task of changing gears showed too much variability within subjects to be a properly automated process, therefore more complicated aspects of the driving task are highly unlikely to be fully automatic. However it is well-established that novices spend a disproportionate amount of time and concentration controlling the vehicle, and that these tasks take less effort as the novice driver gains experience (MacDonald, 1994).

As novices develop skills in controlling the vehicle, they also develop mental representations of road situations, called mental models or schemata. These are abstractions of a certain situation, which may contain expectations about where information is likely to be found, what other agents are likely to do, and what pattern of actions is appropriate. Some models of driving hold that in experienced drivers, a scene such as an intersection activates a schema and the associated pattern of actions (e.g. Riemersma, 1988). These expectations can assist drivers when the road environment conforms to them; for example, in a high-speed freeway environment it is important for a driver to know where to find navigational signage. However, if the road environment is not congruent with drivers' expectations (for example advertising signage placed on gantries above freeways where drivers expect to find navigation signage), driving performance can be impaired. Research has found that signs are not noticed when they are in unexpected locations (Shinoda, Hayhoe, & Shrivastava, 2001; Theeuwes, 1996), and that people with much experience on a particular route use their old response pattern when a sign or the layout of the route is changed (Martens & Fox, 2007; Van Elslande & Faucher-Alberton, 1997). Degraded visual information (for example when visibility is poor due to fog or rain) leads to interpretation of the scene based on expectations (Fuller, 2002). In short, what drivers expect to see influences what they perceive; this factor is likely to become more important in visually cluttered environments where the driver must select which of many visual inputs to attend.

Mental workload

Some sort of process, be that the development of automatic responses or better mental models of the road environment, reduces the mental workload of experienced drivers compared with novice drivers while the physical workload remains the same. Mental workload is the amount of mental effort required to complete a task; it also includes components of time pressure and perceived psychological stress (Reid & Nygren, 1988). It is a function of the demands of the task and the capacity of the person carrying out the task (de Waard, 2002). Mental workload can be measured in several ways: via physiological measures such as pupil dilation, heart rate variability, EEG signals; via secondary task performance, which is assumed to worsen as the primary task workload increases; or by asking the person under load, i.e. subjective ratings (Kantowitz, 1987). Mental workload will not always correspond to primary task performance, as explained below.

Limited capacity and optimal stimulation

It has long been established that humans cannot attend to every simultaneous stimulus (Broadbent, 1957). This limitation on attentional processing is also recognized in the driving literature (Shinar, 1976). Attentional capacity varies across individuals and within individuals across situations. The level of attentional capacity determines the optimum level of stimulation.

Early researchers developed the Yerkes-Dodson law: plotting performance against arousal on a graph gives an inverted-U shape, with optimum performance at medium levels of arousal (Wickens, 1993). 'Arousal' in this context refers to how stimulated the person is, for example by noise, anxiety, or information. This law can be adapted to describe the relationship between task demands, workload and performance. When task demands are below the optimum, drivers can improve performance only by exerting state-related effort, that is, concentrating hard to prevent boredom (de Waard & Brookhuis, 1997), or increasing task difficulty to the optimum level (Fuller & Santos, 2002). When task demands are above the optimum, the driver will have to exert more task-related effort to maintain performance. In this area of the curve, performance may not show any effect of increased demand, but workload measures will. At a certain level of demand, the driver will be unable to maintain performance even with maximum effort, and the driving tasks will not be performed optimally (de

Waard & Brookhuis, 1997). To avoid overload, drivers may seek to limit the number of information sources they use when making decisions (Wright, 1974), but this strategy can also result in impaired driving if drivers make the wrong decision (Cooper & Zheng, 2002).

Effects of high workload on driving

Consistent with the Yerkes-Dodson law, research has found that increasing the task demands in relatively complex situational environments will result in impaired driving performance. Lee and Triggs (1976) found that drivers missed more lights in a peripheral detection task while driving through busier and more complex environments. Martens and van Winsum (2000) found negative effects on both reaction time and hit rate for a peripheral detection task when driving task difficulty was increased by external causes such as narrow curves or the appearance of an unexpected obstacle. Baldwin and Coyne (2003) found similar effects on secondary task performance when they increased workload by increasing the traffic density. Wood and colleagues (2003) found that drivers took longer to brake for critical events when they were given the task of counting the number of a certain type of pedestrian. Hoyos (1988) notes that high workload can decrease the probability of drivers recognising hazards (and thus accurately perceiving the level of risk in a driving situation), as well as increase the probability of drivers making risky decisions due to time pressure.

It should be noted that workload is not synonymous with performance decrements. When task-demand is low enough that drivers can compensate by increasing effort, adding further tasks may increase subjective workload without affecting performance (e.g. Slick, Cady, & Tran, 2005). However, even when it seems unlikely that an individual event or object causes driver stress or overload, the cumulative effect of sustaining attention through many such strain-inducing events is a source of stress which can reduce attentional capacity (Hancock & Warm, 1989).

Divided attention/task switching

When two tasks are performed simultaneously, the combined workload is more than the sum of the workload of the two tasks. Individuals differ in the ability to share or rapidly switch attention between two tasks; this ability can improve with practice (Wickens, 1987). How much difference a secondary task makes to performance on a primary task depends on how closely related the primary and secondary tasks are to each other. Wickens' (1987) Multiple Resource Theory suggests that tasks can be represented as points in a three-dimensional space, where the axes represent information modality (e.g. visual/auditory); stages of processing (encoding, central processing, responding) and response types (e.g. manual, vocal). The closer two tasks are in this space, the more they will interfere with each other, as they compete for more shared resources. For example, gear changing may interfere with steering control as both require preparation of a motor response: a laboratory study has found that discrete responses from the left hand cause hesitations in a right-hand tracking response (Klapp, Kelly, & Netick, 1987).

Task complexity can be defined as the number of different resource types demanded, while task difficulty is how much of a resource (or resources) is demanded. The driving task altogether is quite complex, as driving subtasks between them require all visual, auditory and tactile information modalities, all stages of processing, and responding via both hands and at least one foot. Multiple Resource Theory predicts that it will be difficult to perform such a task simultaneously with a secondary task.

Possible interactions between different sources of workload

There has been little research on the interaction between external to vehicle and internal to vehicle sources of workload (Regan, 2004). Obviously when drivers have to look at something inside the vehicle, they cannot simultaneously look outside the vehicle, so their ability to respond to external events suffers. In addition to this obvious effect of internal sources of workload, many driving simulator studies have shown that even non-visual tasks can affect visual perception. Recarte and Nunes (2000, 2003) found that participants' gaze direction varied less (fixations were longer and saccades were smaller) when they were performing mental tasks. Rantanen and Goldberg (1999) found that participants' visual fields (as measured by a visual perimeter) shrank and changed shape during tone counting tasks. Harbluk, Noy and Eizenman (2002) found that addition tasks reduced the overall number of saccades, scanning to the periphery, and checking instruments & mirrors; while incidents of hard braking increased. Olsson and Burns (2000) found that counting backwards interfered with the detection of peripheral lights. Strayer, Drews and Johnston (2003) found that when participants were involved in a hands-free phone conversation, they responded slower to the leading vehicle's brake lights, and remembered less of what they had seen during the drive. Horberry and colleagues (2006) found that a simulated hands-free mobile phone conversation impaired drivers' responses to a pedestrian crossing the road.

The results described above suggest that secondary tasks can increase driver workload, decrease the area of visual space in which the driver fixates on objects, and cause drivers to perceive less of those objects on which they do fixate – which is likely to be even more of a problem in cluttered road environments where drivers may already have difficulty selecting relevant objects out of the many potential objects to attend.

Mental workload is a vital concept for understanding driving performance, as high workload affects and is affected by both visual information gathering and processing of information. Because the driving task is actually a collection of many subtasks, the effects of dividing attention and/or switching attention between two or more subtasks will always be relevant. Tasks at different levels of the driving task hierarchy will be affected differently by the level of mental workload; i.e. lower level tasks for experienced drivers are automatic and do not require much higher level processing, therefore will not be as badly affected. The level of mental workload will depend on the complexity of the situation: it is more difficult to track and predict future behaviour for all relevant agents in a complex situation than in a simple one. Drivers' levels of experience and consequently their ability to rely on expectations and mental models/schemata of various road situations will also affect the level of mental workload experienced. Further detail on these individual factors can be found in the section on 'Factors that may interact with visual clutter'.

If visual clutter affects levels of workload, it will impair driving performance. The next section will examine visual information gathering and how it might be affected by the presence of visual clutter. These effects flow on to information processing, driver workload, and thus driving performance.

Visual information collecting

Although it may not be possible to declare an exact percentage, it is clear that the primary source of information when driving is visual (Sivak, 1996). Drivers use vision to maintain situation awareness, respond to any hazards, and search for information to support decision-making. Wierda (1996) provides a taxonomy of visual driving tasks, comprising determination of position, speed, acceleration, heading angle and changes in heading angle; perception of obstacles, route indications, road users and traffic situations; and control over the selective visual perceptual system (i.e. movements of body, head and eyes to gather visual information). Tasks in the first set involve continuous monitoring of visual cues such as looming, and can be performed using peripheral vision (Summala, Lamble, & Laakso, 1998; Summala, Nieminen, & Punto, 1996). These visual tasks, which form the basis for the lowest level of driving tasks (vehicle control), are less likely to be affected by visual clutter. (It is possible that high background complexity could affect optic flow rates and thus speed estimation, but as most Australian cars possess a working speedometer this is not considered as a major issue.) The second set of visual tasks (perception of obstacles, route indications, road users and traffic situations) are most likely to be affected by visual clutter, which will in turn affect response tasks at the tactical/maneuvering level of driving.

Visual selection

Although we perceive the world as if we have fully processed every visual stimulus within our field of view, the visual system is limited in the amount of information it can deliver to conscious awareness. As well as the cognitive limitation on the number of items that can be held in short-term memory (Broadbent, 1958), there is the visual limitation that less than one degree of the visual field can be processed by the highest resolution area of the retina (Findlay & Gilchrist, 2003). While the brain can attend to areas other than where the eyes are focussed, doing so impairs processing of the item at fixation (Posner, 1980). This means that to read a sign, for example, the eyes must move over the text and the reader must attend to the text rather than other stimuli within the visual field. A great deal of research has been undertaken on how attention orients to items in the visual field, both with and without eye movements (Egeth & Yantis, 1997; Eriksen, 1988; Posner, 1980; Rayner, 1998).

Theeuwes (1993, 1994) divides control of attentional selection into two modes: endogenous, in which selection is controlled by the goals of the observer, and exogenous, in which selection is controlled by the properties of the stimulus. He concludes that endogenous control can set the size and location of the attentional window (from the size of a single item to the size of the entire visual field), but that within the window, attention will automatically be allocated to the item with the largest local difference from its surroundings.

Trick and colleagues (2004) note that this division can be crossed with Schneider and Shiffrin's (1977) two forms of information processing to create four modes of attentional selection. These modes are summarised in Table 1 and explained below.

Table 1. Modes of attentional selection

Type of information processing	Automatic (fast, effortless, not limited by working memory)		Controlled (slow, effortful, capacity limited)	
Type/source of control	Exogenous (Stimulus properties)	Endogenous (Observer goals)	Exogenous (Stimulus properties)	Endogenous (Observer goals)
Mode of selection	Reflex (Attentional capture)	Habitual	Exploration	Deliberation (Visual search)

Reflex (exogenous automatic) selections are when the properties of the stimulus attract attention despite the intentions of the observer. Habitual (endogenous automatic) selections are also performed automatically, but not because the visual system is innately constructed to select items with some property; instead the selection results from a habitual association between the stimulus (properties) and the response (to attend that stimulus). In exploration mode (exogenous controlled), the observer intends to look around the scene, leaving the innate rules of the visual system to determine what is selected. In deliberation mode (endogenous controlled) the observer is looking for something in particular, that is, they are engaging in visual search. Each mode has different uses and will be subject to different errors. For example, when in deliberative mode an observer may select an object that shares features with the search target; a different type of error would be when the selection switches to reflex mode during the search and the observer's attention is captured by a highly conspicuous object. Wickens (1993) makes the similar point that errors of selective attention (for example, attending a similar-looking object to the target of a visual search) are quite different from errors of focussed attention (when the observer intends to look for something, but looks at another object due to its high conspicuity).

The following sections examine each type of control over attentional selection and the implications for performing the driving task.

Endogenous control of selection: goals of the observer

Visual search

There is a large amount of literature on the subject of visual search for a particular target among 'distractor' items, such as searching for a direction sign among a number of other road signs and advertising signs. While opinions are varied on the exact mechanisms by which the effect occurs (and that debate is beyond the scope of the present work), it is well-known that visual search for a particular target is hindered by the presence of similar-looking 'distractors' (e.g. Duncan & Humphreys, 1989; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). In the driving domain, this implies that visual search for traffic signs will be more difficult when there are multiple traffic signs, and/or advertisements of similar appearance in the vicinity.

A number of studies have investigated this possibility. Holahan and colleagues (1978), for example, made slides consisting of a stop sign and varying numbers and colours of distractor signs on a white background. Reaction time to locate the sign increased with the number of distractors, similarity of colours, and proximity to the target sign. Noble and Sanders (1980) used a similar visual search task and also asked participants to perform a manual tracking task to simulate controlling a vehicle. They found that both tracking and search were impaired if the target signs could not be easily differentiated by a unique colour and when there were more signs in the display to search through. Participants were less accurate at both tasks when performing them simultaneously than when performing either separately, which suggests that difficult conditions for visual search will add to driver workload as well as directly impairing the task of reading traffic signs. Shoptaugh and Whitaker (1984) used a more naturalistic background: they embedded target street signs in photographs with varying levels of complexity. Participants were fastest to respond to signs in residential environments, and slowest for signs in shopping strips which contained other traffic, directional, and business signs. Boersema and Zwaga (1985, 1988; 1989) showed students slides of railway stations and asked them to find routing signs (which were always white on blue) in various backgrounds. More advertisements and/or larger advertisements decreased the probability of subjects correctly locating the routing sign, and increased the time taken to do so. Kooi and Toet (1999) developed Engel's work (discussed above) on conspicuity area as an alternative measure to response time in visual search tasks, and confirmed that objects were less conspicuous against backgrounds with many other objects.

Visual search can also be affected by the organisation of the scene. Biederman (1972) found that it was more difficult to find a target object in scenes which had been divided into six segments and jumbled up than in the original scenes. Thus it is possible that traffic signs in cluttered environments may be hard to find even when there are no similar-looking distractors, merely due to the disorganisation and complexity of the background.

These findings imply that one contributor to the level of visual clutter in a road environment will be the presence of many other objects or patterns that interfere with the selection of a searched-for target.

Information theory

When selection is controlled endogenously, an important consideration is the amount of information the observer must sort through. Shannon's (1949) Information Theory was popular in psychological experiments in the 1950s and 1960s, but has since gone out of fashion. However the general idea – that information reduces uncertainty, and that the amount of information conveyed by a certain stimulus depends on the number of possibilities in the set of potential stimuli from which it came – has been incorporated into information processing models (Luce, 2003).

In the driving domain, Senders and colleagues (1967) showed that drivers will modify behaviour in order to maintain the rate of information needed for task performance. The experiments involved participants driving with a visor which occluded their vision part of the time. With shorter viewing times/longer occlusion times, drivers chose lower speeds; when the speed was fixed and the drivers could choose when to look, they looked more frequently at higher speeds. Drivers looked more frequently on curves because of the limited view ahead.

More recently, Liu (2005) used a simplified version of information theory to determine how the information content of signs affects visual search time. Participants responded more slowly to signs with higher information content, and made more errors when answering questions about what had been on the sign.

Information theory has also been applied to the regulation of advertising. Du Tuit and Coetzee (2001) explain that the South African 'Regulations on Advertising on or visible from National Roads 2000' evaluation criteria for advertising signs include the number of bits of information permissible, as well as a specification that such signs should not disrupt the flow of information to the driver from traffic signs.

The level of information in the environment may thus contribute to the level of visual clutter, independent of the presence of search distractors. It should be noted that 'bits of information' in 'information theory' has a very specific meaning to do with the reduction in the level of uncertainty (for example, each successive letter in a word conveys less information as the number of potential words it could be shrinks). It is less easy to quantify the level of information given by the radius of a curve, or the presence of an intersecting road, or the type of building on the roadside.

Exogenous control of selection: visual properties of the object

Conspicuity of traffic signs

Much of the early work on sign visibility focused on what would now be called conspicuity: how well the sign attracts attention. Forbes (1939) placed signs on the roadside and asked drivers to call out "all warning, route marker, and destination signs which seemed pertinent to their driving" as they drove. Drivers generally called out signs when they were 200-400 feet away, in contrast to the previously determined legibility distance (point at which the signs could be read) of 800 feet. Forbes (1939) made no attempt to determine what factors affected what he termed the "target value" (i.e. conspicuity), but speculated that "relative size, colour contrast, location, and the simplicity of message and layout" (p681) would be important. Later work (Forbes, Fry, Joyce, & Pain, 1968; Forbes, Pain, Fry, & Joyce, 1967; Forbes, Pain, Joyce, & Fry, 1968) found that the luminance and color contrast of the sign against the background affected which sign was attended first when a number of signs were presented simultaneously.

Engel (1971) defined conspicuity as "that combination of properties of a visible object in its background by which it attracts attention via the visual system" (p563). He went on to develop the idea of the "conspicuity area" as the "retinal locus within which the object to be searched for was noticed in a single 75msec exposure" (p564). Engel (1974) found that when factors such as the luminance and size of the target relative to the background were varied, the conspicuity area of an item depended mostly on the factor which was most different to the background. While earlier studies had been on items which were the target of visual search, a later study (Engel, 1977) showed that the probability of eye movements towards objects which are *not* the search target is related to their conspicuity areas.

Cole and Hughes (1984) defined "attention conspicuity" as the ability of an object to attract attention whether or not the observer is currently looking for that object (in exploration mode), and "search conspicuity" as the ability of an object to be found when an observer is deliberately looking for it (i.e. when it is the search target in deliberation mode). In an on-road study, they found that high workload lessens the search conspicuity of an object, while visual clutter (in shopping strips) lessens both attention conspicuity and search conspicuity. A subsequent paper (Hughes & Cole, 1986) found that only 15-20% of traffic control devices are reported when drivers are asked to report what catches their attention while driving. Hughes and Cole (1986) suggest that the attentional conspicuity of signs should be increased, while acknowledging that drivers may not have reported most signs because they were redundant or irrelevant. It is possible that these irrelevant signs are actually contributing to visual clutter by reducing the attentional conspicuity of other signs.

Cole and Hughes (1988) list “eccentricity [distance from the center of fixation], background complexity, contrast, colour and the boldness of the internal structure of the object” as important determinants of an object’s conspicuity. Relative size is also important (Cole & Jenkins, 1984). Lansdown (2004a) suggests that the conspicuity of a sign should be matched to the driver’s information needs: high attentional conspicuity for safety-related signs that all drivers need to see and search conspicuity for navigational information that is only relevant for a subset of drivers, while non-driving-related advertising signage should be “constrained in its attention demanding capacity appropriately”.

Conspicuity and visual distraction

The other important property of conspicuity is that it determines how likely an object is to distract visual attention when it is not the target of search; in other words, to be a source of visual distraction. Driver distraction is of increasing concern, with a recent study suggesting that some form of driver inattention precedes nearly 80% of crashes (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Of crashes where distraction/inattention is involved, it has been estimated that the source of distraction is outside the vehicle in 30-35% of cases (Glaze & Ellis, 2003; Stutts, Reinfurt, Staplin, & Rodgman, 2001). However not all forms of distraction are the same.

A general definition of driver distraction is “any driver involvement that takes his or her attention away from their intended driving task” (p1, McAllister, Dowsett, & Rice, 2001). However, three slightly different meanings of distraction are used in the literature on visual perception and driving safety. Studies of the number of crashes due to “distraction” tend not to separate them; however such a distinction is useful to understand what led to a particular distraction event.

“Visual distraction” or “attentional capture” refers to a situation in which the driver’s attention is involuntarily attracted by a conspicuous object (Crundall, van Loon, & Underwood, 2006). Of course auditory stimuli can also capture attention, but this thesis is concerned with visual stimuli. “Cognitive distraction”, “internal distraction” or “inattention” is when the driver is thinking about something else and not devoting full attention to the driving task (Recarte & Nunes, 2000). There may not be a specific trigger for this type of distraction, and so some authors do not count it as distraction (e.g. Stutts et al., 2001). Finally, distraction has often been used to mean a situation in which the driver voluntarily takes their eyes off the road in order to complete some in-vehicle task, such as dialling a mobile phone (e.g. Horberry et al., 2006). This is better described as a “secondary activity” (McLean, Aust, Brewer, & Sandow, 1979) to emphasise that the driver is still controlling the direction of attention, although what the driver chooses to attend may not be optimal for driving performance.

Objects that may be defined as visual clutter could potentially cause any of these three types of distraction: involuntary capture of visual attention (e.g. by flashing lights), involuntary capture of mental “attention” (e.g. thinking about a shop just past), or voluntary direction of visual and mental attention away from the road (e.g. looking at a billboard featuring an attractive item). This is not to say that all visual clutter causes distraction, or that any distracting object by itself will immediately make a scene visually cluttered. However it seems reasonable to link the concept of visual distraction with that of visual clutter, as both will interfere with the selection and processing of visual stimuli.

Conspicuous non-driving-related objects will presumably attract attention most often when the driver is in “exploration” mode, that is, when they are not looking for anything in particular. It would be expected that they will only pose a problem when something unexpected occurs simultaneously; that is, they may interfere with hazard detection if a hazard appears at the same time as a conspicuous irrelevant object. Such objects may also impair situation awareness, as the driver has a limited time to gather information while moving through a constantly change environment. Time which is spent looking at non-driving-related objects is time which is not spent gathering information about the road and traffic situation.

Some objects may attract attention even when the observer is specifically looking for something else. Flashing lights seem to be one such object. Crawford (1962) found that while flashing signals are noticed more quickly than steady signals against a background of steady lights, a background of flashing lights makes it very difficult to see a steady signal light (and it is even more difficult if the signal itself is flashing). Most Australian states limit flashing lights on advertising signs, due to the likelihood that they would interfere with drivers seeing flashing lights on emergency vehicles or important traffic signals (Main Roads Queensland, 2002; Main Roads Western Australia, 2000; VicRoads, 2004). Empirical evidence for this is provided by Theeuwes and colleagues (Theeuwes, Kramer, Hahn, & Irwin, 1998) who have shown that abrupt onsets disrupt planned saccades towards search targets, and suggest that there are two parallel neurological structures responsible for directing eye movements, one for each type of control. The problems of visual distraction are likely to be more severe for objects which flash or change abruptly.

Research on visual perception

To examine the effects of visual clutter, it is necessary to be able to quantify the level and density of visual information in a scene.

As noted above, one field that has examined the effect of the number of objects/amount of information in a scene on visual performance is the visual search paradigm. Typically these experiments are performed with a limited number of simple objects against a blank background, so that it is easy to determine the number of objects. In many visual search tasks, the time required to detect the target increases as a function of the number of items in the display (e.g. Treisman & Gelade, 1980). However, in natural scenes it is difficult to define what should be counted as an ‘object’. Is a building an object? A window, awning, or sign on the building? A single letter on a sign? The level of visual clutter is likely to vary depending on the scale at which the observer views the scene.

At the smaller end of the spatial scale, there are various effects of nearby features on the perception of a fixated object. It is outside the scope of the present work to examine the structure of neuronal receptive fields at various levels of the visual cortex and the interactions between these. However, sensory effects such as crowding and lateral masking may well play a role in visual search performance (Levi, 2008; Poder, 2004; Wertheim, Hooge, Krikke, & Johnson, 2006 & Johnson, 2006 #575). Crowding and lateral masking refer to the phenomenon of impaired visual discrimination for a target surrounded by distractors; the effect is greatest when the spacing between target and distractors is small, and the retinal eccentricity of the target is large. However, as in natural scenes attention is primarily at the same location as fixation (Findlay & Gilchrist, 2003), such low-level effects are less likely to influence drivers’ ability to perceive important targets.

The present thesis focuses on visual clutter at the larger end of the scale; the scale of natural scene perception. Much research on visual perception uses simple artificial 'scenes' with very few objects; eye movements are often not required and sometimes explicitly not permitted. These tightly controlled conditions allow the examination of basic aspects of visual perception without any confounding variables; however they do not reflect the complexity of real scenes. A smaller amount of research has looked at eye movements in natural scenes under free-viewing and goal directed search conditions, what aspects of a scene are perceived in a brief glance, and what can be changed in a scene without the viewer noticing. There is a difficult-to-bridge gap in research methods that would allow both the use of complex scenes and the manipulation of aspects of those scenes. In particular, there is a lack of research on quantifying the amount of visual information in a scene, and therefore a lack of research on how the level/density of information affects gist perception, object recognition, visual guidance and selection, etc. For this reason, likely effects must be inferred from more general concepts within the literature on visual perception.

Visual selection involves a complex interaction between the visual properties of a stimulus or object and the goals and intent of the observer. Visually cluttered environments can affect selection in several ways. When the observer/driver is in exploration mode, high conspicuity cluttering objects may attract attention away from driving-related objects and prevent the driver from maintaining adequate situation awareness. This visual distraction may be particularly dangerous if it occurs at the same time as a hazard appears, in which case the driver will take longer to respond. Visually cluttered environments (via similar-looking but irrelevant objects, conspicuous objects, and background complexity/disorganization) lower the conspicuity of traffic signs, making them more difficult to see both in general exploration and when specifically looking for signs. This increase in the difficulty of selecting relevant information from the background means that visual clutter will increase the demand (i.e. workload) of the visual portion of the driving task.

Once a source of information has been located and selected, the amount of information it contains becomes important. The more information, the longer it will take for the driver to read and/or process it, and the higher will be the mental workload on the driver. Thus environments with a high information load from either driving-related objects such as other vehicles and traffic signs, or driving-unrelated objects such as advertising billboards and other scenery, require the driver to operate under high workloads which may at times exceed their capacity.

Factors that may interact with visual clutter

There are many factors which will influence how a particular driver at a given moment in time will be affected by visual clutter. These include differences between drivers, and differences within a driver depending on the situation. As visual clutter affects selection of visual information as well as workload, it is reasonable to assume that there may be interactions between the effects of visual clutter and individual and situational factors which also affect visual selection and workload.

Individual differences

Two groups who may be especially vulnerable to the effects of visual clutter and distraction are novice drivers, and elderly drivers.

Age

Shinar and Schieber (1991) explain the correlations between various visual functions which deteriorate with age and accident involvement. Ball and colleagues have performed a number of studies on older driver's 'useful field of view' (UFOV), which is the area of the visual field in which 'useful information' can be acquired within one eye fixation. For example, one study (Ball, Beard, Roenker, Miller, & Griggs, 1988) found that while increasing central task demand decreased accuracy on a peripheral task for all age groups, the effect was worst for the oldest group. The consequences of this effect in a driving context are that older drivers miss roadside signs and peripheral targets (Wood, 2002). While this effect might imply that older drivers should be less affected by peripheral clutter, the visual clutter within the central field around fixation would be expected to raise central task demand and therefore make it more difficult for older drivers to detect peripheral search targets and hazards.

A further implication of a smaller UFOV is that older drivers may need to fixate on the periphery more often than younger drivers, so that objects and events occurring on the roadside fall within the UFOV (Mapstone, 2001). The increased need to saccade relatively long distances across the visual field can slow response times to hazards appearing in front of the driver, as well as those in the periphery. Older drivers in driving simulator studies have been found to respond later than younger drivers to hazards (Edwards, Creaser, Caird, Lamsdale, & Chisholm, 2003), even though they drive more slowly (Charlton et al., 2005). This slowness is likely to be exaggerated in high-clutter scenes in which there are more potential targets to saccade to. For example, a study by Ho and colleagues (2001) using photographs of road scenes found that older subjects took longer to find a target sign and made more fixations than younger drivers, especially on high clutter scenes.

The functions of the eye and visual system are not the only ones affected by age; higher processing is also degraded. These higher functions can in fact be more important than purely visual functions; Ball and colleagues (2006) found that cognitive tests can predict motor vehicle accident involvement among older drivers where visual tests cannot. Increasing age correlates with decreasing information processing ability, which may be due to impaired selection, lower capacity, or slowed processing (Simoes, 2002). Simulator research has found that older drivers' reactions to hazards are more slowed than those of younger drivers in a complex/cluttered environment (Horberry et al., 2006).

Older adults are impaired in several facets of attention (McDowd & Shaw, 2000); a full discussion is beyond the scope of the present thesis, so only those facets that relate to driving performance will be discussed here. Older persons are less able to divide attention between two tasks than younger persons are (Ponds, Brouwer, & Van Wolffelaar, 1988), particularly when one of the tasks is difficult (McDowd & Craik, 1988) or when both require the same response mode (Brouwer, Waterink, Van Wolffelaar, & Rothengatter, 1991). This may cause difficulties in switching between the several subtasks involved in driving, such as navigating, gear changing and searching for hazards. Older drivers are also more affected by distraction (Lesch & Hancock, 2004; Shinar, Tractinsky, & Compton, 2005). This may lead to particular difficulties when sources of workload inside and outside the vehicle are combined.

This is not necessarily the case: McPhee and colleagues (2004), using a similar visual search task to that of Ho and colleagues (2001, described above) plus a secondary auditory task found that although older adults were more impaired than younger adults on high clutter scenes and when performing tasks simultaneously, these two conditions did not interact. While dual task experiments are always difficult to analyse because of the potential for different participants to prioritise the tasks differently, older adults were worse on both the primary task of searching and the secondary auditory task, and in neither task was there an interaction between age and clutter level. However, this is only one study, and previous research suggests that interactions between visual clutter and other sources of workload are likely for older drivers.

The combination of difficulty perceiving, slowed reactions, and difficulty dealing with multiple activities, means that older drivers have most difficulty making decisions in complex situations. For example, older drivers are slower and less accurate in deciding whether to turn across traffic at intersections; particularly when they need to inhibit a learned response (Staplin & Fisk, 1991). Visually cluttered scenes are likely to be complex in terms of the amount of information that needs to be selected and processed, which means that older drivers are likely to have more difficulty in visually cluttered road environments.

An important point is that variability in any function, visual or cognitive, increases with age; some older persons may have severe impairments, while some will retain their abilities completely intact. As there is currently no consensus among researchers or government bodies as to the appropriateness of age-based driver screening (Hakamies-Blomqvist, 1997), it is important to design a forgiving road environment which enables drivers with a wide range of abilities to drive safely.

Inexperience

As discussed in the section on workload, inexperienced drivers have to put more effort into controlling the vehicle. These drivers will therefore have less attentional resources to spare from vehicle control and may not be able to divide attention effectively. Even when they have sufficient capacity to attend to tasks other than vehicle control, inexperienced drivers may have difficulty in selecting which information to attend due to their impoverished and less accurate mental models of the road environment (Underwood, Chapman, Bowden, & Crundall, 2002). Novice drivers fixate more traffic signs, including more irrelevant traffic signs, than experienced drivers when both drive an unfamiliar route (Sprenger, Schneider, &

Derkum, 1997). When there are more irrelevant signs (i.e. in a visually cluttered environment), novices might be expected to have additional difficulty in selecting the relevant information.

In driving simulator tasks, novices have been found to spend more time than experienced drivers looking at the instrument panel (Lansdown, 2002) and to be more prone to distraction from secondary tasks (Greenberg et al., 2003). Novice drivers scan less, particularly horizontally, and do not increase the width of the area scanned on complex roads (Underwood, 2007). This is possibly a strategy to restrict the amount of information to a level at which they can process it all, in which case scanning might be restricted further when the level of information in the central fixation area increases due to visual clutter. This difference in scanning affects their situation awareness: novice drivers are not as good as experienced drivers at remembering road layout and location of other vehicles, and predicting future location of other vehicles (Groeger et al., 2002).

Novice drivers have longer fixations than experienced drivers, particularly on hazards (Chapman, Underwood, & Roberts, 2002), and this impairs their ability to quickly respond to peripheral targets (Crundall, Underwood, & Chapman, 2002). Novices are also slower and less accurate than experienced drivers when responding to hazards (Whelan, Groeger, Senserrick, & Triggs, 2002). Visually cluttered environments may contain more potential hazards, so novices' slow reactions may disadvantage them more than in a simpler environment.

Crash data is another way of examining how young and inexperienced drivers are disadvantaged. McKnight and McKnight (2003) analysed behavioural contributors of accidents involving drivers aged 16-19. Most non-fatal accidents resulted from errors in attention, visual search, speed relative to conditions, hazard recognition, and emergency manoeuvres; in other words, young inexperienced drivers failing to perceive the scene accurately and/or make an appropriate decision. Young inexperienced drivers may also be more vulnerable to distraction. Stutts and colleagues (2001) found that teenage drivers were more likely than drivers over the age of 20 to be distracted at the time of a crash. Lam (2002) found that drivers aged 16-19 had a slightly higher risk of being involved in a crash caused by an external-to-vehicle distraction than other age groups. In Australia, a survey found that younger drivers (18–30 years) were significantly more likely to report distracting activities, to perceive distracting activities as less dangerous, and to have crashed as a result (McEvoy, Stevenson, & Woodward, 2006). It is not possible to determine whether these effects are due to the changes in brain maturation that occur in the late teens and early twenties, or to these drivers' lack of experience, or to some combination of the two.

Given that novice drivers have fewer mental resources to spare for the task of scanning the environment, search less effectively, are more easily and often distracted and take longer to disengage from something that has their attention, it would be expected that visually cluttered environments where there is more information to select and process are likely to be especially detrimental to the driving performance of members of this group. No studies were identified as having examined this possibility.

Personality/cognitive factors

Other individual differences which may affect susceptibility to visual clutter are cognitive ability, perceptual style or field dependence, distractibility, and risk-taking.

Gonzales (2005) found that individuals with low cognitive ability (i.e. non-verbal fluid intelligence, as tested by the Raven Standard Progressive Matrices task) were worse at a dynamic decision-making task than individuals with high cognitive ability, and were more detrimentally affected by increases in task workload. If visual clutter increases task workload, it would be expected to affect drivers of low cognitive ability more than drivers of high cognitive ability.

Field dependence is the ability to separate a foreground figure from a complex background. It has been found to correlate with long response times when searching for signs (Lambert & Fleury, 1994) as well as number of previous accidents (Loo, 1978). Visually cluttered scenes are likely to be more detrimental for those who have difficulty separating out foreground figures.

Distractibility is the extent to which one is able to maintain focus on the primary task. It differs from vigilance in that vigilance is a state which can be high or low for any one person depending on the situation and how long they have been performing a task, whereas distractibility is thought to be a long-term trait which is constant across adulthood for a particular person. There is evidence that this varies across drivers: a study of 44 truck drivers revealed that a small number of drivers were responsible for a large percentage of distraction-related crashes (Hanowski, Perez, & Dingus, 2005). The potentially distracting effects of visual clutter are likely to be worse for drivers who are more vulnerable to distraction.

Some people are more willing than others to accept risks, in driving and other areas of life. The risk homeostasis theory (and the related task difficulty homeostasis theory) holds that drivers have a target level of risk (or task difficulty) and will modify the driving task so that the target range of risk/difficulty is maintained, primarily by controlling speed (Fuller, 2005; Wilde, 1982). Drivers who accept higher levels of risk will therefore driver faster and increase the information flow rate, and thus will be more affected when visual clutter increases the difficulty of extracting necessary information from the environment.

Situational factors

As discussed in the section on workload, drivers have limited attentional resources. Attentional capacity may increase with arousal under conditions of high demand (Matthews, 1988). However it is likely to decrease when the driver is fatigued (Williamson, 2005) or physiologically stressed (by heat, cold, noise, etc) (Hancock & Warm, 1989), and perhaps when the driver is under the influence of alcohol or other drugs. It should also be noted that attentional capacity decreases after a period of low stimulation/workload (Young & Stanton, 2007), so sudden transitions in the level of workload provided by the visual environment (and other sources) should be avoided (Ogden, 1996). Although overall capacity is not affected by secondary tasks such as interacting with passengers or adjusting climate controls, while engaged in these activities the driver has less spare capacity to deal with any sudden increases in the demand of the driving task.

Older drivers are especially vulnerable to the detrimental effects of visual clutter due to their smaller Useful Field of View and degraded information processing capacity. Young novice drivers are especially vulnerable due to their lower level of spare capacity and their deficient mental models of road situations. Drivers with high field dependence scores or high distractibility have impaired visual selection which is likely to be worse in situations of high visual clutter. Drivers with low cognitive ability, high risk-taking behaviour, or temporary low spare capacity caused by fatigue, stress, monotonous low-stimulation environments, or a secondary activity will be operating near the boundary between acceptable and unacceptable workload; increases in the visual clutter of the environment are therefore more likely to increase the demand of the driving task so that it exceeds their capacity.

The effects of visual clutter on driving

Clutter and visual search

The first published study to attempt to examine the effects of 'visual clutter' in the road environment on performance was Jenkins' (1982) paper. Participants were asked to detect discs of various contrasts that had been placed in photographs of various road scenes. Jenkins also asked participants to rate the scenes from most to least cluttered, and found that there was a relationship ($r = .54$, $p < .05$) between the clutter ranking and how well participants were able to detect the disc targets. Although not specifically defined, the implication from this study is that visual clutter is related to task difficulty. Jenkins suggested that the participants ranked scenes based on the overall complexity, whereas detection of the disks was affected by local complexity in target area, and that this was why the correlation was not higher. A difficulty with the ranking technique used here is that it does not allow the extent of difference in the level of clutter between two scenes to be assessed; the scenes might be very similar in clutter or one might be considerably more cluttered than the other, but the only data collected is that one is 'more' and one is 'less'.

The next study to specifically investigate visual clutter was not for another two decades, when Ho and colleagues (Ho et al., 2001) asked participants to classify a set of real-world photographs into 'high clutter' or 'low clutter' groups. A different set of participants then searched for a target sign; they made more errors in the 'high clutter' scenes. McPhee and colleagues (2004) extended this by adding a secondary task to the primary visual search task; distraction from the secondary task and high visual clutter had an additive effect on search time and accuracy. The use of separate groups of participants to classify and to search through the scenes ensures that neither task was affected by the other. This is an advance over Jenkins' (1982) study. However, grouping scenes as either 'high' or 'low' does not provide very much information about gradations in the level of visual clutter. Like Jenkins, these authors also fail to analyse the characteristics of scenes that were grouped together, so that these studies do not advance the understanding of what visual clutter is and why it might have an effect on visual search performance.

Bravo and Farid (2004) used scenes comprised of a random collection of everyday objects, in which participants had to search for a particular object. They found that in sparse scenes (with few objects) it did not matter how many parts comprised the object. However in cluttered scenes, compound objects (with multiple parts) took longer to find than simple objects. The implication is that signs which have multiple components (e.g., green part with directions plus brown part with tourist information) will be particularly difficult to segment from a background cluttered with other signs. The cluttered condition in this study involved objects (all of a similar size) shown overlapping each against a blank background, as opposed to clearly separated from each other against the same background in the sparse condition. Clutter is thus implicitly defined as meaning no space between, or overlapping of, two objects. However this does not extend very much the understanding of clutter in a road scene with a complicated background and objects of multiple sizes.

It is fairly clear from the above studies that visual clutter can interfere with drivers' ability to search for traffic signs. However, none of these studies provided a definition of visual clutter.

Scene complexity

Elvik (2006) proposes four 'laws of accident causation', one of which suggests that crash rates will increase with environmental complexity (measured in units of information to be attended per unit of time). Elvik cites studies on junction complexity (i.e., number of legs) and the number of driveways per kilometre; as both increase, so does the accident rate. Both of these findings can be explained as the consequence of an increased number of conflict points.

However, Smith & Faulconer (1971) performed a study correlating the number of accidents with attributes of the visual environment. They used perceptual grouping principles to extrapolate what might make a 'poor visual environment for driving': many objects/areas in motion, many objects/areas with contrasting colours, and/or a higher degree of man-made than natural areas. These factors correlated highly with the number of accidents and the amount of congestion on the eight arterial roads studied. The study examined only mid-block sections, presumably to avoid confounding factors that might influence the accident rate at intersections. Photographs were taken at the ends of each section and both directions in the middle, and the number of perceptual groupings required to analyse the scene were calculated. Scenes with more perceptual groups were described as more visually cluttered. While this study can only indicate correlation, not causation (as there may be confounding factors that were not controlled for), it is an intriguing result.

Agaki and colleagues (1996) defined a ‘visual noise ratio’ as the area of objects hindering driver view (such as billboards and buildings) divided by the total area of the driver’s field of view (defined as a 75 degree arc in front of the driver). Nine participants drove past six national highway number signs, and were asked to confirm the number when they could see the sign. The maximum distance at which a sign was seen was 320m. The authors then took photographs at 20m intervals from 320m before the sign and calculated the visual noise ratio for each photograph, and then the average visual noise ratio on the whole approach. There was a negative correlation ($r=0.38$, $p<.01$) between this ratio and the distance at which drivers fixated on the sign; i.e. on approaches with more visual noise, participants had to be closer to the sign to see it. The authors go on to analyse the results by participant attributes such as age and gender, but with only nine participants the results are unlikely to be generalisable. The authors note that a problem with their method was the use of photographs, which may not cover the entire driver field of view, to determine visual noise. One advantage of their method is that using area does not rely on being able to count the number of objects in the scene. However, as everything outside the roadway and the sky was counted as ‘visual noise’, it is not possible to determine what type of objects in particular may have contributed to the effect.

Evans and Stevens (1997) investigated 'graphical complexity', defined as the difficulty with which a driver extracts information from a display. Of their complexity measures, a weighted count of the number of discrete features, subjective ratings of complexity, and a compression algorithm (how much code was required to capture the display) correlated highly with people’s ability to perform a route-following task using the display. The display used for this experiment was a simplified visual representation of a junction (bird's eye view) with the route the driver should take, the lane the driver should be in, and 'some redundant information'. The task was to report the required lane and manoeuvres to pass through the intersection. This was a secondary task, conducted while dividing attention between the display and a primary display showing signs to be reported at random intervals (approximately every 2 sec). Participants pressed a button to indicate when they had extracted enough information, at which point the displays went blank and participants reported information to the experimenter. Time to extract information was not examined, only errors in the reported information. It is therefore possible that participants could have maintained high accuracy levels by increasing the amount of time spent looking at the display, which would decrease the correlation between complexity and task performance. Although the display was symbolic (and therefore on the lower end of complexity compared to a natural scene), it would be expected that the complexity of natural scenes would also influence the ease of extracting information.

These studies imply that road environments with greater amounts of information to sort through, and environments from which useful information is more difficult to extract, make the driving task more difficult.

Potential measures of clutter

A simple measure used by previous studies (see above) is simply to ask people how cluttered a scene is. Alternatively a more formal scale could be developed. Lansdown (2004b) suggests that standard subjective rating scales for workload such as the NASA-TLX might also be used for visual demand. Visual demand/ visual workload and visual clutter both refer to the difficulty of extracting relevant information from the scene, so this might be an alternative subjective measure. Pauzie and Pachiandi (1997) suggest that in driving contexts the 'Physical Demand' component of the NASA-TLX is relatively constant; they proffer their own Driving Activity Load Index, which separates perceptual demand (visual and auditory) from cognitive components (effort, temporal demand, situational stress, interference from other tasks).

Another approach is to use the properties of the scene when displayed on a computer. Fletcher and colleagues (2005) have found that sections of video footage of roads which compress very well correlate with sections of road identified by humans as monotonous. This could work in reverse as a measure of visual clutter. The authors note that the JPEG file size for a single frame is a measure of the complexity of a scene, while the MPEG dynamic compression specifies how much change occurs between frames. Roads with little change over time are rated as monotonous, while roads with multiple changes in the visual environment may be seen as cluttered. It was not specified how many humans rated the monotony of each clip, however the rating was based on the monotony of the driving task rather than the visual scene (thus a road with no line markings that compressed very well was not subjectively rated as monotonous due to the difficulty of maintaining lane position without lane markings).

Cloete (2006) found that the edge density calculated by a computer algorithm correlated well with subjective clutter ratings for 8 scenes. However when participants had to select which of four signs had been presented in a scene after brief viewing exposure, neither response time nor error rate were significantly affected by the level of clutter/edge density in the scene. Cloete initially asked 5 observers to rate the level of clutter in 168 scenes on a 6 point Likert scale. Four suburban low clutter scenes (mean rating < 2) and four urban high clutter scenes (mean rating > 5) were chosen for a subsequent experiment. Twelve traffic signs were presented in six possible positions against each of the eight backgrounds. Twenty-eight participants viewed each scene for 400ms, and then chose out of four alternatives which sign had been in the scene. It is not certain whether the forced-choice response may have restricted the effect of clutter, or whether the scenes presented simply did not contain a large enough range of visual clutter to affect performance. This is a significant concern, as there is no point in developing a reliable measure of visual clutter unless the measure also correlates with performance.

Recently, Rosenholtz and colleagues (2007) investigated several potential measures of visual clutter in displays. The authors define clutter as ‘the state in which excess items, or their representation or organization, lead to a degradation of performance at some task.’ The three measures comprised Feature Congestion, which calculates the local variability in several feature dimensions; Subband Entropy, which is a measure of the level of redundancy or predictability in the scene; and Edge Density, the percentage of pixels that are on an edge between areas of the scene. All three measures significantly correlated with task performance on visual search and contrast threshold discrimination using maps as backgrounds: the correlations were .74 for Feature Congestion and search, .75 for Subband Entropy and search, .83 for Edge Density and search (no significant differences between measures); and .93 for Feature Congestion and contrast threshold, .68 for Subband Entropy and contrast threshold, and .83 for Edge Density and contrast threshold (Feature Congestion significantly better than Subband Entropy). Feature congestion was superior when the visual search task was repeated in maps with monochrome red or grey backgrounds. The three measures also predicted the results of two recently published studies of visual search in naturalistic (not natural) scenes. However the measures have yet to be tested on actual photographs of natural scenes, such as roadscapes.

Computer-based methods of calculating visual clutter may prove to be the optimal solution for research. However more work is needed to align results from computer models with subjective experiences of the visual demand posed by a scene. It would also be useful to have a scale of visual clutter which could be used for three-dimensional, dynamic road situations as well as static photographs.

Studies specifically investigating visual clutter have found impairments to visual search. The related concept of background complexity also seems to correlate with difficulty in selecting relevant information, which flows on to increased crash rates. Although new computer-based methods of calculating the level of visual clutter in a scene show promise, none has yet been applied to research on the effect of visual clutter on driving performance.

Special focus: billboards

One form of visual clutter where guidelines are currently under debate is the advertising billboard. Advertising billboards are highly conspicuous due to their size, colouration, and location usually near major roads. The outdoor advertising industry promotes billboards as attention-grabbing, for example ‘Out-of-home advertising provides visual impact that commands complete attention, and offers total cut-through’ (Eyecorp, 2004). It might therefore be expected that they would distract attention from the driving task. There is in fact a small collection of research which suggests that this is the case, although most papers lack a theoretical basis to explain their findings. As explained in the section on conspicuity and visual distraction, visually distracting objects are visual characteristics of the road environment that can disrupt driving performance, and therefore included in the present thesis as a subset of visual clutter.

Johnston and Cole (1976) performed a series of five laboratory experiments in which participants moved a joystick to track arrows that appeared on a screen, while distracting advertisements were occasionally presented just above the arrows. They concluded that distractions from advertising billboards probably do not affect vehicle control (simulated by a tracking task) but probably do affect hazard detection (simulated by peripheral target detection, which was an additional task in three of the experiments). Luoma (1986) recorded eye movements while participants viewed slides of road scenes; he found that advertising billboards did not change eye movements towards traffic signs in the scenes, but did affect how well participants recalled traffic signs when questioned afterwards.

More recently, advances in eye-tracking equipment have allowed researchers to investigate how much time drivers spend looking at advertising billboards as they are driving past. Lee, Olsen and DeHart (2003) analysed the visual behaviour and vehicle control of subjects driving a 35-mile on-road route past 30 billboard sites. They compared the data recorded in the 7 seconds prior to passing each billboard site to data recorded on the approach to 'baseline' sites with 'no visual elements such as buildings or signs present'. They found no significant differences in eye glances, however the study analysed glances to left and right roadsides without regard for which side of the road the billboard was on – one might expect a billboard on the left to produce more left-forward glances than one on the right, and vice versa, but because all billboards were analysed together it is not possible to tell if such a pattern occurred.

The authors improved their analysis technique for a later study (Lee, McElheny, & Gibbons, 2007) on digital/LED billboards which change the display every eight seconds. This time, instead of just analysing glances to left and right, they analysed glances in the direction of a billboard. They found that digital billboards attracted longer glances than baseline sites. At night they also attracted more glances, and decreased the percentage of time drivers had their eyes on the road ahead. Interestingly, ‘comparison sites’ chosen to be as similar as possible to digital billboards (including landmark buildings, murals, and on-premise signs; 25% included ‘digital elements’ such as scrolling text or even full-motion video) were just as attention-grabbing as digital billboards, which suggests that even small moving displays are distracting.

Beijer, Smiley and Eizenman (2004) analysed glances at advertising signs on a Canadian expressway. Active signs (those with moveable displays or components) made up 51% of signs, but received 69% of glances, and 78% of glances that lasted more than 0.75 sec. Unfortunately this paper did not analyse glances at any other objects, which makes it difficult to investigate whether advertising receives a disproportionate amount of visual attention. In a related study, Smiley, Smahel and Eizenman (2004) analysed glances at video advertising signs in a downtown area; when these are present, they receive 2% of glances at all objects. Twenty-three percent of these glances are for longer than 0.75 seconds. The authors used this figure as the minimum perception-response time to react to a braking vehicle, rather than the more common figure of 1.5 sec (Olson, 2002). If drivers take their eyes off the road in front for longer than the minimum perception-response time, there is the possibility that they will miss a sudden stop by the vehicle in front and be involved in a rear-end crash.

Crundall, van Loon & Underwood (2006) recorded eye movements as participants watched videos of driving past advertising signs, which could be situated at street-level (SLA) or raised (RLA). SLAs were fixated more often and for longer, but this did not translate to better recognition on a subsequent memory task; in fact, memory for SLAs was worse than that for RLAs. Participants who were instructed to look for hazards fixated on SLAs more than those who were instructed to remember advertisements for the subsequent test. The authors suggest that this is because advertisements at street level fall into the driver’s search zone for potential hazards, and subsequently capture attention. Participating drivers rated the videos containing SLAs as more hazardous than those containing RLAs.

In combination, these studies provide evidence that some billboards may capture drivers’ attention at inappropriate times, and hold it for long enough that they might be unable to avoid a crash should a critical incident occur. Reviews of the literature on billboards and crash rates from Australia and North America (see below) concluded that billboards are associated with higher crash rates, with the usual caveat that correlation does not equal causation.

Cairney and Gunatillake (2000) reviewed eight studies correlating crash data with advertisement location. No meta-analysis was possible due to the wide range of methods and analysis techniques used; the authors note that some studies have been badly designed and/or presented in too little detail to determine whether the design was adequate to support the conclusions drawn. One important factor which can impair interpretation of correlations is traffic density: both advertising and crashes tend to increase with traffic volumes. The three studies which controlled for traffic density found higher crash rates in the presence of advertising. Of the other five, three found some effect of advertising and two found no effect, but it is difficult to interpret these results as either the methodology or the reporting was insufficiently rigorous.

Farbry and colleagues (2001) concentrated on the effect of electronic billboards on crash rates. In addition to the studies reviewed by Cairney and Gunatillake (2000), they review a six-year study of crash rates in the vicinity of a variable message sign at a sports stadium which found an increase in crashes per vehicle mile travelled. They also describe a recent court case in which a jury found the owner of an electronic billboard responsible for a distraction-related crash. They concluded that crash rates are higher where electronic billboards are installed.

One recent study (Tantala & Tantala, 2007) analysed accident rates near 7 digital billboards in Ohio and failed to find high correlations. However the analyses given do not control for various important factors (such as heavy snow the winter before the billboards were converted to digital format, and the fact that billboards tend to be placed on roads with a higher traffic volume) and no statistical tests, confidence intervals, or power calculations are reported. Given that only one year before and one year after conversion was studied, it may be that limited sample size produced low correlations.

Wallace (2003) reviewed the literature on billboards (mainly those cited in Farbry et al., 2001) and noted that the presence of billboards correlated with high crash rates in some circumstances, but not others. Higher crash rates were associated with billboards in two situations: at intersections, where billboards can function as visual clutter and interfere with the driver's ability to perceive important traffic signs; and on long monotonous stretches of road, when drivers may be surprised by the sudden appearance of a billboard, or fixate upon it as the brightest object in their visual field. Wallace concluded that more research should be done into what situations billboards interfere to a dangerous extent with the driving task.

The research thus far has shown that advertising billboards attract long glances, impair hazard detection, impair recall of traffic control devices, and are associated with high crash rates in certain situations. What is missing from the research on billboards is an overarching theoretical basis for why they might have these effects, and why studies of billboards in different situations or experimental paradigms do not always give the same result. The present work argues that advertising billboards are a highly conspicuous form of visual clutter, and that they therefore fit within the theoretical framework advanced by this thesis. As noted in the section on visual distraction above, both visual distraction from conspicuous items such as billboards and the level of information and quantity of items are properties of road scenes than can impair information selection and processing. While one billboard may not make a scene 'cluttered', the visual properties and information content of the billboard should be considered together with the visual properties and information content of other items and backgrounds in the scene as characteristics that can contribute to the level of visual clutter.

Conclusions from the literature review

Possible effects of visual clutter

Sheridan (2004) describes a model of driver distraction (caused by in-vehicle devices) from the perspective of control theory. Various functions within the control loop are described: intentions, sensing, decision making, vehicle dynamics, and driver state or activation. In normal control there is a feedback loop between sensing, decision making, and vehicle dynamics. When the driver is distracted by a secondary activity, the sensing and decision making functions are not used for the driving task, and the loop becomes open rather than closed – actions are set at the last decision. While visual distraction and other effects of visual clutter are usually not so dramatic as removing two crucial functions from the control loop, visual clutter does create disturbances to the sensing and decision making functions which will be passed on to the motion of the vehicle.

Visual distraction from highly conspicuous cluttering objects will only drastically impair vehicle control if it occurs for a sufficiently long period of time (which will depend on the driver's speed and the road environment – a billboard located at a bend on a high-speed road may be more dangerous than one on a straight low-speed road, as the driver in the former situation needs to check vehicle heading more often). A second case in which visual distraction from conspicuous objects will have similar effects to other forms of distraction is when the driver's attentional resources are diverted away from the road at the same moment as the sudden appearance of a hazard. However visual distraction can have more subtle effects, i.e. delayed response to traffic control devices and impaired situation awareness.

There are several other pathways through which visual clutter can affect driving performance. In particular, the literature shows that visual clutter in the form of irrelevant signage interferes with visual search for traffic signs (see section on 'Clutter and visual search'). Visual clutter also makes it more difficult to extract useful information from the visual environment, not just in directed search, but in general exploration of the scene for maintaining situation awareness (see sections on 'Scene complexity' and 'Visual information collecting').

In addition to these direct effects, a better idea of the range of potential effects of visual clutter is gained by considering the driving task as a whole. In order for the visual information gathering/sensing and information processing/decision making functions to be performed properly, the driver must be able to easily select driving-relevant information, and mental workload must remain within the driver's capacity.

Complex environments in which it is difficult to select relevant information and objects which interfere with visual search for traffic signs will both increase the complexity of the information-gathering portion of the driving task and therefore the demands placed on the driver. It is possible that the demands of selecting relevant information from a complex environment will themselves be a source of strain, which reduces the attentional resources of the driver (see section on ‘Effects of high workload on driving’). Distraction from conspicuous objects will also temporarily reduce or remove the attentional resources of the driver from the driving task (see section on ‘Conspicuity and visual distraction’).

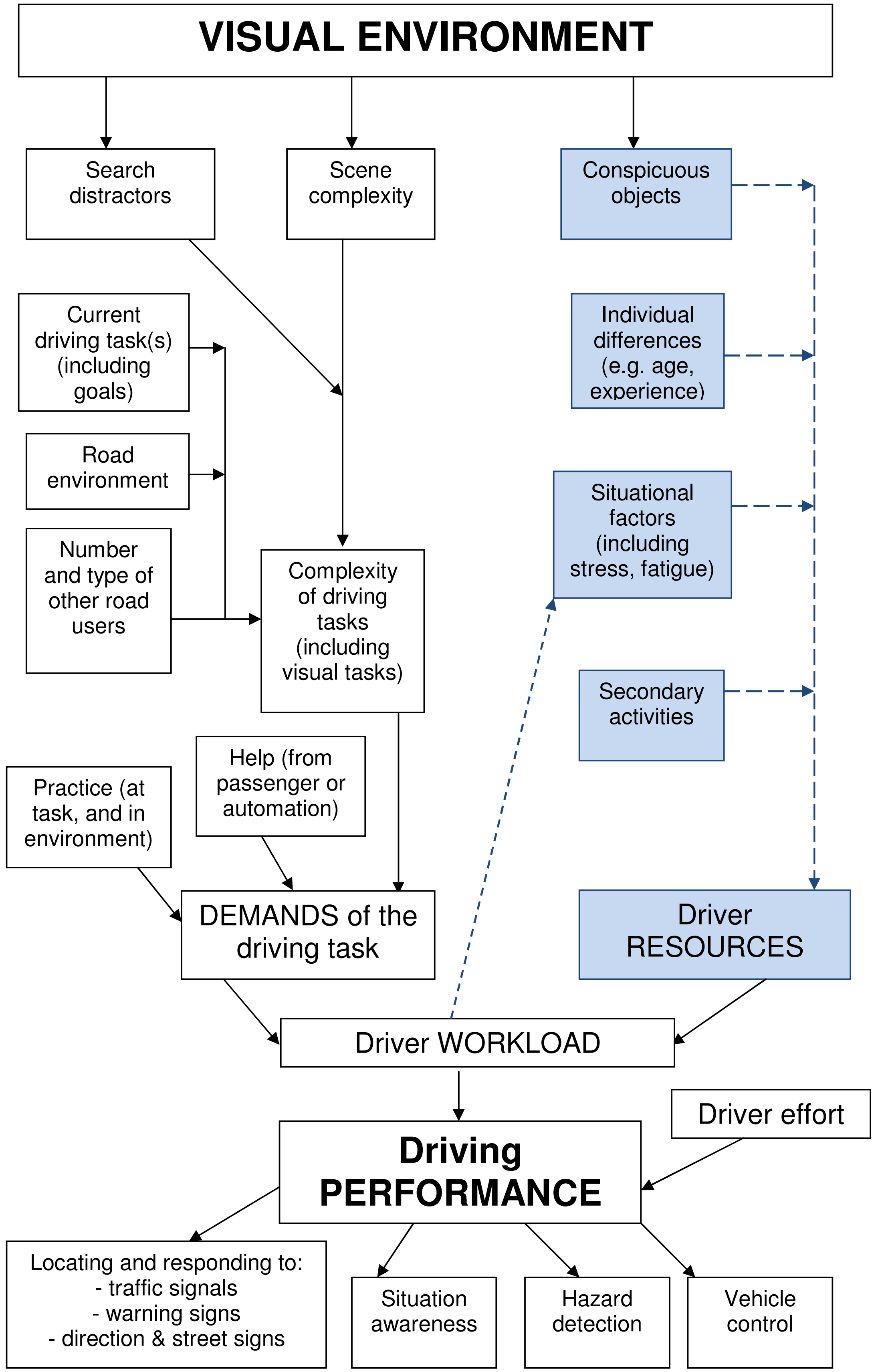
Visual clutter can therefore increase the demands of the driving task, as well as lowering the driver’s capacity to deal with these demands. As explained in the section on workload, as the demands of the tasks undertaken rises relative to the available resources, workload increases. Drivers can compensate for increased workload to a certain extent by increasing the effort they devote to the task. However eventually the driver will get to a point when task demands exceed the resources of the driver, and driving performance will be affected. This will be visible as effects on driving subtasks such as vehicle control, response to traffic control devices, situation awareness and hazard perception/response to hazards.

The model of the effects of visual clutter developed in this thesis, based on the review of literature presented above, is summarized in the following flowchart. Across the top is the visual environment, and immediately below are the features of the visual environment that may contribute to visual clutter. Search distractors are objects that look similar to the target of a visual search (e.g. for a road sign); these will interfere with the ‘deliberation’ mode of visual selection (see Table 1). Scene complexity refers to the level of organization of the scene, which will impair information extraction though both deliberate search modes and exploration modes. Conspicuous objects (defined by their size, luminance, colour contrast, eccentricity etc – see section on conspicuity) will be selected by reflex or attentional capture; they will thus interfere with endogenous modes of selection, taking driver resources away from the visual tasks of driving.

On the left are factors that relate to the demand of the driving task, including search distractors, scene complexity, and various factors not related to the visual environment that may interact with visual clutter in their effects of driving task demand/driver workload). The complexity of the driving task itself, in addition to visual factors, depends on what task goals are currently selected (eg maintaining speed and lane position, versus navigating through a complex intersection to get to a specific exit), the road environment (a simple road with one lane each direction and good markings, versus a potholed track, a winding highway, or a complex intersection), and the number and type of other road users (a few cars, versus a large number of other vehicles with different sizes, speeds, and acceleration/deceleration capacities). The more complex the driving task is, the higher will be the demands of the driving task. This can be reduced by familiarity with the task, as well as familiarity with the environment or similar environments (see section on 'Automaticity, schemata and expectancies'). In-vehicle technology or even a passenger taking on part of the driving task (e.g. navigation) can also reduce the demand of the driving task.

On the right, shaded in blue, are factors that can reduce driver resources. These include conspicuous (distracting) objects, individual differences (such as age, experience, and personality), situational factors (such as the driver's current level of fatigue or stress), and secondary activities (tasks not related to driving, such as adjusting the entertainment system or talking to passengers). Note the link back from the level of driver workload to the driver's level of stress and fatigue, which will affect resources, which will affect workload.

The amount of the driver's available cognitive resources taken up by the demand of the driving task is the level of driver workload. Drivers can maintain performance at high workload by increasing effort, but only to a certain point. When the demands of the driving task exceed the driver's resources, performance of driving tasks (specified at the bottom of the chart) will be impaired.


VISUAL ENVIRONMENT
Search distractors
Scene complexity
Conspicuous objects
Current driving task(s) (including goals)
Road environment
Number and type of other road users
Complexity of driving tasks (including visual tasks)
Individual differences (e.g. age, experience)
Situational factors (including stress, fatigue)
Secondary activities
Practice (at task, and in environment)
Help (from passenger or automation)
DEMANDS of the driving task
Driver RESOURCES
Driver WORKLOAD
Driver effort
Driving PERFORMANCE
Locating and responding to:
- traffic signals
- warning signs
- direction & street signs
Situation awareness
Hazard detection
Vehicle control

Gaps in the literature

Table 2 summarises the studies that have specifically investigated visual clutter or closely related concepts such as visual complexity. It can be seen that there is no agreed definition in the literature, no consensus on what to include as visual clutter, and a variety of measurement techniques.

Table 2. Previous studies of visual clutter

Author, year	**Definition of clutter**	**Compared (stimulus type)**	**Found**
Jenkins 1982	None – participants ranked photographs	Clutter rankings to accuracy of visual search for disc target (250ms viewing time, forced choice: left or right) (Natural scenes)	Significant, large correlation
Ho et al 2001	None – participants classified photographs as high or low visual clutter	Response time and accuracy on visual search for road signs for high vs low clutter photos (Natural scenes)	More search errors in high clutter scenes
McPhee et al 2004	Same as Ho et al 2004	Same as Ho et al 2004 with addition of secondary task (Natural scenes)	High visual clutter and distraction effects have additive detrimental effects on search time and accuracy
Bravo & Farid 2004	Overlapping objects	Overlapping objects vs clearly separated objects (Natural objects in artificial scene - blank background)	Simple objects just as easy to find in cluttered scenes Compound objects (with multiple parts) more difficult to find in cluttered scenes

Smith & Faulconer 1971	Scenes that required multiple perceptual groupings (many objects/areas in motion, many objects/areas with contrasting colours, more man-made vs natural areas)	Number of perceptual groupings with amount of congestion and number of accidents for 8 arterial roads (Natural scenes)	Large correlations
Agaki et al 1996	'Visual noise' = proportion of field of view covered by objects hindering view (e.g. billboards, buildings)	Visual noise ratio with distance at which participants could identify a highway number sign (Natural scenes)	Significant , large negative correlation
Evans and Stevens 1997	'Graphical complexity' = difficulty with which a driver extracts information from a display	Number of discrete features, subjective ratings of complexity, computer compression algorithm with errors in task performance (Task display)	Large correlations
Fletcher et al 2005	Opposite of monotony	Subjective ratings of monotony with MPEG compression (Video footage of natural scenes)	High correlations
Cloete 2006	None – participants rated on 5 point scale	Subjective ratings of visual clutter with edge density and accuracy on four-alternative forced-choice sign recognition (Natural scenes with superimposed signs)	High correlations with edge density, low with sign recognition
Rosenholtz et al 2007	'excess items, or their representation or cognition, lead to performance degradation'	Three algorithms with visual search performance and contrast threshold discrimination (Maps)	High correlations

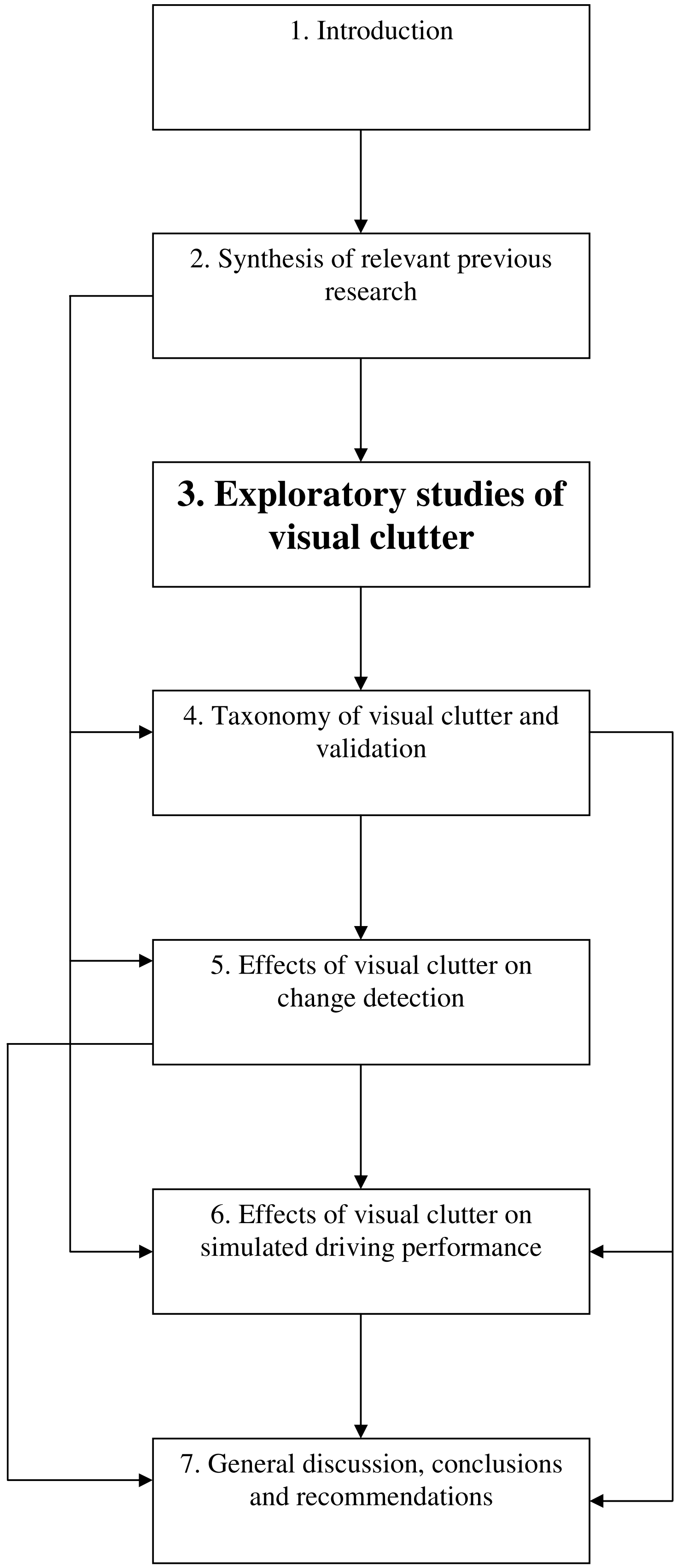
A major gap in research on the effects of clutter is that there is currently no commonly accepted definition of visual clutter and no agreed taxonomy of objects that might contribute to visual clutter (see Table 2). Any such definition and taxonomy should be tested in terms of the effect visual clutter has on driving performance, as visual clutter is only of concern to road safety when it impairs the ability of the driver to adequately perform all the tasks involved in safe driving.

Another major research gap in terms of applicability is the lack of any method to measure clutter and determine what level of visual clutter will be a safe range (for most road users, most of the time). Road authorities need to provide enough information for drivers and other road users to achieve their goals. A recent analysis of the road system in Victoria, Australia concluded that the system did not provide enough guidance information (Salmon, Stephan, Lenné, & Regan, 2005). However this information must be displayed at such a rate that the driver can absorb and process it in time to make the appropriate decision.

Driver workload is an important mediating variable between visual clutter and driving performance. As workload can be cumulative, it is obvious that clutter should be minimised where driver workload is already high (for example at complex intersections), but further research on the interaction between road design and visual clutter would help to define the range of safer and less safe levels of visual clutter.

The mechanisms by which visual clutter might impair driving performance seem possible to define: the problems are interference with visual search, distraction from the driving task, and overload. Because optimum workload will vary across drivers (due to factors such as age and personality) and within individual drivers across time (due to temporary factors such as fatigue), findings of no significant effect from any one study must not be taken to mean that visual clutter will never affect any driver's performance. Research should investigate the situations in which visual clutter is likely to be problematic for particular drivers, especially as more of Australia's population moves into the vulnerable older driver group.

Subsequent chapters of this thesis move towards a definition and taxonomy of visual clutter, and then determine its effect on driving performance, particularly for vulnerable groups such as older drivers.


1. Introduction
2. Synthesis of relevant previous research
3. Exploratory studies of visual clutter
4. Taxonomy of visual clutter and validation
5. Effects of visual clutter on change detection
6. Effects of visual clutter on simulated driving performance
7. General discussion, conclusions and recommendations

Chapter Three

Exploratory studies of visual clutter

As established in chapter 2, ‘visual clutter’ is a term that is often used, but rarely defined. The only studies that have specifically investigated the effects of visual clutter in the road environment are Jenkins (1982), Ho and colleagues (2001) and McPhee and colleagues (2004). Visual clutter was not explicitly defined in any of these studies; instead, participants were asked to rate or rank photographs in terms of how much clutter they contained. These clutter ratings were then correlated with how easily participants could find a disc target (Jenkins) or a certain traffic sign (Ho et al, McPhee et al) in each photograph. All of these studies found that visual search was more difficult in photographs rated as high in visual clutter.

These findings raise important questions with respect to road safety. Why is visual search impaired? Is attention distracted from the search by conspicuous objects, such as brightly painted buildings and advertising billboards? Are there too many objects that look similar to the target traffic sign, or disc? Are there simply too many objects to be attended overall? Knowing what makes a visually cluttered scene look cluttered could help road authorities reduce the level of clutter, allowing drivers to more easily find traffic signs and other important objects.

In 2004 when the present work commenced, there were no published measures of visual clutter. The only model available was the use of subjective ratings, which does not produce any insight for measuring visual clutter in new scenes without a group of raters. Most of the studies using computers to analyse photographs and other pictures (Cloete, 2006; Evans & Stevens, 1997; Fletcher et al., 2005; Rosenholtz et al., 2007) had not yet been published. Even if these methods for displays had been available, none of the above papers suggest ways to establish the level of clutter in a three dimensional world containing three dimensional objects which will be viewed from multiple perspectives.

The existing literature does not give any guidance to road authorities looking to reduce visual clutter. Nor does it provide sufficient specifications for researchers looking to investigate the effects of visual clutter. The first priorities of the present research were therefore to clarify the meaning of the term ‘visual clutter’, as perceived by drivers, and to attempt to determine what was consistent across scenes described as high in visual clutter. These aims were achieved via a series of focus group discussions (Study 1), and by asking drivers to rate the level of visual clutter in a variety of photographs of road scenes (Study 2).

How to operationalise 'visual clutter' is of course an important topic for a study of the effects of visual clutter. It was decided to begin by examining driver perceptions of what visual clutter is in order to ensure face validity for later experiments which would manipulate the level of visual clutter and determine the effects. It might be argued that 'visual clutter' that does not affect performance in some way is not actually clutter. For this reason it is important to have some idea of the specific objects and scene characteristics which make a scene cluttered in terms of the particular task required.

Several options were considered for the initial exploratory studies. Commentary driving was one possibility, however as the workload of the driving task may have affected the verbal reports given (especially for more inexperienced drivers) this was not chosen.

The use of photographs as stimuli was chosen, as this ensures consistency of stimuli between participants, and multiple photographs can be shown within a relatively short time period.

The repertory grid technique was considered, however this technique works best for eliciting a range of constructs about how stimuli differ (Riemersma, 1988), and the only construct of interest in the present experiment was clutter. It was thought that the use of this technique was likely to force participants to generate road/scene characteristics that were not related to their conception of visual clutter.

Ranking of scenes, either for a whole set or as a series of pair comparisons, does not allow assessment of the magnitude of differences between scenes. The use of ratings avoids this problem. Ratings of scenes can however only provide information about the sources of visual clutter in the scenes displayed; while a wide range of road scenes were collected for the experiment, an additional more open-ended measure was desired to ensure that drivers could give information about visual clutter in other road environments.

Thus it was decided to use a series of focus group discussions (Study 1), as well as asking drivers to rate the level of visual clutter in a variety of photographs of road scenes (Study 2).

Both of these measures are expected to capture only aspects of visual clutter that are available to conscious awareness, which may not include all the visual characteristics of a scene that have the potential to affect driving performance. Later parts of this thesis will determine whether these consciously available aspects of visual clutter are consistent with the visually cluttering characteristics that appeared in the literature review, or whether the performance decrements and the subjective concept of 'visual clutter' spring from different sources.

Study 1 – Focus groups

The initial step was to explore what drivers understand the term ‘visual clutter’ to mean. These qualitative findings were expected to assist interpretation of the clutter rating study.

Method

Participants

Fifty-four drivers (19 male and 35 female) were recruited by advertising in the university’s staff notices bulletin and on the student job website. All participants received a small cash payment as compensation for their time and travel costs. Participants’ age ranged from 18 to 58 (mean age 31.6 years), and their solo driving experience ranged from a few months to forty years.

Procedure

All focus group discussions took place in February 2005. Participants were allocated to one of six groups (based on time they could attend, although an attempt was made to ensure that each group contained a range of ages and experience levels). Each group contained between seven and ten people. The author facilitated all discussions. Each focus group discussion started with general questions about what participants thought visual clutter was, and what effects it had on them while driving. Participants were then shown a photograph of a crowded city scene and asked a series of questions about what captured their attention first; which objects contributed to the amount of clutter in the scene; what could distract them from the driving task; and how easy they thought it would be to find a street sign and detect a potential hazard while driving down the road in that scene. These questions were repeated for a second photograph, which showed a low-traffic road in a rural environment. For a full list, and wording, of questions see Appendix A. The discussion was recorded on audiotape for later transcription by the experimenter.

Results

1.a) 'What do you think visual clutter is?

The first question elicited four points of view. Simplest was the idea that 'cluttering' objects are those that occlude (get in the way of seeing) other objects. Perhaps surprisingly, this idea was not what most drivers thought of first – all the other points of view were related to attention.

One of the most common ideas was that visual clutter is everything you can see. Proponents of this viewpoint agreed that visual clutter took up attention, but they thought that everything in the visual field has to be attended briefly in order to assess whether it needs to be attended to in more detail. The other common viewpoint was that clutter is made up of objects that distract the driver from the driving task. Drivers talked about conspicuous objects that grabbed attention whether they intended to look or not: "things that distract you from where you should be looking". A corollary to this idea was the view that cluttered scenes are those with many objects to which the driver must attend in order to drive safely. For example, roads with many signs or intersecting roads demand attention.
The consistent theme that comes through is that drivers feel the amount of visual clutter in a scene is related to the amount of attention demanded by objects in that scene (whether because of the visual characteristics of the object, its importance to the driving task, or the sheer number of objects to be sorted through).

1.b) What are the most common forms of visual clutter in the driving environment?

These again fell into the categories of 'objects that require attention as part of the driving task' (signs, other cars, trams, pedestrians etc), 'objects that distract attention from the driving task' (billboards and other advertising signs), and 'objects that occlude vision' (tall buildings, trees, trams and other cars to a certain extent).

Table 3. Driver's perceptions of visual clutter and cluttering objects

What is visual clutter?	**What are the most common forms of visual clutter?**
Objects which occlude other objects	tall buildings, trees, trams, other cars
Objects which require attention	signs, other cars, trams, pedestrians
Objects which distract attention	billboards and other advertising signs
Everything visible	All of the above

2. What effect do you think visual clutter in the road environment has on your driving?

Two consistent themes emerged here: clutter could distract drivers, and cause attention overload. An example of the latter view: "processing time – [the more visual clutter,] the longer it takes to sift out the important things from the unimportant things". Both visual distraction and attentional overload resulted in drivers missing traffic signs and potential hazards.

Drivers reported that familiarity could ameliorate the effects of a highly cluttered environment, as could a passenger giving navigation instructions. Both of these result in a lessening of the driver's cognitive load, allowing the driver to concentrate more on the current traffic situations (rather than having to, for example, look for a particular street sign – a navigating passenger can do that for them, and familiarity with the area means they can use other cues to know when to turn). Familiarity also allows a driver to 'tune out' the objects that they know are not relevant, for example shop fronts, which again increases the amount of attention they can give to the driving task.

Figure 1. City scene

3.a) I'm going to show you a photograph of a road scene, and I would like you to tell me what you notice first.

The most commonly reported ‘first noticed object’ was a large billboard on the right hand side of the scene, on the side of a building (see Figure 1). Also quite common was a ‘shop for lease’ sign in bright colours on the building on the left hand side of the road. Other responses included the buildings on either side of the road and/or their height; a tree near the centre of the picture which was bright green; the traffic further down the road; the tram and/or tram safety zone in the middle of the road with waiting pedestrians; the green light; and the hook turn sign which was hung high above the road. This latter is an interesting response, because many people admitted in later discussion that they had not noticed the hook turn sign until somebody else mentioned it.

3.b) Would you describe this photograph as cluttered?

In two groups, all participants agreed that the city scene was cluttered. The other four contained mixed opinions. Those who thought the scene was not so cluttered tended to have more experience in driving in the city. They commented that the traffic was all on the other side of the intersection, there were no pedestrians crossing the road, and few traffic signs. Some noted that it would be more cluttered across the intersection when they would have to deal with traffic. Another respondent noted that although the scene did not contain many objects related to driving (such as traffic signs), there were many visible objects that were not related to driving. These objects had more effect on those who said that the city scene was cluttered; when asked what made the scene cluttered, they made comments such as ‘lots of things in your vision’, ‘lots of potential for stuff to happen’, ‘there's a lot of other things to distract you’.

- If I were to take some objects out of this scene, would that make it less cluttered? Which objects would I have to take out?

As with the responses to common forms of visual clutter, the objects that people would remove to reduce clutter fell into a few categories: those which must be watched to drive safely (parked cars, trams); those which distract attention from the driving task (advertising signs, billboards – because of size, colour, and presence of writing, which takes extra time to read); and those which occlude other objects (parked cars again, and trees).

E.g. ‘I might take out all the words, because if you see something written you read it and it takes time and concentration’. One person noted that some of the advertising signs were particularly distracting because they had some characteristics of a traffic sign.

3.c) Would you be able to easily find a street sign in this scene?

This question received mixed responses; some drivers felt it would be quite difficult to distinguish a street sign from all the other signs, while others felt that the unique size, shape, and positioning would enable them to find street signs easily.

- What about potential hazards like pedestrians?

This question also received mixed responses, mostly due to the presence of parked cars blocking view of potential pedestrians down the road. The general feeling was that drivers should expect pedestrians in this sort of road environment and be on the lookout.

3.d) Imagine you are driving down this road. Would you be distracted by anything in this scene?

The billboard and the shop for lease sign were most commonly mentioned in response to this question. Note that a large number of participants noticed these two objects first, and said that their removal would reduce clutter.

Figure 2. Rural scene

4. a) Now I'm going to show another photograph. Again, please tell me what grabs your attention first.

In this rural scene, containing only one sign, the sign was mentioned most commonly as the first thing seen. Other answers included the mountains/horizon/view, the car in front, the sky, the embankment on the right of the road, and "nothing in particular".

b) Would you describe this scene as cluttered?

All participants in all groups described this scene as not cluttered.

- *What is it about this scene that makes it not cluttered?*
- *What are the important differences between this scene and the previous scene?*

Drivers felt the rural scene was less cluttered for two reasons: less of everything that made the previous scene cluttered meant less to look at and less to think about. Drivers felt that the scene was more predictable (i.e. fewer objects in the scene were likely to move), and that if an unexpected hazard appeared they would have more time to deal with it than it the urban scene. Some drivers also noted that the sign was the only object that required extra attention; there was nothing else to distract from steering and maintaining speed. One participant commented that almost everything in this scene was natural rather than manmade (and vice versa in the urban scene);

she added that manmade objects tended to grab the attention more. A participant in another group commented that the rural scene contained less vertical and horizontal lines, which made it feel less cluttered to him.

c) Would you be able to easily find a street sign in this scene?
- What about potential hazards like pedestrians?
All participants answered yes to both these questions.

d) Imagine you are driving down this road. Would you be distracted by anything in this scene?
Drivers felt that the only distraction in the rural scene is the view of the mountains. Some participants noted that because there is no clutter and the scene is so relaxing, they would be concentrating on their driving less than they would in the city scene.

Discussion

Drivers' comments about visual clutter tended to revolve implicitly around the concept of attention. Statements that visual clutter is when there are too many objects, and specifically too many driving-related objects that need to be attended, are both forms of the idea that visual clutter increases mental workload. This idea is reinforced by drivers' comments that familiarity with the environment or help from a passenger could reduce the effects of visual clutter. Both familiarity and assistance can reduce the demands of the navigation task, allowing the driver to concentrate on other aspects of driving. Automated navigation aids could serve a similar function, although they were not mentioned by any participant in the focus group. However it should be noted that when the focus group discussions were held in early 2005, navigation/route guidance aids were not nearly so common as they became during 2007. Much research effort has been focussed on how to determine whether such automated aids increase or decrease driver workload. As an introduction to the HASTE project explains: "Every new information source could add to the information load of drivers, potentially counteracting the potential benefits of decreased workload from the same information." (Carsten & Brookhuis, 2005)

The alternative idea that objects that distract attention from the driving task increase visual clutter explains the studies that have found impaired visual search in visually cluttered environments. Of course, which objects are search targets and which are irrelevant distractors is subjective and changes depending on the situation; what is an unnecessary sign to one driver might be a useful navigation landmark to another. As with automated driver aids, signage should balance the need to give information with the need to give the driver enough space and time to process the information.

The effects of visual distraction are not limited to the task of looking for traffic signs. Drivers were concerned that some visual clutter could involuntarily capture their attention when they should be looking at something else. As explained in chapter 2 (page 23), such visually distracting objects can interfere with situation awareness as well as hazard perception.

These concerns with conspicuous/distracting objects and increased visual demand are the same as the pathways by which the literature suggests visual clutter might affect performance on (visual) driving tasks: clutter can diminish driver resources, or it can increase the demand of the driving task. Whether a scene is described as cluttered relates not only to the number and nature of the items in the scene, but to the observers' relationship to those items in terms of goals and familiarity. It is particularly interesting that drivers with less experience of city driving pointed to the large number of objects as causing clutter, while drivers with more experience stated that these objects were not relevant and could be ignored, therefore not cluttering. Thus, any visual feature, background or object that increases the proportion of driver capacity which is taken up by visual tasks is visual clutter; any visual characteristic or object that does not have this effect is not visual clutter; but which objects are in these two categories varies. This person-task-environment interaction makes it more difficult to define clutter absolutely. However, we have the beginnings of a theory here: multiple objects are obviously cluttering, but in particular, objects that are necessary to attend for the driver's task and objects that distract attention from the driver's task create visual clutter.

Study 2 – Ratings of photographs

The photograph rating study was an attempt to investigate what elements are common in highly cluttered road environments. It goes further than the work of Jenkins, Ho and colleagues and McPhee and colleagues, in that the subjective ratings are analysed with respect to the type of road and the presence of certain objects.

Scenes were from four different types of road: commercial, arterial, freeway, and residential/rural roads. It was hypothesised that the commercial roads would be rated as highest in visual clutter, and the residential/rural scenes rated lowest.

The objects examined were billboards, parked cars, and signage (including signals). Background complexity was also examined. These objects were chosen to represent the pathways by which visual clutter can affect driving performance, described in chapter 2 (page 44). Billboards are a conspicuous object which might cause visual distraction; parked cars are hazards that must be monitored, which increase the demand of the driving task; multiple signs/signals make it more difficult to find a particular sign; and background complexity increases the difficulty of extracting relevant information from the scene. It was hypothesised that the versions of photographs with billboards, parked cars, more signage, or a more complex background would be rated as more cluttered than the versions without.

<u>Method</u>

Participants

Study 2 was performed concurrently with study 1, using the same 54 participants. The focus group discussion was conducted after the photograph ratings, so that participants' ratings were not affected by the opinions of others.

Design

There were sixteen pairs of photographs, plus four unpaired photographs included to reduce the amount of repetition. Eight pairs of photographs were comprised of one version with and one without a billboard. Three pairs had versions with and without parked cars. Two pairs were rural backgrounds with and without signs. One pair showed a shopping strip with and without shop signs. One pair depicted a residential intersection with and without signal lights. The final pair examined background complexity. The 16 pairs were from various different road types: four pairs were photographs of freeways, four of arterial roads, four of commercial scenes (roads with shops along one or both sides), two of residential roads and two of rural roads.

The four extra photographs were all of commercial scenes. Figure 3 and Figure 4 show examples of photograph pairs.

a)

b)

Figure 3. Pair of photographs. The original picture is a), while the billboard has been removed in b).

a) 

b) 

Figure 4. The same cluster of signs against a) a complex commercial background, and b) a residential background.

The photographs were shown in six blocks of six, with each block containing two commercial scenes, at least one freeway scene, at least one arterial road scene, at least one residential/rural scene, plus a second photograph from one of the latter three categories. The order of photographs in each block was randomised. The two practice blocks contained a similar mix of photographs, again with the order randomised.

Procedure

The experimenter took photographs of a variety of real-world road scenes using a Canon Digital Ixus V camera with a resolution of 2.1M pixels. Adobe Photoshop was used to add or remove an object from each scene so that each photograph now came in two versions. For the background complexity pair, it was not possible to digitally replace the entire background of a scene without the result looking unrealistic; instead two photographs were taken of the same set of signs at two similar intersections with differing backgrounds.

As the focus group discussion was held directly after the ratings, participants undertook the experiment in groups of seven to ten. Participants began by filling out a brief questionnaire (see Appendix B) covering their age, sex, licence type, and driving experience, which was attached to the booklet in which they were instructed to rate photographs for their level of clutter. Subsequently, participants viewed a series of photographs projected onto a screen of approximately 1 metre square. They were seated 2-3 metres from the screen, so that the screen took up approximately 20-25 degrees of visual angle. (As the experiment was performed in groups it was not possible for every participant to have the same viewing distance and visual angle.) Each photograph was rated on a graphical scale consisting of a horizontal line anchored on the left by the words *very low amount of clutter* and on the right by the words *very high amount of clutter*. There were no further markings on the scale, as the experimenters wished to influence the subjects' choice of where to mark the scale as little as possible. The experimenter explained the rating process using a 'baseline' picture (of a low-traffic rural road), which was also shown between each block. Participants viewed two practice blocks of six photographs each, with the opportunity to ask questions after each block. When the experimenter was satisfied that all participants understood the instructions, the six blocks of experimental photographs were shown.

The purpose of the practice blocks and the baseline picture was not only to ensure participants understood the rating process, but also to avoid the problem of drivers changing their opinions about what was a high clutter scene and what was a low clutter scene partway through the study as they saw more photographs.

Results

The first analysis was a repeated measures ANCOVA on all 32 photographs, with road category as the within-subjects factor and years since gaining licence as a covariate. The number of years since drivers gained their licence was judged the best measure of driving experience, as many drivers had difficulty accurately estimating how many kilometres they drove per year. There was a significant main effect for type of road: $F(3, 153) = 24.89$, $p < .001$, $\eta^2 = .33$ (small to medium effect). Figure 5 shows that rural and residential roads received the lowest clutter ratings. Commercial roads received the highest ratings, but arterial roads were not far below. Freeways were as rated significantly less cluttered than commercial roads, but could not be differentiated from arterial roads.

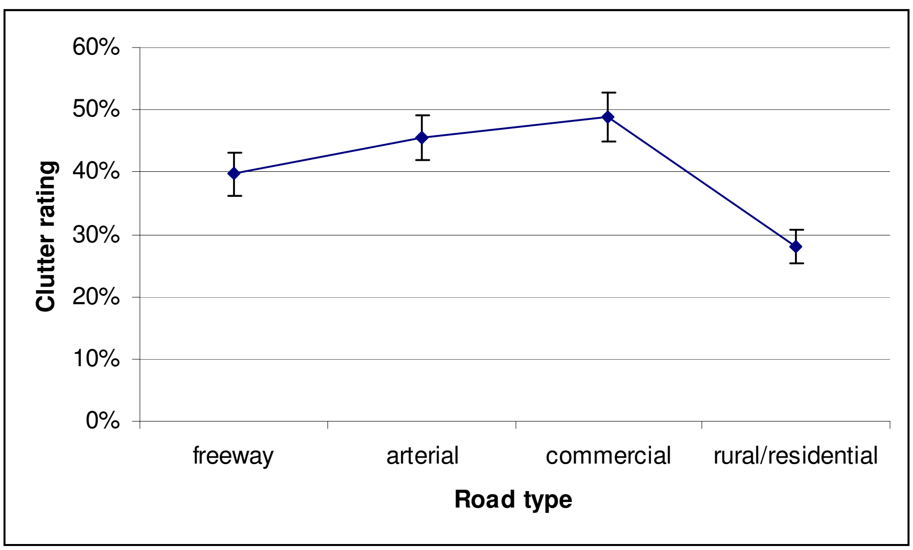


Figure 5. Mean clutter ratings and 95% confidence intervals for different types of road

Although the main effect of experience was not significant, it interacted significantly with road type: $F(3, 153) = 6.07$, $p < .01$, $\eta^2 = .11$ (small effect). Figure 6 shows that more experienced drivers rated commercial and arterial roads higher, but freeways lower than did inexperienced drivers.

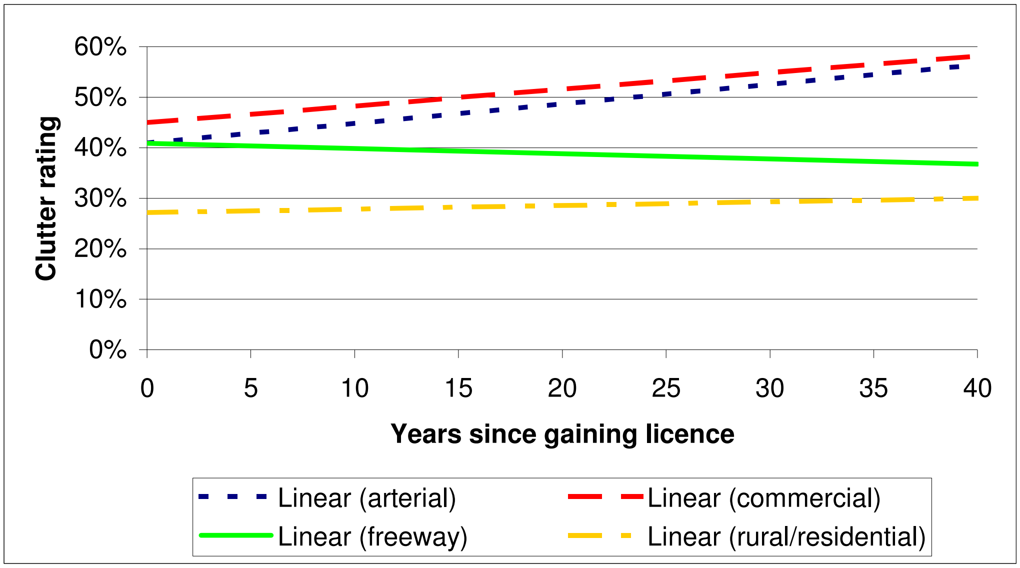


Figure 6. Linear trend for clutter ratings by experience for each road category.

The photographs were split into groups to analyse the effect of specific objects: billboards, parked cars, rural signs, traffic signals, background complexity and shop signage. For all groups, the initial analysis was a repeated measures ANCOVA with years since gaining driving licence as the covariate.

Billboards

The largest of these groups contained the eight pairs of photographs in which one contained a billboard and the other did not; four of these scenes were freeways, two were arterial roads, and two were commercial roads. Because Mauchly's test of sphericity failed for scene and the interaction between scene and billboard presence, it was necessary to adjust degrees of freedom using the Huynh-Feldt correction (Howell, 1997). There were significant main effects for scene, $F(7, 357) = 15.11$, $p < .001$, $\eta^2 = .23$; and billboard presence, $F(1, 51) = 6.04$, $p < .05$, $\eta^2 = .07$. These was also a significant two-way interaction between scene and billboard presence, $F(7, 357) = 3.93$, $p < .001$, $\eta^2 = .07$. Figure 7 reveals an unexpected finding. For each pair of photos, the version that contained the billboard was expected to receive higher clutter ratings than the version which did not. While this occurred for six pairs, for the other two (one commercial scene and one arterial scene), this pattern was reversed. A content analysis of the eight scenes failed to reveal any differences which might account for the result.

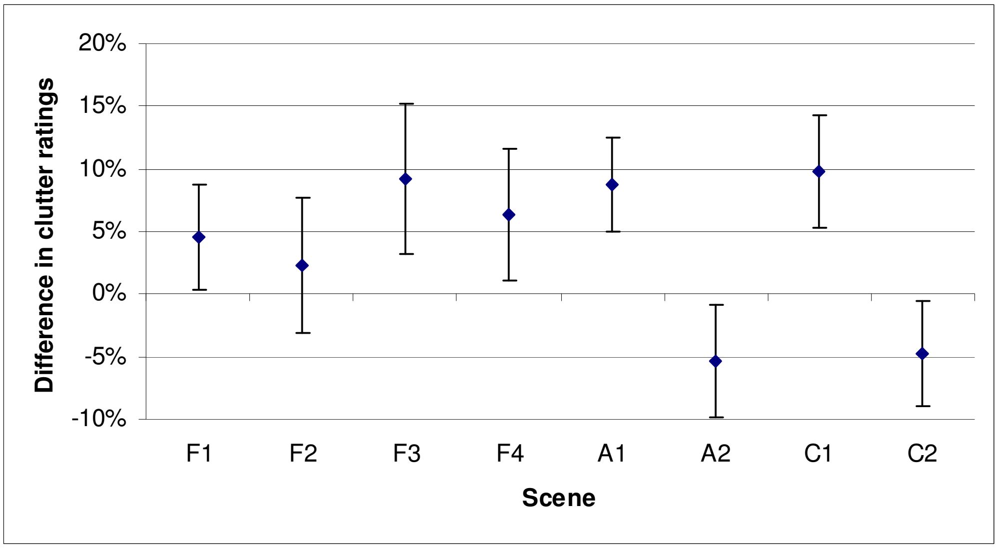


Figure 7. Mean (and 95% CI) difference in clutter ratings between versions of each scene with and without billboards (F1-4 = freeway scenes 1 to 4, A1&2 are arterial scenes, C1&2 are commercial scenes)

An examination of the photographs in the order in which they were presented revealed a potential explanation. Scene A2b was presented after a very low clutter rural scene, and it is possible that A2b may have been rated more highly than it otherwise would have been. F2b may have been similarly affected. C2b was presented after a residential scene which was not quite as low clutter, but still may have had some effect. Graphs of ratings by photograph order are presented at the end of the results section. Caution should be used however in interpreting the following results as there may be further effects of presentation order.

Although years of driving experience did not have a main effect, there was a significant two-way interaction between driving experience and scene, $F(7, 357) = 4.48$, $p < .001$, $\eta^2 = .08$. Figure 8 shows that more experienced drivers rated arterial roads higher than less experienced drivers, while this effect was lessened for commercial roads and nonexistent for freeways.

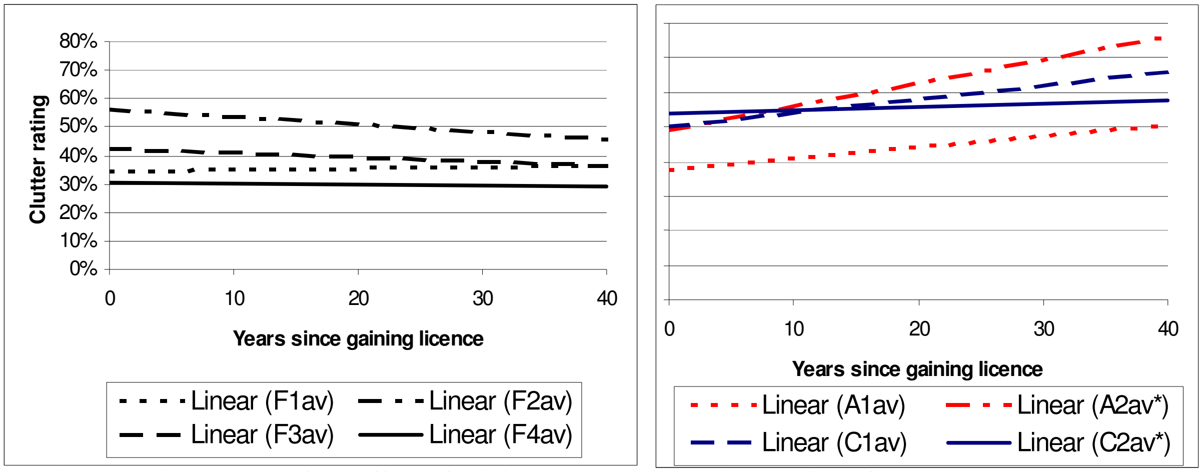


Figure 8. Linear trend of the effect of driving experience on clutter ratings for scenes containing billboards

Parked cars

In the next set of three photograph pairs, version A contained cars that had been removed in version B. There was a significant effect for the presence of parked cars, $F(1, 51) = 13.43$, $p = .001$, $\eta^2 = .20$. The main effect of scene was not significant, but there was a significant interaction between scene and presence of cars, $F(2, 102) = 9.63$, $p < .001$, $\eta^2 = .16$. Figure 9 shows that the difference between versions was actually nonsignificant for the arterial and commercial scenes, but highly significant for the residential scene, in which the cars were closest to the camera. For this scene only, the version with cars was rated more cluttered than the version without cars.

It should be noted that the commercial scene with cars in this set was after a low clutter rural scene, which may have artificially boosted ratings.

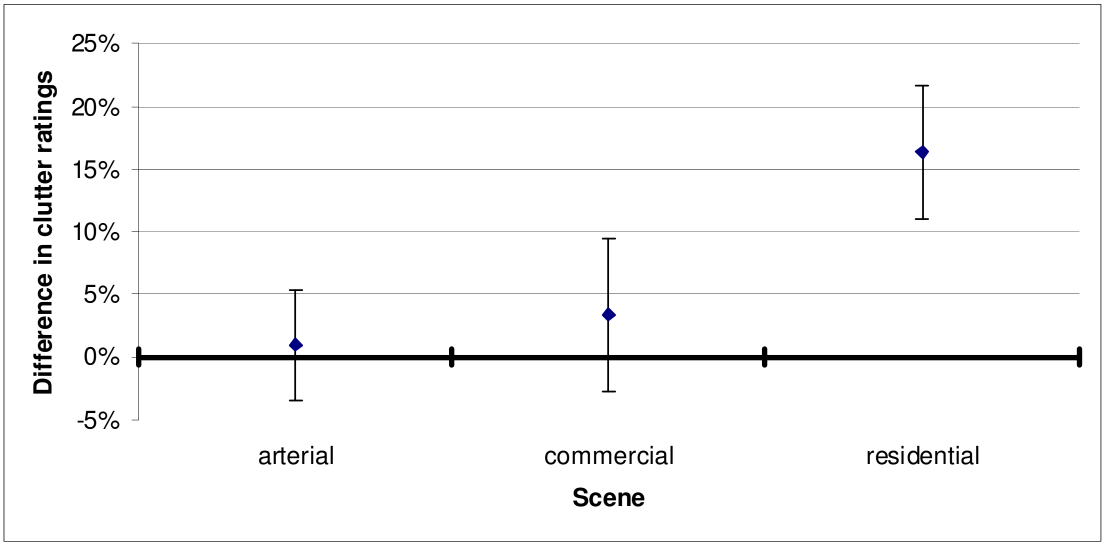


Figure 9. Mean (and 95% CI) difference in clutter ratings for photographs with and without parked cars

The effect of experience was also significant, $F(1, 51) = 8.09$, $p < .01$, $\eta^2 = .14$. The trend for more experienced drivers to give higher ratings can be seen in Figure 10.

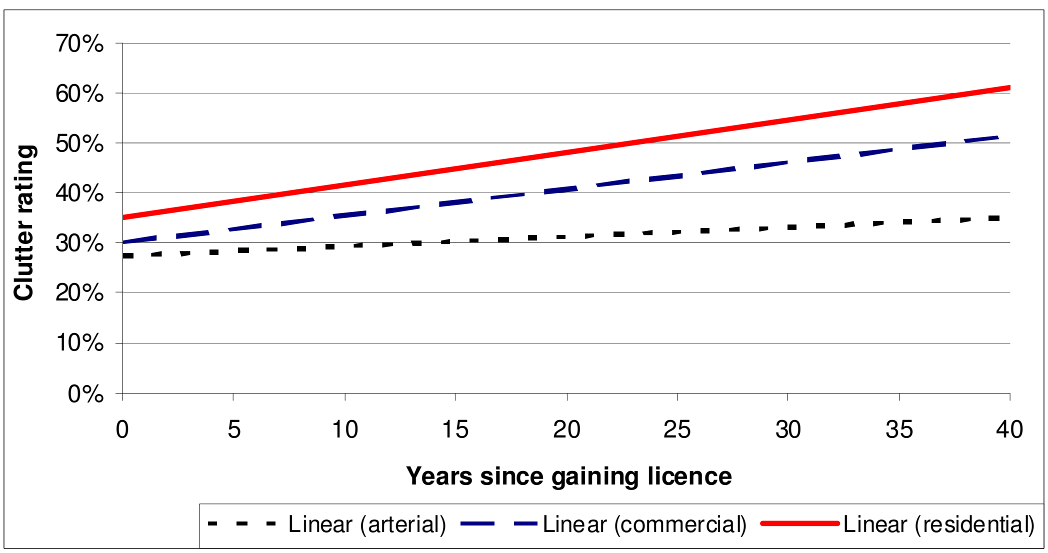


Figure 10. Linear trend for effect of driving experience on clutter ratings (averaged across both versions of each scene)

Rural signs

The third set of photos comprised the two rural pictures. One scene contained a roadside advertisement that was absent in the altered version; the other contained a warning sign that was absent in the second version. The main effect of sign presence on clutter ratings was not significant, $F(1, 51) < 1$. The two scenes were significantly different, $F(1, 51) = 12.28$, $p < .001$, $\eta^2 = .19$; the scene containing more traffic was rated as more cluttered (see Figure 11).

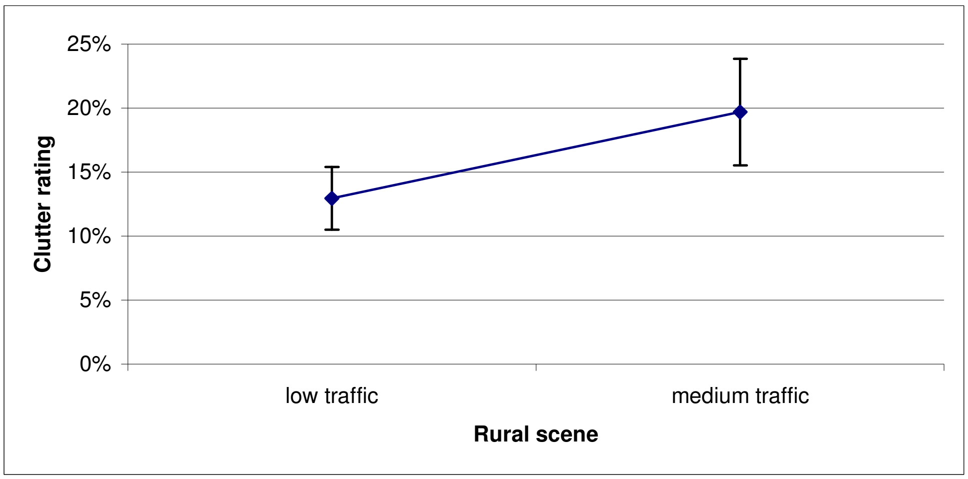


Figure 11. Mean clutter ratings and 95% CIs for the two rural scenes (averaged over versions with and without signs)

The main effect of experience was significant, $F(1, 51) = 7.18$, $p <. 01$, $\eta^2 = .12$. Figure 12 shows that less experienced drivers rated these scenes as more cluttered than did more experienced drivers.

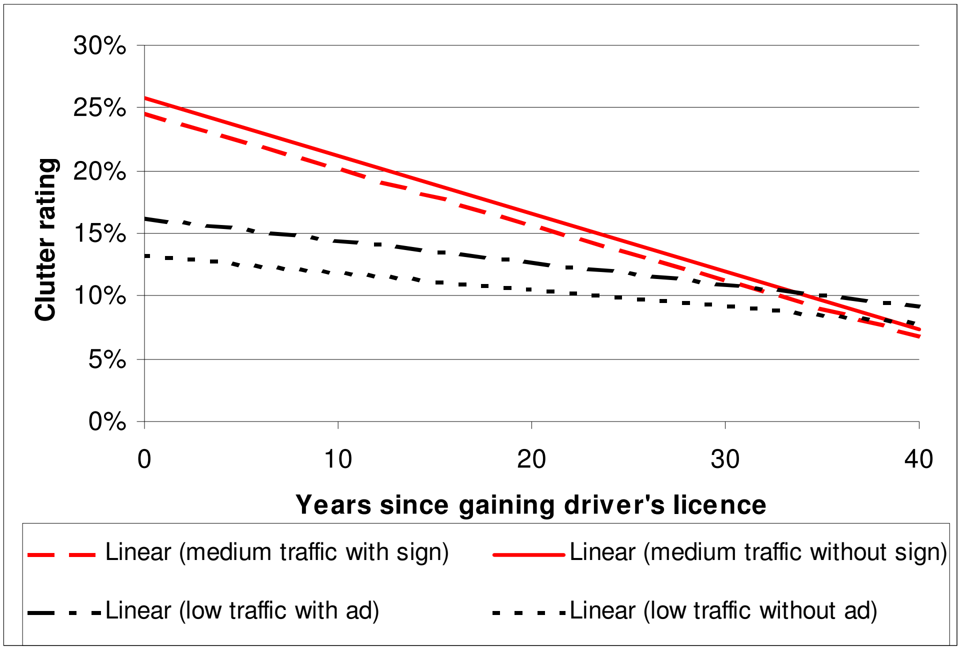


Figure 12. Linear trend for effect of experience on clutter ratings for rural signs

Signal lights

This scene was of a residential intersection showing a set of traffic lights. In the second version, the lights were removed. Although this version was rated as slightly less cluttered than the version with lights, the difference did not reach significance, $F(1, 51) < 1$. Neither experience nor the interaction between experience and version reached significance.

Background complexity

The next pair of photographs investigated background complexity. Both photographs contained a cluster of five identical traffic signs around a traffic light. In one version, the background was a shopping strip with parked cars and shop signage visible. The second version was in a residential area where the most noticeable objects were trees. There was a significant difference between the two versions, $F(1, 51) = 48.65$, $p < .001$, $\eta^2 = .49$ (medium effect); the version with the shopping strip was rated as more cluttered (see Figure 13). Neither experience nor the interaction between experience and version reached significance.

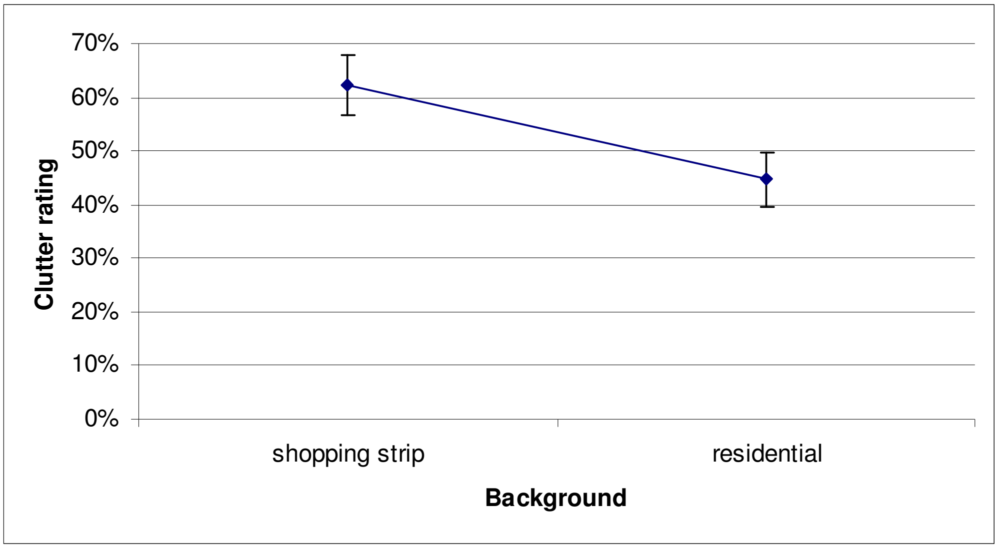


Figure 13. Mean clutter ratings and 95% CI for photographs of the same cluster of signs against different backgrounds.

Shop signage

The final analysis looked in more detail at shopping strips. One version was the original photograph of a commercial shopping strip, and in the other version most of the shop signage was removed. This version was rated less cluttered than the version with visible signage, but the difference did not reach significance, $F(1, 51) < 1$. The main effect of experience was not significant, however there was a significant interaction between experience and version, $F(1, 51) = 6.52$, $p < .05$, $\eta^2 = .11$. Figure 14 shows that the version with signs was rated as more cluttered by drivers with more experience.

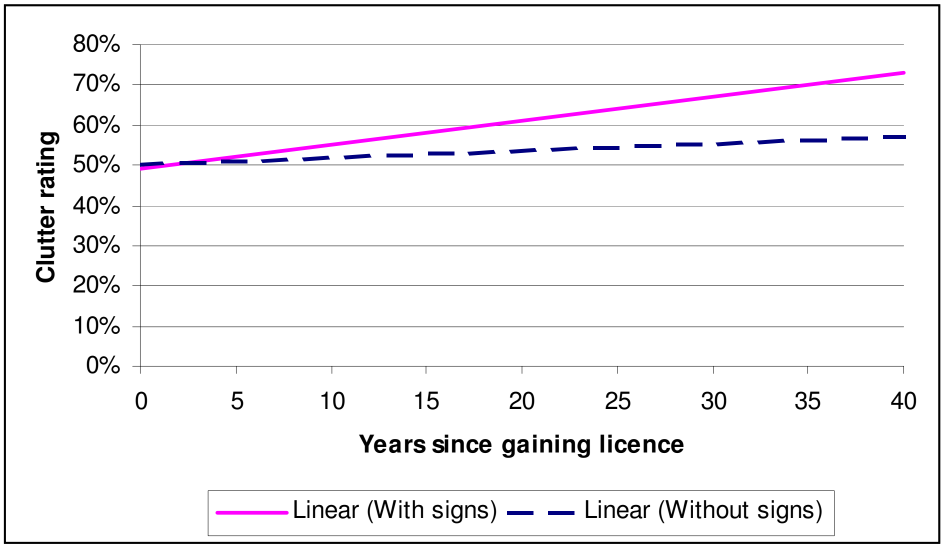


Figure 14. Effect of experience on clutter ratings for shopping strip scene.

Effects of order

The graphs below show the mean rating for each scene in the order in which they were presented. It can be seen that rural scenes R3a&b and R4a&b received extremely low ratings compared to all the other scenes. It is possible that the contrast with these scenes may have boosted ratings for the photographs that followed them, ie C4a, A2b, and F2b. C4a was a commercial scene with distant vehicles that was rated slightly higher than C4b, the same scene without vehicles; the order effect here could have made the effect of vehicles look slightly larger, although the variability of ratings for this scene was quite large and thus the vehicle effect did not appear significant in any case (see Figure 9). A2b and F2b were scenes which had had billboards removed; the order effect for these scenes is likely to have decreased the apparent effect of billboards, which would explain why these scenes did not show the same increased clutter rating for billboards than the other billboard pairs (see Figure 7).

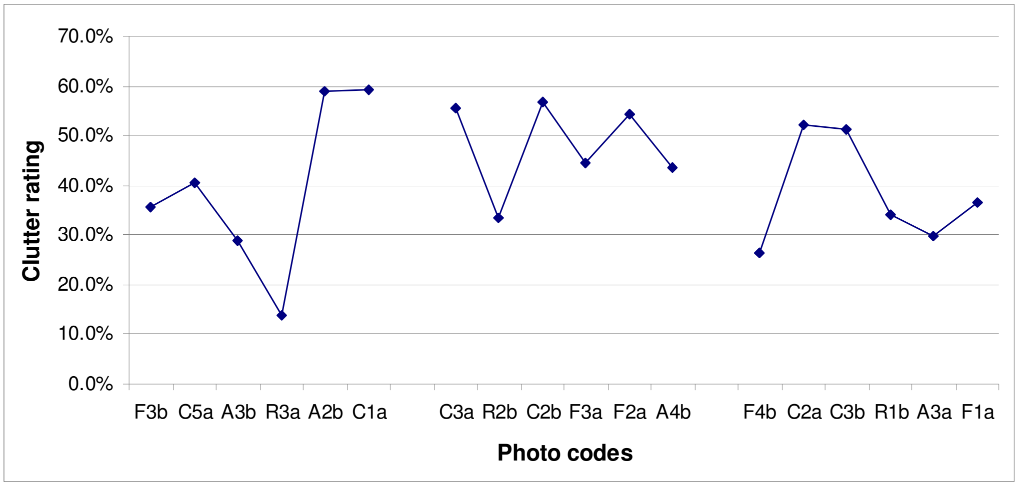


Figure 15. Ratings in presentation order for blocks 1-3

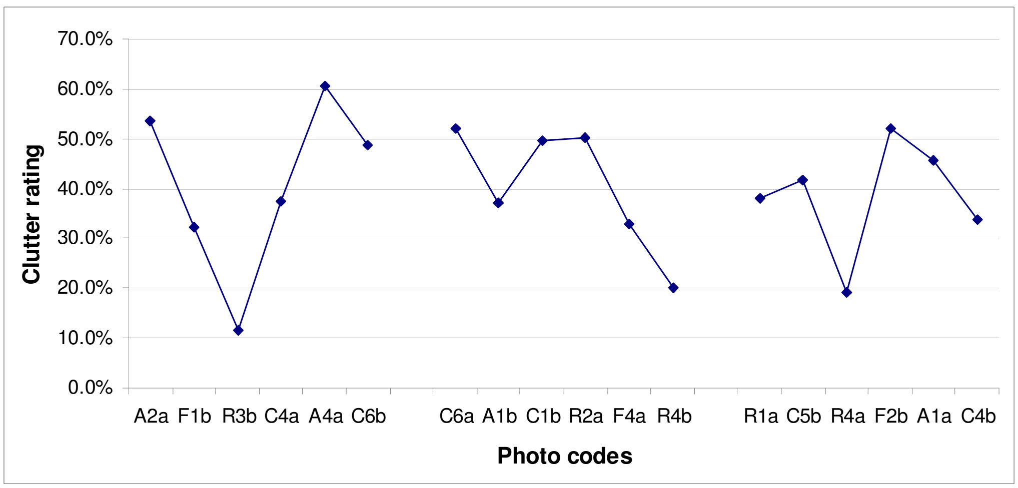


Figure 16. Ratings in presentation order for blocks 4-6

<u>Discussion</u>

The general roadside environment, as expected, affects ratings of visual clutter. It is notable that rural and residential roads were rated lower than all other road types. Commercial and arterial roads were rated as most cluttered, with freeways rating somewhat lower. Freeways, rural and residential roads all tend towards relatively uniform roadsides; either vegetation or solid walls, rather than many buildings of different types as may be found in arterial and commercial road scenes. This suggests that background complexity may be a more important contributor to visual clutter than any single object.

The scenes with and without billboards provided some interesting results. Although the effects of order may have interfered with the comparison for some pairs, it seems that billboards in general raise subjective ratings of visual clutter in a variety of road types.

The effect of parked cars depended on how far away the vehicles were from the camera. It is unfortunate that this confounding factor was not controlled for, however the results suggest that vehicles affect clutter ratings under at least some circumstances and therefore should be examined further. Examining the effect of vehicle presence in a dynamic environment may shed more light on their contribution to clutter. The results of the rural scenes show that in low-clutter environments the presence of other vehicles is particularly important for ratings of visual clutter, so this factor is a good candidate for more systematic investigation.

The effects of signs were mixed. In low clutter rural and residential scenes, adding a single advertisement, sign or set of traffic signals had no effect. However in the shopping strip scene, while there was no main effect, the difference in ratings between versions with and without signage was greater for drivers with more experience. It is possible that the low median driving experience of the participants in the present study (6 years) contributed to the lack of an effect for this factor.

The effects of experience should be examined in a more systematic fashion. The results of the photograph ratings suggest that experienced drivers gave a wider range of scores: scenes that were high in clutter (commercial and arterial roads, plus the residential scene with parked cars) were rated as more cluttered by experienced drivers than inexperienced drivers, while scenes that were low in clutter (freeways and rural roads) were rated as less cluttered by experienced drivers than inexperienced drivers. This may be because experienced drivers have a greater knowledge of the range of visual clutter in road environments and so were better able to place each scene on a scale consisting of recalled examples of various levels of clutter (Annett, 2002).

It was unfortunate that the software used to show the pictures for a certain amount of time each did not allow randomisation, so the order of the photographs was the same for every participant. Order is therefore a confounding variable and the results should be interpreted with some caution. However this was an exploratory study only, and the results do provide some information about the potential contributors to visual clutter.

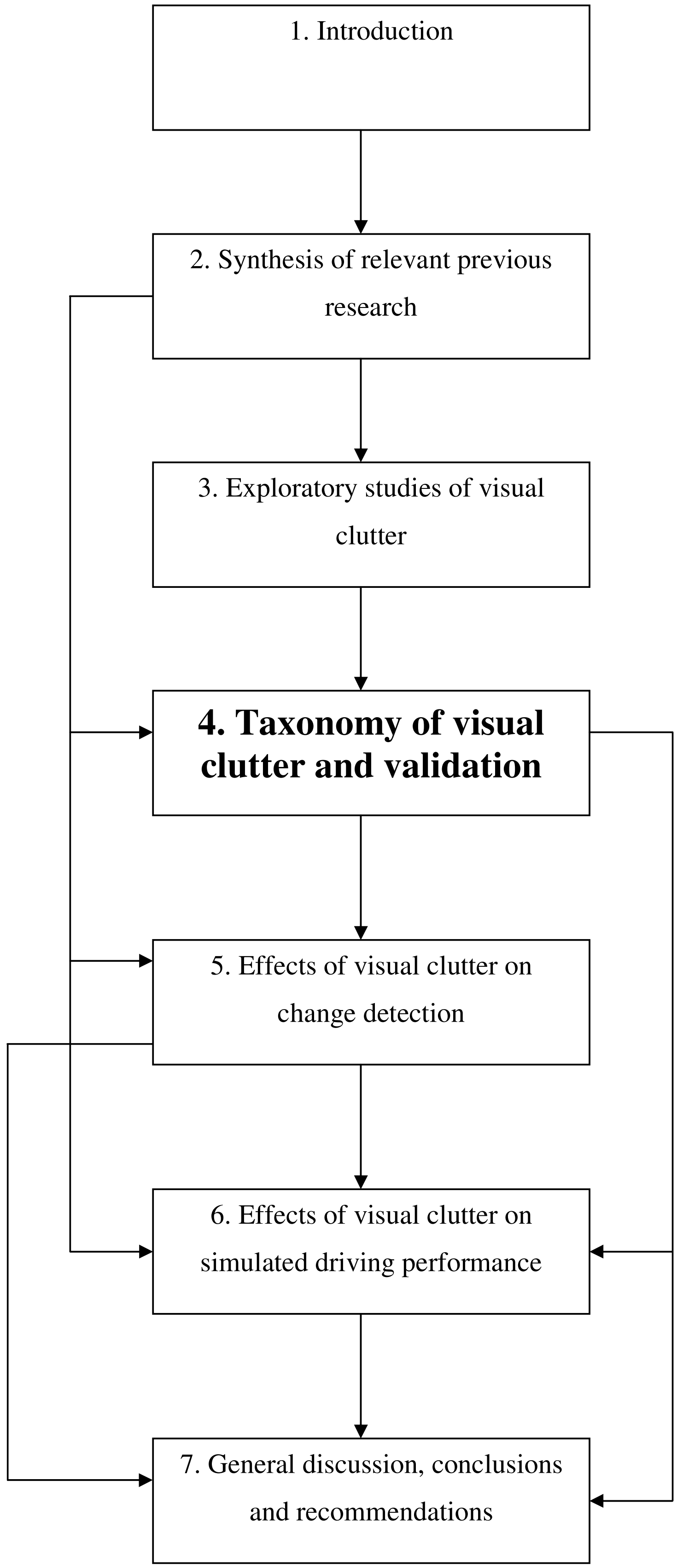
General discussion

The exploratory studies provided some structure to the hitherto nebulous concept of 'visual clutter'. The focus group results suggested visual clutter could be divided into three categories: objects that require attention as part of the driving task (both traffic control devices and other road users); objects that distract attention from the driving task (billboards, shopfronts and other non-driving-related signs); and objects that occlude vision. These findings were reinforced by the results of the photograph rating study, in which commercial and arterial roads were rated as more cluttered than freeways, residential and rural roads, and removing billboards and vehicles decreased the visual clutter rating given to the scene.

The present studies confirm the link between background complexity and visual clutter. Elvik's (2006) definition of a complex background as one with a high number of units of information to be attended per unit of time corroborates the focus group opinion that objects which require attention increase visual clutter. Objects that occlude vision are the focus of Akagi et al's (1996) 'visual noise ratio'. Objects that distract attention from the driving task (including billboards and commercial streetscapes) are encompassed by Smith and Faulconer's (1971) 'poor visual environment for driving' (as they are manmade rather than natural, and include many areas of contrasting colour).

Taking the results of the present studies with previous research by Jenkins (1982) and Ho et al (2001), it might be expected that it would be difficult to find road signs in commercial and arterial road scenes with many vehicles and billboards. However this is not certain because the above papers did not include any description or content analysis of the scenes which their participants rated as being high in visual clutter. The current research is a step forward in the measurement of visual clutter. Having gained some knowledge of which objects correlate with high subjective ratings of visual clutter, it is possible to base a measurement system on the levels of these objects.

The next step is to create and validate a system for classifying the level of visual clutter in a road environment, and then to determine the effects of various levels of visual clutter on driving performance.


1. Introduction
2. Synthesis of relevant previous research
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Chapter Four

A taxonomy of visual clutter

As revealed in the two exploratory studies reported in Chapter 3, drivers describe visual clutter as objects that distract from driving, objects that occlude other objects, and objects that require attention for safe driving. Drivers generally rate road scenes as higher in visual clutter when they include many such objects, such as billboards, vehicles that may interfere with the driver's movement, and general background complexity. In the present chapter these results are formalised into a taxonomy of sources of visual clutter.

Castro, Horberry and Tornay (2004) note that nearby advertisements have been shown to decrease conspicuity and increase reaction time to traffic signs. They propose that reducing the visual clutter of the environment by reducing advertising signage would increase the effectiveness of traffic signs. Lansdown (2004a) notes that in complex city environments, the required signage itself may overload the driver. He suggests that signage should be prioritised such that the most important signage has the highest conspicuity, and that excessive low-priority signage should be removed to reduce visual demand.

The idea of vehicles being a source of visual clutter may on the surface seem strange, as studies on visual clutter have typically been concerned with background objects. However the drivers in the focus group rightly noted that vehicles and other road users must be attended; the more vehicles, the higher the workload of the driving task. The present thesis argues that a comprehensive theory of visual clutter must include all visual sources of workload in the road environment, as the presence of workload from different sources is likely to interact (see chapter 2 page 14). Road authorities may not be able to regulate traffic volumes, but they should certainly take them into account when designing and regulating the rest of the road environment.

Taxonomy development

Taking the results of studies 1 and 2 into account, a basic taxonomy of clutter was proposed. This taxonomy is summarised in Table 4. As objects which occlude other objects are already taken into account by road safety authorities in guidelines such as visibility distance for signs and tree pruning guidelines (and the reason such objects impair driving performance is obviously because they impair visibility), they will not be considered further. This leaves two types of visual clutter: objects to attend, and distracting objects.

The type of clutter involving objects requiring attention as part of the driving task includes both objects which are temporarily part of the environment (other road users) and more permanent objects (traffic control devices). The new taxonomy therefore divides this type of visual clutter into two categories.

'Situational clutter', or traffic, includes all the temporary, moving objects on and next to the road that must be attended for safe driving (this includes pedestrians as well as other vehicles).

'Designed clutter', or signage, includes all those permanent objects that road authorities use to communicate with the driver, such as road markings, traffic signs and signals; these items must also be attended for safe driving, but in contrast to situational clutter, road authorities can control the level and layout of designed clutter.

A third category of 'built clutter' includes all other potential sources of visual clutter: buildings and other infrastructure, shop signage, and advertising billboards. This category broadly corresponds to the description of clutter as comprising objects that distract attention from the driving task, but also includes the factor of background complexity.

Table 4. Proposed taxonomy of visual clutter

Type of object	**Clutter category**	**Examples**
Objects that must be attended for safe driving	**Situational clutter**	Vehicles, including cyclists, and pedestrians
	Designed clutter	Road markings, traffic signs and signals
Objects that distract from safe driving	**Built clutter**	Billboards/other roadside advertising, shops
Background complexity		Buildings, other infrastructure e.g. light poles, tram wires, phone lines
Objects which occlude other objects	*(Already taken into account)*	May include examples from any category of clutter

The present chapter describes a study explicitly directed at validating the taxonomy using drivers' visual clutter ratings for various road scenes. It is important to test whether the taxonomy matches subjective ratings of visual clutter, as so far the only indicators we have for the effect of visual clutter on performance are based on subjective opinions of what visual clutter is.

In this study, the stimuli were video clips instead of photographs, to determine whether movement through the environment affected drivers' ratings of visual clutter. Age and experience were deliberately sampled in order to better investigate their effects. It was expected that higher levels of objects classifed as contributing to built, designed or situational clutter would lead to higher clutter ratings for a clip. Using a balanced factorial design enabled investigation of potential interactions between the three factors.

Method

Participants

39 participants (19 males and 20 females) took part in this study, split into 3 groups (see Table 5). The probationary group consisted of fourteen participants aged 18-25; this group was restricted to those who held probationary licences (the first stage of driving without a supervisor in Victoria's graduated licensing system) that were less than a year old, as the first year of unsupervised driving has been reported to be the most dangerous (Mayhew, Simpson, & Pak, 2003). The fully licenced group consisted of thirteen participants aged 25-55 who held full licences and thus had a minimum of three years solo driving experience. This group served as a comparison group for the other two groups. The older driver group comprised twelve participants aged over 65 years who held full driver's licences.

Participants were recruited by notices in the university's staff bulletin, on the student job website, and at nearby Senior Citizens clubs. All received a small cash payment as compensation for their time and travel costs.

Table 5. Participant characteristics.

Group	**Proportion of males**	**Mean age**	**Mean driving experience**	**(Self-estimated) Mean distance driven**
Probationary	5/14	19.9 years	0.5 years	4,500 km/year
Fully licensed	8/13	40.8 years	22.2 years	13,300 km/year
Older	6/12	76.8 years	48.0 years	6,300 km/year

Design

Thirty-three video clips of 10 seconds duration each were shown during the experiment, with a further nine used for practice. With the exception of the 'baseline' clip (see procedure), all clips were part of a pair. Each pair comprised one clip of a certain road during a low traffic period, and one clip of the same road during a high traffic period, in order to determine the effect of situational clutter. The sixteen pairs were divided into four categories: four roads contained a low level of built clutter and a low level of designed clutter, four contained low built clutter and high designed clutter, four contained high built clutter and low designed clutter, and four were high on both built and designed clutter. Clips were designated as high in built clutter if the section of road visible was bordered by commercial development and/or multi-storey buildings, while low built clutter clips contained no buildings, residential buildings (houses and low apartment blocks) or low industrial buildings such as petrol stations and car yards. The level of designed clutter was assessed by counting the number of traffic control devices (TCDs, i.e. road markings, signs and signals). The maximum number of TCDs within a clip was 10, so those with a total of more than five such devices within the ten seconds were assigned to the high designed clutter group. Three clips had exactly five devices; of these, the two with more salient devices (one contained a set of traffic lights, one contained a direction sign with multiple directions) were assigned to the high group and the other (containing only small road signs) to the low group. All videos were of roads within the Melbourne metropolitan area, and were recorded via a camera attached between the two front seats of a small car.

Procedure

Videos were projected onto a screen approximately 1 metre square, with the participant sitting approximately 1.5 meters away and slightly to the right of the screen to simulate the position of the driver. The projected image took up approximately 33 degrees of visual angle.

The experimenter explained the study purpose and rating system to the participant, and then showed two example clips: first the low clutter ‘baseline’ clip (a residential street with a park on one side and no traffic), followed by a high clutter clip (a typical shopping strip with a tram line in the middle of the road, parked cars on either side, and high traffic, as well as pedestrians). Participants then rated eight practice clips. The computer played a ‘beep’ noise after 1 second, 5 seconds and 9 seconds of each clip to prompt participants to verbally rate the current level of clutter. Clutter was rated on a scale from 1 to 10, with 1 signifying low clutter and 10 high clutter. The experimenter asked what had changed if a participant gave a different rating at the second or third rating point.

If after the eight practice clips participants were not comfortable with the rating technique, the experimenter showed further practice clips until they were comfortable.

At the start of the experimental block and between every eight clips, the experimenter showed the baseline clip. This was intended to reinforce an 'anchor' point for the low end of the scale and reduce the time effect of holding a scene in mind while viewing other scenes (Annett, 2002). The order of the other clips was randomly varied for each participant, with the exception that high and low traffic clips alternated, and the two versions of each clip were shown in different halves of the block.

After rating the video clips, participants completed a brief questionnaire on their age, sex, licence type, driving experience, and how familiar they were with the roads shown in the video clips (see Appendix B).

Results

Main analysis

The three ratings that each participant gave for each clip were averaged, and then ratings for each combination of levels for built, designed, and situational clutter were averaged across clips. The averaged data was analysed using a mixed-model ANOVA with three within subject factors and one between subjects factor. The three within subject factors were: built clutter (high or low), designed clutter (high or low), situational clutter (high or low). The between subjects factor was group: probationary, fully licensed or older driver.

Although the standard method for reporting ANOVA is to start with the highest significant interaction and work down to simple/main effects, this requires prior understanding of lower level effects in order to interpret the higher interaction (Keppel, 1991). As there is no existing research on the proposed three clutter types and their possible interactions, the following section will start with main effects and work upwards.

Group membership was not significant, $F(2, 36) = 2.32$, $p > .1$, $\eta^2 = .11$. The main effects of built clutter ($F(1, 36) = 170.07$, $p < .001$, $\eta^2 = .83$), designed clutter ($F(1, 36) = 75.52$, $p < .001$, $\eta^2 = .68$), and situational clutter ($F(1, 36) = 212.97$, $p < .001$, $\eta^2 = .86$) were all significant. Examination of marginal means showed that a higher level of any of these factors led to a higher clutter rating. The partial eta squared values show that situational clutter and built clutter had large effects, while the effect of designed clutter was somewhat smaller.[1]

A number of interactions with the level of built clutter were significant. Built clutter interacted with group, $F(1, 36) = 5.45$, $p < .01$, $\eta^2 = .23$. Analysis of simple effects showed that the effect of group was not significant at low built clutter, $F(2, 36) = 1.29$, $p > .1$, $\eta^2 = .07$, but was significant at high built clutter, $F(2, 36) = 3.46$, $p < .05$, $\eta^2 = .16$. Post-hoc Dunnett's t-tests for the high built clutter videos revealed that the older drivers rated videos significantly lower than the fully licensed drivers ($p < .05$). Probationary drivers also gave lower ratings than fully licensed drivers, but the difference was not significant ($p > .1$).

[1] Eta squared values lie between 0 and 1, and can be interpreted as the proportion of the variation in the scores accounted for by the independent variable (Howell, 1997). Partial values treat the variable under consideration as if it were the only variable in the analysis, which is why the proportions do not add up to 1; however even though much variation is shared, these figures are all quite large.

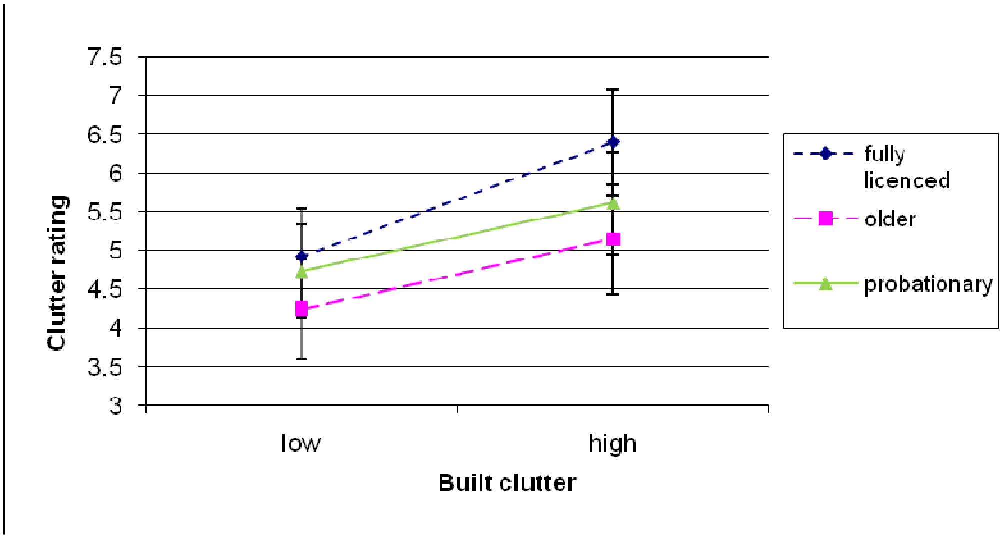


Figure 17. Mean ratings of visual clutter and 95% confidence intervals by age/experience group.

There were also significant two-way interactions between built and situational clutter ($F(1, 36) = 27.54$, $p < .001$, $\eta^2 = .43$), and built and designed clutter ($F(1, 36) = 5.44$, $p < .05$, $\eta^2 = .13$). Finally, the three-way interaction of all three clutter types was significant, $F(1, 36) = 24.97$, $p < .001$, $\eta^2 = .41$. None of the remaining interactions were significant.

The three-way interaction was examined by lower interactions at each level of the third factor. The interaction of designed and situational clutter was highly significant ($p<.001$) at both levels of built clutter. When split into the four combinations of built and designed clutter, the effect of situational clutter was highly significant ($p<.001$) for all categories. However, Figure 18 shows that when situational clutter is high, adding one other sort of clutter increases ratings while adding a second does not. When situational clutter is low, adding designed clutter has more effect when built clutter is already high.

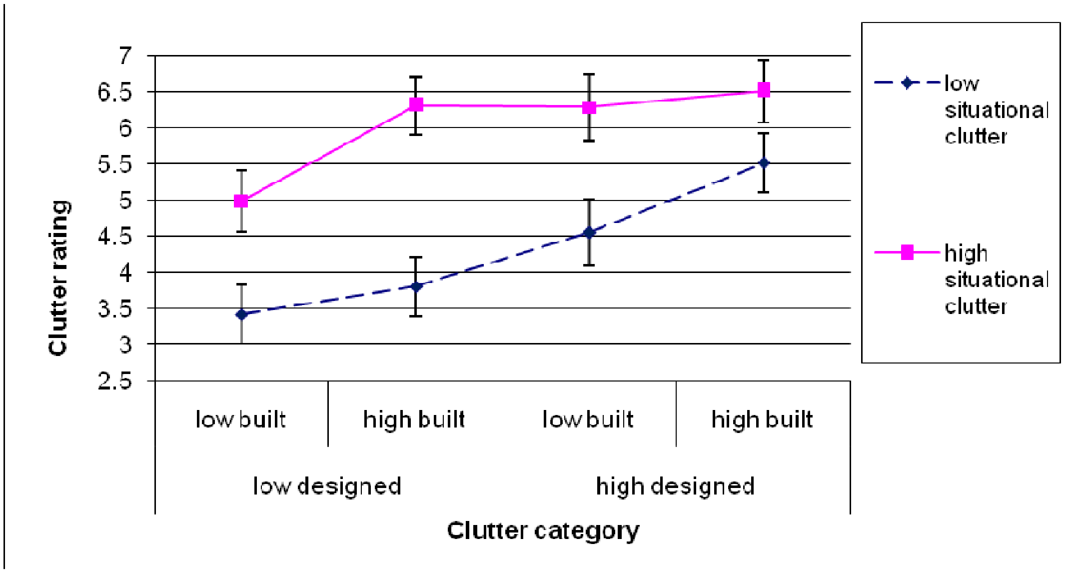


Figure 18. Mean ratings of visual clutter and 95% confidence intervals by categories.

<u>Within clip analysis</u>

Certain clips were examined in more detail to see if it were possible to identify cluttering objects by the change in the clutter rating as the clip progressed. A mixed-model ANOVA with two within subject factors (level of traffic – high or low; time – 1 second, 5 seconds or 9 seconds into clip) and one between subject factor (group membership, as above) was performed separately for two roads. These clips were chosen because each contained a large billboard that was visible at some points in the clip, but not at others. Road 1 was a shopping strip. A billboard on the ground storey of a corner building became visible between the first and second beep, and remained visible until the end of the clip. Road 2 was a four lane divided arterial road, bordered by commercial development. Two billboards were visible at the start of the clip, one of which passed just before the third beep. It was expected that the addition of a billboard would increase clutter ratings, while the disappearance of a billboard would decrease clutter ratings.

For Road 1, the only significant variable was traffic, $F(1, 36) = 17.90$, $p < .001$, $\eta^2 = .33$. The clip with more traffic received higher ratings of visual clutter.

For Road 2, traffic was again highly significant, $F(1, 35) = 26.96$, $p < .001$, $\eta^2 = .44$. The time variable failed the assumption of sphericity, so the Huynh-Feldt correction was used. The main effect of time was not significant $F(2, 70) = 3.24$, $p > .05$, $\eta^2 = .08$, but there was a significant interaction between time and traffic, $F(2, 70) = 6.77$, $p < .01$, $\eta^2 = .16$. Simple effects were analysed using MANOVA rather than RMANOVA, as this does not require the violated assumption of sphericity (Howell, 1997). There was no effect of time in the high traffic version, Pillai's trace = 0.15, $p > .05$, $\eta^2 = .15$; but there was a significant effect of time in the low traffic version, Pillai's trace = 0.22, $p < .05$, $\eta^2 = .22$. The mean clutter ratings (see Figure 19) dropped steadily over time for the low traffic version only, rather than the drop in ratings for both versions at the third test point which was expected. This could be due to the fact that during the low traffic version, the vehicle must slow for a red traffic signal; at the end of the clip the vehicle is stopped at the lights with no cars in front of it. Some participants lowered ratings when the vehicle was moving more slowly and dropped their ratings to 1 (the lowest rating) when stopped.

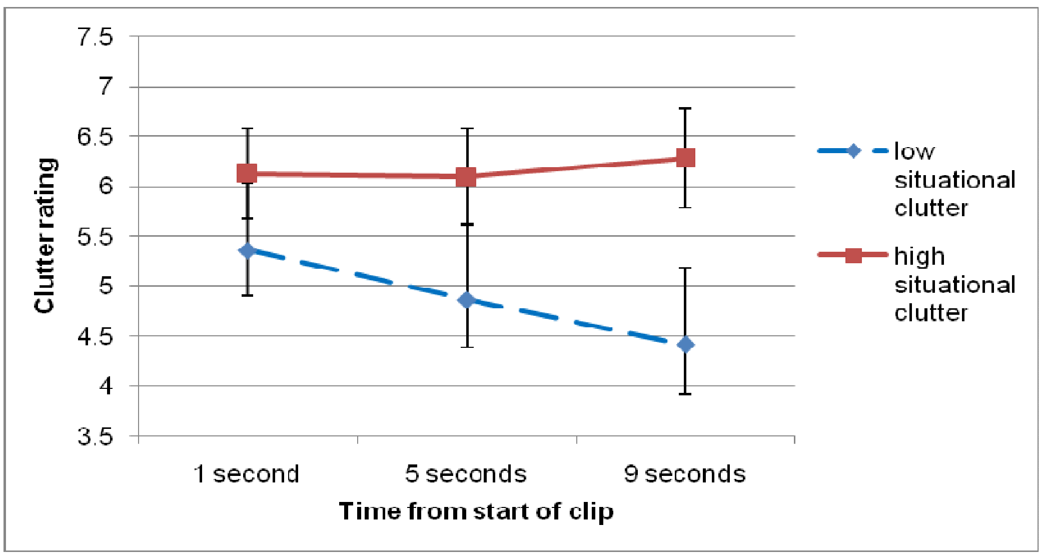


Figure 19. Clutter ratings over time for both versions of road two (arterial road bordered by commercial development, with one billboard present for the entire clip and one billboard disappearing between the second and third rating points).

<u>Qualitative data</u>

Participants were asked what had changed in the clip when their rating at the second or third rating point was different from the previous rating. These comments were coded into the categories that emerged from study one (Chapter 3): objects that need to be attended to drive safely (hazards), objects that distract from safe driving (distractions), objects that occlude other objects (obstructions), and the total number of objects (overall). As Table 6 demonstrates, the predominant concern was hazards – mostly other vehicles braking, changing lanes, or getting closer. This was true across all age/experience groups, although fully licensed drivers were more likely to mention other objects as well.

Table 6. Participants' comments on what changed clutter ratings: number of comments which could be classified into categories from initial studies

Group	**Hazards**	**Distractions**	**Obstructions**	**Overall**	**Total**
Probationary	11	4	2	1	**18**
Full	10	3	3	5	**21**
Older	11	0	3	3	**17**
Total	**32**	**7**	**8**	**9**	**56**

An alternative way to categorise these comments is using the taxonomy of situational, built and designed clutter described at the start of the present chapter.

Table 7. Participants' comments on what changed clutter ratings: number of comments which could be classified into taxonomy of visual clutter

Group	**Situational** (traffic, other road users)	**Designed** (road signs, signals, markings)	**Built** (buildings, trees, shops, billboards, poles/wires etc)	**Total**
Probationary	11	5	5	**21**
Full	9	6	6	**21**
Older	10	3	2	**15**
Total	**30**	**14**	**13**	**57**

As Table 7 shows, just as many of participants' comments could be classified using these three categories as using the categories from the initial studies. It also allows comparison between participants' comments and their ratings for clips classified by the experimenter. Clearly situational clutter is deemed most important as 30 of 39 participants mentioned vehicles or other road users as causing them to change their ratings. This agrees with the effect sizes found in the main analysis (page 83); situational clutter had the largest effect on ratings over all video clips. Built clutter had a much larger effect size than designed clutter, but this is not reflected in the number of comments about objects within each category. This could reflect some sort of bias in participants' comments (perhaps they felt they should mention more driving-related objects as the study was described as being about road safety); or it could be that the effect of built clutter is reflected in the comments about 'overall' clutter levels as well as comments about specific objects such as buildings and billboards.

Discussion

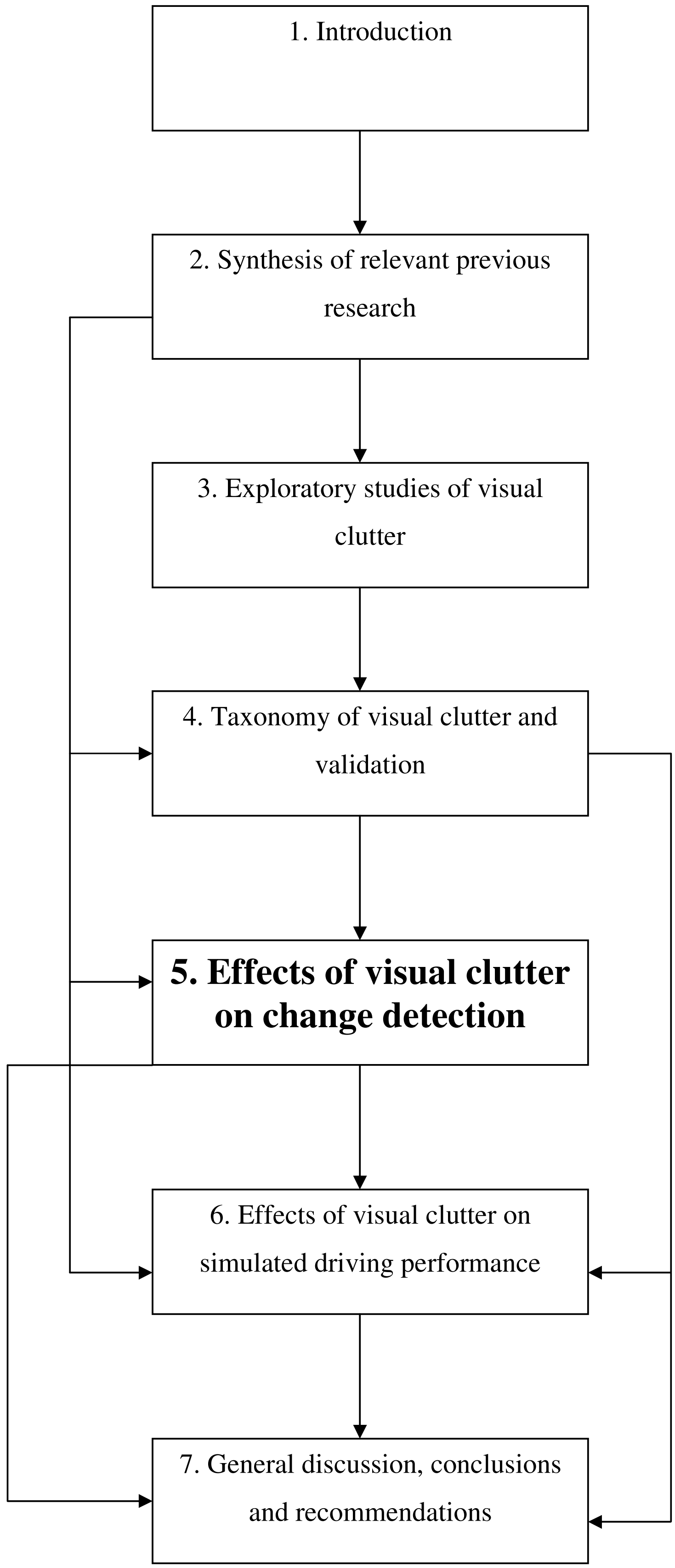
All three types of visual clutter specified in the proposed taxonomy increase subjective ratings of visual clutter by drivers watching video clips. Other vehicles (situational clutter) have the largest effect. Drivers did not change their ratings over time very much in the short clips used (10 seconds); when they did, it was mainly in response to the vehicles' speed (and the rate of information flow) rather than to any change in the built environment.

The interactions between the three types of clutter are particularly interesting. At low levels of clutter, adding more clutter has more effect, whereas when situational clutter in particular is high, adding more than one other type of clutter does not increase average ratings. Once clutter reaches a certain level it is possible that observers may simply not notice any additional objects. It is also possible that this effect may merely be an artifact of the subjective rating scale used. Subjective rating scales do have the problem that different people may interpret the question that is being asked differently. The finding that some participants used the lowest rating when the vehicle was stopped, for example, indicates that their understanding of 'visual clutter' was very much linked to the level of workload they would experience as a driver in such a situation. Several such participants explained that when they were not moving they did not have to attend anything. This is interesting, as it implies that drivers innately understand that visual clutter and workload are highly related; this finding agrees with comments from the focus groups with a different set of drivers.

Age/experience does not seem to be a reliable predictor of subjective clutter ratings, although there may be some effects depending on the type of clutter: distracting ‘built’ clutter, mostly found in arterial and commercial scenes, seems to be more important to fully licensed drivers than to inexperienced/probationary drivers and older drivers. However, interpreting effects of different driver groups on subjective ratings is difficult. If drivers were (as discussed above) interpreting the task as rating ‘how well would I be able to handle the workload in this scene?’, subjective estimates of personal competence would be confounded with objective levels of risk (Brown & Groeger, 1988). Thus, the lack of a difference between novice and more experienced drivers could merely be an artifact of the young drivers overestimating their capabilities.

Ratings of video clips agreed with ratings of photographs and focus group discussions. All suggest that drivers feel that objects that demand attention increase visual clutter. These attention-demanding objects may be extraneous to the driving task (such as billboards and shop signage), in which case drivers may become distracted. Alternatively, when there are too many demands on a driver’s attention from objects that are necessary to the driving task (such as other vehicles and traffic signs) drivers also feel cluttered and overwhelmed.

Further research is needed to link subjective ratings of clutter to actual driving performance measures. This has already been done for visual search, but visual clutter may well affect other tasks such as hazard perception and control of following distance, for example. The next chapters of this thesis seek to make this link, using the taxonomy developed above.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Chapter Five

Effects of visual clutter on change detection

Having developed a taxonomy of visual clutter and established that the three factors of built clutter, designed clutter and situational clutter correlate with driver ratings of visual clutter, it remains to determine the effects of these factors on driving performance. As discussed in chapter 2 (page 16), certain visual tasks and the response tasks which depend on them are more likely to be affected by visual clutter. One of these is visual search for road signs, as three studies have confirmed (see page 32 in chapter 2). The others are perception of obstacles, road users and traffic situations; in other words, situation awareness (see page 9), including hazard perception. Change detection performance (Rensink, 2002) can serve as a surrogate measure for hazard perception and situation awareness, as well as visual search. To detect a change in a road sign, an observer must search the scene to locate all the road signs. To detect a change in a vehicle, an observer must be aware of other road users and notice any (potentially hazardous) changes to the situation.

The change detection paradigm

There are many methodological variants of the change detection paradigm (see Simons, 2000, for a review). The current work uses the ‘flicker’ method, as described by Rensink, O’Regan and Clark (1997). The flicker method involves inserting a briefly displayed white screen between the two versions of a picture, and alternating the two versions until the participant detects the change. This yields more data than the typical correct/incorrect forced choice single presentation version; analyses can be performed both on the time it takes observers to detect the change, and on the pattern of errors for those scenes where observers do not correctly detect the change. Rensink and colleagues (1997) found that participants were faster to notice changes to objects described as being of central interest than changes to objects of marginal interest. This finding adds a new tool to the set of methods that can be used by researchers investigating what drivers attend.

A great deal of research has been done using the change blindness paradigm. A brief survey of the studies most relevant to the present work follows. Werner & Thies (2000) investigated the effect of domain experience. They found that people who had played football for more than three years were faster to detect changes in football scenes than football novices. Extending this concept to driving, we would expect that experienced drivers would be better able to detect changes than probationary drivers. Famewo, Trick & Nonnecke (2006) investigated this hypothesis in a driving simulator, with new vehicles occasionally appearing after 'blinks' in the display. They found that experienced drivers were better than inexperienced drivers at detecting new vehicles. Scenarios were dynamic and each change only happened once, however it seems likely that drivers who are more likely to see a change presented once will be faster to see changes presented repeatedly.

McCarley, Vais, Pringle, Kramer, Irwin and Strayer (2004) investigated age differences in change detection for urban and suburban road scenes using the flicker paradigm. Older drivers took longer to detect changes, and had more trials in which they could not find the changing object after 60 alternations. So it seems that age as well as inexperience with the situation depicted can impair people's ability to detect changes.

Finally, Beck, Levin & Angelone (2007) found that participants were less likely to detect changes in scenes which were more complex (i.e. contained more objects which could potentially change). It is therefore likely that high levels of visual clutter will impair change detection.

In addition to the three subcategories of visual clutter investigated in the previous experiment, this experiment will also investigate the presence of billboards. Advertising billboards are part of the built clutter subcategory, but as they are separate items they are more easily controlled than roadside development and on-premise signage. Road authorities are coming under increasing pressure from outdoor advertising companies to allow the erection of more billboards along roadsides, so it is important to understand the likely effects of adding billboards to various road environments. As discussed in chapter 2, previous research has discovered that billboards attract visual attention, and that the presence of billboards correlates with higher crash rates. However, apart from Johnston and

Cole's (1976) laboratory study (which found that advertisements impaired peripheral detection) there has been little work on which aspects of driving performance might be affected by billboard presence.

Based on the previous work and the earlier findings of this research on visual clutter, the present experiment examined drivers' ability to detect changes to road signs and other vehicles in photographs of road scenes with varying levels of visual clutter. It was hypothesized that participants would detect changes to vehicles faster than changes to signs, as vehicles are more physically conspicuous than signs as well as being of more central interest to the driver (as moving, potentially hazardous objects that need to be monitored and responded to).

High levels of built clutter, designed clutter, or situational clutter were expected to increase the time taken to detect changes. A subset of scenes also contained billboards, and it was hypothesized that changes would take longer to detect in these scenes. To investigate the effects of driving experience, the experiment included drivers who had less than one year's experience of unsupervised driving. It was hypothesized that these probationary drivers would take longer than experienced drivers to detect changes. The experiment also included drivers over 65 years; it was hypothesised that these older drivers would take longer than younger drivers to detect changes to road scenes.

Method

Participants

Forty-five participants (23 males and 22 females) took part in this study, split into 3 groups. The probationary driver group included fifteen drivers aged 18-25 who had obtained their probationary drivers' licence less than a year ago. The fully licensed driver group consisted of fifteen drivers aged 25-55 who held full licences. This group served as a comparison group for the other two groups. The older driver group comprised fifteen drivers aged over 65 years who held full driver's licences. Table 1 has further characteristics of participants in each group. Astute readers who are familiar with road safety literature will notice that the fully licensed drivers' estimated mileage is somewhat lower than is usually reported for this group, while the older drivers' estimated mileage is somewhat higher than would be expected. It should be noted that these figures are self-reported, and many people had difficulty in accurately estimating their annual mileage. While ideally the experiment would have a perfectly representative sample of each group of drivers, the present research is limited to drivers who volunteered to participate. The mileage quirks are not expected to greatly affect the results of the experiment.

Participants were recruited by notices in the university's staff bulletin, on the student job website, and at nearby Senior Citizens clubs and Universities of the Third Age. All received a small cash payment as compensation for their time and travel costs.

Table 8. Participant characteristics

Group	**Proportion of males**	**Mean age**	**Mean driving experience**	**(Self-estimated) Mean distance driven**
Probationary	7/15	19.3 years	0.4 years	2,700 km/year
Fully licensed	4/15	34.8 years	14.6 years	10,500 km/year
Older	12/15	73.0 years	52.7 years	15,600 km/year

Apparatus and stimuli

Participants viewed photographs of road scenes on a 15-inch LCD screen at a distance of approximately 60cm. The photographs thus subtended 14 degrees horizontally x 11 degrees vertically of visual angle.

Stimuli were 96 pairs of photographs taken from the perspective of an automobile driver on arterial roads around Melbourne, Australia. The roads selected were all major through roads, ranging in capacity from suburban main streets to multilane highways. They were chosen to ensure a variety of road environments and levels of visual clutter.

Levels of each type of clutter were assigned as follows: if the scene contained shops or tall buildings next to the road, it was designated high in built clutter; if it contained only trees and houses, it was designated low in built clutter (as in the video ratings study reported in Chapter 4).

The maximum number of traffic control devices counted for a single scene was five (although most had far fewer). Therefore scenes were designated high in designed clutter if they contained three or more traffic control devices. This cut-off is the same as that used for the initial validation of the taxonomy against the photographs rated in Chapter 3 and reported in Chapter 4. It is different from that used in the video study, as during 10 seconds of driving more traffic control devices come into view than are visible in a single photograph.

The situational clutter classifications were also based on the classifications used in the video rating study (in which videos were taken of the same road at periods with high and low traffic). In the present experiment, using the same road twice might have made it easier to detect changes in the second scene. Therefore photographs were designated as low in situational clutter if photographing the road with more vehicles on it than the current photograph would be easier than photographing it with fewer; if the reverse held, the photograph was designated as high situational clutter. Where this could not be determined, the photograph was discarded and replaced. High situational clutter scenes all contained at least 6 visible vehicles, unless the distance to the vehicle in front and the distance between vehicles in the adjacent lane was less than 2 car lengths (as in these situations, the nearby vehicles block the view of other vehicles). Low situational clutter scenes all contained fewer than 5 vehicles (unless most of the vehicles were on the other side of an intersection).

For each pair of photographs, one of the pair was modified such that a car, a road sign, or some other item was missing or its size changed. Figure 20 shows an example pair of photographs.

a)

b)

Figure 20. The a) original, and b) modified versions of one road scene. In this case the changing item is the ‘slippery when wet’ warning sign on the left.

Design

Table 9 shows the composition of the 96 pairs of photographs.

Table 9. Design of the experiment showing numbers of photograph pairs in each category.

Built clutter	High				Low			
Designed clutter	High		Low		High		Low	
Situational clutter	High	Low	High	Low	High	Low	High	Low
Changing signs	5	5	5	5	5	5	5	5
Changing cars	5	5	5	5	5	5	5	5
Other objects	2	2	2	2	2	2	2	2

Only the forty pairs with changing signs and the forty pairs with changing cars were analysed; the remaining sixteen pairs were included in order to keep participants scanning the whole scene rather than only looking at vehicles and road signs.

Although the original experimental design planned to analyse the effects of each type of clutter individually, situational clutter had to be removed from the analysis. Piloting showed that it was extremely difficult to manipulate traffic levels in a static photograph to a degree where a majority of the eight pilot observers agreed on whether the scene contained high or low levels of situational clutter (i.e. traffic). This was mainly due to the problem of vehicles immediately in front blocking the view of the road ahead. However avoiding this problem would require taking photographs from an angle other than the driver's perspective, which would introduce validity problems. Scores from scenes which had been labelled as high or low situational clutter were therefore averaged. The final analysis included the variables age/experience group (probationary driver, fully licensed driver, or older driver); type of object that changed (car or sign); built clutter (high or low); and designed clutter (high or low).

Procedure

Participants filled out the demographic questionnaire (see Appendix B), then the experimenter gave a demonstration of the program.

To reduce any learning effects, participants performed ten practice trials before commencing the experiment. So that all participants started scanning from the same place for each scene, each trial began with a fixation cross at the centre of the screen. After one second the computer displayed the first picture in the pair for 400ms, then a grey screen for 100ms, then the second picture for 400ms, then the grey screen for 100ms, then back to the first picture. This pattern repeated for 45 seconds, or until the participant responded by pressing the space bar. Participants then used the mouse to indicate the location of the changing object. The experiment was self-paced so that participants could take a break between trials. The order of the scenes was randomised.

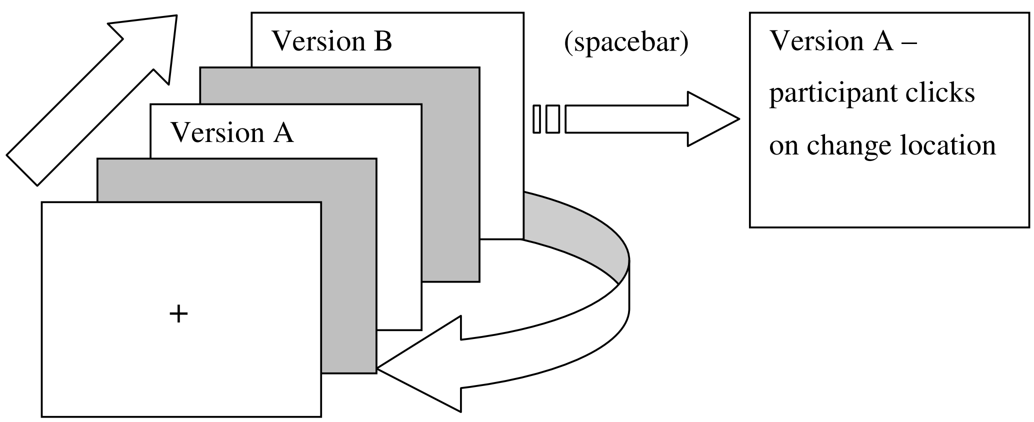


Figure 21. Procedure for change detection 'flicker' task

Results

Following the procedure of Rensink and colleagues (1997), the number of times both versions of the picture were displayed (number of repeats) before the participant responded was recorded. Trials on which the participant responded incorrectly were excluded from the analysis, as they did not reflect the time taken to accurately detect the change. (These trials comprised 0.7% of the data set for the probationary group, 0.7% for the fully licensed group and 2.1% for the older group; this proportion is not high enough to do a separate analysis on the pattern of errors.) The data set showed positive skew, as is often the case for response time and related dependent variables. A square root transformation did not improve normality. Instead it was decided to reduce the influence of the longer response times by replacing them with the mean plus 3.29 times the standard deviation for each cell, rounded down to the nearest integer (so that all values were integers – a picture cannot be displayed 4.5 times…). This approach retains the information provided by longer than usual response times, while ensuring that the analysis is not overly affected by extremely long response times (Tabachnick & Fidell, 2001).

Main analysis

The main analysis included 80 photographs in a mixed-model ANOVA with the between-subject factor being age/experience group, and the within-subjects factors level of built clutter, level of designed clutter, and type of object that changed. As explained in chapter 4, as the present research is building a model rather than testing it, the results start with the main effects and work up to the highest level interactions rather than the reverse as in the traditional reporting technique.

The main effect of age/experience on the number of times the change occurred before it was detected was significant, $F(2, 42) = 25.06$, $p < .001$, $\eta^2 = .54$. Table 10 shows means and confidence intervals for each group. As indicated by the confidence intervals, only the older drivers were significantly slower at noticing changes than the reference group of fully licensed drivers. Dunnett's post-hoc t-test showed that the probationary and fully licensed groups were not significantly different on time to notice changes, $t(28) = -0.88$, $p > .1$, but that older drivers took significantly longer to notice changes, $t(28) = 5.65$, $p < .001$.

Table 10 also contains means for each level of the other three factors, all of which were significant at the $p < .05$ level as indicated by non-overlapping confidence intervals.

The type of change had a significant effect: $F(1, 42) = 173.05$, $p < .001$, $\eta^2 = .80$. Changes to signs took longer to detect than changes to cars.

Built clutter had a significant effect: $F(1, 42) = 127.95$, $p < .001$, $\eta^2 = .75$. Changes in scenes in high levels of built clutter took longer to detect than changes in scenes with low levels of built clutter.

Designed clutter had a significant effect: $F(1, 42) = 52.46$, $p < .001$, $\eta^2 = .55$. Changes in scenes in high levels of designed clutter took longer to detect than changes in scenes with low levels of designed clutter.

Table 10. Mean response times (seconds) and 95% confidence intervals for main effects.

* indicates differences that were significant at the .001 level.

			95% confidence interval for mean	
Effect	**Mean**	**Difference**	Lower bound	Upper bound
Age/experience				
Probationary	2.62	0.17	2.35	2.90
Full licence	2.79	(control)	2.52	3.07
Older	3.89	-1.10*	3.61	4.17
Change type				
Sign	3.65	1.10*	3.43	3.87
Car	2.56		2.42	2.69
Built clutter				
High	3.40	0.59*	3.22	3.58
Low	2.81		2.65	2.97
Designed clutter				
High	3.34	0.48*	3.15	3.53
Low	2.87		2.71	3.02

The interaction between change type and age group was significant: $F(2, 42) = 9.33$, $p < .001$, $\eta^2 = .31$. Pairwise comparisons showed that the effect of change type on time to detect change was significant at the $p < .001$ level for probationary, fully licensed, and older drivers. Figure 22 shows that the interaction is due to the difference between change types in time to detect change being largest for the older drivers.

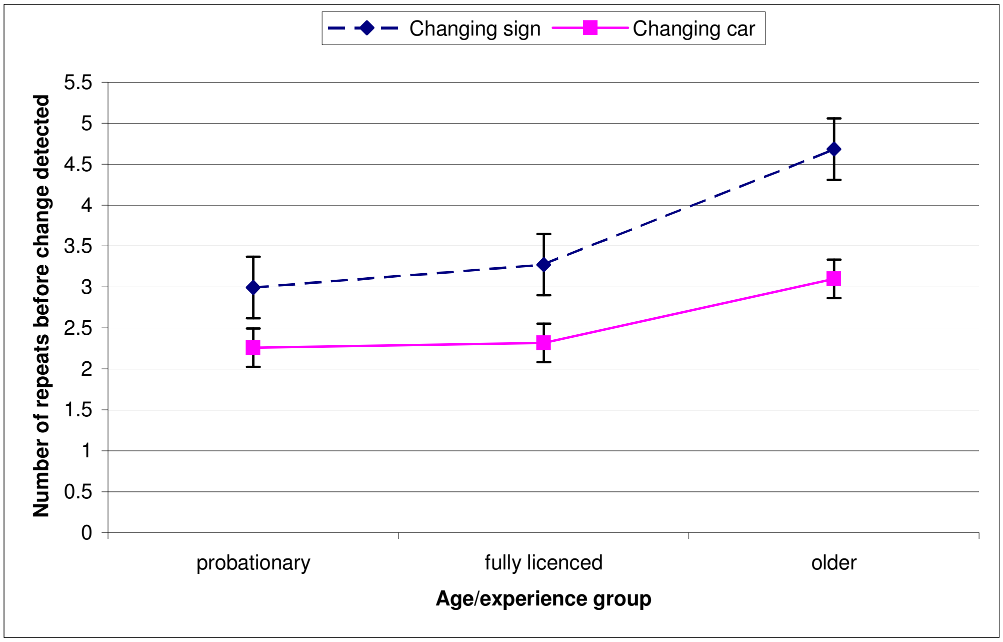


Figure 22. Mean number of repeats and 95% confidence intervals for each age group for both change types

The interaction between change type and level of built clutter was significant: $F(1, 42) = 8.10$, $p > .01$, $\eta^2 = .16$. Figure 23 demonstrates that the effect of built clutter on time to detect change was greater for changing signs than for changing cars, although for both change types the effect of built clutter was highly significant ($p < .001$).

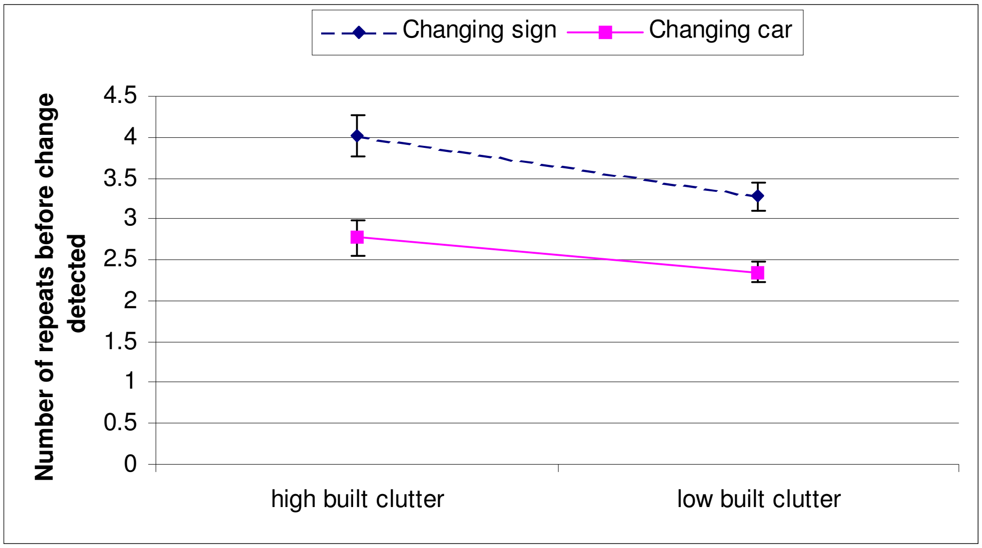


Figure 23. Mean number of repeats and 95% confidence intervals for each change type at high and low levels of built clutter

The interaction between change type and level of designed clutter was significant: $F(1, 42) = 55.01$, $p < .001$, $\eta^2 = .57$. Further analyses showed that the effect of designed clutter on time to detect change was highly significant for changing signs, $F(1, 42) = 84.76$, $p < .001$, $\eta^2 = .67$. However when a vehicle was the changing object the effect of designed clutter was not significant, $F(1, 42) = 0.07$, $p > .1$, $\eta^2 = .00$.

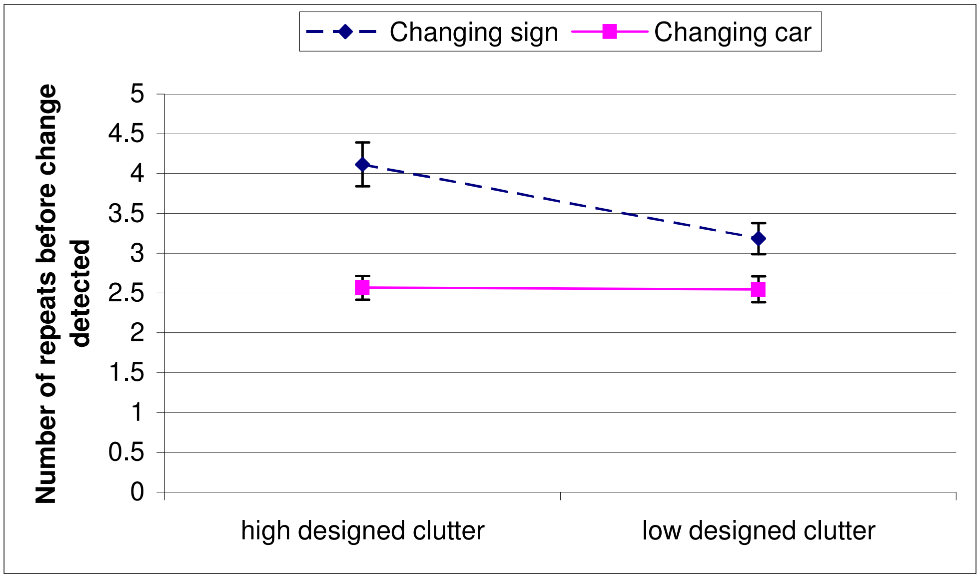


Figure 24. Mean number of repeats and 95% confidence intervals for each change type at high and low levels of designed clutter

The interaction between level of built clutter and level of designed clutter was significant: $F(1, 42) = 8.23$, $p < .01$, $\eta^2 = .16$. Although the effect of designed clutter on time to detect change was significant ($p < .001$) for both levels of built clutter, Figure 25 shows it was easier to detect changes when both built and designed clutter were low.

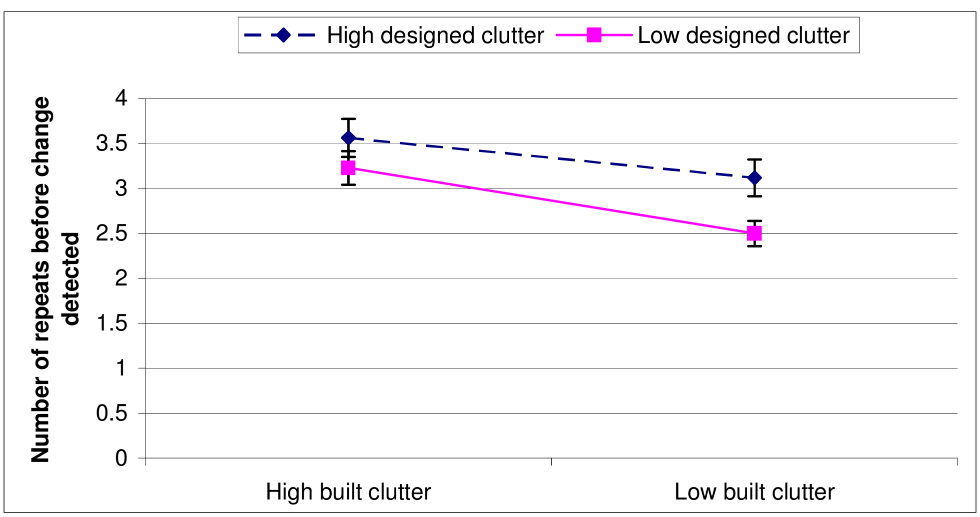


Figure 25. Mean number of repeats and 95% confidence intervals for combinations of high and low built and designed clutter

Finally, there was a significant three-way interaction between built clutter, designed clutter and age group, $F(2, 42) = 4.49$, $p < .05$, $\eta^2 = .18$. This interaction is illustrated in Figure 26. Post-hoc analyses for each age group separately showed that the interaction of built and designed clutter was not significant for probationary drivers, $F(1, 14) = 0.08$, $p > .1$, $\eta^2 = .01$, or fully licensed drivers, $F(1, 14) = 0.46$, $p > .1$, $\eta^2 = .03$, but was significant for older drivers, $F(1, 14) = 12.05$, $p < .01$, $\eta^2 = .46$. Pairwise comparisons for the older drivers showed that the effect of designed clutter on time to detect change was not significant when built clutter was high ($p = .218$), but was highly significant when built clutter was low ($p < .001$).

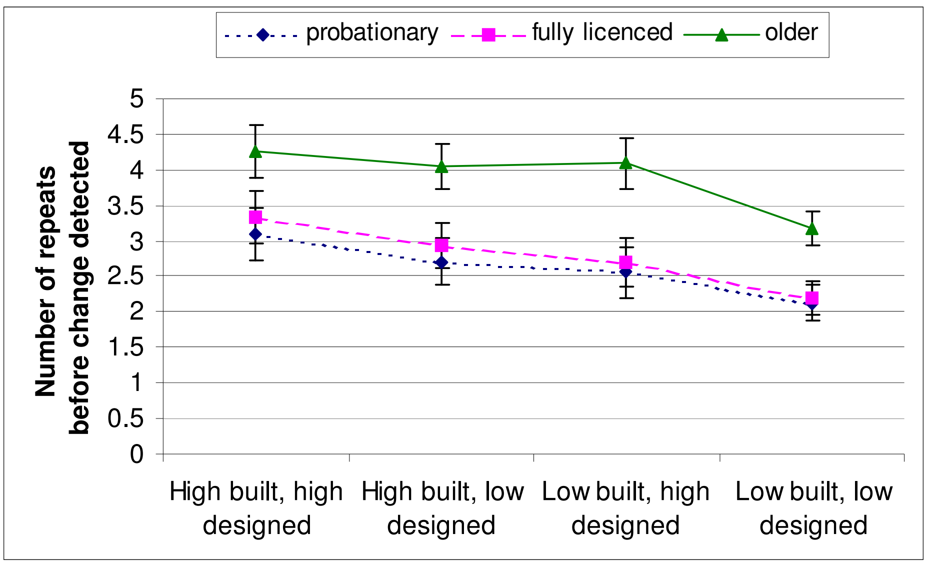


Figure 26. Change detection time mean and 95% confidence intervals for each age group at each combination of high and low built and designed clutter

The potential four-way interaction between the two types of clutter, change type and age was not significant.

Sub-analysis: scenes with and without billboards

Method: Design for billboard sub-experiment

A subset of the photograph pairs either included a billboard or had been modified to include a billboard. These were matched with scenes that did not contain billboards, but had the same level of built clutter and designed clutter, and the same sort of change. Table 4 explains the design for this analysis.

Table 11. Design of sub-experiment on effect of billboards

	Built clutter	High		Low		
Changing object	**Designed clutter**	High	Low	High	Low	Total
Sign	With billboard	4	4	4	4	16 pairs
	Without billboard	4	4	4	4	16 pairs
Car	With billboard	4	4	4	4	16 pairs
	Without billboard	4	4	4	4	16 pairs
		16	16	16	16	*64 pairs*

A mixed-model ANOVA with age/experience group as a between-subjects factor, and level of built clutter, level of designed clutter, type of object that changed, and presence or absence of billboards as within-subjects factors, found a number of significant effects.

Results for billboard sub-experiment

As in the main analysis, the effects of type of object that changed, built clutter, designed clutter, and age/experience group were significant at $p < .001$. So were the interactions of change type with designed clutter and with age group. All effects were in the same direction as found in the main analysis, so there is no reason to think that the scenes involved in this analysis were in some way different from the full set of scenes.

The sub-analysis revealed a significant main effect of the presence of billboards, $F(1, 42) = 30.11$, $p < .001$, $\eta^2 = .42$. Participants took longer to detect the change in scenes that contained billboards. Presence of billboards interacted significantly with built clutter, $F(1, 42) = 9.44$, $p < .01$, $\eta^2 = .18$; and with designed clutter, $F(1, 42) = 5.82$, $p < .05$, $\eta^2 = .12$. In both cases, the effect of billboard presence on time to detect change was larger for scenes with high clutter.

There was a significant three-way interaction between presence of billboards, type of change and level of designed clutter, $F(1, 42) = 8.95$, $p < .01$, $\eta^2 = .18$. Analysis of each change type separately (see Figure 27) revealed that the interaction of billboard presence with designed clutter was not significant for changing cars, $F(1, 42) = 1.68$, $p > .1$, $\eta^2 = .04$, but was significant for changing signs, $F(1, 42) = 9.23$, $p < .01$, $\eta^2 = .18$. For the changing sign pairs with billboards, the effect of designed clutter on time to detect change was significant, $F(1, 42) = 41.23$, $p < .001$, $\eta^2 = .50$. However it was not significant for the changing sign pairs without billboards, $F(1, 42) = 2.90$, $p = .1$, $\eta^2 = .06$.

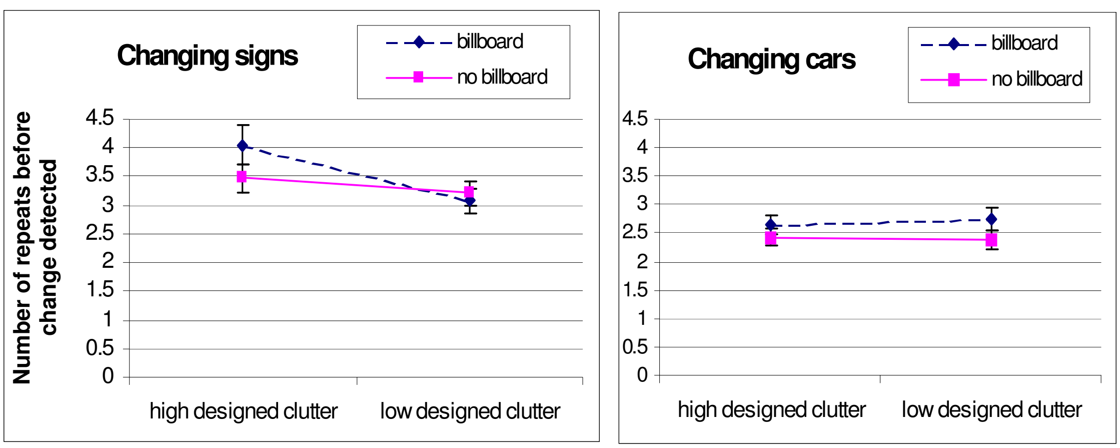
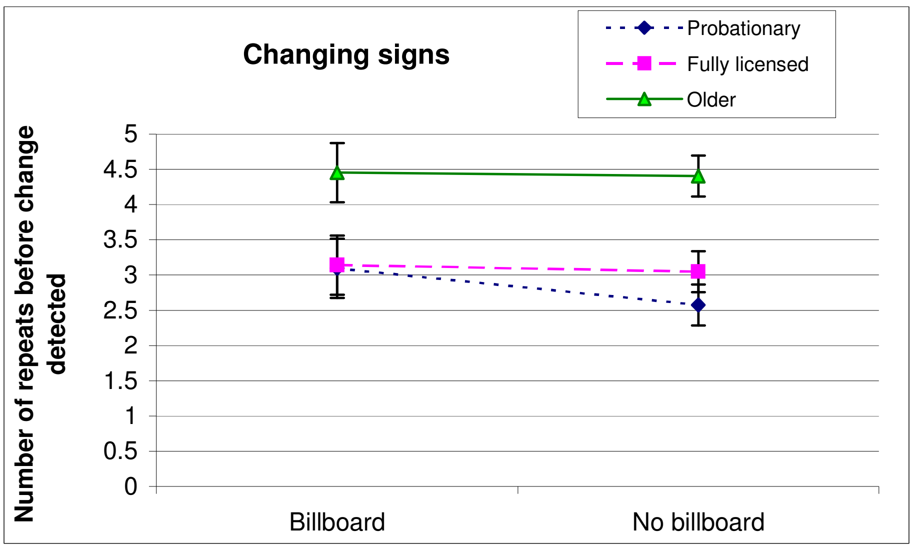


Figure 27. Billboard effect for changes to signs and cars at high and low designed clutter.

There was also a significant three-way interaction between presence of billboards, type of change and age/experience group, $F(2, 42) = 5.19$, $p = .01$, $\eta^2 = .20$. Analysis of each change type separately revealed that the interaction of billboard presence with age group was not significant for changing cars, $F(2, 42)$

= 2.33, $p > .1$, $\eta^2 = .10$, but was significant for changing signs, $F(2, 42) = 3.77$, $p < .05$, $\eta^2 = .15$. Mean detection times for each change type are shown in Figure 28. For the changing sign pairs with billboards, the effect of age group on time to detect change was significant, $F(2, 42) = 13.69$, $p < .001$, $\eta^2 = .50$. Dunnett's post-hoc t-test showed that the older drivers took significantly longer to detect changes than did the fully licenced group ($p < .001$) while the probationary drivers could not be differentiated ($p > .5$). For the changing sign pairs without billboards, the effect of group on time to detect change was larger, $F(2, 42) = 43.45$, $p < .001$, $\eta^2 = .67$. Not only were the older drivers significantly slower ($p < .001$), but the probationary drivers were significantly faster than fully licensed drivers ($p < .05$).



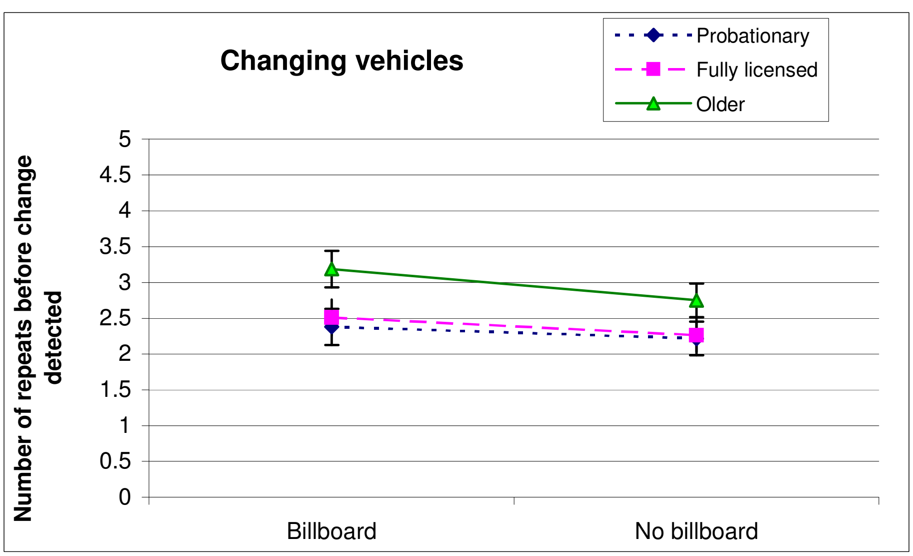


Figure 28. Effect of billboards for each age group on time to detect changes to signs and cars.

Finally, there was a three-way interaction between billboard presence, built clutter and designed clutter, $F(1, 42) = 21.85$, $p < .001$, $\eta^2 = .34$. Pairwise comparisons between scenes with billboards and scenes without billboards were performed for each combination of high or low built and designed clutter. Mean time to detect change and 95% confidence intervals for each of these combinations are shown in Figure 29. When both built and designed clutter were high, adding billboards did not have a significant effect on time to detect change, $t(44) = 1.94$, $p = .059$. When built clutter was high but designed clutter was low or vice versa, drivers took longer to detect changes in scenes with billboards than in scenes without billboards (high built, low designed $t(44) = 5.10$, $p < .001$; low built, high designed $t(44) = 5.81$, $p < .001$). When both built and designed clutter were low, drivers were faster to detect changes in scenes with billboards, $t(44) = -3.82$, $p < .001$.

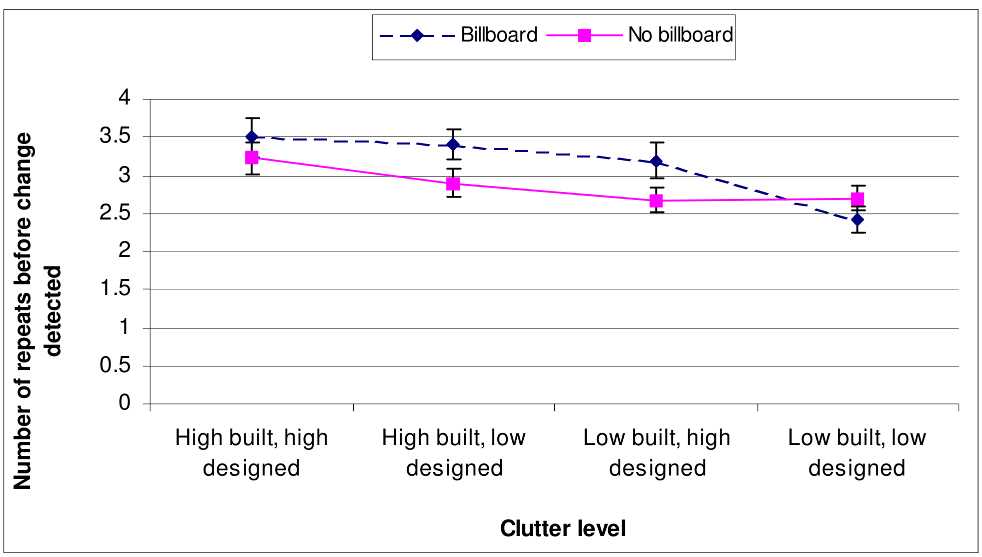


Figure 29. Effect of billboards by level of built and designed clutter.

This last result was unexpected, so the conspicuity of the changes was checked. Changes in the low built clutter, low designed clutter set without billboards were somewhat larger than changes in the LBLD set without billboards (and larger than the average change size), but it would be expected that this would make the response time for this set shorter, rather than longer.

Conspicuity check

To make sure that differences in conspicuity could not account for the main effects, the area of screen covered by the change and the eccentricity of (the centre of) each change from the centre of the screen were calculated. Table 12 shows that the average area and eccentricity of changes in each category were similar.

Table 12. Area and eccentricity of changes in pixels (scene resolution = 1024x768pixels)

Category	Area	% of total screen area	Z score area	Eccentricity	% of half diagonal	Z score eccent.
HBHD	15719	2.0%	-1.2	307.18	48%	-0.14
HBLD	29133	3.7%	1.1	329.24	51%	1.45
LBHD	20569	2.6%	-0.4	301.47	47%	-0.55
LBLD	25357	3.2%	0.5	298.504	47%	-0.76
average	**22694**	**2.9%**		**309.10**	**48%**	
HBHD						
billboard	15308	1.9%	-0.9	324.69	51%	-0.8
no billboard	14906	1.9%	-1.0	354.53	55%	1.2
HBLD						
billboard	38428	4.9%	1.5	351.37	55%	1.0
no billboard	27331	3.5%	0.3	315.82	49%	-1.4
LBHD						
billboard	24798	3.2%	0.1	338.94	53%	0.1
no billboard	23506	3.0%	-0.1	335.34	52%	-0.1
LBLD						
billboard	18625	2.4%	-0.6	316.26	49%	-1.4
no billboard	39600	5.0%	1.6	329.38	51%	-0.5
BB subset average	**24046**	**3.2%**		**336.78**	**52%**	

Discussion

Main effects were all in the expected direction. It took longer for participants to detect changes in scenes with high built clutter, high designed clutter, and/or billboards. Older participants took longer than younger participants, and changing signs took longer to detect than changing cars.

The hypotheses that high levels of built clutter and/or high levels of designed clutter would adversely affect change detection were supported. This reinforces the taxonomy of visual clutter developed earlier in the thesis and links it to effects on performance: the same characteristics which lead to road scenes being rated as high in visual clutter lead to slower change detection. It is also notable that the interaction of built and designed clutter appeared in both experiments. Adding one sort of clutter when both are low has a greater effect than adding one sort of clutter when the other is high, for both ratings of clutter and speed of change detection.

Changes to road signs were harder to detect than changes to other vehicles, as expected. This confirms that drivers tend to pay more attention to vehicles in road environments. Designed clutter significantly affected the speed of detection for changing signs, which is consistent with the visual search literature: it is harder to search for an item amongst other similar items (Duncan & Humphreys, 1989; Holahan et al., 1978). However designed clutter did not affect time to detect change to vehicles, again reinforcing the attentional primacy of vehicles over road signs.

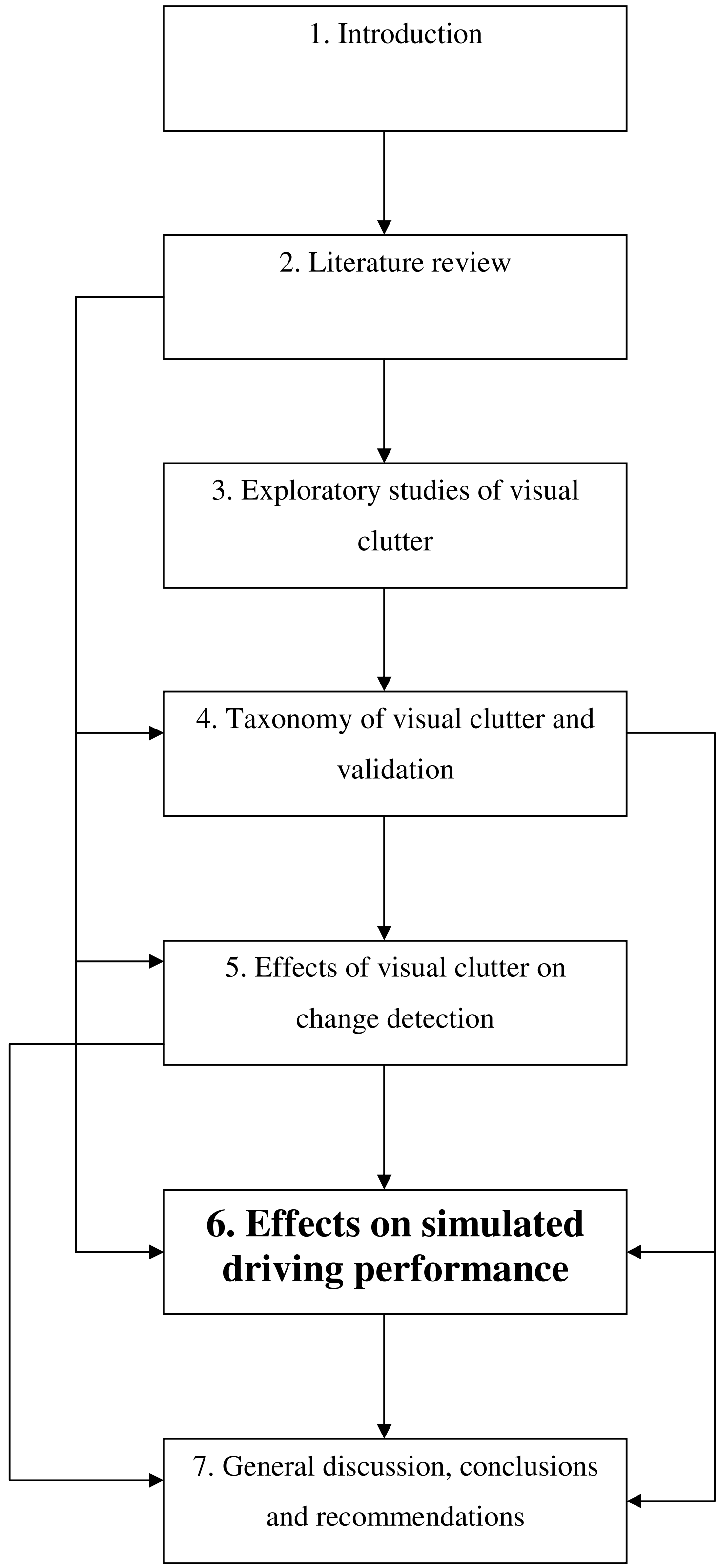
Built clutter not only increased the time to detect changing signs, but also the time to detect changing vehicles. This is particularly interesting as it cannot be explained as an effect of similar items distracting attention from the searched-for object. Vehicles are highly conspicuous objects, yet the detection of a large change such as a vehicle entirely disappearing from the scene was still affected by the amount of visual clutter in the built environment surrounding the vehicle.

The present experiment also confirmed that older drivers are slower to detect changes in road scenes. The results for age are interesting. The main effect of age can be explained as the result of generally slower information processing, however the interactions show that older drivers have difficulty detecting changes in particular situations: when searching for road signs (which are both less conspicuous and of less immediate importance than vehicles), and when the environment is more complex due to high levels of built and designed clutter. These results fit with previous research (Ho et al., 2001; Wood, 2002) and have important implications for the design of road systems that are safe for an ageing population. Implications of the results will be discussed in chapter seven.

The present experiment did not find an effect of experience. This may mean that the probationary drivers in the present experiment (some of whom had been driving solo for as little as 2 weeks) are just as good as experienced drivers at noticing important objects such as other vehicles and road signs. Alternatively, the relative youth of this group may have speeded their reaction times, compensating for any inefficiency in search patterns. It should be noted that the present experiment did not include a driving task; so it is possible that probationary drivers were able to devote resources to the scanning task that would normally be occupied by vehicle control (MacDonald, 1994).

The finding that the presence of billboards increases time to detect changes is an important one. This result lends support to the idea that billboards can automatically attract attention when drivers are engaged in other tasks, delaying their responses to other aspects of the environment. The effect of billboards is particularly strong in scenes where response times are already lengthened by high levels of built or designed clutter. Designed clutter and billboard presence have a multiplicative effect on time to detect changing signs. This suggests that in road scenes with many traffic control devices and billboards competing for attention, some road signs simply will not be perceived. The effect of billboards on ability to follow road signs will be further investigated in the next chapter.

It is now clear that visual clutter, be it from the built environment, designed by road authorities, or situation-dependent traffic levels, can affect the perception of important elements in road scenes. These findings imply that visual clutter is likely to affect driving performance as well. The next chapter will examine the effects of visual clutter on simulated driving performance.


1. Introduction
2. Literature review
3. Exploratory studies of visual clutter
4. Taxonomy of visual clutter and validation
5. Effects of visual clutter on change detection
6. Effects on simulated driving performance
7. General discussion, conclusions and recommendations

Chapter Six

Effects of visual clutter on simulated driving performance

The experiments reported in chapters 3 and 4 revealed that subjective ratings of visual clutter are affected by the levels of built, designed and situational clutter present in a scene, and chapter 5 showed that built and designed clutter affected people's ability to discern changes in traffic and road signs. To gauge actual behavioural responses, further investigations of the effect of visual clutter on driving performance require a dynamic simulation of the driving environment together with a driving task.

The driving simulator at MUARC, as currently configured (2007), is not capable of running footage from actual road scenes previously judged as high in visual clutter. Therefore it was necessary to simulate selected aspects of visual clutter. As discussed in the previous chapter, one type of built clutter which may affect driving performance is the presence of advertising billboards. The previous experiment showed that billboards can affect detection of changes to objects such as road signs and vehicles. The present experiment extends this work to investigate whether billboards affect responses to road signs and traffic signals during a simulated drive. The previous experiment used only static photographs, so it was not possible to determine whether billboards that move or change are any more distracting than static billboards. The present experiment includes both static and dynamic billboards. The simulation also included two different levels of traffic (situational clutter).

Responses to road signs and traffic signals were investigated under three conditions: the absence of billboards, the presence of static billboards, and the presence of billboards with displays that changed (dynamic billboards). It was expected that billboards would impair responses, with dynamic billboards having more impact than static billboards (see the Hypotheses section below for more detail). The environment simulated was an arterial road bordered by industrial buildings, with occasional intersections controlled by signal lights. This environment was chosen because, of the simulated environments available, it was closest to the type of road where advertising billboards are most often located. As discussed in the hypotheses section, it was expected that age and inexperience might affect the extent of any billboard effects, so probationary, fully licensed and older drivers were compared. Each participant performed one drive with no other traffic, and one drive in which three lead vehicles drove at approximately the speed limit (70km/hr) in the three lanes ahead of the participant.

Hypotheses and rationale

The following dependent variables were examined:

- Subjective ratings of visual clutter
- Subjective ratings of workload
- Response to traffic signals
    - Number of people failing to yield at amber lights.
    - Time to brake at red lights (rather than number of people who yield, as the number of people who run red lights is expected to be low).
- Response to signs directing the driver to change lanes
    - Time to change lanes
    - Lane change errors
- General vehicle control
    - Speed
    - Speed variability
- Eye movements
    - Time to first fixate lane change sign
    - Proportion of time fixating
        - on lane change signs
        - on road ahead/lead vehicles
        - on roadsides
    - Gaze variability (at lane change signs)

- horizontal
- vertical

Expected effects on subjective ratings

Subjective ratings of visual clutter were gathered to provide a link with the previous experiments reported in this thesis and check whether the stimuli used in the driving simulator actually created a cluttered environment. It was hypothesised that billboards, road signs and lead vehicles would increase subjective ratings of clutter, as their presence increases levels of built, designed, and situational clutter respectively.

Subjective ratings of workload were gathered after each drive using the NASA-TLX (Hart & Staveland, 1988); an unweighted arithmetic average of factors was used rather than individually calculated weightings, as this has been found to be just as sensitive a measure of overall task workload as a weighted average (Hendy, Hamilton, & Landry, 1993). It was not possible to determine the effect of billboards on subjective workload, as both drives contained billboards. However it was expected that probationary drivers would report higher subjective workload as their lower level of experience and skill at controlling the vehicle would require more effort (MacDonald, 1994). It was also predicted that the presence of lead vehicles would increase subjective workload due to the increased visual clutter.

Expected effects on responses to traffic signals

Correct responses to traffic signals involve the early onset of braking, and yielding at a signal which turns amber at such a distance that it will be red when the driver reaches the intersection if they keep travelling at their current speed. It was hypothesised that billboards would impair these responses due to distraction. When distracted (by a cognitive task), drivers glance less often at traffic lights, braking in response to a red signal is later and harder, and drivers stop closer to the intersection (Consiglio, Driscoll, Witte, & Berg, 2003; Hancock, Simmons, Hashemi, Howarth, & Ranney, 1999; Harbluk, Noy, Trbovich, & Eizenman, 2007). Drivers also brake later for red signals in more complex driving environments (Lee, Caven, Haake, & Brown, 2001). When distracted by reading a roadside sign, drivers take longer to react to the lead vehicle braking (Regan, Triggs, Mitsopolous, Symmons, & Tomasevic, 2001). Probationary and older drivers may be particularly vulnerable to these effects: novice drivers miss more movements by other vehicles, especially when distracted (Greenberg et al., 2003), and therefore might also be more likely to miss smaller changes like the colour of a traffic light. Older drivers miss more peripheral target lights while driving (Wood, 2002), and respond later to vehicle brake lights (Wolffsohn, McBrien, Edgar, & Stout, 1998); this pattern may hold for signal changes as well.

Expected effects on responses to road signs

The road signs used directed drivers to change lanes at regular intervals. Correct responses to lane change signs involve few errors, and changing lanes before passing the sign. It is hypothesised that distraction due to billboards will impair these responses, as advertisements increase the length of time taken to find direction signs (Boersema & Zwaga, 1985; Boersema et al., 1989) and affect fixations to and recall of roadside signs (Luoma, 1986). When distracted (by an auditory task), drivers take longer to react to signs (Parkes, Luke, Burns, & Lansdown, 2007) and perform worse at the Lane Change Task (Burns, Trbovich, McCurdie, & Harbluk, 2005). It is expected that probationary drivers will be particularly distracted by billboards, as novices fixate more signs than experienced drivers and more irrelevant signs the first time they drive a route (Sprenger et al., 1997). Older drivers have been found to report fewer roadside signs (Wood, 2002), so they are more likely to respond later or not at all.

Time to change lanes was measured from 50m after the appearance of the lane change sign, so that the driver could finish responding to the previous sign. The signs appeared every 150m so that the driver was almost continually switching lanes. If the driver did not enter the correct lane within the distance 90m before passing the sign to 50m after it, no time data was recorded; these occurrences were analysed as errors.

Expected effects on vehicle control

Good vehicle control involves maintaining speed at the goal of 70 km/hr with low variability. Billboards are expected to decrease mean speed and increase speed variability. When distracted by a visual task, drivers reduce speed (Engstrom, Johansson, & Ostlund, 2005). When distracted (by an auditory, manual, or visual task), drivers show increased speed variability (Merat, Anttila, & Luoma, 2005; Parkes et al., 2007). Older drivers have been found to have more difficulty maintaining high speeds, especially when distracted (Shinar et al., 2005), and it is expected that this will also be the case for the present experiment.

Expected effects on eye movements

For optimal responses to lane change signs, the driver must see and comprehend the sign in time to respond; i.e. good performance requires rapid fixations on lane change signs. The time spent fixating on lane change signs needs to be enough to read the sign; it is difficult to tell what this is, but because the signs were all identical, it can be assumed that any reduction in the amount of time spent fixating lane change sites when billboards are present may be detrimental. Proportion of time fixating on the road ahead should be high, especially in the drive with lead vehicles (Crundall, Shenton, & Underwood, 2004). Proportion of time fixating on the roadsides (i.e. ‘other’ areas) should be low, as there are no hazards in this area so no reason for drivers to look to the sides. The on-road studies discussed above could not analyse how billboards changed gaze patterns as the environment cannot be sufficiently controlled to attribute differences to billboards alone. However, it was hypothesised that billboard presence would draw fixations away from lane change signs and the road ahead, and towards roadsides and the billboards themselves. Probationary drivers may spend proportionately less time fixating ahead, especially when there are distracting stimuli present (Lee, Olsen, & Simons-Morton, 2006).

Horizontal and vertical gaze variance measures how often and how widely drivers scan around the centre of expansion. Normal scanning involves fixating mostly on the centre of expansion (i.e. the road ahead), with regular sideways scans in a horizontal ellipse around this point to search for hazards; novice drivers have lower horizontal gaze variability, even in complex roads (Underwood, 2007). In an environment like the one simulated, with tallish buildings on either side and no hazards ever appearing from the sides, it seems likely that this pattern would change (for all drivers) to scanning up and down the road ahead, i.e. less horizontal variability and more vertical variability. In such an environment, billboards distracting attention may be reflected in higher gaze variability – either vertical (if they distract when they appear in the forward visual field) or horizontal (if they distract when they are close and more legible). Novice drivers have been found to take longer to disengage attention from hazards (Crundall et al., 2002), and this may also hold for visual distractions such as billboards. Older drivers have been found to make fewer fixations than younger drivers overall, but make more fixations to peripheral areas, perhaps because they are unable to monitor peripheral events with covert attention (Mapstone 2001); this may leave them more vulnerable to distraction from billboards.

Expected effects of aging

With aging, there is a decline in cognitive processing that may be caused by any of lowered attentional/working memory capacity, slower information processing, or impaired selective attention (Simoes, 2002). If the latter holds, billboards are likely to be particularly distracting for older drivers. If selective attention is preserved, even if capacity or information processing speed is lower, billboards will have less effect as older drivers will be able to ignore them and/or disengage attention rapidly. Older drivers also have more difficulty dividing attention between two tasks. McDowd and Craik (1988) found older drivers performed worse when dividing attention between visual and auditory tasks; furthermore, increasing task difficulty on either task decreased performance for older subjects more than younger subjects. This holds even when both tasks are visual, for example a tracking task and a choice-response task (Ponds et al., 1988). However older persons have been found to pay less attention to peripheral stimuli when central task demand is high (Ball et al., 1988) which could reduce the distracting effect of peripheral billboards.

Expected effects of lead vehicles

Lead vehicles may increase the effect of the billboards due to increased workload. Strayer, Drews and Johnston (2003) found that adding vehicles increased perceptual load and the effect of a secondary task. However it is also possible that lead vehicles may attenuate the effect of billboards as drivers will concentrate on the vehicle ahead in order to maintain the specified headway.

Expected effects of instructions

As the billboards used in this study were very simple (the logo and tagline of a company only) they are potentially less conspicuous and less likely to retain attention than billboards used in the real world (which tend to contain a picture and more text). To simulate the effects of more attention-grabbing billboards, half of the participants in each age/experience group were instructed to report any billboards they saw. The participants who were reporting billboards were therefore expected to show greater effects of billboard presence.

It was hypothesised that the group who were instructed to report billboards would definitely fixate on billboards, whether or not the simple billboards in the present experiment were sufficiently attention-grabbing to capture fixations in the non-reporting group. The instruction manipulation thus enables examination of the effects on simulated driving of fixations outside the vehicle on elements of the scene other than the forward roadway. To the author's knowledge, the effects of such fixations have never been previously examined, so this was expected to provide useful information. Combined with the studies summarised in Chapter 2 on the effects of real billboards on eye movements while driving on-road, knowing the effects of such eye movements on simulated driving is an important link in the chain of evidence about the effects of billboards on driving.

Method

Participants

48 participants (30 males and 18 females) took part in this study, split into 3 groups. The probationary driver group consisted of sixteen drivers aged 18-25 who had gained their probationary licence less than one year ago. The fully licensed driver group consisted of sixteen drivers aged 25-55 who held full licences; this group served as a comparison group for the other two groups. The older driver group comprised sixteen drivers aged over 65 years who held full driver's licences. Table 13 shows further details of participant characteristics.

Participants were recruited by notices in the university's staff bulletin, on the student job website, and at nearby Senior Citizens clubs and Universities of the Third Age. All received a small cash payment as compensation for their time and travel costs.

Table 13. Participant characteristics.

Group	Proportion of males	Mean age	Mean driving experience	(Self-estimated) Mean distance driven
Probationary	7/16	19.4 years	0.6 years	10,400 km/year
Fully licensed	11/16	35.1 years	15.4 years	14,700 km/year
Older	12/16	73.6 years	53.0 years	15,400 km/year

Apparatus and stimuli

The experiment was performed in Monash University Accident Research Centre's driving simulator (see Figure 30). This consists of a 2003 Holden Calais sedan mounted on a motion platform, with three projection screens at the front. From the driver's viewpoint the three screens in front of the car provide a field of view subtending angles of approximately 180 degrees horizontally and 40 degrees vertically. The display has a resolution of 1280 x 768 pixels for the front panel and 640 x 480 pixels for the side panels. The projectors update the image at a rate of 30Hz. A Crystal River Audio Reality Accoustetron II audio system generates appropriate sounds. Data is collected from the brake pedal, accelerator pedal and steering wheel at a rate of 30Hz. Participants' head and eye movements were tracked using faceLab™ head and eye tracking hardware and software. This system has a resolution of three degrees of visual angle. Data collection from faceLab and the vehicle was linked to the display updates.

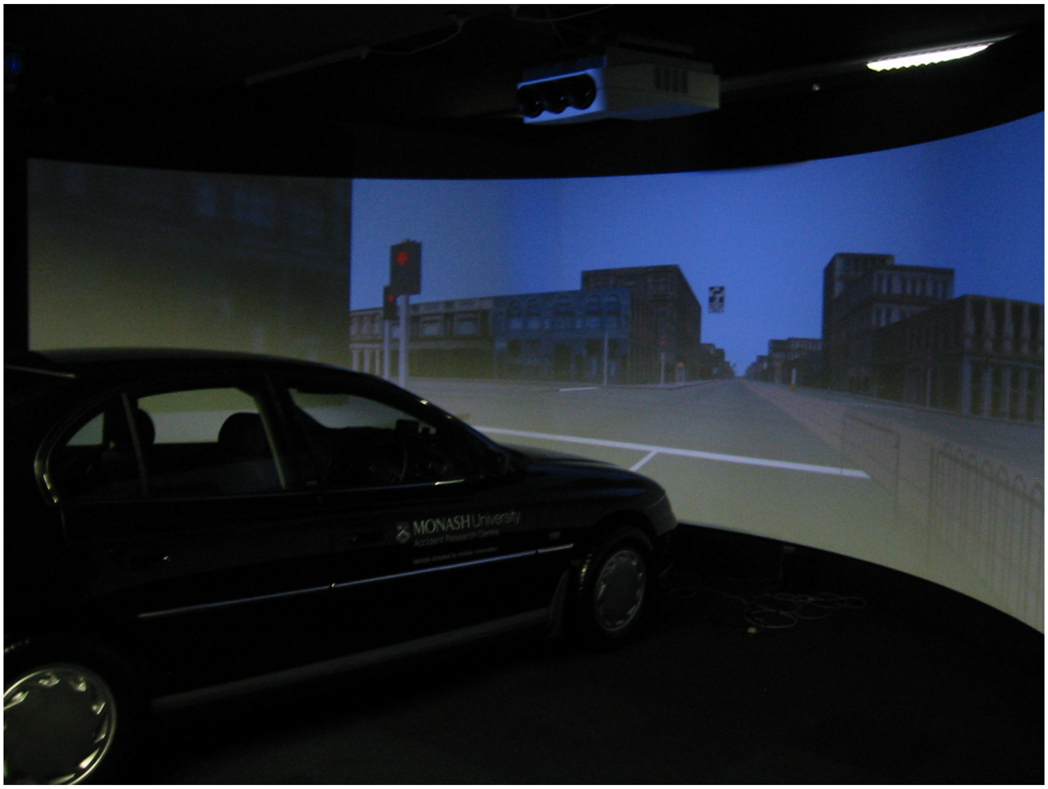


Figure 30. The Advanced Driving Simulator at MUARC.

The simulated scenarios consisted of three-lane divided arterial roads through commercial and industrial environments. In one drive there was no traffic travelling in the same direction as the participant; the other drive involved three lead vehicles, one in each lane, driving at 70km/hr. Signal timing was based on the algorithms for an arterial road with speed limit 70km/hr, which result in an amber time of 4 seconds; red time was reduced to 10 seconds to shorten the drives.

The lane change signs measured 2x1m and were spaced approximately every 150m; they did not become visible until the participant was 140m from them. Each sign contained two crosses and one arrow indicating the lane into which the participant should change. Figure 31 shows an example of a lane change sign.

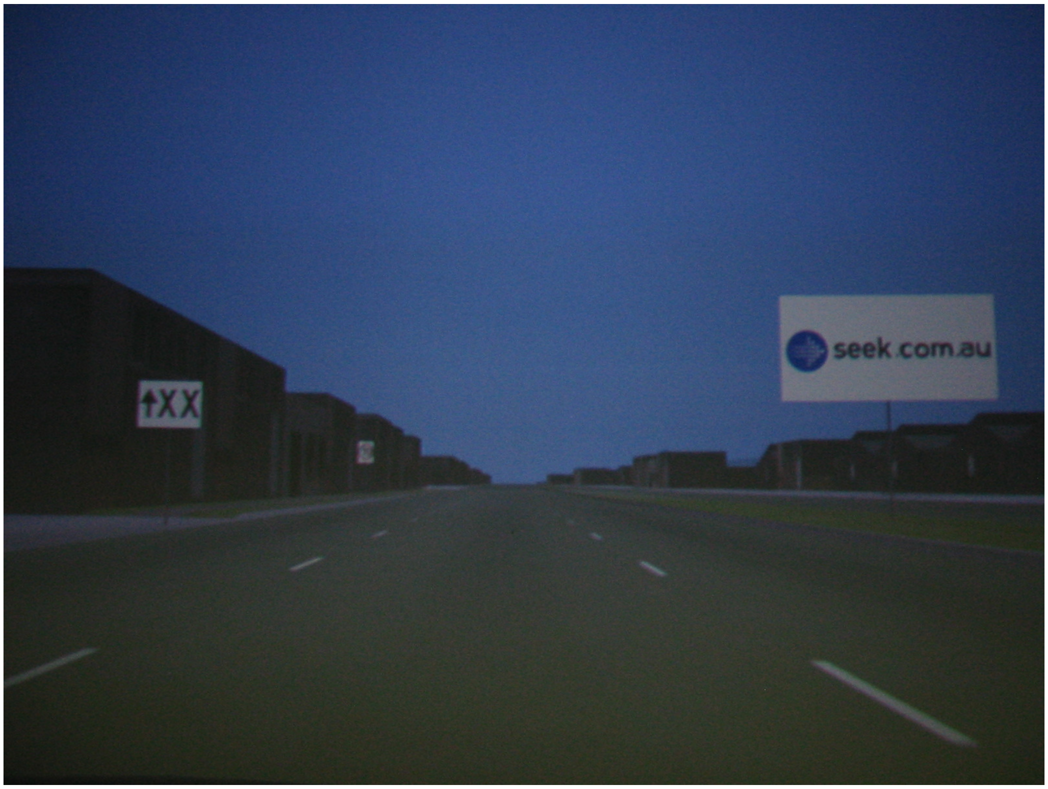


Figure 31. Screenshot of simulated environment showing billboard and lane change sign.

Billboards used were logos of companies with a large advertising presence (see Figure 31 for an example). These were chosen so that they would be clearly recognisable in the simulator to most participants. Billboards measured 8x5m and ‘popped up’ when the participant was 140m away from the billboard location. ‘Static’ billboards displayed the same logo for the whole 140m; ‘dynamic’ billboards switched from one logo to another when the participant was 85m away from the billboard. (This time was chosen so that it matched the change in some traffic signals. Unfortunately due to technical constraints, it was not possible to program the simulator to mimic billboards like those starting to come into use on the roads, which change more frequently.) Figure 3 explains the timing of billboard changes relative to traffic signal changes.

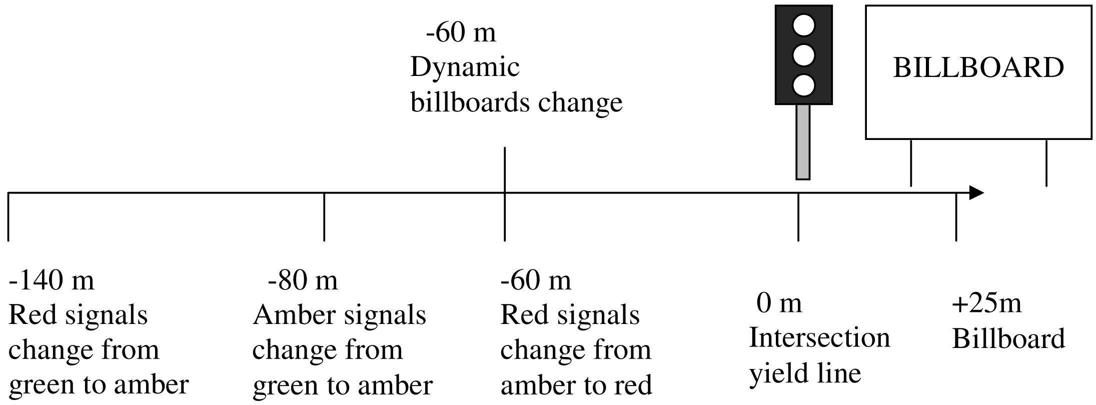


Figure 32. Approach to intersection, showing distances from intersection at which various events occurred.

Procedure

At the start of their experimental session, participants completed the demographic questionnaire. Participants then drove a short sequence with the experimenter seated in the passenger seat, to familiarise themselves with the controls of the vehicle. The experimenter then returned to the control room, from where there is two-way communication with the participant in the simulator vehicle. The next drive was performed solo, and allowed the participant to practice the car following and lane change tasks. Finally, the two experimental drives were performed. Half the participants drove the high traffic condition first, while the other half drove the no traffic condition first. In the high traffic condition, participants were instructed to maintain a following distance of approximately 2 seconds behind the lead vehicles; in the no traffic condition, they were instructed not to exceed the speed limit of 70km/hr. After each condition, participants completed the NASA-RTLX mental workload scale. At the end of the session, participants sat in the simulator without driving while the experimenter brought up various scenes from each drive. Participants rated the level of visual clutter in each scene on a scale of one to ten.

Design

Each experimental drive contained a total of 37 lane change signs. At two signs instructing the participant to change from the centre lane into the left lane, and at two signs instructing the participant to change from the centre to the right lane, a static billboard was present on the opposite side of the road. Similarly, four signs had dynamic billboards opposite them, while four were 'control' sites with no billboards. Table 14 summarises this design. The remaining 25 signs were not analysed; they were used to direct the driver back into the centre lane, or from the left to the right lane (so that the driver could not predict which lane they would be directed into next).

Table 14. Within subjects variables for the 'lane change task' part of the simulator experiment

	No traffic		**Lead vehicles**	
Sign instructions:	**Centre lane → left lane**	**Centre lane → right lane**	**Centre lane → left lane**	**Centre lane → right lane**
No billboard	2 signs	2 signs	2 signs	2 signs
Static billboard	2 signs	2 signs	2 signs	2 signs
Dynamic billboard	2 signs	2 signs	2 signs	2 signs

Each experimental drive also contained nine intersections. The left-hand building on the far side of these intersections could contain no billboard, a static billboard or a dynamic billboard. Of the three intersections in each of these conditions, one showed a green traffic signal; one changed from green to amber when the participant was 80m (approximately 4 seconds travel) from the intersection (amber signal); and one changed from green to amber when the participant was 140m away, then to red when the participant was 60m away (red signal). Participants experienced both these changes in the practice drive to familiarise them with the signal timing. (See in Apparatus and Stimuli for a graphical representation of signal timing.) The design for this part of the experiment is summarised in Table 15.

Table 15. Within subject variables for the ‘response to traffic signals’ part of the simulator experiment

	No traffic			**Lead vehicles**		
Signal colour:	**Red**	**Amber**	**Green**	**Red**	**Amber**	**Green**
No billboard	1 signal	1 signal	1 signal	1 signal	1 signal	1 signal
Static billboard	1 signal	1 signal	1 signal	1 signal	1 signal	1 signal
Dynamic billboard	1 signal	1 signal	1 signal	1 signal	1 signal	1 signal

Half of the participants in each age group were not told to expect the billboards. The other half were asked to report what was advertised by any billboards they passed. This instruction was to simulate the effect of being distracted by a particularly conspicuous billboard. Table 16 shows the number of participants allocated to each group.

Table 16. Between subjects variables for the simulator experiment, and number of participants per cell

	Probationary	**Fully licensed**	**Older**
Normal instructions	8	8	8
Report billboards	8	8	8

<u>Data analysis</u>

Results for each dependent variable were analyzed using separate mixed-model ANOVAs. First methodological checks were performed to make sure that the group who were instructed to report billboards followed this instruction, and to check whether the intended manipulations of workload and visual clutter levels succeeded. Then each dependent variable was examined for the effects of the independent factors presence/type of billboard, presence of lead vehicles, type of instructions, and age/experience group.

Results

Table 17 provides a summary of the results for comparison with hypotheses. As can be seen, the hypotheses concerning the effects of billboards were mostly supported, while the results for interactions between billboards and other factors were more mixed.

Table 17. Summary of results.

	Main effect of Billboards	Expect -ed?	**Interaction of instructions and billboards**	Expect-ed?
Effect of:	Static and/or dynamic		Reporting billboards	
The 'expected?' columns contain a Y if the effect was as predicted, N if the effect was counter to predictions, ~ if no specific prediction was made.				
Subjective ratings				
- Clutter	increase	Y	interact with age	~
Response to traffic signals				
- Red time-to-brake	no effect	N	no interaction	N
- Amber yielding	no effect	N	no interaction	N
Response to lane change signs				
- Time to change lanes	increase	Y	increase	Y
- Lane change errors	increase	Y	increase	Y
General vehicle control				
- Speed	decrease (no traffic only)	Y	no interaction	~
- Speed variability	no effect	N	no interaction	N
Eye movements				
- Time to first fixate lane change sign	no effect	N	interaction with traffic	~
- Proportion of time fixating				
- on lane change signs	no effect	~	no interaction	~
- on road ahead/ lead vehicles	decrease	Y	increase for prob. & older drivers	~
- on roadsides	increase	Y	interact with age	~
- Gaze variability (at signs)				
- horizontal	no effect	N	no interaction	N
- vertical	increase (dynamic only)	Y	no interaction	N

Table 17 continued

	Interaction of lead vehicles and billboards	Expect-ed?	**Interaction of age/experience and billboards**	Expect-ed?
Effect of:	Lead vehicles present		Probationary (P) or older (O)	
The 'expected?' columns contain a Y if the effect was as predicted, N if the effect was counter to predictions, ~ if no specific prediction was made.				
Subjective ratings				
- Clutter	decrease BB effect	~	interact with instructions	~
Response to traffic signals				
- Red time-to-brake	no interaction	N	no interaction	N
- Amber yielding	no interaction	N	no interaction	N
Response to lane change signs				
- Time to change lanes	slightly decrease	Y	less effect of dynamic BBs for P drivers	N
- Lane change errors	increase	~	older increase	Y
General vehicle control				
- Speed	decrease(method?)	~	no interaction	~
- Speed variability	no interaction	N	no interaction	N
Eye movements				
- Time to first fixate lane change sign	interaction with instructions	~	no effect	~
- Proportion of time fixating				
- on lane change signs	interaction with age	~	interaction with vehicles	~
- on road ahead/ lead vehicles	no interaction	N	Increase for P & O drivers reporting BBs	~
- on roadsides	decrease effect of static BBs for P & F drivers	Y	interact with instruct and vehicles	~
- Gaze variability (at signs)				
- horizontal	no interaction	N	no interaction	N
- vertical	decrease BB effect	Y	no interaction	N

The next section goes into these results in more detail. Because of the large number of factors involved in the analysis, a number of interactions were not of particular relevance to the hypotheses. For the sake of clarity, the results section includes only the results pertaining to the hypotheses. The remaining results are presented in Appendix C.

1. Methodological checks

1.1 Responses to billboards for the group instructed to report billboard content

On average, 89% of the billboards in each drive were correctly reported. Accuracy was best for static signs; 99% of static signs in each drive were reported correctly. Dynamic billboards were not reported with the same degree of accuracy, perhaps because drivers had less time to look at them. The first logos in each pair tended to be either not noticed at all or not correctly identified, presumably as these logos were visible for only 55m when the billboard was further away and smaller. However, drivers still reported 77% of the first-in-a-pair logos correctly, and 93% of the second-in-a-pair logos.

The lowest score per driver was 70% of billboards reported correctly, with most reporting over 90% of billboards correctly. This suggests that drivers followed the instructions to look out for billboards. It is interesting that even under the condition of being specifically asked to look for and report the content of billboards, every participant missed at least one. This suggests that even in a simulator drivers will prioritise the driving task over secondary tasks.

Chi-square tests for differences between groups revealed that both the probationary and older drivers reported billboards less accurately than the control group of fully licensed drivers.

Table 18. Responses to billboards for the group instructed to report billboard content

Group	% correct	χ^2	N	p	Odds ratio	95% CI for odds ratio
Probationary	89	8.42	1344	<.01	0.53	0.34-0.82
Control	91					
Older	82	23.09	1344	<.001	0.45	0.32-0.63

There was no difference in the number of billboards reported correctly between drives with and without lead vehicles, χ^2 (1, N=2016) = 1.181, p = .277, odds ratio = 0.85 (95% confidence interval for odds ratio = 0.64 - 1.14).

1.2 Workload

The NASA-RTLX contains six subscales which are averaged to give an overall score out of 100. Both drives involved a moderate amount of workload: participants' mean rating for the no traffic drive was 44 (*SD* = 18) and for the high traffic drive 41 (*SD* = 17). This difference was significant, $F(1, 42) = 6.03$, $p < .05$, $\eta^2 = .13$. (Several participants commented that they found it easier to maintain a constant headway than a constant speed; this is probably due to the higher salience of a lead vehicle relative to a speedometer.) Note that the predicted difference was in the opposite direction to what was observed.

The main effect of age/experience was significant, $F(2, 42) = 5.48$, $p < .01$, $\eta^2 = .21$. The probationary drivers reported higher workloads than the fully licensed drivers (mean difference = 16.79, $p < .01$), as would be expected given that they are less experienced with the driving task. Older drivers could not be reliably distinguished from fully licensed drivers. Drivers who were asked to report billboards reported higher workload than drivers who were not given the extra instructions, $F(1, 42) = 8.15$, $p <. 01$, $\eta^2 = .16$.

1.3 Ratings of visual clutter

Participants rated the arterial road scene as low in visual clutter (overall mean rating: 4.4 out of 10; *SD* = 2.1). Figure 33 shows that scenes with lead vehicles, lane change signs, billboards and intersections received higher clutter ratings.

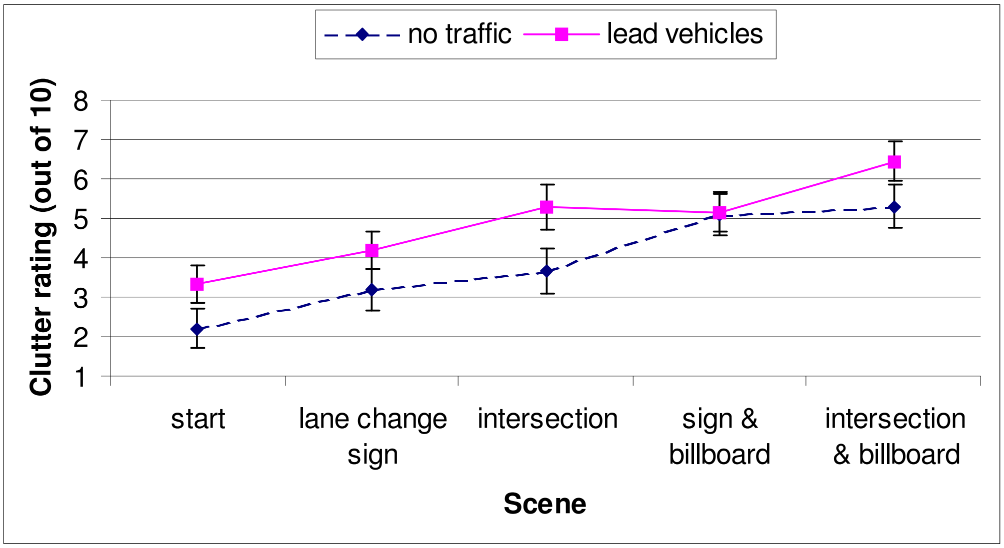


Figure 33. Ratings of visual clutter for simulated driving scenes.

A mixed-model ANOVA including the within-group factors billboard presence/absence, scene type (midblock with lane change sign or intersection), presence/absence of lead vehicles, and between-groups factors age/experience and instruction group, was performed. (It was not possible to compare static and dynamic billboards as participants rated single frames taken from the simulated drives. The start scene without either a sign or intersection was not included as there was no equivalent of this scene with a billboard.)

There was a significant main effect of billboard presence, $F(1, 41) = 154.67$, $p < .001$, $\eta^2 = .79$: the presence of a billboard increased the clutter rating of a scene. Presence of billboards interacted significantly with traffic, $F(1, 41) = 16.32$, $p < .001$, $\eta^2 = .28$: the effect of billboards was greater for scenes without lead vehicles. There were also significant interactions between traffic, billboards and age/experience, $F(2, 41) = 5.14$, $p = .01$, $\eta^2 = .20$; scene type, billboard and age, $F(2, 41) = 5.37$, $p < .01$, $\eta^2 = .21$; and between billboard, age and instruction, $F(2, 41) = 3.46$, $p < .05$, $\eta^2 = .14$. As these results are not of primary interest, further analyses were not performed.

2. Responses to traffic signs and signals

2.1 Yielding behaviour at amber signals

Instances in which the driver crossed an intersection yield line while the traffic light was red were recorded as failures to yield. Pearson's χ^2 was used to analyse this binary data (yield vs. fail to yield) for each intersection where the signal was amber during the last 80m of the driver's approach (amber signals).[2]

The main effect of billboard type on yielding behaviour was not significant, $\chi^2(2, N = 288) = 1.09$, $p > .1$. Static and dynamic billboard sites were collapsed into one category to improve power. This combined effect of billboard presence on yielding was not significant, $\chi^2(1, N = 288) = 0.62$, $p > .1$, odds ratio = 0.80, 95% confidence interval around odds ratio = 0.45 - 1.41.

The combined billboard presence variable was examined at each level of the other variables to check whether there were any interactions.

There were no differences between instruction groups. For both the group instructed to report billboards and the group given normal instructions, there was no significant effect of billboard presence on yielding: report group $\chi^2(1, N = 144) = 0.58$, $p > .1$, odds ratio = 1.00 (0.47 - 2.11); normal group $\chi^2(1, N = 144) = 0.11$, $p > .1$, odds ratio = 1.08 (0.41 - 2.87).

There was no significant effect of billboard presence on yielding in either the drive in which participants followed lead vehicles, $\chi^2(1, N = 144) = 0.18$, $p > .1$, odds ratio = 0.84 (0.37 - 1.89); or the drive without any traffic (in which participants attempted to maintain a constant speed of 70km/hr), $\chi^2(1, N = 144) = 0.48$, $p > .1$, odds ratio = 0.75 (0.34 - 1.68).

There were no differences in the effect of billboard presence on yielding between age/experience groups. The presence of billboards was not significant for probationary drivers, $\chi^2(1, N = 96) = 0.03$, $p > .1$, odds ratio = 1.09 (0.39 - 3.03); fully licensed drivers, $\chi^2(1, N = 96) = 0.62$, $p > .1$, odds ratio = 0.78 (0.30 - 2.05); or older drivers, $\chi^2(1, N = 96) = 0.29$, $p > .1$, odds ratio = 0.59 (0.22 - 1.59).

---

[2] A logistic regression was initially attempted, but the number of times drivers failed to yield was too low relative to the number of times drivers correctly yielded.

Further interactions were not tested as this would reduce the expected cell value to an unacceptably low value.

2.2 Time to brake at red signals

The overall mean time to brake from the time when the signal turned amber (140m before intersection) was 2.94 seconds. A mixed-model ANOVA with the within-subjects factors of billboard type and traffic level, and the between-subjects factors of age/experience and instructions, found no significant main effects or interactions.

The analysis was repeated using the time until time brake pressure >=10% of possible pedal depression as the dependent variable. (The threshold of 10% ensures that the data captured is when drivers actually brake, not just when they rest their foot on the brake pedal.) The mean time to reach 10% of brake pressure was 4.73 seconds. An ANOVA found a significant effect only for age/experience, $F(2, 38) = 7.84$, $p = .001$, $\eta^2 = .29$, which was due to the probationary drivers reaching 10% of maximum braking later than the fully licensed drivers.

2.3 Time to change lanes when directed by a roadside sign

The overall mean time to change lanes was 6.9 seconds, which equates to 125m at drivers' average speed of 66km/hr. As lane change signs were on average 150m apart, drivers did not have a lot of leeway to delay lane changes.

A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found several significant effects and interactions. There was a significant effect of billboard type on time to change lanes, $F(2, 84) = 35.03$, $p < .001$, $\eta^2 = .45$. This effect was consistent despite two-way interactions between billboard type and the other variables: in all cases, lane changes when passing sites with billboards took longer than lane changes when passing control sites.

There was a significant effect of lead vehicles, $F(1, 42) = 11.41$, $p < .01$, $\eta^2 = .21$; as well as a significant interaction between vehicle presence and billboard type, $F(2, 84) = 4.51$, $p < .05$, $\eta^2 = .10$. Lane changes took less time in the drive with lead vehicles. As can be seen in Figure 34, the interaction between lead vehicles and billboard was due to the longest lane changes being at static billboard sites in the drive with lead vehicles and at dynamic billboard sites in the drive without lead vehicles. (*F, p* and η^2 values for post-hoc comparisons are reported in Table 19.)

Table 19. Post-hoc comparisons for interaction effect between vehicles and billboards on time to change lanes

Comparison	***df***	***F***	***p***	η^2
Lead vehicles – effect of billboards	2, 84	22.38	<.001	0.35
- static vs. control	1, 42	33.09	<.001	0.44
- dynamic vs. control	1, 42	22.98	<.001	0.35
No traffic – effect of billboards	2, 84	18.54	<.001	0.31
- static vs. control	1, 42	22.05	<.001	0.34
- dynamic vs. control	1, 42	29.02	<.001	0.41

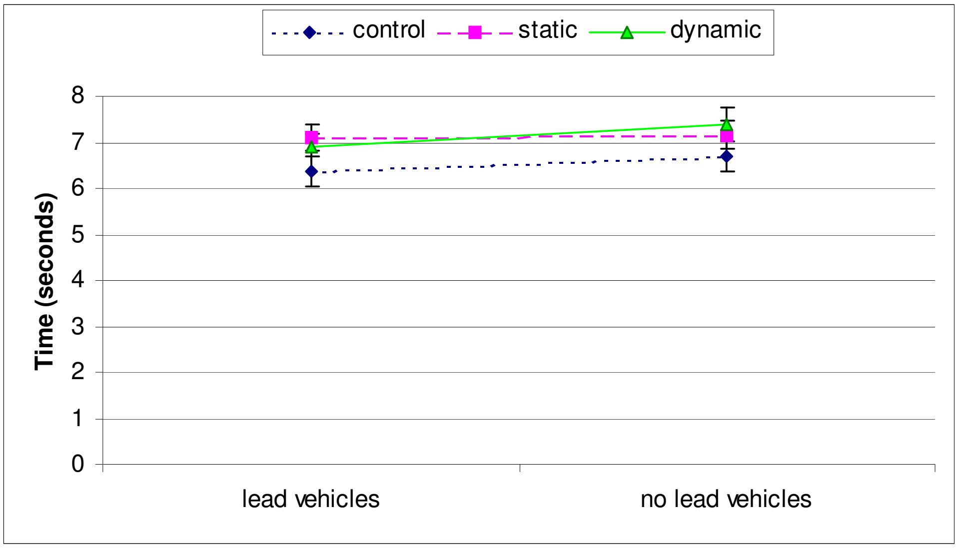


Figure 34. Mean and 95% confidence intervals for time to change lanes, by traffic and billboard type.

There was a significant main effect of age/experience group, $F(2, 42) = 6.17$, $p < .01$, $\eta^2 = .23$. Post-hoc Dunnett's t-tests revealed that probationary drivers were not significantly different from fully licensed drivers, but older drivers took longer to change lanes than fully licensed drivers, $p < .01$. There was also a significant interaction between billboard type and age/experience group, $F(4, 84) = 2.85$, $p < .05$, $\eta^2 = .12$. This is illustrated in Figure 35. Further analyses revealed that in the probationary group only, lane changes at dynamic billboards were not significantly different from those at control sites. For all other contrasts, lane changes were faster at control than at billboard sites. (See Table 20 for *F, p* and η^2 values for these analyses.)

Table 20. Post-hoc comparisons for interaction effect of age and billboards on time to change lanes

Comparison	***df***	***F***	***p***	η^2
Probationary drivers – effect of billboards	2, 28	6.21	<.01	.31
- static vs. control	1, 14	12.43	<.01	.47
- dynamic vs. control	1, 14	3.04	>*.1*	.17
Fully licensed drivers – effect of billboards	2, 28	34.22	<.001	.71
- static vs. control	1, 14	45.25	<.001	.76
- dynamic vs. control	1, 14	63.09	<.001	.82
Older drivers – effect of billboards	2, 28	8.29	.001	.37
- static vs. control	1, 14	7.77	<.05	.36
- dynamic vs. control	1, 14	14.45	<.01	.51

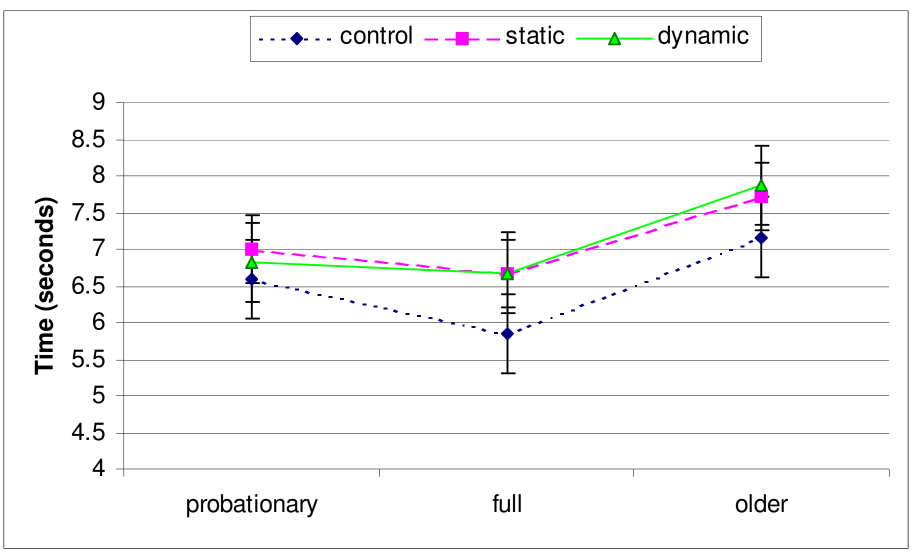


Figure 35. Mean time and 95% confidence intervals for time to change lanes, by age and billboard type.

Billboard type also interacted significantly with instructions, $F(2, 84) = 6.87$, $p < .01$, $\eta^2 = .14$ (see Figure 36). The effect of billboards was larger for the group instructed to report billboards, although it was still highly significant for the group given normal instructions. (For *F, p* and η^2 values for comparisons see Table 21.)

Table 21. Post-hoc comparisons for interaction effect of instructions and billboards on time to change lanes

Comparison	***df***	***F***	***P***	η^2
Normal instructions – effect of billboards	2, 42	5.47	<.01	.21
- static vs. control	1, 14	8.34	<.01	.28
- dynamic vs. control	1, 14	7.64	.01	.27
Report billboards – effect of billboards	2, 28	37.03	<.001	.64
- static vs. control	1, 14	41.44	<.001	.66
- dynamic vs. control	1, 14	57.34	<.001	.73

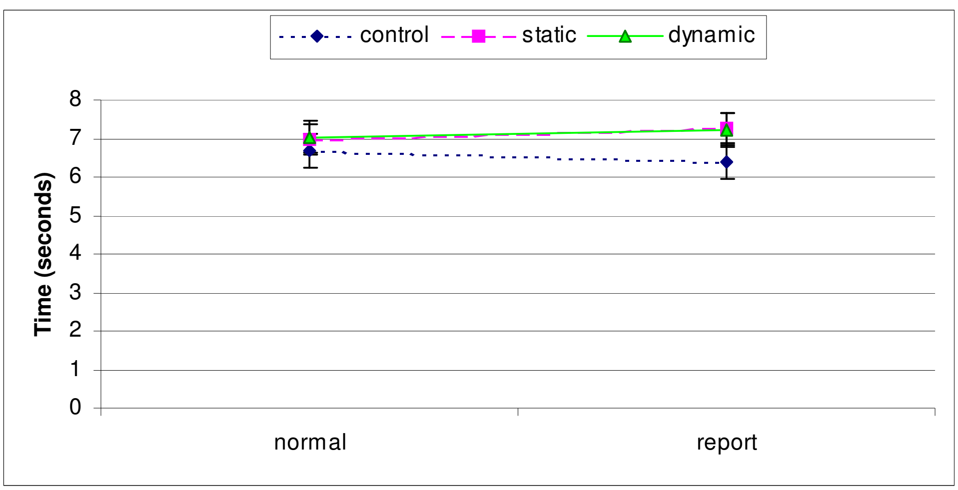


Figure 36. Mean and 95% confidence interval for time to change lanes, by instructions and billboard type.

2.4 Number of incorrect lane changes

This analysis includes cases when the driver changed into the wrong lane, as well as cases where participants failed to change lanes within the segment of road 90m before passing the lane change sign to 50m after it.

As this data is discrete it is not possible to use ANOVA. A logistic regression was initially attempted, but because only 5% of lane changes resulted in errors the equation consistently predicted a correct lane change. Therefore a chi-squared analysis was used.

First, the main effect of billboards was tested. Using the 3-level billboard factor (control/static/dynamic), the effect of billboard type was not found to be significant, $\chi^2(2, N = 1152) = 5.86, p > .05$. Because of the limited power and the inability to calculate odds ratios for a three-category factor, static and dynamic billboards were collapsed to form one category: billboard present. (All following analyses use this dichotomous variable.) The presence of billboards was found to be significant: $\chi^2(1, N = 1152) = 5.76, p < .05$. The odds ratio of 2.16 indicates that at sites with billboards, drivers were 2.16 times more likely to make an error. The 95% confidence interval around this ratio is 1.13 - 4.10. (Note that this confidence interval does not include 1: this implies that at the lowest estimate of the odds ratio with a confidence level of 95%, drivers are still more likely to make an error at sites with billboards.)

Secondly, the interaction between billboard presence and instruction was tested. For the group given normal instructions, there was no significant effect of billboard presence: $\chi^2(1, N = 1152) = 0.49, p > .1$, odds ratio =1.29 (0.63 – 2.66). For the group instructed to report billboards, the effect of billboards was highly significant: $\chi^2(1, N = 1152) = 9.057, p < .01$, odds ratio = 11.61 (1.55 – 86.78).

The interaction of age/experience group and billboard was tested next. Separate analyses for each age group showed that the effect of billboard presence was not significant for probationary drivers, $\chi^2(1, N = 1152) = 1.56, p > .1$, or for fully licensed drivers $\chi^2(1, N = 1152) = 0.31, p > 0.1$, but was significant for older drivers $\chi^2(1, N = 1152) = 4.62, p < .05$. Odds ratios are illustrated in Table 22.

Table 22. Odds ratios and 95% confidence intervals for effect of billboards on lane change errors by age/experience group.

		95% confidence interval around odds ratio	
Age/experience group	**Odds ratio**	Lower	Upper
Probationary	3.57	0.43	29.34
Fully licensed	1.39	0.43	4.46
Older	2.47	1.06	5.76

Finally the interaction of lead vehicles and billboards was tested. Separate analyses for each drive showed that the effect of billboards was significant for the drive with lead vehicles, $\chi^2(1, N = 1152) = 6.54$, $p = .01$, odds ratio = 5.50 (1.28 - 23.69) but not for the drive without lead vehicles, $\chi^2(1, N = 1152) = 1.11$, $p > .1$, odds ratio = 1.49 (0.71 – 3.12).

The effect of higher interactions was not tested as breaking down the data into further categories would reduce the expected cell value to an unacceptably low level. (Number of observations per cell can be found in Appendix C.)

3. Vehicle control (i.e. ability to maintain speed/headway during lane change task)

3.1 Mean speed in the 90m before passing each lane change sign

The overall mean speed was 66km/hr (SEM 0.3km/hr). Participants were told to either stay as close as possible to the speed limit of 70km/hr (no traffic drive) or to maintain a fixed speed/headway behind the lead vehicles which were driving at ~70km/hr (high traffic drive). Due to a slight mismatch between the car speedometer and the simulator, when participants were driving at ~70km/hr (as shown on the speedometer) the speed recorded was ~67km/hr. Thus it appears that participants followed the instructions fairly well.

A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found a significant effect of traffic: $F(1, 42) = 6.26$, $p < .05$, $\eta^2 = .13$. Mean speed was lower for the drive when participants were following lead vehicles (as they could not drive faster than the lead vehicles). There was also a main effect of billboard type, $F(2, 84) = 7.88$, $p < .001$, $\eta^2 = .16$. This was modified by an interaction between traffic level and billboard type, $F(2, 84) = 4.45$, $p < .05$, $\eta^2 = .10$. Analyses for each drive separately revealed that the effect of billboards was only significant for the low traffic drive. Contrasts for the low traffic data only showed that speeds were higher when passing control sites than when passing either static ($F(1, 42) = 10.49$, $p < .01$, $\eta^2 = .20$) or dynamic ($F(1, 42) = 15.16$, $p < .001$, $\eta^2 = .27$) billboards. This interaction is illustrated in Figure 37.

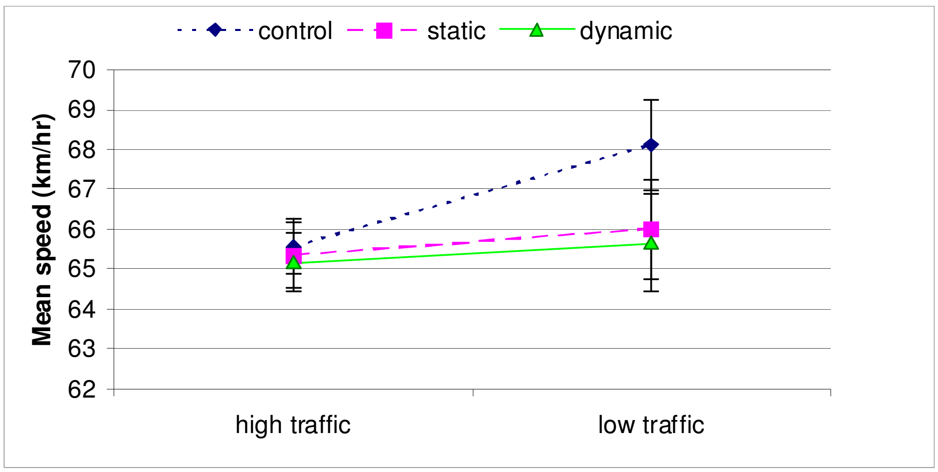


Figure 37. Mean speed & 95% confidence intervals, by traffic level and billboard type.

3.2 Standard deviation of speed in the 90m before passing each lane change sign

A repeated measures ANOVA on the standard deviation of speed with billboard type, level of traffic, age/experience group and instructions as factors found significant effects for traffic and age (speed was more variable for older drivers, and in the drive without lead vehicles) but no main effect or interactions with billboards.

4. Eye movements

4.1.1 Time to first fixate lane change sign

Participants fixated on lane change signs on average 1.6 seconds after they appeared. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found a significant interaction of billboard type, instructions and drive, $F(2, 68) = 3.27$, $p < .05$, $\eta^2 = .09$. Post-hoc analyses for the drive with lead vehicles showed no significant interaction for billboard type by instructions, nor main effects for either. The drive with no traffic showed a significant interaction between billboard type and instructions, $F(2, 76) = 5.66$, $p < .01$, $\eta^2 = .13$. For this drive only, the effect of billboards was significant for both the normal instruction group, $F(2, 36) = 4.03$, $p < .05$, $\eta^2 = .18$, and the group reporting billboards, $F(2, 40) = 3.83$, $p < .05$, $\eta^2 = .16$. Contrasts showed that for the normal instruction group, only dynamic billboards were different from control sites, $F(1, 18) = 7.74$, $p = .01$, $\eta^2 = .30$; while for the report billboard group, only the static billboards were different from control sites, $F(1, 20) = 10.12$, $p < .01$, $\eta^2 = .33$. Figure 38 a) and b) illustrate this interaction and reveal an odd phenomenon: in the normal instruction group, billboards increased the time to the first fixation on a lane change sign (as expected). However in the group reporting billboards, time to first fixation of lane change sign was shorter at billboard sites than at control sites.

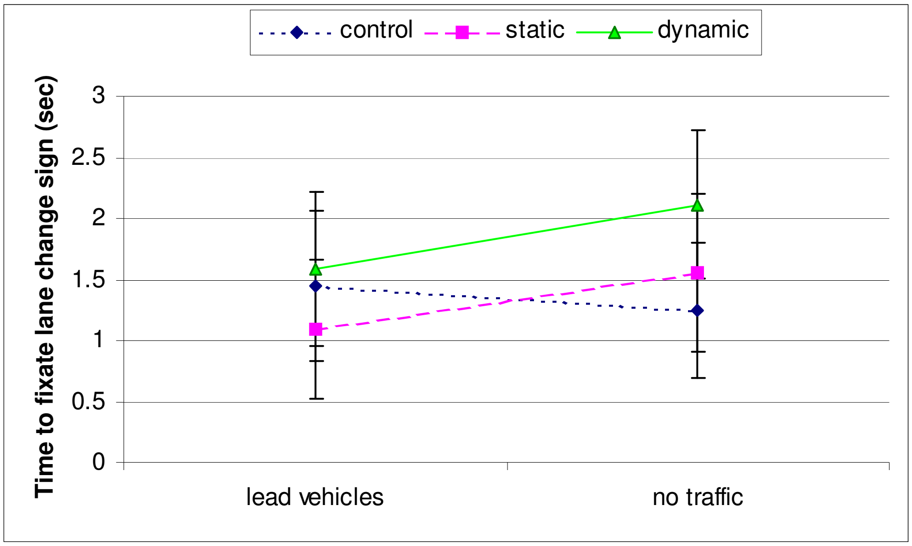


Figure 38 a). Mean time to fixate lane change signs and 95% confidence intervals for the group given normal instructions.

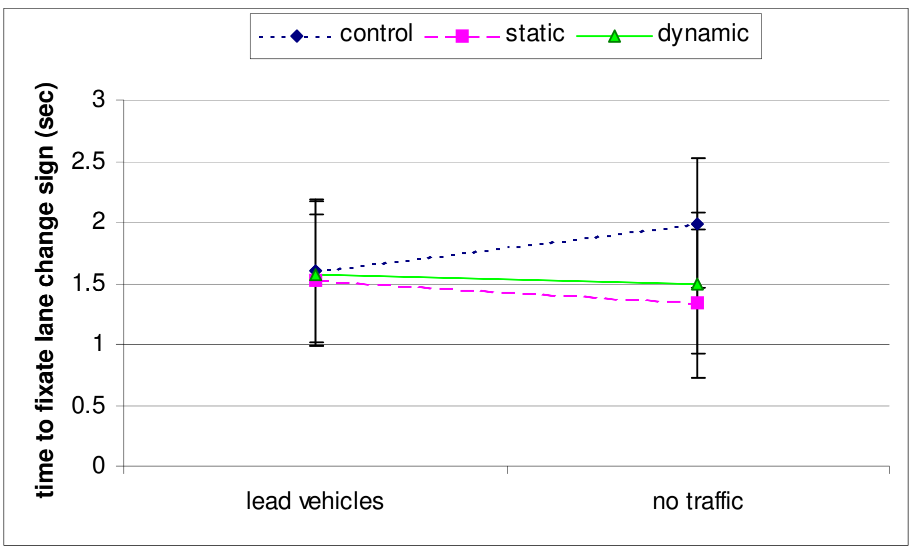


Figure 38 b). Mean time to fixate lane change signs and 95% confidence intervals for the group asked to report billboards.

4.1.2 Time to first fixate billboards versus lane change signs

A mixed-model ANOVA was conducted to compare the time to first fixation on billboards versus the time to first fixation on lane change signs. The analysis included billboards and lane change signs at sites with billboards.

There was no significant difference between lane change signs and billboards, nor was there an interaction with age, or with instruction group.

Higher order interactions are reported in Appendix C.

4.2 Proportion of time spent fixating on various objects/areas of the visual field

(in the 140m between the appearance of lane change signs/billboards and the driver passing the signs).

4.2.1 Billboards:

Overall, drivers spent 9.4% of time when a billboard was present fixating the billboard. (NB: these proportions are calculated from approaches to lane change signs, and do not include billboards at intersections. These were situated directly behind traffic signals, so it would be difficult to discriminate between fixations on the signal and fixations on the billboard.) A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found only one significant effect: the interaction between traffic and instructions, $F(1, 42) = 8.11$, $p < 0.01$, $\eta^2 = .16$. Further analysis revealed that instructions did not have a significant effect in the high traffic drive, $F(1, 42) < 1$, $p > .1$, $\eta^2 = .00$. However in the low traffic drive, the group who were reporting billboards spent more time looking at billboards, $F(1, 42) = 11.14$, $p < .01$, $\eta^2 = .21$). This is illustrated in Figure 39.

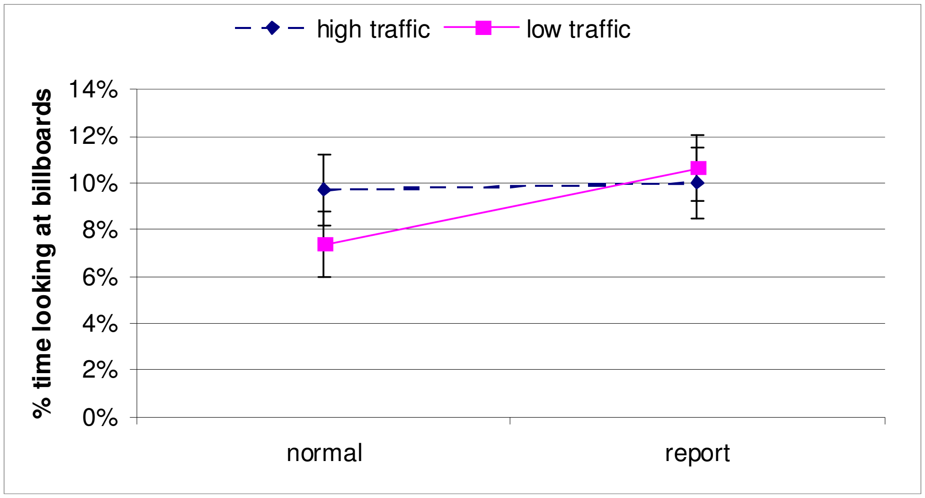


Figure 39. Proportion of time spent fixating on billboards and 95% confidence intervals

4.2.2 Lane change signs:

Overall, drivers spent 8.8% of time on the approach to a lane change sign fixating the sign. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found only one significant effect: the interaction between traffic, billboard and age/experience, $F(4, 84) = 2.88$, $p < 0.05$, $\eta^2 = .12$.

Further analyses revealed that for fully licensed drivers only, lead vehicles significantly increased fixations on lane change signs opposite static billboards but not those opposite dynamic billboards or control sites. This interaction is graphed in Figure 40 a) and b).

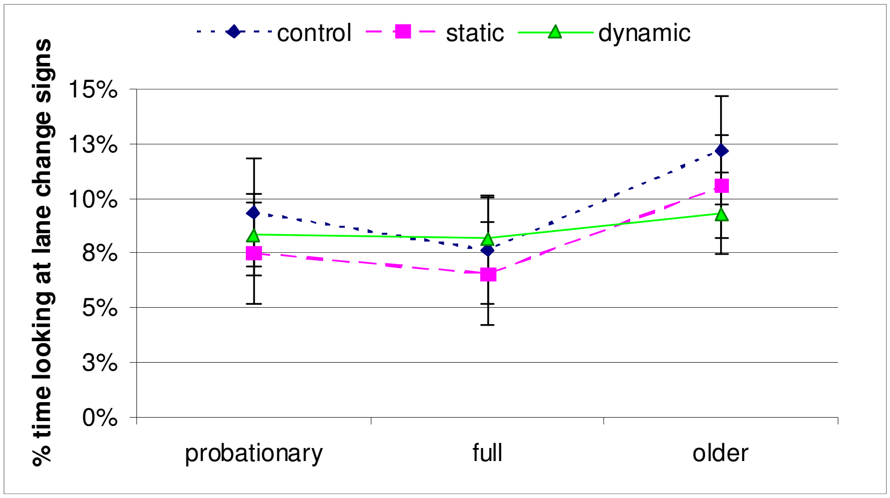


Figure 40 a). Proportion of fixations on lane change signs and 95% confidence intervals for the drive without any traffic.

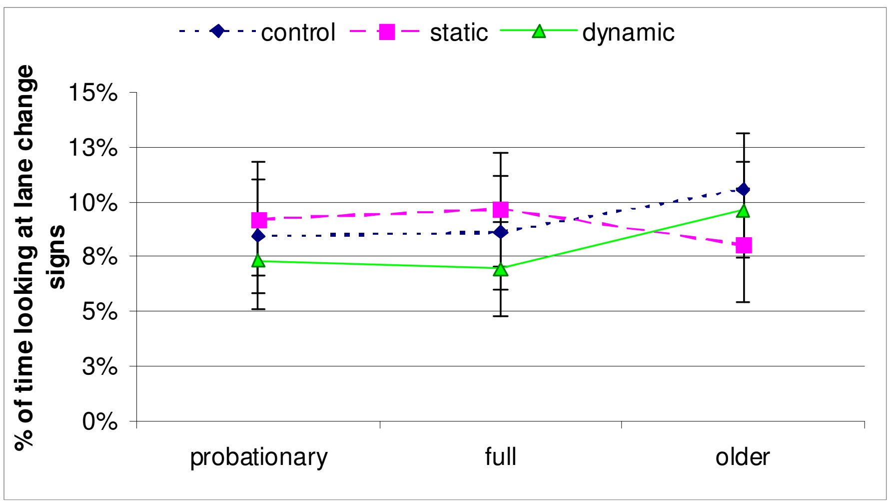


Figure 40 b). Proportion of fixations on lane change signs and 95% confidence intervals for the drive with lead vehicles.

Because this does not allow much insight into the effect of billboard presence (whether static or dynamic), further t-tests compared the mean of the static and dynamic billboards to the control sites for each combination of age and traffic in which the static and dynamic billboard results were consistent. Using the Bonferroni method, these tests were evaluated at a critical alpha level of 0.017 (=0.05/3). Differences were not significant for older drivers with lead vehicles, mean difference = 0.02, $t(15) = 1.08$, $p > .1$; older drivers without lead vehicles, mean difference = 0.02, $t(15) = 1.52$, $p > .1$; or probationary drivers without lead vehicles, mean difference = 0.01, $t(15) = 1.77$, $p > .05$.

4.2.3 Billboards compared with lane change signs:

A mixed-model ANOVA was conducted to compare the proportion of time on approach spent fixating on billboards versus lane change signs. The analysis included billboards and lane change signs at sites with billboards.

There was no significant difference between proportions for lane change signs and billboards, but there was an interaction with instruction group, $F(1, 42) = 6.32$, $p < .05$, $\eta^2 = .13$. Further analyses showed that the two object types received the same amount of time from the group given normal instructions, $F(1, 21) < 1$, $p > .1$, $\eta^2 = .01$. However, the group who were reporting billboards spent less time fixating lane change signs and more time fixating billboards, $F(1, 21) = 14.80$, $p = .001$, $\eta^2 = .41$. This interaction is graphed in Figure 41.

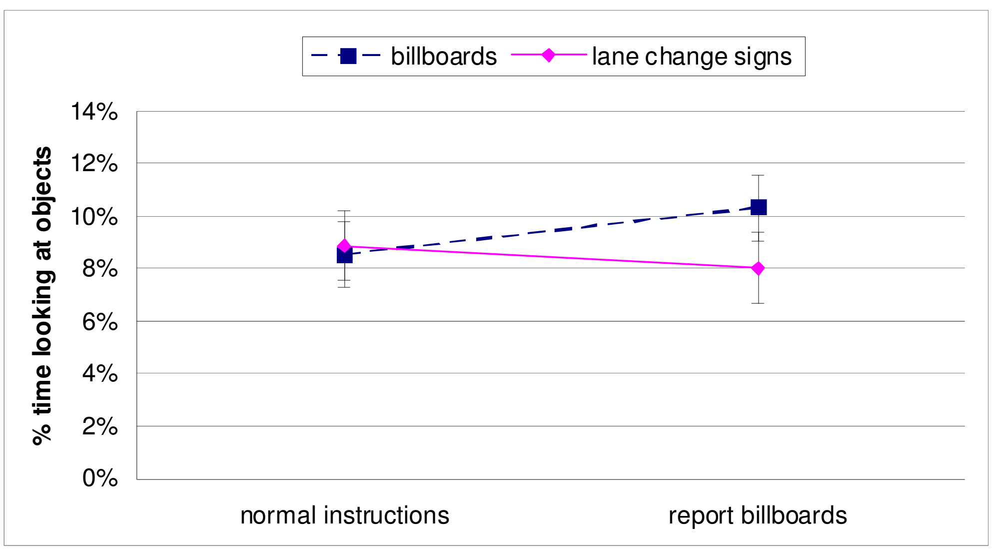


Figure 41. Mean and 95% confidence intervals for percentage of time spent fixating on each object type.

Higher interactions are reported in Appendix C.

4.2.4 Road ahead including lead vehicles:

Overall, drivers spent 55.9% of time on the approach to a lane change sign fixating the road ahead. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found a main effect of billboard type, $F(2, 84) = 43.2$, $p < .001$, $\eta^2 = .51$; and an interaction between billboard type, instructions and age/experience group, $F(4, 84) = 2.99$, $p < .05$, $\eta^2 = .12$.

Further analyses showed that the simple interaction of billboard type and age was only significant for the group instructed to report billboards, $F(4, 42) = 4.88$, $p < .01$, $\eta^2 = .32$. Results for this group are illustrated in Figure 42. When this group was divided by age, only the fully licensed drivers did not show a significant effect of billboard type, $F(2, 14) = 1.52$, $p > .1$, $\eta^2 = .18$. Billboard type was significant for probationary drivers, $F(2, 14) = 28.06$, $p < .001$, $\eta^2 = .80$; contrasts showed that both static ($F(1, 7) = 41.33$, $p < .001$, $\eta^2 = .86$) and dynamic ($F(1, 7) = 40.24$, $p < .001$, $\eta^2 = .85$) billboards were associated with less time spent fixating on the road ahead. For older drivers, again the effect of billboard type was significant, $F(2, 14) = 15.97$, $p < .001$, $\eta^2 = .70$, with both billboard types associated with reduced time fixating on the road ahead: static $F(1,7) = 31.04$, $p < .001$, $\eta^2 = .82$; dynamic $F(1,7) = 7.64$, $p < .05$, $\eta^2 = .81$.

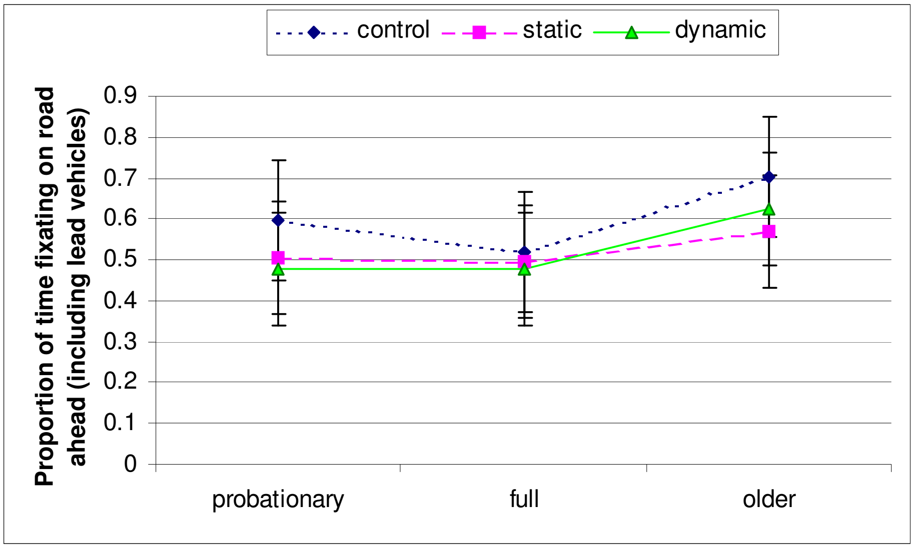


Figure 42. 'Report billboards' group: Mean and confidence intervals for proportion of time fixating on road ahead.

For the group given normal instructions, the interaction between billboard type and age was not significant, $F(2, 21) < 1$, $p > .1$, $\eta^2 = .04$; nor was the main effect of age $F(1, 21) < 1$, $p > .1$, $\eta^2 = .07$. The main effect of billboard was significant, $F(2, 42) = 16.94$, $p < .001$, $\eta^2 = .45$. Both static ($F(1, 21) = 39.07$, $p < .001$, $\eta^2 = .65$) and dynamic ($F(1, 21) = 22.19$, $p < .001$, $\eta^2 = .51$) billboards were associated with less time fixating on the road ahead, as shown in Figure 43.

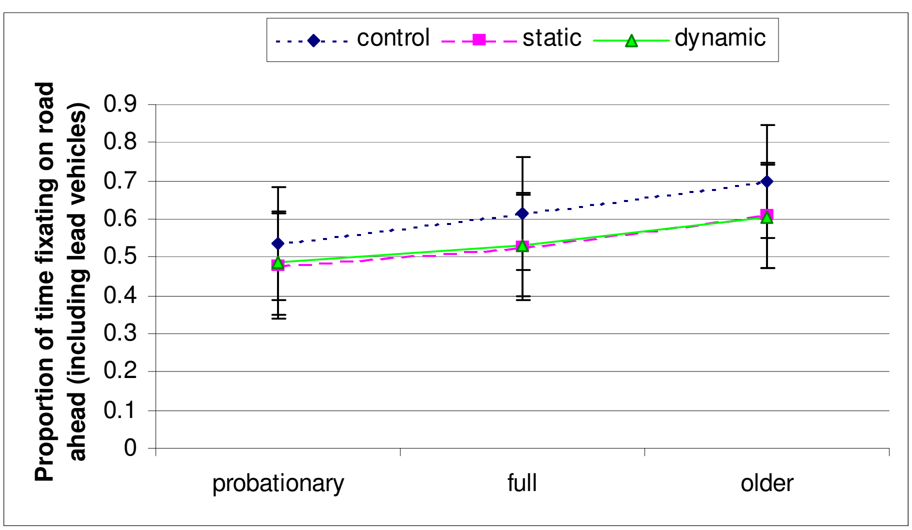


Figure 43. Normal instructions group: Mean and confidence intervals for proportion of time fixating on road ahead.

4.2.5 Other areas:

Overall, drivers spent 28.2% of time on the approach to a lane change sign fixating on other areas of the scene, i.e. the roadside to left and right. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found several significant effects. Billboard type was significant, $F(2, 40) = 4.02$, $p < .05$, $\eta^2 = .09$: contrasts showed that sites with dynamic billboards had significantly more roadside fixations than control sites, $F(1, 42) = 7.88$, $p < 0.01$, $\eta^2 = .16$, while sites with static billboards were in between.

There was a significant interaction between billboard type, instructions, and age/experience, $F(4, 84) = 2.78$, $p < .05$, $\eta^2 = .12$. Further analyses showed that the interaction of billboard and age was only significant for the group who were reporting billboards, $F(4, 42) = 4.34$, $p < .05$, $\eta^2 = .29$. Results for this group are illustrated in Figure 44. When this group was split by age, billboard type had no significant effect for probationary drivers, $F(2, 14) = 2.18$, $p > .1$, $\eta^2 = .24$, nor fully licensed drivers, $F(2, 14) = 1.36$, $p > .1$, $\eta^2 = .16$. Billboard type did have a significant effect for older drivers, $F(2, 14) = 12.46$, $p < .001$, $\eta^2 = .64$: both static ($F(1, 7) = 24.92$, $p < .01$, $\eta^2 = .78$) and dynamic ($F(1, 7) = 9.61$, $p < .05$, $\eta^2 = .58$) billboards were associated with more time fixating on the roadsides.

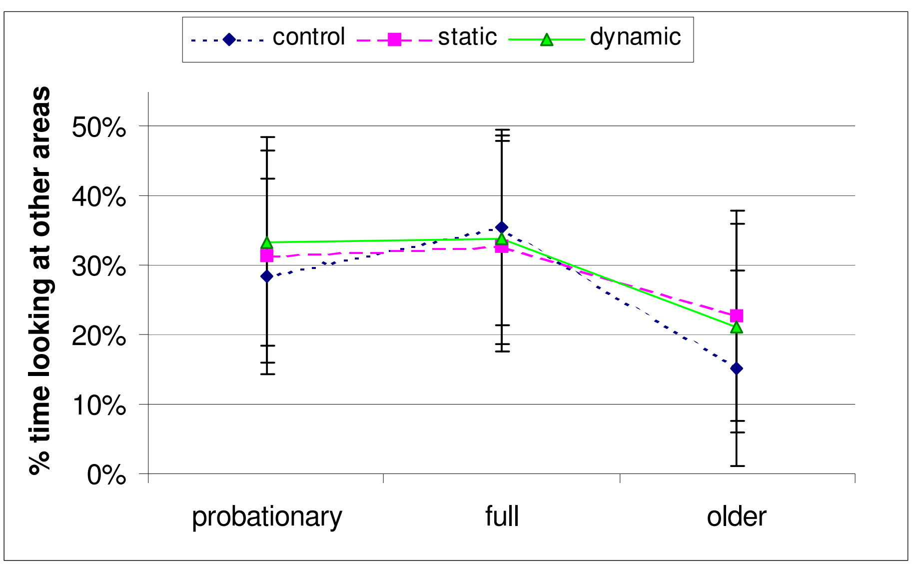


Figure 44. 'Report billboards' group: Mean and confidence intervals for proportion of time fixating on other areas.

For the group given normal instructions, neither billboard type, age, nor the interaction of the two were significant (see Figure 45).

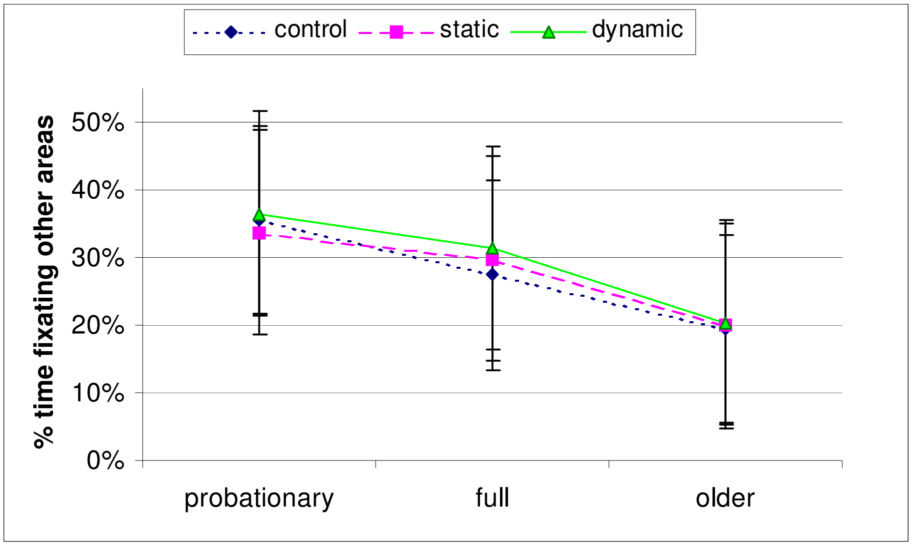


Figure 45. Normal instructions group: Mean and confidence intervals for proportion of time fixating on other areas.

Traffic interacted significantly with billboard type, $F(2, 84) = 15.02$, $p < .001$, $\eta^2 = .26$; this interaction was subsumed in a higher interaction with age/experience, $F(4, 84) = 2.78$, $p < .05$, $\eta^2 = .12$ (see Figure 46). Further analyses revealed that the interaction of billboard type and age was only significant for the drive with lead vehicles, $F(4, 84) = 3.71$, $p < .01$, $\eta^2 = .15$. Data for this drive only was examined separately for each age group. There was a significant effect of billboard type for both probationary drivers ($F(2, 28) = 3.85$, $p < .05$, $\eta^2 = .22$) and fully licensed drivers ($F(2, 28) = 3.81$, $p < .05$, $\eta^2 = .21$). For both groups, drivers spent significantly less time fixating on roadsides at static billboard sites than at control sites (probationary: $F(1, 14) = 6.21$, $p < .05$, $\eta^2 = .31$; fully licensed: $F(1, 14) = 6.39$, $p < .05$, $\eta^2 = .31$). There was no effect for dynamic sites (probationary: $F(1, 14) = 2.09$, $p > .1$, $\eta^2 = .13$; fully licensed: $F(1, 14) = 3.20$, $p > .05$, $\eta^2 = .19$). There was no significant effect of billboard for older drivers, $F(2, 28) = 2.04$, $p > .1$, $\eta^2 = .13$.

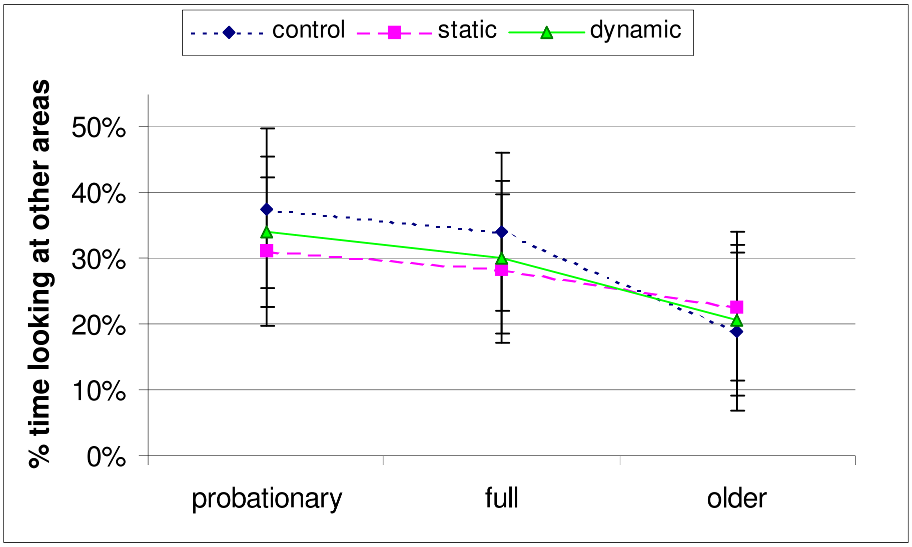


Figure 46. Lead vehicle drive: Mean and confidence intervals for proportion of time fixating on other areas.

For the drive without lead vehicles, neither the interaction of billboard type with age nor the effect of age were significant. The effect of billboard type was significant, $F(2, 84) = 16.09$, $p < .001$, $\eta^2 = .28$. For this drive, drivers spent more time fixating on the roadside at both static ($F(1, 84) = 19.24$, $p < .001$, $\eta^2 = .31$) and dynamic billboard sites ($F(1, 84) = 26.27$, $p < .001$, $\eta^2 = .38$) than at control sites (see Figure 47).

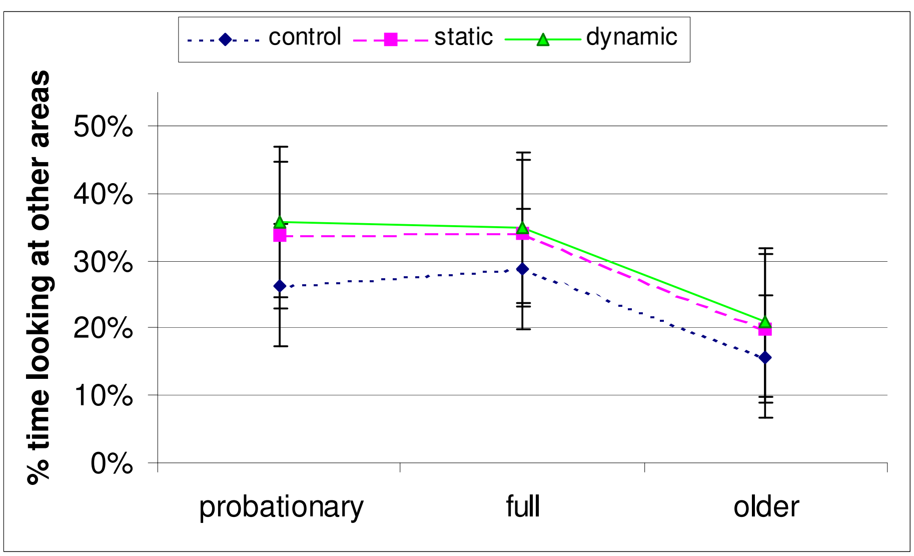


Figure 47. No traffic drive: Mean and confidence intervals for proportion of time fixating on other areas.

4.3 Gaze variability on approach to lane change signs

During data screening for the 150m approaching lane change signs, 5 cases were found to have extremely large values for gaze variability due to a low number of captured frames. They were deleted from the dataset used for analysis, leaving 43 cases.

4.3.1 Standard deviation of horizontal gaze direction:

The average standard deviation across conditions and participants was 0.051 degrees. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found no significant differences.

4.3.2 Standard deviation of vertical gaze direction:

The average standard deviation across conditions and participants was 0.068 degrees. A mixed-model ANOVA including the within-subject factors of billboard type and presence of lead vehicles, and the between-subjects factors of instructions and age/experience, found several significant effects. The effect of billboard type was marginally significant: $F(2, 74) = 3.27$, $p < .05$, $\eta^2 = .08$. Contrasts showed that drivers showed higher vertical gaze variability while approaching sites with dynamic billboards than control billboards, $F(1, 37) = 7.3$, $p = .01$, $\eta^2 = .16$. Static billboard sites were in between.

Presence of lead vehicles interacted with billboard type, $F(2, 74) = 7.49$, $p = .001$, $\eta^2 = .17$. Further analyses showed that the effect of billboard type was only significant for the no traffic drive (see Figure 48). When lead vehicles were not present, drivers varied gaze direction more when approaching billboards than when approaching control sites, both for static ($F(1, 37) = 5.84$, $p < .05$, $\eta^2 = .14$) and dynamic ($F(1, 37) = 25.48$, $p < .001$, $\eta^2 = .41$) billboard sites.

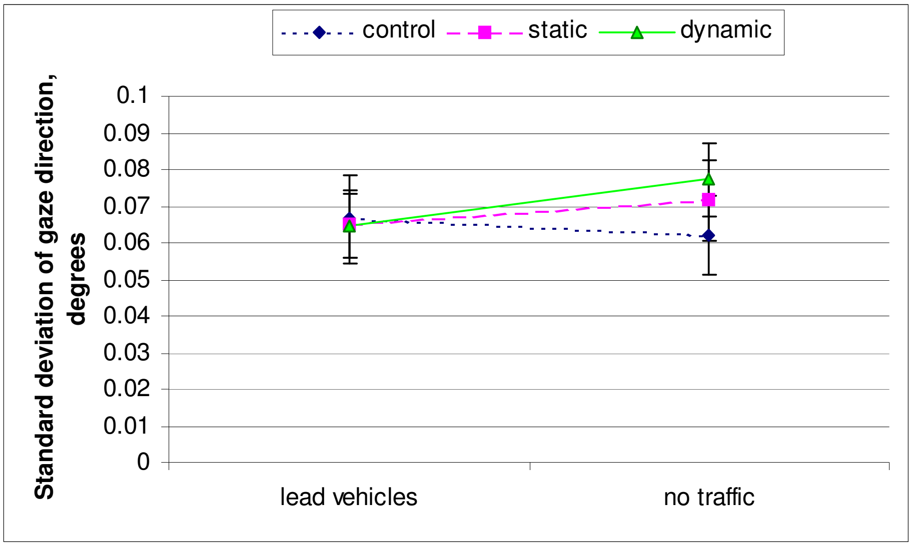


Figure 48. Standard deviation of vertical gaze direction on approach to lane change signs

Discussion

Seven of the twelve hypotheses about the effects of billboards on driving performance were supported. Where the results did not match the hypotheses, it was usually because the predicted effect was not significant, rather than an effect appearing which was not predicted.

The primary effects of the presence of billboards in this study were to impair speed maintenance and responses to road signs, although responses to traffic signals were not affected. These results are similar to results found by other studies on distraction by auditory and visual in-vehicle tasks (Burns et al., 2005; Engstrom et al., 2005; Parkes et al., 2007) and suggest that billboards, like in-vehicle forms of distraction, should be considered as potentially harmful.

The effect on speed could be because drivers are aware that they are visually distracted and are deliberately compensating for this by driving more slowly, or because drivers are simply paying less attention to the speed at which they travel. In either case, unexpected decreases in speed may cause difficulty for following drivers.

Billboards also increased the proportion of time spent looking at roadsides, at the expense of the amount of time looking at the road ahead and lead vehicles when present. Although responses to a slowing lead vehicle were not investigated in the present experiment, it seems likely that reduced observation of lead vehicles due to billboards might lead to a delayed response when the lead vehicle brakes. Lamble, Laako and Summala (1999) found that the response time to a braking lead vehicle rose with increasing eccentricity from the driver's gaze direction, so are likely to be particularly dangerous when they are close and at a large visual angle from the road ahead.

An unexpected finding was that the presence of billboards reduced the time to first fixate on the lane change signs for participants who were reporting billboards in the drive without lead vehicles. It is possible that the simultaneous appearance of the billboards drew attention towards the lane change signs. Billboards and signs were situated on opposite sides of the road to minimise this possibility, however when they appeared the driver was 140m away so they were separated by only six degrees of visual angle. This effect might have been lessened in the lead vehicle drive as the presence of the lead vehicles themselves drew attention towards the centre of expansion, and the reason it did not occur in the group given normal instructions may be that they were less primed to look out for billboard/sign type objects.

It was also unexpected that the present experiment did not find an effect of billboards on responses to traffic signals. This could be because changes in traffic signals are so salient (both physically and in terms of the driver's task) that they are always noticed. Or it could be due to low power; SPSS calculated that the power of the current experiment to find a time-to-brake difference with a significance of p=.05 was only 0.1. It is unfortunate that there was no previous research on which to base power calculations.

The present study suggests that individual factors can affect the distraction caused by billboards. Older drivers made more lane change errors overall, but particularly when billboards were present. As the population ages, it will become more important to design roads that are safe for all drivers, not just the average driver.

Despite the inclusion of a driving task, the present study did not find that the effects of billboards were worse for probationary drivers. It is possible that the scenes and changes used did not capture the subtle changes in situation which can lead to crashes. Underwood (2007) presents research showing that novice drivers behave similarly to experienced drivers in simple road environments, but do not scan complex road scenes as much as they should. He suggests that novice drivers lack appropriate mental models for complex road situations. This idea is supported by McKnight and McKnight's (2003) analysis of crash data. They found that most non-fatal accidents involving young novice drivers resulted from errors in attention, visual search, speed relative to conditions, hazard recognition, and emergency manoeuvres; i.e. the driver's failure to perceive the scene accurately and/or make the appropriate decision.

Individual factors include not only consistent differences such as a driver's age and experience, but also temporary factors such as the driver's current set of goals. The group who were asked to report billboards spent less time looking at lane change signs and more time looking at billboards than the group who received normal instructions. This resulted in an even greater delay in the time taken to change lanes, and an increase in the number of signs which were not followed correctly. This result demonstrates that drivers who look at billboards more often suffer more detrimental effects on their driving. While the present experiment did not examine individual or situational differences in terms of distractibility and task focus, it implies that drivers who are less focussed on the task of driving may be more affected by billboards and other visually distracting objects.

It should be noted that the billboards used in this study were very simple, comprising only the logo and tagline of a company. Billboards used in the real world (with more complicated pictures and text) are likely to hold drivers' attention for longer. This increases the probability of adverse effects on driving safety; Horrey and colleagues (2006) found that the length of glances to an in-vehicle display correlated with response time to a hazard.

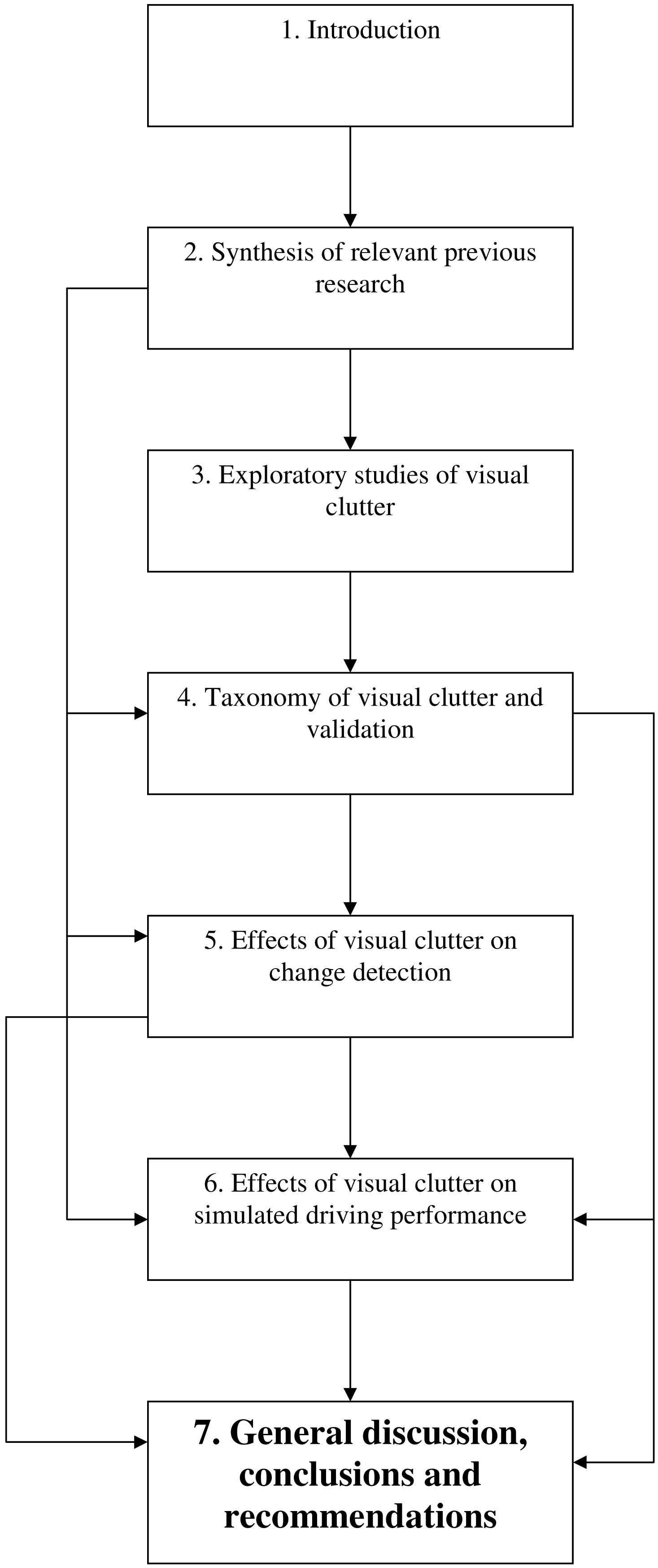
Subjective ratings of visual clutter confirmed the results of previous experiments: the presence of billboards, vehicles, and road signs increased rated clutter. However, overall ratings were low. Subjective ratings of workload were also low. Although the present experiment attempted to manipulate workload via traffic levels, it did not succeed. Baldwin and Coyne (2003) also failed to find an effect of traffic density on the NASA-TLX, although they do not report mean scores so it is not possible to compare the workload involved in their (driving simulator) study with the workload of the task in the present study.

The effect of billboards on driving performance on-road or in a driving simulator is difficult to investigate. Most distraction research has focussed on in-vehicle tasks: participants are instructed to share attention between, say, a mobile phone conversation and the driving task for a certain period, and this period can be compared with a baseline period. However the experimenter cannot control the amount of time a participant looks at a billboard. The distraction potential of the billboard varies over time; some billboards may be most distracting when they suddenly appear around a corner or from behind a building; others when they are closer and the driver tries to read the text. In addition to this, one billboard may have a different salience level for different drivers depending on individual factors (although this differential engagement can also be a problem when investigating in-vehicle tasks).

As billboards have been suggested to have greater effects in more cluttered environments, future research should attempt to simulate a highly cluttered scene. Future research should also investigate billboards in combination with high workloads, perhaps through a more demanding driving task, the occurrence of unexpected hazards, or the addition of a secondary loading task. Another useful approach would be to examine the effect of multiple billboards within a section of road.

Dynamic billboards pose another set of issues. The rate of change that should be allowed is currently under contention worldwide, with outdoor advertising companies and sign manufacturers lobbying for a change rate of 6-8 seconds (Minnetonka, 2007), while some road safety authorities insist that changes should happen no more frequently than every 30 seconds (e.g. Vicroads Operational Requirements for Variable Advertising Message signs, 2007). Future research could examine the effect of different change rates for dynamic billboards in a complex simulated environment, for example an intersection with many vehicles, lanes of traffic, and traffic control devices, as this is typical of the sort of environment where the expensive dynamic billboards are located. Alternatively, research could make use of the fact that distraction from the driving task depends on whether the change (and associated apparent motion) occurs when driver should be looking at something else. One option would be to use the ‘mudsplash’ change blindness technique, with billboards changing at same time as a driving-related object such as brake lights on a lead vehicle, traffic lights, or the appearance of a pedestrian.

While much research remains to be done (particularly on dynamic billboards), the present experiment has demonstrated that even simple billboards can affect vehicle control as well as responses to road signs in a high-fidelity simulated driving task. It is likely that billboards also have these potentially dangerous effects when driving on-road.


1. Introduction
2. Synthesis of relevant previous research
3. Exploratory studies of visual clutter
4. Taxonomy of visual clutter and validation
5. Effects of visual clutter on change detection
6. Effects of visual clutter on simulated driving performance
7. General discussion, conclusions and recommendations

Chapter Seven

General discussion, conclusions and recommendations

The present thesis aimed to determine the sources of visual clutter in the road environment, and to examine its effects on driving performance, particularly for young novice and older drivers. These aims, with the limitations discussed below, have been fulfilled. This chapter will bring together the research; in particular it will discuss the results of the work with reference to the work of other researchers, note some limitations of the present work, present the possibilities for future research, and highlight the theoretical and practical implications.

Outcomes of the thesis

Chapter 1: Introduction

Chapter One set the scene by explaining the problem of visual clutter in road environments. The aim and scope of the thesis were defined.

Chapter 2: Synthesis of previous research:

Chapter Two drew together strands of research from many different disciplines, concluding with a model of how visual clutter might affect driving performance and an inventory of the research gaps which need to be filled.

The driving task is defined as a collection of subtasks, including setting goals, gathering relevant information, processing the information with respect to the driver's goals, making decisions and executing actions. Successfully performing the driving task requires that visual and mental workload on the driver remains under a certain critical level.

It was argued that visual clutter interferes with the driving task by impairing the information gathering and information processing steps of the continuous control loop that is the driving task. Visual clutter in the form of irrelevant signage interferes with visual search for traffic signs, visual clutter in the form of background complexity impairs the selection of relevant information from the environment required for hazard detection and maintaining situation awareness, and visual clutter in the form of excessive levels of information forces the driver to process this extra information in order to determine whether it is relevant to the current goals. These effects will increase the demands placed on the driver. The accumulated stress from performing a demanding task may in itself reduce the attentional resources of the driver. Visual clutter in the form of highly conspicuous objects may distract the driver and temporarily capture the driver's attentional resources. When the demands of the driving task exceed the driver's attentional resources for any of these reasons, driving performance will be impaired.

Chapter 3: Initial studies

Results of the initial exploratory studies corroborated the model of visual clutter developed from the review of previous research, which was based on the interlocking themes of visual selection, information processing and workload. The aim of these studies was to gain a better understanding of visual clutter, its sources and effects, and to find some consistency in subjective ratings of visual clutter which earlier studies on the topic (Bravo & Farid, 2004; Ho et al., 2001; Jenkins, 1982) had failed to provide.

The focus group results suggested visual clutter could be divided into three categories: objects that require attention as part of the driving task (both traffic control devices and other road users); objects that distract attention from the driving task (billboards, shopfronts and other non-driving-related signs); and objects that occlude vision. These comments implicitly recognise the important role of visual clutter in driver workload. The demand of the driving task is increased when there are more objects that must be attended in order to drive safely. Driver resources are diminished when attention is distracted by non-driving-relevant objects. Visually distracting objects, as well as objects that occlude vision, also impair visual selection.

Chapter 4: Taxonomy of clutter

The next chapter took the findings of the initial studies a step further, and proposed a taxonomy of visual clutter. Three types of visual clutter were described:

'Situational clutter', or traffic, includes all the moving objects on and next to the road that must be attended for safe driving (including pedestrians as well as other vehicles).

'Designed clutter', or signage, includes all those objects that road authorities use to communicate with the driver, such as road markings, traffic signs and signals; these items must also be attended for safe driving.

'Built clutter' includes all other potential sources of visual clutter: buildings and other infrastructure, shop signage, and advertising billboards. These objects may distract attention from the driving task and/or make the background visually complex.

The taxonomy was validated against subjective ratings of visual clutter. Video clips were used instead of static photographs in order to check whether a dynamic environment had any effect. A balanced factorial design was used in order to ascertain the relative effect of each type of clutter and any potential interactions. In addition, the factors of age and inexperience were investigated by specifically including a group of young novice drivers and a group of elderly drivers as well as a group of control drivers. To the author's knowledge, this is the first study to systematically manipulate different potential sources of visual clutter, and the first to use dynamic rather than static stimuli.

All three types of visual clutter specified in the proposed taxonomy increased subjective ratings of visual clutter by drivers watching video clips. Other vehicles (situational clutter) had the largest effect. Drivers did not change their ratings over time very much in the short clips used (10 seconds); when they did, it was mainly in response to the vehicles' speed (and the rate of information flow) rather than to any change in the built environment.

The effect of combining different types of visual clutter does not seem to be simply additive. At low levels of clutter, adding more clutter has more effect, whereas at high levels, it seems there is a 'ceiling effect'. However it is possible that this effect is an artifact of the subjective rating scale used.

There were some interesting interactions between the factors of age and experience, and the type of clutter which increased ratings most. However it is difficult to interpret effects of different driver groups on subjective ratings as subjective estimates of driver ability may be confounded with ratings of the environment.

A particularly interesting finding was that some participants used the lowest rating when the vehicle was stopped, explaining that when they were not moving they did not have to attend anything. This implies that drivers were interpreting the instruction to 'rate the level of visual clutter' as something more like 'rate how difficult it would be to drive with the visual workload imposed by this environment'. This adds further weight to the results of the focus group which also implied that driver workload was an important factor in visual clutter, as well as the subjective ratings from the photograph study.

After this study, the understanding of visual clutter had progressed to a point where it was possible to perform more formal experiments exploring the effect of visual clutter on visual perception and driving performance.

Chapter 5: Effect on change blindness

The first dependent variable explored was drivers' ability to detect changes between two rapidly alternating road scenes. This paradigm has previously been used to explore differences between novices and experts, as well as to determine which objects are noticed first in naturalistic scene scanning. In terms of driving subtasks, change detection is necessary for hazard perception and maintaining situation awareness.

As in the video ratings study, the design used was a balanced factorial design allowing comparison of, and investigation of interactions between, the three types of clutter. Unfortunately it proved too difficult to adequately manipulate the level of situational clutter in static photographs so this variable was dropped from the final analysis. Age and experience of the driver was a between subjects factor. Changes to cars and changes to signs were both explored. A subset of the scenes contained billboards to investigate whether these have an effect over and above the level of built visual clutter.

The results showed that participants took longer to detect changes in scenes with high built clutter and/or high designed clutter. Subjective ratings of visual clutter are now linked to effects on visual performance through the taxonomy of visual clutter sources. The same characteristics which lead to road scenes being rated as high in visual clutter lead to slower change detection. The interaction between levels of different sorts of clutter that appeared in the video ratings study also appeared in the change detection results: adding one sort of clutter when both are low has a greater effect than adding one sort of clutter when the other is high.

Changes to vehicles were detected faster that changes to road signs. This is consistent with both the conspicuity literature (vehicles are larger than signs, therefore more conspicuous, and therefore noticed earlier) and the change detection literature (vehicles are of greater interest to drivers, and therefore are visually explored earlier). Also consistent with this is that designed clutter (i.e. multiple signs) did not affect the time to detect vehicles.

Built clutter and designed clutter both significantly increased the time taken to detect changing signs, which is consistent with the general visual search literature and the studies which have specifically investigated visual search for road signs in cluttered environments.

Built clutter also increased the time taken to detect changing vehicles. This cannot be explained as the result of similar items distracting attention from the searched-for object. The literature review suggested that visual clutter and highly complex backgrounds can impair the visual selection of relevant objects, and these results confirm this supposition. It is an important finding that the level of built clutter in the environment can delay the detection of a change as large as the appearance and disappearance of a vehicle by half a second. A vehicle travelling at 70km/hr travels 10 metres or two car lengths in this period of time; so it is entirely possible that the level of built visual clutter in a road environment could affect the number of near misses and even collisions.

Older drivers were slower to detect changes in road scenes, particularly for changes to road signs and in scenes with high levels of built and designed clutter.

These results are consistent with previous research. However probationary drivers were no slower than experienced drivers. This may have been because this group were younger than other participants and therefore had faster cognitive processing; or it may have been because the lack of a driving task in this experiment meant they were able to devote resources to the scanning task that would normally be occupied by vehicle control.

Billboards increased time to detect changes, particularly for scenes with high levels of built or designed clutter. The combined effect of designed clutter and billboard presence was particularly damaging when the changing object was a road sign. This implies that drivers are likely to have particular difficulty in following directions on traffic signs in road environments which have multiple traffic control devices as well as roadside advertising.

Chapter 6: Effect on driving performance

The final experiment in the present series used the MUARC Advanced driving simulator to investigate the effects of billboards and lead vehicles (forms of built and situational clutter) on visual behaviour, vehicle control and responses to traffic signs and signals.

Subjective ratings of visual clutter confirmed the results of previous experiments: the presence of billboards, vehicles, and road signs increased rated clutter. However, overall ratings were low. Subjective ratings of workload were also low. The presence of lead vehicles was expected to increase driver workload, however results showed that drivers experienced slightly less workload when following a lead vehicle than when attempting to maintain a constant speed on an empty road. More vehicles which interact more with the participant's vehicle are presumably necessary in order to increase driver workload (as suggested by participants in the focus group study).

In the presence of billboards, participants drove more slowly, took longer to change lanes in response to road signs, and made more errors when changing lanes. These results are in agreement with results found by other studies on distraction by auditory and visual in-vehicle tasks, and suggest that billboards, like in-vehicle sources of distraction, should be considered potentially harmful to safe driving performance.

Billboards increased the proportion of time spent looking at roadsides for some drivers, and for all drivers decreased the amount of time looking at the road ahead and lead vehicles when present. These results are consistent with some previous studies of billboards and eye movements (Lee et al., 2007), although not with others (Lee et al., 2003). Previous studies have found greater effects for electronic billboards which frequently change (Beijer et al., 2004). However, the present study found significant effects using static billboards and billboards that changed only once during the period in which they were visible. This may be because of the relatively monotonous nature of the simulated environment; although an industrial environment was simulated rather than a low-clutter rural or residential scene, the simulated visual environment becomes repetitive fairly quickly. Thus these results are likely to generalise best to low-clutter highways and freeways, rather than more crowded urban environments.

The lack of any significant effect on responses to traffic signals could be due to low power, or to the relatively high salience of traffic signals relative to traffic signs. To differentiate between these possibilities would require a further experiment involving a larger number of intersections and/or a larger number of participants. Unfortunately neither option was possible within the constraints of the present PhD work; however the PhD experiment provides a framework for a potential future experiment examining these possibilities.

Individual factors were important in moderating the effects of billboards. Older drivers made more lane change errors overall, but particularly when billboards were present. Drivers who were instructed to report billboards spent less time looking at lane change signs and more time looking at billboards than the group who received normal instructions. This resulted in an even greater delay in the time taken to change lanes, and an increase in the number of signs which were not followed correctly.

It should be noted that the billboards used in this study were much simpler than those found on roadsides today. These more conspicuous, more complicated billboards are likely to hold drivers' attention for longer, which increases the probability of adverse effects on driving performance.

Overall summary

Prior to the present work, only a handful of disjointed papers had investigated the effects of visual clutter in the road environment on driving performance. There was no description or definition of visual clutter in the road environment, and no theoretical framework to explain why visual clutter might have an effect.

The present thesis suggests that sources of visual clutter in the road environment can be divided into built clutter, designed clutter, and situational clutter. Higher numbers of objects which fall into these categories impair visual selection, including the ability to detect changes in a scene. This has flow-on effects for driving performance, including speed maintenance and the ability to follow directions on traffic signs. Older drivers are particularly affected by visual clutter in road environments.

Limitations of the thesis

Initially it was hoped that the PhD work might supersede the current method of rating visual clutter by using a pilot group to rate or rank images of scenes. Although the taxonomy of sources of visual clutter is a step in the right direction, it was not possible to develop a scale of visual clutter which can be used by a single operator to rate real road scenes. It is hoped that the checklist below (see Implications for road safety practitioners) will provide some guidance to those who seek to rate levels of visual clutter, whether for research or road design purposes.

Although situational clutter was found to be a significant (indeed, the largest) contributor to subjective ratings of the level of visual clutter, it proved difficult to manipulate this factor both in the change detection experiment and the driving simulator experiment. This is an unfortunate gap, as interactions with other vehicles are likely to make up a large amount of the driver's workload. However future research could build on the work presented here and use an alternative way of manipulating the level of situational clutter.

The present work was unable to properly investigate the new technology of full-motion, full-colour dynamic billboards. However as the conclusions above apply to simple static billboards, and the literature on visual attention suggests that colour and motion add to the conspicuity of an object, the same conclusions are likely to apply even more strongly to dynamic billboards.

Ideally, the driving simulator experiment would have investigated responses to hazards as well as traffic control devices. Unfortunately time and budget constraints prevented including such events in the programming for the experiment.

The driving simulator itself suffers from the problem of all computer-generated environments, in that it is less rich and varied than a real-world environment both because of the computing power required to display moving graphics in such a way that the observer feels like they are driving, and because of the simple fact that the scene is projected at a constant distance onto a two-dimensional surface. This visual sparseness may mean that some of the visual cues which would normally guide eye movements are missing.

In addition to the potential differences in visual behaviour between the simulator and actual road environments, workload in the driving simulator may be lower than when driving through complicated, non-repetitive urban visual environments and interacting with unpredictable human drivers. It is difficult to see how the problems of a sparse visual environment in a driving simulator can be avoided, and thus perhaps photographs and videos of real roads are more appropriate for the investigation of visual clutter. It should be noted however that despite the relatively low-clutter nature of the visual environment in the simulator, the effects of billboards observed in this experiment are consistent with the results of the change detection experiment.

Implications for research

Contributions to knowledge

This thesis has drawn together strands of previous research from the disparate domains of applied vision, cognition, ergonomics, and driver distraction, and moulded a coherent theory of how qualities of the visual environment can affect driving performance.

Visual clutter is more than the impairments to visual search found in previous research (Ho et al., 2001; Jenkins & Cole, 1982; McPhee et al., 2004). Visual clutter can involve objects that are similar to search targets, objects that are more conspicuous than search targets, complex and disorganised backgrounds, or excessive levels of information. All of these characteristics will have the effect of impairing selection and processing of visual information, as explained in chapter 2.

The present research locates visual clutter as a source of disturbance in the continuous control loop of the driving task. It explains which of the many subtasks involved in driving are likely to be affected by visual clutter, and at what level of the driving hierarchy these tasks fall. While these were predictable from the literature (once brought together), the present series of experiments showed the progression from impairment of visual perception to effects on vehicle control and responses to traffic control devices. Previous research has only concentrated on one level of performance (such as visual behaviour, or lab responses, or crash rates), whereas the present research tracks the pathway by which visual clutter impairs driving performance.

The taxonomy of visual clutter itself, although of more practical implications, also makes a contribution to theory in that it recognises the important role of driver workload as a mediating variable between visually cluttered environments and driving performance.

The inclusion of workload in the model is vital, as it allows the theoretical framework to move away from examining the low-level visual effects of characteristics of two-dimensional scenes, to examining the dynamic interaction between a driver and the road environment. This broader framework enables the concept of 'visual clutter' to include not only background objects and textures, but objects that are part of the driving task itself, and objects that distract (visual and cognitive) attention from the driving task. The author believes that this new, broad conception of visual clutter makes the theoretical background advanced here of greater usefulness for both practical applications and further research.

For example, much research in road safety is currently focussed on the impact of in-vehicle technologies. The concern is that these new technologies could increase driver workload and distract the driver's gaze and attention away from the road at critical points (see e.g. Sheridan, 2004; Young, Regan, & Hammer, 2003). The present work shows that sources of workload and visual distraction **outside** the vehicle should also be considered. Although it was not possible to evaluate other forms of visual clutter in the driving simulator, the present work showed that billboards have an effect on driving performance similar to visual demand created by in-vehicle technologies (Engstrom et al., 2005).

The thesis also investigated individual differences that may interact with visual clutter. The literature reviewed in chapter 2 suggested that the driving performance of both inexperienced and older drivers might be particularly impaired by visually cluttered environments. These factors were examined as part of the study of subjective ratings of the taxonomy of visual clutter (to determine whether these groups experienced visual clutter differently to other drivers), and in terms of performance on a visual change detection task and in the driving simulator. There was little effect for inexperienced drivers, however older drivers were, as expected, more affected by visual clutter.

The thesis also makes methodological contributions. Driving simulators, although useful for many tasks, are not ideal for the study of visual clutter. Instead it is preferable to use stimuli derived from actual road environments such as photographs and video footage. The change blindness 'flicker' technique is one such method which lends itself to using such stimuli, and which could profitably be used in a number of further experiments.

<u>Further research</u>

There have already been a number of studies on the effect of multiple signs (e.g. Castro et al., 2004; Cloete, 2006; Jamson, Tate, & Jamson, 2005; King, Sneed, & Schwab, 1991; Sprenger et al., 1997). Future research could concentrate on the effects of situational clutter and of billboards, as these have been explored in less detail.

Several potential approaches for future research on billboards were outlined at the end of Chapter Six. Another important point that the present research did not cover is the effect of billboard content. The literature on information theory shows that the more information conveyed by a sign, the longer it will take to be processed (e.g. Liu, 2005). This increases the potential for distraction (du Toit & Coetzee, 2001); however further research specific to advertising (or other non-driving-related signs) rather than traffic signs would consolidate this finding. Another facet of content that has so far received little research is that of emotional content. Most et al (2005) found that emotional images caused an attentional blink during rapid serial visual presentation of images, and suggested that this could be a problem when images that evoke an emotional reaction are placed on billboards. More applied research is needed to confirm whether this finding for simple responses in a lab-based task translates into an effect on real-world driving performance, although the results of the present research suggest that this is highly likely.

Exploring situational clutter in static scenes has proved difficult. It is suggested that future research should use dynamic stimuli, which better convey the workload induced by the surrounding vehicles even if no driving task is included. An alternative to counting the number of vehicles present in each stimulus would be to use a metric such as the average daily traffic count through the road, where available.

One potential avenue for studying both topics would be the use of an instrumented vehicle to investigate effects on driving performance. This would be the most valid test of driving performance as it would involve the full driving task as well as actual driving environments. Unlike with studies of new in-vehicle technologies, ethical concerns are unlikely to prevent an on-road study as people drive through these environments at the moment, and yet there is no body of knowledge of the effects of such environments on real-world driving performance.

Implications for road safety practitioners

The three sources of visual clutter described in the thesis – built, designed, and situational clutter – should be taken into account when designing and regulating roadscapes. When deciding whether to place a new traffic sign or approve roadside advertising, practitioners may find the following checklists useful:

Table 23. Checklist for built clutter

Development
Scenes with shops and high buildings are rated as more cluttered, and are harder to detect changes in.
Is the road next to commercially zoned land?
Are there currently (or likely to be in future) shops facing on to the road?
Are there currently (or likely to be in future) tall buildings next to the road?
Complexity
Complex scenes are rated more cluttered, and make visual search more difficult.
Is there any other infrastructure such as overhead wires, bridges, and multiple poles that might create a visually complex background?
Advertising
Billboards increase time to detect changes and respond to road signs.
Is there existing roadside advertising near the proposed location for the new sign?

Table 24. Checklist for designed clutter

Number of existing TCDs
More than three in one scene, or five in a ten-second drive, increase clutter ratings and time to detect changes.
How many traffic control devices are visible in the range where the new sign is expected to be read?
Amount of text
More information to read and process increases visual distraction.

Are drivers asked to read a great deal of text (e.g. sorting through multiple destinations)?

Does the location require reserve capacity to be left for important messages (e.g. tunnel ahead closed/extended shopping hours for December/etc…)?

Driver response

Signs which require a response induce higher workload.

Are drivers asked to make decisions (e.g. time limited regulations, choosing the correct lane for a particular destination)?

Does the location contain warning signs for hazards that are not visible from other cues, such as traffic lights or merging lanes concealed by a curve, bridge or crest?

Table 25. Checklist for situational clutter

Number of vehicles

More vehicles increase clutter ratings and workload.

What is the traffic volume for the road?

How often is it near capacity?

Workload

Interactions such as overtaking and merging increase driver workload.

Are there multiple lanes?

Are there different types of vehicles (e.g. cars, buses, trucks, cyclists) which may travel at different speeds and require extra manoeuvres from drivers?

Are there parking bays along the side of the road with cars reversing in and exiting frequently?

The three types of clutter should be considered in combination with each other and with other sources of workload in the road environment. For example, a road with multiple lanes and high traffic volumes but low roadside development may be an acceptable location for roadside advertising – but not if placed just before a sharp bend concealing traffic lights or merging lanes.

The finding that billboards can impair change detection regardless of the level of built clutter, and impair responses to traffic signs in the relatively low-clutter road environment of the driving simulator, suggests that these objects should be carefully regulated. Road authorities are justified in using information theory approaches and restriction distances around areas of high driver workload (such as intersections, merges and freeway exits) in order to ensure that the safety of road users is not compromised.

The finding that older drivers have difficulty detecting changes and following instructions on road signs in cluttered environments is particularly important, as an increasing proportion of Australia's population is moving into the over-65 age group, and an increasing fraction of this age group now hold licences. Road environments should therefore be designed so as not to disadvantage this growing group. This may require increased spacing between points which demand driver attention (e.g. complex signage, merges, billboards), removal of excess signage, and/or advance warning of hazardous situations with 'priming' road signs (Charlton, 2006).

Conclusion

This work is particularly timely due to the proliferation of both traffic signs and billboards, new advertising technologies such as full-motion, full-colour billboards, an increasing proportion of drivers aged over 65 years and a developing interest (from both a practical and academic perspective) in the problem of driver distraction.

The issue of visual clutter in road environments has been ignored and fragmented into parts for too long, and the present work has, for the first time, drawn these issues into a theoretical framework which allows prediction of effects. It is hoped that the understanding of visual clutter provided by this work is of use to both researchers and road safety practitioners.

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Appendix A - Focus group questions

These questions were used for the focus group discussions reported in Chapter 3.

1. What do you think visual clutter is?

1.a) What are the most common forms of clutter in the driving environment?

2. What effects do you think visual clutter in the road environment has on your driving?

3.a) I'm going to show you a photograph of a road scene, and I would like you to tell me what grabs your attention first.

b) Would you describe this scene as cluttered?

- Why is it cluttered?
- If you took some objects out of the scene, would it still be cluttered?
- Which objects? (*prompt if necessary: cars, buildings, signs, trees, shop displays…)*

c) Would you be able to easily find a street sign in this scene?

- What about potential hazards like pedestrians?

d) Imagine you are driving down this road. Would you be distracted by anything in this scene?

4. a) Now I'm going to show another photograph. Again, please tell me what grabs your attention first.

b) Would you describe this scene as cluttered?

- What is it about this scene that makes it not cluttered?
- What are the important differences between this scene and the previous scene?

c) Would you be able to easily find a street sign in this scene?

- What about potential hazards like pedestrians?

d) Imagine you are driving down this road. Would you be distracted by anything in this scene?

Appendix B – Demographic Questionnaire

You do not have to answer these questions, but it would be helpful to us if you do.

Are you: □ male or □ female?

What is your age? …..…………..years

For how long have you held a full driving licence? ……………..years (/months for probationary drivers)

What sort of licence do you hold?…………………………………..

Please estimate about how many kilometres you drive each year, on average (a rough guess is fine):…………………….

For the video rating study (chapter 4), the change detection experiment (chapter 5) and the driving simulator experiment (chapter 6) the following guide to estimating yearly mileage was included:

1. Estimate how many kilometres you drive per week:……………………………km

2. How many weeks you would drive this pattern (to work or uni):………………wks

3. Multiply the above:………………………………………………………………..

4. Estimate the approximate number of kilometres that

you drive while on holidays (total for the year):……………………….km

5. Add answers 3 & 4 to find your total mileage:…………………….……. km/year.

If you don't want to do the calculations that's fine, but please fill in 1, 2 and 4 so that I can. Thanks!

For the video rating study (chapter 4), the following scale was added to determine familiarity with the roads used:

Are you familiar with any of the following roads:

Road name, Suburb name	No	A little	Fairly	Very

Appendix C - Full Statistics from Chapter 6

This appendix contains the full statistical analyses performed on the data from the driving simulator experiment reported in Chapter Six. The results listed here are not interpreted, as all results of pertinence to the hypotheses of the experiment were discussed in chapter 6. However they are included here for the sake of completeness.

Variable names:

'Group' refers to whether the participant was a probationary, fully licensed or older driver.

'Instruct' refers to whether the participant was instructed to report billboards, or just instructed to drive as they normally would.

'Vehicles' refers to the presence or absence of lead vehicles.

'Billboard' refers to whether the scene contained no billboard, a static billboard, or a dynamic billboard. For some analyses these levels are collapsed into scenes with billboards vs. scenes without billboards.

Analysis of variance (repeated measures) is used for continuous data; chi-square for discrete data.

1. Methodological checks

1.1 Responses to billboards for the group instructed to report billboard content

Test for diffs between static & dynamic bbs

Chi-square tests for differences between groups revealed that both the probationary and older drivers reported billboards less accurately than the control group of fully licensed drivers.

Group	% correct	χ^2	N	p	Odds ratio	95% CI for odds ratio
Probationary	89	8.42	1344	<.01	0.53	0.34-0.82
Control	91					
Older	82	23.09	1344	<.001	0.45	0.32-0.63

There was no difference in the number of billboards reported correctly between drives with and without lead vehicles, χ^2 (1, N=2016) = 1.181, p = .277, odds ratio = 0.85 (95% confidence interval for odds ratio = 0.64 - 1.14).

1.2 Workload

Participants rated their workload once after each drive, so it was not possible to compare the effect of billboards during the drives.

Source	***df***	***F***	***p***	η^2
	Between subjects			
group	2	5.48	.01	.21
instruct	1	8.15	.01	.16
group * instruct	2	2.40	.10	.10
Error	42			
	Within subjects			
vehicles	1	6.03	.02	.13
vehicles * group	2	0.80	.46	.04
vehicles * instruct	1	1.81	.19	.04
vehicles * group * instruct	2	0.80	.46	.04
Error(vehicles)	42			

Means for age/experience group:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
probationary	51.14	3.59	43.89	58.39
full	34.35	3.59	27.10	41.60
older	41.93	3.59	34.68	49.18

Dunnett's T-test for effect of group:

Comparison	**Mean Difference**	**Standard Error**	**Sig.**	**95% Confidence Interval**	
				Lower Bound	Upper Bound
Probationary vs. fully licensed	16.79	5.08	<.01	5.16	28.42
Older vs. fully licensed	7.58	5.08	.24	-4.05	19.21

Means for instruction groups:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
normal instructions	36.55	2.93	30.63	42.47
report billboards	48.40	2.93	42.48	54.32

Means for drives with and without lead vehicles:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
lead vehicles	40.81	2.20	36.37	45.24
no vehicles	44.14	2.17	39.77	48.52

1.3 Ratings of visual clutter

The initial analysis used only scenes without billboards. It was not possible to include the billboard factor in this analysis as there were no scenes containing billboards which did not also contain either a lane change sign or an intersection. The point of this analysis was to ascertain whether lane change signs and/or intersections increased clutter ratings relative to road scenes without either. 'Object' refers to whether the scene contained only road, or a lane change sign or intersection.

Source	*df*	*F*	*p*	η^2
Between subjects				
group	2	2.00	.15	.09
instruct	1	0.08	.78	.00
group * instruct	2	0.08	.93	.00
Error	41			
Within subjects				
vehicles	1	35.52	<.001	.46
vehicles * group	2	2.02	.14	.09
vehicles * instruct	1	2.39	.13	.06
vehicles * group * instruct	2	0.61	.55	.03
Error(vehicles)	41			
object	2	91.66	<.001	.69
object*group	4	9.46	<.001	.31
object*instruct	2	0.25	.78	.01
object*group*instruct	4	0.55	.70	.03
Error(object)	82			
vehicles*object	2	7.68	.001	.16
vehicles*object*group	4	2.06	.09	.09
vehicles*object*instruct	2	0.38	.69	.01
vehicles*object*group*instruct	4	0.63	.65	.03
Error(vehicles*object)	82			

Within-subject contrasts for object:

Source	*df*	*F*	*p*	η^2
lane change sign vs. road alone	1	72.90	<.001	.64
Intersection vs. road alone	1	115.47	<.001	.74

Means for road scenes with different objects:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Road alone	2.77	0.22	2.34	3.21
With lane change sign	3.68	0.23	3.22	4.14
With intersection	4.47	0.24	3.97	4.96

Means for road scenes with different objects, split by age/experience group:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
		Probationary drivers		
Road alone	2.50	0.37	1.75	3.25
With lane change sign	3.78	0.39	3.00	4.56
With intersection	5.22	0.42	4.38	6.06
		Fully licensed drivers		
Road alone	3.28	0.37	2.53	4.03
With lane change sign	4.13	0.39	3.34	4.91
With intersection	4.75	0.42	3.91	5.59
		Older drivers		
Road alone	2.54	0.38	1.76	3.31
With lane change sign	3.13	0.40	2.32	3.94
With intersection	3.43	0.43	2.56	4.30

Means for road scenes with different objects with and without lead vehicles:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
		Lead vehicles		
Road alone	2.22	0.23	1.75	2.70
With lane change sign	3.19	0.27	2.65	3.74
With intersection	3.67	0.29	3.09	4.25
		No vehicles		
Road alone	3.32	0.24	2.83	3.81
With lane change sign	4.17	0.23	3.70	4.64
With intersection	5.26	0.26	4.73	5.80

The second analysis included scenes with lane change signs and intersections for each drive with and without billboards. It was not possible to compare static and dynamic billboards as participants rated static frames from the simulation.

'Object' refers to whether the scene contained a lane change sign or an intersection.

'Billboard' refers to whether the scene contained a billboard or not.

Source	***df***	***F***	***p***	**η^2**
Between subjects				
age/exp group	2	3.04	.06	.13
instruct	1	0.57	.46	.01
age/exp group * instruct	2	0.47	.63	.02
Error	41			
Within subjects				
vehicles	1	25.55	<.001	.38
vehicles * group	2	0.06	.95	.00
vehicles * instruct	1	0.95	.34	.02
vehicles * group * instruct	2	0.18	.83	.01
Error(vehicles)	41			
object	1	74.81	<.001	.65
object*group	2	3.30	.05	.14
object*instruct	1	0.00	.97	.00
object*group*instruct	2	1.19	.31	.06
Error(object)	41			
billboard	1	154.67	<.001	.79
billboard * group	2	1.05	.36	.05
billboard * instruct	1	2.35	.13	.05
billboard * group * instruct	2	3.46	.04	.14
Error(billboard)	41			
vehicles*object	1	48.41	<.001	.54
vehicles*object*group	2	0.86	.43	.04
vehicles*object*instruct	1	0.38	.54	.01
vehicles*object*group*instruct	2	1.92	.16	.09
Error(vehicles*object)	41			
vehicles * billboard	1	16.32	<.001	.28
vehicles * billboard * group	2	5.14	.01	.20
vehicles * billboard * instruct	1	3.37	.07	.08
vehicles * billboard * group * instruct	2	0.71	.50	.03
Error(vehicles*billboard)	41			
object * billboard	1	0.07	.80	.00
object * billboard * group	2	5.37	.01	.21
object * billboard * instruct	1	0.72	.40	.02
object * billboard * group * instruct	2	0.44	.65	.02
Error(object*billboard)	41			
vehicles * object * billboard	1	4.32	.04	.10
vehicles * object * billboard * group	2	2.16	.13	.10
vehicles * object * billboard * instruct	1	2.98	.09	.07
vehicles * object * billboard * group * instruct	2	0.26	.77	.01
Error(vehicles*object*billboard)	41			

Means for age/experience group:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
probationary	5.27	0.37	4.53	6.01
full	5.03	0.37	4.29	5.77
older	4.04	0.38	3.27	4.81

Dunnett's T-test for effect of group:

Comparison	Mean Difference	Standard Error	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
Probationary vs. fully licensed	1.23	.53	.05	.03	2.44
Older vs. fully licensed	.99	.53	.12	-.22	2.20

Means for instruction groups:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
normal instructions	4.62	0.31	4.00	5.24
report billboards	4.94	0.30	4.34	5.55

Means for drives with and without lead vehicles:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
lead vehicles	4.31	0.25	3.81	4.81
no vehicles	5.25	0.22	4.81	5.70

Means for scenes with different objects:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lane change sign	4.40	0.22	3.96	4.84
Intersection	5.16	0.22	4.72	5.61

Means for scenes with and without billboards:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
With billboards	4.07	0.23	3.61	4.54
Without billboards	5.49	0.21	5.06	5.92

Means at smallest cell size (not collapsed across any variables):

Groups	Within-subjects factors	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Probationary, normal instructions					
	No vehicles				
	Lane change sign				
	Billboard	3.25	.65	1.93	4.57
	No billboard	6.00	.60	4.78	7.22
	Intersection				
	Billboard	4.25	.69	2.85	5.65
	No billboard	5.88	.63	4.61	7.14
	Lead vehicles				
	Lane change sign				

Billboard	4.38	.56	3.24	5.51
No billboard	5.63	.57	4.48	6.77
Intersection				
Billboard	6.13	.64	4.84	7.41
No billboard	6.63	.60	5.42	7.83
Probationary, report billboards				
No vehicles				
Lane change sign				
Billboard	3.13	.65	1.81	4.45
No billboard	5.63	.60	4.41	6.84
Intersection				
Billboard	4.00	.69	2.60	5.40
No billboard	6.00	.63	4.73	7.27
Lead vehicles				
Lane change sign				
Billboard	4.38	.56	3.24	5.51
No billboard	5.50	.57	4.36	6.64
Intersection				
Billboard	6.50	.64	5.21	7.79
No billboard	7.13	.60	5.92	8.33
Fully licensed, normal instructions				
No vehicles				
Lane change sign				
Billboard	3.25	.65	1.93	4.57
No billboard	4.63	.60	3.41	5.84
Intersection				
Billboard	4.25	.69	2.85	5.65
No billboard	4.38	.63	3.11	5.64
Lead vehicles				
Lane change sign				
Billboard	4.38	.56	3.24	5.51
No billboard	4.63	.57	3.48	5.77
Intersection				
Billboard	5.25	.64	3.96	6.54
No billboard	5.88	.60	4.67	7.08
Fully licensed, report billboards				
No vehicles				
Lane change sign				
Billboard	3.75	.65	2.43	5.07
No billboard	6.19	.60	4.97	7.40
Intersection				
Billboard	3.88	.69	2.47	5.28
No billboard	6.13	.63	4.86	7.39
Lead vehicles				
Lane change sign				
Billboard	5.13	.56	3.99	6.26
No billboard	6.07	.57	4.92	7.21
Intersection				
Billboard	5.63	.64	4.34	6.91
No billboard	7.13	.60	5.92	8.33

Older, normal instructions				
No vehicles				
Lane change sign				
Billboard	3.14	.70	1.73	4.55
No billboard	4.29	.64	2.99	5.59
Intersection				
Billboard	3.00	.74	1.50	4.50
No billboard	4.57	.67	3.22	5.93
Lead vehicles				
Lane change sign				
Billboard	3.00	.60	1.78	4.22
No billboard	4.29	.60	3.07	5.51
Intersection				
Billboard	3.71	.68	2.34	5.09
No billboard	6.14	.64	4.85	7.43
Older, report billboards				
No vehicles				
Lane change sign				
Billboard	2.63	.65	1.31	3.95
No billboard	3.88	.60	2.66	5.09
Intersection				
Billboard	2.63	.69	1.22	4.03
No billboard	4.75	.63	3.48	6.02
Lead vehicles				
Lane change sign				
Billboard	3.75	.56	2.61	4.89
No billboard	4.75	.57	3.61	5.89
Intersection				
Billboard	4.38	.64	3.09	5.66
No billboard	5.75	.60	4.55	6.96

2. Responses to vehicles signs and signals

2.1 Yielding behaviour at amber signals

Instances in which the driver crossed an intersection yield line while the traffic light was red were recorded as failures to yield.

Crosstabulation: Billboard type by whether participant stopped at intersection

	Billboard			
	Control	Static	Dynamic	**Total**
Fail to yield	25	19	23	67
Yield	71	77	73	221
Total	96	96	96	288

Pearson $\chi^2(2, N = 288) = 1.09$, $p = .58$.

Static and dynamic billboards were collapsed into one variable: billboard present.

	Billboard		
	Billboard site	Control site	**Total**
Fail to yield	42	25	67
Yield	150	71	221
Total	192	96	288

Pearson $\chi^2(1, N = 288) = 0.622$, $p = .43$, odds ratio = 0.80, 95% confidence interval around odds ratio = 0.45 - 1.41.

Interaction between billboards and instructions:

	Billboard		
	Billboard site	Control site	**Total**
	Report billboards		
Fail to yield	28	17	45
Yield	68	31	99
Total	96	48	144
	Normal instructions		
Fail to yield	14	8	22
Yield	82	40	122
Total	96	48	144

Effect of billboard presence for each instruction group:

df = 1, N = 144 for all comparisons				**95% confidence interval for odds ratio**	
	χ^2	***p***	**Odds ratio**	Lower bound	Upper bound
Report billboards	0.58	.45	0.75	0.36	1.57
Normal instructions	0.11	.74	0.85	0.33	2.20

Interaction between billboards and age/experience group:

	Billboard		
	Billboard site	Control site	**Total**
	Probationary		
Fail to yield	15	7	22
Yield	49	25	74
Total	64	32	96
	Fully licensed		
Fail to yield	15	9	24
Yield	49	23	72
Total	64	32	96
	Older		
Fail to yield	12	9	21
Yield	52	23	75
Total	64	32	96

Effect of billboard presence for each age/experience group:

df = 1, N = 96 for all comparisons	χ^2	*p*	**Odds ratio**	**95% confidence interval for odds ratio** Lower bound	Upper bound
Probationary	0.03	.86	1.09	0.39	3.03
Fully licensed	0.25	.62	0.78	0.30	2.05
Older	1.10	.29	0.59	0.22	1.59

Interaction between billboards and vehicles:

	Billboard Billboard site	Control site	**Total**
	Lead vehicles		
Fail to yield	21	12	33
Yield	75	36	111
Total	96	48	144
	No vehicles		
Fail to yield	21	13	34
Yield	75	35	110
Total	96	48	144

Effect of billboard presence for each drive:

df = 1, N = 144 for all comparisons	χ^2	*p*	**Odds ratio**	**95% confidence interval for odds ratio** Lower bound	Upper bound
Lead vehicles	0.18	.67	0.84	0.37	1.89
No vehicles	0.48	.49	0.75	0.34	1.68

Higher-order interactions were not tested as this would reduce the expected cell value to an unacceptably low value.

Number of persons failing to yield per cell:

n per cell = 16 for 'billboard' = 8 for 'no billboard' N = 288.		Lead vehicles Billboard	No billboard	**No traffic** Billboard	No billboard
Probationary	Normal instructions	4	1	4	1
	Report billboards	2	2	5	3
Fully licensed	Normal instructions	0	0	0	0
	Report billboards	8	4	7	4
Older	Normal instructions	4	3	2	3
	Report billboards	3	2	3	2

2.2 Time to brake at red signals

Red signals were those in which the signal was red for the last 60m of approach to the intersection, and a stop was clearly required.

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	1.53	.22	.04
age/exp group	2	1.22	.31	.06
age/exp group * instruct	2	0.18	.84	.01
Error	41			
Within subjects				
vehicles	1	0.97	.33	.02
vehicles * instruct	1	0.18	.68	.00
vehicles * age/exp group	2	0.02	.98	.00
vehicles * age/exp group * instruct	2	0.64	.53	.03
Error(vehicles)	41			
billboard	2	1.11	.34	.03
billboard * instruct	2	0.90	.41	.02
billboard * age/exp group	4	0.84	.51	.04
billboard * instruct * age/exp group	4	0.85	.50	.04
Error(billboard)	82			
vehicles * billboard	2	0.74	.48	.02
vehicles * billboard * instruct	2	0.17	.85	.00
vehicles * billboard * age/exp group	4	0.71	.59	.03
vehicles * billboard * instruct * age/exp group	4	0.06	.99	.00
Error(vehicles*billboard)	82	0.97	.33	.02

The analysis was repeated using the time until time brake pressure >=10% of possible pedal depression.

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	2.42	.13	.06
age/exp group	2	7.84	.00	.29
age/exp group * instruct	2	0.69	.51	.04
Error	38			
Within subjects				
vehicles	1	1.35	.25	.03
vehicles * instruct	1	0.11	.74	.00
vehicles * age/exp group	2	0.55	.58	.03
vehicles * age/exp group * instruct	2	2.83	.07	.13
Error(vehicles)	38			
billboard	2	0.31	.73	.01
billboard * instruct	2	0.00	.00	.00
billboard * age/exp group	4	1.70	.16	.08
billboard * instruct * age/exp group	4	0.65	.63	.03
Error(billboard)	76			
vehicles * billboard	2	0.23	.80	.01
vehicles * billboard * instruct	2	0.91	.41	.02
vehicles * billboard * age/exp group	4	0.90	.47	.05
vehicles * billboard * instruct * age/exp group	4	0.71	.59	.04
Error(vehicles*billboard)	76	1.35	.25	.03

Means for age/experience group:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
probationary	5.70	0.31	5.07	6.33
full	4.48	0.34	3.80	5.16
older	4.02	0.30	3.41	4.63

Dunnett's T-test for effect of age/experience group:

Comparison	**Mean Difference**	**Standard Error**	**Sig.**	**95% Confidence Interval**	
				Lower Bound	Upper Bound
Probationary vs. full	-1.22	0.46	.02	-2.27	-0.17
Older vs. full	0.49	0.45	.45	-0.54	1.53

2.3 Time to change lanes when directed by a roadside sign

Source	*df*	*F*	*p*	η^2
Between subjects				
instruct	1	0.06	.80	.00
age/exp group	2	6.16	.00	.23
age/exp group * instruct	2	0.20	.82	.01
Error	42			
Within subjects				
vehicles	1	11.41	.00	.21
vehicles * instruct	1	0.32	.57	.01
vehicles * age/exp group	2	0.18	.84	.01
vehicles * age/exp group * instruct	2	0.67	.52	.03
Error(vehicles)	42			
billboard	2	35.03	.00	.45
billboard * instruct	2	6.87	.00	.14
billboard * age/exp group	4	2.85	.03	.12
billboard * instruct * age/exp group	4	2.12	.09	.09
Error(billboard)	84			
vehicles * billboard	2	4.51	.01	.10
vehicles * billboard * instruct	2	0.57	.57	.01
vehicles * billboard * age/exp group	4	0.40	.81	.02
vehicles * billboard * instruct * age/exp group	4	1.31	.27	.06
Error(vehicles*billboard)	84			

Highest level interactions are the two-way interactions between billboard type and each of the other factors.

Mean time to change lanes for sites with static, dynamic or no billboard, split by age/experience group:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Probationary drivers				
Control site	6.60	0.27	6.06	7.14
Static billboard	7.00	0.23	6.54	7.46
Dynamic billboard	6.83	0.27	6.28	7.37
Fully licensed drivers				
Control site	5.85	0.27	5.31	6.39
Static billboard	6.67	0.23	6.21	7.13
Dynamic billboard	6.68	0.27	6.13	7.22
Older drivers				
Control site	7.16	0.27	6.62	7.71
Static billboard	7.72	0.23	7.26	8.19
Dynamic billboard	7.87	0.27	7.33	8.42

Mean time to change lanes for sites with static, dynamic or no billboard, split by instruction group:

Comparison	Mean	Standard Error	95% Confidence Interval Lower Bound	Upper Bound
	Normal instructions			
Control site	6.67	0.22	6.23	7.12
Static billboard	6.99	0.19	6.61	7.37
Dynamic billboard	7.02	0.22	6.58	7.47
	Report billboards			
Control site	6.40	0.22	5.96	6.84
Static billboard	7.28	0.19	6.90	7.65
Dynamic billboard	7.23	0.22	6.78	7.67

Mean time to change lanes for sites with static, dynamic or no billboard with and without lead vehicles:

Comparison	Mean	Standard Error	95% Confidence Interval Lower Bound	Upper Bound
	Lead vehicles			
Control site	6.37	0.16	6.05	6.70
Static billboard	7.12	0.14	6.83	7.40
Dynamic billboard	6.88	0.15	6.57	7.19
	No vehicles			
Control site	6.70	0.17	6.36	7.03
Static billboard	7.15	0.15	6.85	7.45
Dynamic billboard	7.37	0.19	6.99	7.75

Despite the significant interaction between age/experience group and billboard type, for every billboard type fully licensed drivers changed lanes fastest, then probationary drivers, then older drivers. This is reflected in the significant main effect for age/experience group.

Mean time to change lanes for each age/experience group:

Comparison	Mean	Standard Error	95% Confidence Interval Lower Bound	Upper Bound
probationary	6.81	0.24	6.32	7.30
full	6.40	0.24	5.91	6.89
older	7.59	0.24	7.10	8.08

Dunnett's T-test for effect of age/experience group:

Comparison	Mean Difference	Standard Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Probationary vs. full	0.41	0.34	.39	-0.38	1.20
Older vs. full	1.19	0.34	.00	0.40	1.97

For all types of billboard, time to change lanes was shorter in the presence of lead vehicles, reflected in the significant main effect.

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lead vehicles	6.79	0.14	6.51	7.06
No traffic	7.07	0.16	6.76	7.39

Despite the interactions above, in all age/experience groups, both instruction groups and with or without lead vehicles, sites with billboards were associated with longer lane changes than control sites. This main effect was significant.

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Control site	6.54	0.16	6.22	6.85
Static billboard	7.13	0.13	6.86	7.40
Dynamic billboard	7.13	0.16	6.81	7.44

2.4 Number of incorrect lane changes

This analysis includes cases when the driver changed into the wrong lane, as well as cases where participants failed to change lanes within the segment of road 90m before passing the lane change sign to 50m after it.

Crosstabulation: Billboard type by whether participant changed lanes correctly

	Billboard			
	Control	Static	Dynamic	**Total**
incorrect lane	12	24	26	62
correct lane	372	360	358	1090
Total	384	384	384	1152

Pearson $\chi^2(2, N = 1152) = 5.86, p = .05$.

Static and dynamic billboards were collapsed into one variable: billboard present.

	Billboard		
	Billboard site	Control site	**Total**
incorrect lane	50	12	62
correct lane	718	372	1090
Total	768	384	1152

Pearson $\chi^2(1, N = 1152) = 5.76, p = .02$, odds ratio = 0.46, 95% confidence interval around odds ratio = 0.24 – 0.88.

Interaction between billboards and instructions:

	Billboard: Billboard site	Control site	Total
Report billboards			
incorrect lane	22	1	23
correct lane	362	191	553
Total	384	192	576
Normal instructions			
incorrect lane	28	11	39
correct lane	356	181	537
Total	384	192	576

Effect of billboard presence for each instruction group:

df=1, N = 576 for all comparisons	χ^2	*p*	**Odds ratio**	**95% confidence interval for odds ratio** Lower bound	Upper bound
Report billboards	9.06	<.01	11.61	1.55	86.78
Normal instructions	0.50	.48	1.29	0.63	2.66

Interaction between billboards and age/experience group:

	Billboard: Billboard site	Control site	Total
Probationary			
incorrect lane	7	1	8
correct lane	249	127	376
Total	256	128	384
Fully licensed			
incorrect lane	11	4	15
correct lane	245	124	369
Total	256	128	384
Older			
incorrect lane	32	7	39
correct lane	224	121	345
Total	256	128	384

Effect of billboard presence for each age/experience group:

df=1, N = 384 for all comparisons	χ^2	*p*	**Odds ratio**	**95% confidence interval for odds ratio** Lower bound	Upper bound
Probationary	1.60	.21	3.57	0.43	29.34
Fully licensed	0.31	.58	1.39	0.43	4.46
Older	4.62	.03	2.47	1.06	5.76

Interaction between billboards and vehicles:

	Billboard		
	Billboard site	Control site	**Total**
	Lead vehicles		
incorrect lane	21	2	23
correct lane	363	190	553
Total	384	192	576
	No vehicles		
incorrect lane	29	10	39
correct lane	355	182	537
Total	384	192	576

Effect of billboard presence for each drive:

df=1, N = 576 for all comparisons				**95% confidence interval for odds ratio**	
	χ^2	***p***	**Odds ratio**	Lower bound	Upper bound
Lead vehicles	6.54	.01	5.50	1.28	23.69
No vehicles	1.11	.29	1.49	0.71	3.12

Higher-order interactions were not tested as this would reduce the expected cell value to an unacceptably low value.

Number of lane change errors per cell:

n per cell = 64 for 'billboard' = 32 for 'no billboard' N = 1152.		**Lead vehicles**		**No traffic**	
		Billboard	No billboard	Billboard	No billboard
Probationary	Normal instructions	3	0	0	1
	Report billboards	1	0	3	0
Fully licensed	Normal instructions	0	0	6	4
	Report billboards	2	0	3	0
Older	Normal instructions	8	2	11	4
	Report billboards	7	0	6	3

3. Vehicle control (i.e. ability to maintain speed/headway during lane change task)

3.1 Mean speed in the 90m before passing each lane change sign

Source	*df*	*F*	*p*	η^2
Between subjects				
instruct	1	0.45	.50	.01
age/exp group	2	2.74	.08	.12
age/exp group * instruct	2	0.74	.48	.03
Error	42			
Within subjects				
vehicles	1	6.26	.02	.13
vehicles * instruct	1	0.00	.96	.00
vehicles * age/exp group	2	3.67	.03	.15
vehicles * age/exp group * instruct	2	0.91	.41	.04
Error(vehicles)	42			
billboard	2	7.88	.00	.16
billboard * instruct	2	2.63	.08	.06
billboard * age/exp group	4	0.55	.70	.03
billboard * instruct * age/exp group	4	0.13	.97	.01
Error(billboard)	84			
vehicles * billboard	2	4.45	.01	.10
vehicles * billboard * instruct	2	1.20	.31	.03
vehicles * billboard * age/exp group	4	0.74	.57	.03
vehicles * billboard * instruct * age/exp group	4	1.07	.38	.05
Error(vehicles*billboard)	84			

Highest significant interactions are between billboards and vehicles, and vehicles and age.

Mean speed for sites with static, dynamic or no billboard with and without lead vehicles:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lead vehicles				
Control site	65.57	0.34	64.88	66.26
Static billboard	65.35	0.40	64.54	66.16
Dynamic billboard	65.16	0.36	64.43	65.90
No vehicles				
Control site	68.11	0.56	66.98	69.24
Static billboard	66.01	0.62	64.76	67.25
Dynamic billboard	65.65	0.60	64.44	66.86

For all billboard and control sites and in all age groups, mean speed was lower in the presence of lead vehicles, reflected in the significant main effect.

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lead vehicles	65.36	0.26	64.85	65.88
No traffic	66.59	0.48	65.63	67.55

The significant main effect of billboards is not examined as it is subject to the above interaction – speeds during the lead vehicle drive were limited by the vehicles ahead so participants were not able to demonstrate the pattern of faster driving at control sites that they showed in the drive without lead vehicles.

Mean speed for probationary, fully licensed and older drivers, for drives with or without lead vehicles:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval** Lower Bound	Upper Bound
	Lead vehicles			
Probationary	64.97	0.44	64.08	65.86
Fully licensed	66.58	0.44	65.69	67.47
Older	64.53	0.44	63.64	65.42
	No vehicles			
Probationary	65.20	0.82	63.54	66.87
Fully licensed	66.93	0.82	65.26	68.59
Older	67.64	0.82	65.97	69.30

3.2 Standard deviation of speed in the 90m before passing each lane change sign

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.03	.87	.00
age/exp group	2	6.01	.01	.22
age/exp group * instruct	2	2.72	.08	.11
Error	42			
Within subjects				
vehicles	1	30.93	.00	.42
vehicles * instruct	1	0.00	1.00	.00
vehicles * age/exp group	2	0.58	.56	.03
vehicles * age/exp group * instruct	2	0.36	.70	.02
Error(vehicles)	42			
billboard	2	0.98	.38*	.02
billboard * instruct	2	0.48	.61*	.01
billboard * age/exp group	4	0.78	.54*	.04
billboard * instruct * age/exp group	4	1.12	.35*	.05
Error(billboard)	84			
vehicles * billboard	2	2.58	.09*	.06
vehicles * billboard * instruct	2	0.52	.57*	.01
vehicles * billboard * age/exp group	4	0.08	.98*	.00
vehicles * billboard * instruct * age/exp group	4	0.81	.51*	.04
Error(vehicles*billboard)	84			

*These p values have been modified using the Huynh-Feldt correction for significant non-sphericity for the variables billboard and vehicles by billboard.

No significant interactions. Significant main effects for age/experience group and presence of lead vehicles.

Standard deviation of speed for probationary, fully licensed and older drivers:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Probationary	0.23	0.02	0.20	0.27
Fully licensed	0.22	0.02	0.18	0.26
Older	0.31	0.02	0.27	0.34

Standard deviation of speed for drives with or without lead vehicles:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Lead vehicles	0.28	0.01	0.26	0.31
No traffic	0.22	0.01	0.20	0.25

4. Eye movements

4.1.1 Time to first fixate lane change sign

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.07	.80	.00
age/exp group	2	1.16	.32	.06
age/exp group * instruct	2	0.43	.65	.02
Error	36			
Within subjects				
vehicles	2	1.29	.26	.04
vehicles * instruct	2	0.67	.42	.02
vehicles * age/exp group	4	0.49	.61	.03
vehicles * age/exp group * instruct	4	1.33	.28	.07
Error(vehicles)	68			
billboard	2	2.19	.12	.06
billboard * instruct	2	3.09	.05	.08
billboard * age/exp group	4	2.34	.06	.12
billboard * instruct * age/exp group	4	3.91	.01	.19
Error(billboard)	68			
vehicles * billboard	2	0.11	.90	.00
vehicles * billboard * instruct	2	3.27	.04	.09
vehicles * billboard * age/exp group	4	1.27	.29	.07
vehicles * billboard * instruct * age/exp group	4	0.77	.55	.04
Error(vehicles*billboard)	68			

Highest significant interactions: vehicles * billboard * instruct; billboard * instruct * age/experience group. No lower significant effects.

Time to first fixate lane change sign for sites with static, dynamic or no billboard with and without lead vehicles in each instruction groups:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval** Lower Bound	Upper Bound
	Normal instructions			
Lead vehicles				
Control site	1.45	0.30	0.83	2.06
Static billboard	1.09	0.28	0.52	1.66
Dynamic billboard	1.59	0.31	0.96	2.22
No vehicles				
Control site	1.25	0.28	0.69	1.81
Static billboard	1.55	0.32	0.91	2.20
Dynamic billboard	2.11	0.30	1.50	2.73
	Report billboards			
Lead vehicles				
Control site	1.60	0.29	1.02	2.18
Static billboard	1.52	0.26	0.98	2.06
Dynamic billboard	1.57	0.29	0.98	2.17
No vehicles				
Control site	1.99	0.26	1.46	2.52
Static billboard	1.33	0.30	0.72	1.94
Dynamic billboard	1.50	0.28	0.92	2.08

Time to first fixate lane change sign for sites with static, dynamic or no billboard for probationary, fully licensed and older drivers in each instruction group:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval** Lower Bound	Upper Bound
	Probationary drivers			
Normal instructions				
Control site	1.93	0.42	1.08	2.77
Static billboard	1.74	0.42	0.88	2.60
Dynamic billboard	1.38	0.42	0.53	2.22
Report billboards				
Control site	1.56	0.45	0.65	2.47
Static billboard	1.08	0.46	0.15	2.01
Dynamic billboard	1.45	0.45	0.54	2.36
	Fully licensed drivers			
Normal instructions				
Control site	1.17	0.49	0.17	2.17
Static billboard	1.01	0.50	-0.01	2.02
Dynamic billboard	2.82	0.49	1.82	3.82
Report billboards				
Control site	2.43	0.42	1.58	3.27
Static billboard	1.82	0.42	0.96	2.68
Dynamic billboard	1.81	0.42	0.97	2.66
	Older drivers			
Normal instructions				
Control site	0.94	0.42	0.10	1.79
Static billboard	1.22	0.42	0.36	2.08
Dynamic billboard	1.36	0.42	0.52	2.21
Report billboards				
Control site	1.39	0.39	0.60	2.18
Static billboard	1.38	0.40	0.58	2.18
Dynamic billboard	1.34	0.39	0.55	2.13

4.1.2 Time to first fixate billboards versus lane change signs

This analysis included static and dynamic billboards and lane change signs at sites with billboards.

Source	*df*	*F*	*p*	η^2
Between subjects				
instruct	1	0.00	.98	.00
age/exp group	2	2.89	.07	.16
age/exp group * instruct	2	0.86	.43	.05
Error	31	0.00	.98	.00
Within subjects				
object	1	0.90	.35	.03
object * instruct	1	0.20	.66	.01
object * age/exp group	2	0.17	.85	.01
object * age/exp group * instruct	2	0.00	1.00	.00
Error(object)	31			
vehicles	1	3.78	.06	.11
vehicles * instruct	1	1.64	.21	.05
vehicles * age/exp group	2	0.75	.48	.05
vehicles * age/exp group * instruct	2	2.05	.15	.12
Error(vehicles)	31			
billboard	1	1.97	.17	.06
billboard * instruct	1	2.32	.14	.07
billboard * age/exp group	2	1.88	.17	.11
billboard * instruct * age/exp group	2	3.35	.05	.18
Error(billboard)	31			
object * vehicles	1	0.09	.77	.00
object * vehicles * instruct	1	1.71	.20	.05
object * vehicles * age/exp group	2	2.87	.07	.16
object * vehicles * instruct * age/exp group	2	0.01	.99	.00
Error(object*vehicles)	31			
object * billboard	1	2.28	.14	.07
object * billboard * instruct	1	0.03	.87	.00
object * billboard * age/exp group	2	1.91	.16	.11
object * billboard * instruct * age/exp group	2	3.81	.03	.20
Error(object*billboard)	31			
vehicles * billboard	1	0.11	.75	.00
vehicles * billboard * instruct	1	1.07	.31	.03
vehicles * billboard * age/exp group	2	0.59	.56	.04
vehicles * billboard * instruct * age/exp group	2	0.37	.69	.02
Error(vehicles*billboard)	31			
object * vehicles * billboard	1	0.00	.97	.00
object * vehicles * billboard * instruct	1	2.10	.16	.06
object * vehicles * billboard * age/exp group	2	1.90	.17	.11
object * vehicles * billboard * instruct * age/exp group	2	1.29	.29	.08
Error(object*vehicles*billboard)	31			

Highest significant interaction: object * billboard * instruct * age/experience group.

Time to first fixate billboards (static & dynamic) and lane change signs (opposite (static & dynamic billboards) for probationary, fully licensed and older drivers in each instruction group:

Comparison	**Mean**	**S.E.**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Probationary drivers				
Normal instructions				
Static billboard	1.62	0.36	0.89	2.36
Dynamic billboard	2.10	0.44	1.20	3.00
Lane change sign w static billboard	1.87	0.46	0.94	2.80
Lane change sign w dynamic billboard	1.43	0.46	0.49	2.36
Report billboards				
Static billboard	1.68	0.36	0.94	2.42
Dynamic billboard	1.57	0.44	0.67	2.47
Lane change sign w static billboard	1.08	0.46	0.15	2.01
Lane change sign w dynamic billboard	1.45	0.46	0.51	2.39
Fully licensed drivers				
Normal instructions				
Static billboard	1.59	0.40	0.78	2.40
Dynamic billboard	2.52	0.48	1.53	3.51
Lane change sign w static billboard	1.10	0.50	0.08	2.12
Lane change sign w dynamic billboard	3.02	0.50	1.99	4.04
Report billboards				
Static billboard	2.13	0.34	1.44	2.81
Dynamic billboard	1.80	0.41	0.97	2.64
Lane change sign w static billboard	1.82	0.42	0.96	2.68
Lane change sign w dynamic billboard	1.81	0.43	0.94	2.68
Older drivers				
Normal instructions				
Static billboard	1.28	0.40	0.47	2.09
Dynamic billboard	0.74	0.48	-0.24	1.73
Lane change sign w static billboard	0.80	0.50	-0.22	1.82
Lane change sign w dynamic billboard	1.14	0.50	0.12	2.17
Report billboards				
Static billboard	1.53	0.31	0.89	2.17
Dynamic billboard	1.53	0.38	0.75	2.31
Lane change sign w static billboard	1.38	0.39	0.57	2.18
Lane change sign w dynamic billboard	1.34	0.40	0.53	2.16

4.2 Proportion of time spent fixating on various objects/areas of the visual field

(in the 140m between the appearance of lane change signs/billboards and the driver passing the signs).

4.2.1 Billboards:

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	4.09	.05	.09
age/exp group	2	0.04	.96	.00
age/exp group * instruct	2	0.55	.58	.03
Error	42			
Within subjects				
vehicles	1	2.62	.11	.06
vehicles * instruct	1	8.11	.01	.16
vehicles * age/exp group	2	0.64	.53	.03
vehicles * age/exp group * instruct	2	0.53	.59	.02
Error(vehicles)	42			
billboard	1	2.78	.10	.06
billboard * instruct	1	2.88	.10	.06
billboard * age/exp group	2	0.82	.45	.04
billboard * instruct * age/exp group	2	0.87	.43	.04
Error(billboard)	42			
vehicles * billboard	1	0.09	.77	.00
vehicles * billboard * instruct	1	0.03	.87	.00
vehicles * billboard * age/exp group	2	0.51	.61	.02
vehicles * billboard * instruct * age/exp group	2	2.43	.10	.10
Error(vehicles*billboard)	42			

Highest significant interaction: vehicles by instruct.

Proportion of time spent fixating on billboards in drives with or without lead vehicles in each instruction group:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval** Lower Bound	Upper Bound
	Normal instructions			
Lead vehicles	0.10	0.01	0.08	0.11
No vehicles	0.07	0.01	0.06	0.09
	Report billboards			
Lead vehicles	0.10	0.01	0.08	0.12
No vehicles	0.11	0.01	0.09	0.12

4.2.2 Lane change signs:

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.16	.70	.00
age/exp group	2	2.09	.14	.09
age/exp group * instruct	2	0.05	.95	.00
Error	42			
Within subjects				
vehicles	1	0.05	.82	.00
vehicles * instruct	1	0.47	.50	.01
vehicles * age/exp group	2	1.37	.26	.06
vehicles * age/exp group * instruct	2	0.15	.86	.01
Error(vehicles)	42			
billboard	2	2.38	.10	.05
billboard * instruct	2	1.50	.23	.03
billboard * age/exp group	4	0.63	.64	.03
billboard * instruct * age/exp group	4	1.59	.18	.07
Error(billboard)	84			
vehicles * billboard	2	1.45	.24	.03
vehicles * billboard * instruct	2	0.20	.82	.00
vehicles * billboard * age/exp group	4	2.87	.03	.12
vehicles * billboard * instruct * age/exp group	4	1.21	.31	.05
Error(vehicles*billboard)	84			

Only significant interaction: vehicles * billboard * age/exp group.

Proportion of time spent fixating on lane change signs for probationary, fully licensed and older drivers in drives with or without lead vehicles at control sites, sites with static billboards, and sites with dynamic billboards:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval** Lower Bound	Upper Bound
Probationary drivers				
Lead vehicles				
Control site	0.08	0.01	0.06	0.11
Static billboard	0.09	0.01	0.07	0.12
Dynamic billboard	0.07	0.01	0.05	0.09
No vehicles				
Control site	0.09	0.01	0.07	0.12
Static billboard	0.07	0.01	0.05	0.10
Dynamic billboard	0.08	0.01	0.06	0.10
Fully licensed drivers				
Lead vehicles				
Control site	0.09	0.01	0.06	0.11
Static billboard	0.10	0.01	0.07	0.12
Dynamic billboard	0.07	0.01	0.05	0.09
No vehicles				
Control site	0.08	0.01	0.05	0.10
Static billboard	0.07	0.01	0.04	0.09
Dynamic billboard	0.08	0.01	0.06	0.10
Older drivers				
Lead vehicles				
Control site	0.11	0.01	0.08	0.13
Static billboard	0.08	0.01	0.05	0.11
Dynamic billboard	0.10	0.01	0.07	0.12
No vehicles				
Control site	0.12	0.01	0.10	0.15
Static billboard	0.11	0.01	0.08	0.13
Dynamic billboard	0.09	0.01	0.07	0.11

4.2.3 Billboards compared with lane change signs:

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.38	0.54	.01
age/exp group	2	0.29	0.75	.01
age/exp group * instruct	2	0.25	0.78	.01
Error	42			
Within subjects				
object	1	3.56	.07	.08
object * instruct	1	6.32	.02	.13
object * age/exp group	2	1.13	.33	.05
object * age/exp group * instruct	2	0.36	.70	.02
Error(object)	42			
vehicles	1	1.34	.25	.03
vehicles * instruct	1	2.63	.11	.06
vehicles * age/exp group	2	0.95	.40	.04
vehicles * age/exp group * instruct	2	0.59	.56	.03
Error(vehicles)	42			
billboard	1	3.86	.06	.08
billboard * instruct	1	0.77	.38	.02
billboard * age/exp group	2	0.24	.79	.01
billboard * instruct * age/exp group	2	3.24	.05	.13
Error(billboard)	42			
object * vehicles	1	0.97	.33	.02
object * vehicles * instruct	1	4.61	.04	.10
object * vehicles * age/exp group	2	0.80	.46	.04
object * vehicles * instruct * age/exp group	2	0.11	.90	.01
Error(object*vehicles)	42			
object * billboard	1	0.65	.43	.02
object * billboard * instruct	1	2.81	.10	.06
object * billboard * age/exp group	2	0.80	.46	.04
object * billboard * instruct * age/exp group	2	0.89	.42	.04
Error(object*billboard)	42			
vehicles * billboard	1	1.95	.17	.04
vehicles * billboard * instruct	1	0.00	.95	.00
vehicles * billboard * age/exp group	2	2.76	.07	.12
vehicles * billboard * instruct * age/exp group	2	0.08	.93	.00
Error(vehicles*billboard)	42			
object * vehicles * billboard	1	0.68	.41	.02
object * vehicles * billboard * instruct	1	0.03	.86	.00
object * vehicles * billboard * age/exp group	2	3.36	.04	.14
object * vehicles * billboard * instruct * age/exp group	2	4.05	.02	.16
Error(object*vehicles*billboard)	42			

Highest significant interaction: object * vehicles * billboard * instruct * age/experience group.

Time spent fixating on billboards (static and dynamic) and lane change signs (opposite static and dynamic billboards) in drives with or without lead vehicles for probationary, fully licensed and older drivers in each instruction group:

Comparison	**Mean**	**S.E.**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Probationary drivers				
Normal instructions				
Lead vehicles				
Static billboard	0.12	0.02	0.08	0.16
Dynamic billboard	0.08	0.02	0.04	0.12
Lane change sign with static billboard	0.08	0.02	0.04	0.11
Lane change sign with dynamic BB	0.09	0.02	0.04	0.13
No vehicles				
Static billboard	0.10	0.02	0.07	0.14
Dynamic billboard	0.09	0.02	0.05	0.13
Lane change sign with static billboard	0.13	0.02	0.09	0.18
Lane change sign with dynamic BB	0.12	0.02	0.07	0.16
Report billboards				
Lead vehicles				
Static billboard	0.12	0.02	0.08	0.16
Dynamic billboard	0.13	0.02	0.09	0.17
Lane change sign with static billboard	0.09	0.02	0.05	0.13
Lane change sign with dynamic BB	0.08	0.02	0.04	0.13
No vehicles				
Static billboard	0.13	0.02	0.10	0.17
Dynamic billboard	0.12	0.02	0.08	0.16
Lane change sign with static billboard	0.07	0.02	0.02	0.11
Lane change sign with dynamic BB	0.07	0.02	0.02	0.11
Fully licensed drivers				
Normal instructions				
Lead vehicles				
Static billboard	0.11	0.02	0.07	0.15
Dynamic billboard	0.13	0.02	0.09	0.17
Lane change sign with static billboard	0.10	0.02	0.06	0.13
Lane change sign with dynamic BB	0.09	0.02	0.05	0.14
No vehicles				
Static billboard	0.14	0.02	0.11	0.18
Dynamic billboard	0.10	0.02	0.06	0.14
Lane change sign with static billboard	0.09	0.02	0.04	0.14
Lane change sign with dynamic BB	0.09	0.02	0.04	0.13
Report billboards				
Lead vehicles				
Static billboard	0.09	0.02	0.05	0.13
Dynamic billboard	0.09	0.02	0.05	0.13
Lane change sign with static billboard	0.09	0.02	0.05	0.13
Lane change sign with dynamic BB	0.11	0.02	0.06	0.15
No vehicles				
Static billboard	0.12	0.02	0.08	0.15
Dynamic billboard	0.13	0.02	0.09	0.17
Lane change sign with static billboard	0.09	0.02	0.04	0.13

Lane change sign with dynamic BB	0.09	0.02	0.05	0.14
Older drivers				
Normal instructions				
Static billboard				
Dynamic billboard	0.11	0.02	0.07	0.15
Lane change sign with static billboard	0.07	0.02	0.03	0.11
Lane change sign with dynamic BB	0.11	0.02	0.07	0.14
Static billboard	0.10	0.02	0.05	0.15
No vehicles				
Static billboard	0.12	0.02	0.09	0.15
Dynamic billboard	0.07	0.02	0.03	0.11
Lane change sign with static billboard	0.16	0.02	0.11	0.21
Lane change sign with dynamic BB	0.13	0.02	0.08	0.17
Report billboards				
Lead vehicles				
Static billboard	0.12	0.02	0.08	0.16
Dynamic billboard	0.10	0.02	0.06	0.14
Lane change sign with static billboard	0.11	0.02	0.08	0.15
Lane change sign with dynamic BB	0.11	0.02	0.07	0.16
No vehicles				
Static billboard	0.11	0.02	0.08	0.15
Dynamic billboard	0.11	0.02	0.08	0.15
Lane change sign with static billboard	0.12	0.02	0.08	0.17
Lane change sign with dynamic BB	0.10	0.02	0.06	0.14

4.2.4 Road ahead including lead vehicles:

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.06	.81	.00
age/exp group	2	1.91	.16	.08
age/exp group * instruct	2	0.21	.81	.01
Error	42			
Within subjects				
vehicles	1	0.07	.79	.00
vehicles * instruct	1	0.21	.65	.00
vehicles * age/exp group	2	0.76	.47	.03
vehicles * age/exp group * instruct	2	2.40	.10	.10
Error(vehicles)	42			
billboard	2	43.21	.00	.51
billboard * instruct	2	0.05	.95	.00
billboard * age/exp group	4	1.45	.22	.06
billboard * instruct * age/exp group	4	2.99	.02	.12
Error(billboard)	84			
vehicles * billboard	2	1.70	.19	.04
vehicles * billboard * instruct	2	2.15	.12	.05
vehicles * billboard * age/exp group	4	1.39	.24	.06
vehicles * billboard * instruct * age/exp group	4	0.44	.78	.02
Error(vehicles*billboard)	84			

Highest significant interaction: billboard * instruct * age/exp group.

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Probationary drivers				
Normal instructions				
Control site	0.53	0.07	0.39	0.68
Static billboard	0.48	0.07	0.34	0.62
Dynamic billboard	0.48	0.07	0.35	0.62
Report billboards				
Control site	0.60	0.07	0.45	0.75
Static billboard	0.50	0.07	0.37	0.64
Dynamic billboard	0.48	0.07	0.34	0.61
Fully licensed drivers				
Normal instructions				
Control site	0.62	0.07	0.47	0.76
Static billboard	0.53	0.07	0.39	0.66
Dynamic billboard	0.53	0.07	0.40	0.67
Report billboards				
Control site	0.52	0.07	0.37	0.67
Static billboard	0.50	0.07	0.36	0.63
Dynamic billboard	0.48	0.07	0.34	0.61
Older drivers				
Normal instructions				
Control site	0.70	0.07	0.55	0.84
Static billboard	0.61	0.07	0.47	0.75
Dynamic billboard	0.61	0.06	0.47	0.74
Report billboards				
Control site	0.70	0.07	0.55	0.85
Static billboard	0.57	0.07	0.43	0.71
Dynamic billboard	0.62	0.07	0.49	0.76

4.2.5 Other areas:

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.00	1.00	.00
age/exp group	2	2.08	.14	.09
age/exp group * instruct	2	0.18	.83	.01
Error	42			
Within subjects				
vehicles	1	0.24	.62	.01
vehicles * instruct	1	0.04	.83	.00
vehicles * age/exp group	2	0.53	.59	.02
vehicles * age/exp group * instruct	2	2.05	.14	.09
Error(vehicles)	42			
billboard	2	4.02	.02	.09
billboard * instruct	2	0.79	.46	.02
billboard * age/exp group	4	1.29	.28	.06
billboard * instruct * age/exp group	4	2.78	.03	.12
Error(billboard)	84			
vehicles * billboard	2	15.02	.00	.26
vehicles * billboard * instruct	2	1.66	.20	.04
vehicles * billboard * age/exp group	4	2.78	.03	.12
vehicles * billboard * instruct * age/exp group	4	0.71	.59	.03
Error(vehicles*billboard)	84			

Highest significant interactions were billboard * instruct * age/exp group:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Probationary drivers				
Normal instructions				
Control site	0.36	0.07	0.22	0.50
Static billboard	0.34	0.08	0.19	0.49
Dynamic billboard	0.36	0.07	0.21	0.52
Report billboards				
Control site	0.28	0.07	0.14	0.42
Static billboard	0.31	0.08	0.16	0.46
Dynamic billboard	0.33	0.07	0.18	0.48
Fully licensed drivers				
Normal instructions				
Control site	0.27	0.07	0.13	0.41
Static billboard	0.30	0.08	0.15	0.45
Dynamic billboard	0.31	0.07	0.16	0.46
Report billboards				
Control site	0.35	0.07	0.21	0.50
Static billboard	0.33	0.08	0.18	0.48
Dynamic billboard	0.34	0.07	0.18698	0.49
Older drivers				
Normal instructions				
Control site	0.19	0.07	0.05	0.33
Static billboard	0.20	0.08	0.05	0.35
Dynamic billboard	0.20	0.07	0.05	0.35
Report billboards				
Control site	0.15	0.07	0.01	0.29
Static billboard	0.23	0.08	0.08	0.38
Dynamic billboard	0.21	0.07	0.06	0.36

And vehicles * billboard * age/exp group:

Comparison	**Mean**	**Standard Error**	**95% Confidence Interval**	
			Lower Bound	Upper Bound
Probationary drivers				
Lead vehicles				
Control site	0.38	0.06	0.26	0.50
Static billboard	0.31	0.06	0.20	0.42
Dynamic billboard	0.34	0.06	0.23	0.46
No vehicles				
Control site	0.26	0.04	0.17	0.35
Static billboard	0.34	0.05	0.23	0.45
Dynamic billboard	0.36	0.05	0.25	0.47
Fully licensed drivers				
Lead vehicles				
Control site	0.34	0.06	0.22	0.46
Static billboard	0.28	0.06	0.17	0.40
Dynamic billboard	0.30	0.06	0.19	0.42
No vehicles				
Control site	0.29	0.04	0.20	0.38
Static billboard	0.34	0.05	0.23	0.45
Dynamic billboard	0.35	0.05	0.24	0.46
Older drivers				
Lead vehicles				
Control site	0.19	0.06	0.07	0.31
Static billboard	0.23	0.06	0.11	0.34
Dynamic billboard	0.21	0.06	0.09	0.32
No vehicles				
Control site	0.16	0.04	0.07	0.25
Static billboard	0.20	0.05	0.09	0.31
Dynamic billboard	0.21	0.05	0.10	0.32

4.3 Gaze variability on approach to lane change signs

During data screening for the 150m approaching lane change signs, 5 cases were found to have extremely large values for gaze variability due to a low number of captured frames. They were deleted from the dataset used for analysis, leaving 43 cases.

4.3.1 Standard deviation of horizontal gaze direction:

Source	***df***	***F***	***p***	η^2
Between subjects				
instruct	1	0.06	.81	.00
age/exp group	2	0.23	.80	.01
age/exp group * instruct	2	0.53	.60	.03
Error	37			
Within subjects				
vehicles	1	2.97	.09	.07
vehicles * instruct	1	0.63	.43	.02
vehicles * age/exp group	2	2.54	.09	.12
vehicles * age/exp group * instruct	2	1.75	.19	.09
Error(vehicles)	37			
billboard	2	0.28	.76	.01
billboard * instruct	2	0.65	.53	.02
billboard * age/exp group	4	1.46	.22	.07
billboard * instruct * age/exp group	4	0.95	.44	.05
Error(billboard)	74			
vehicles * billboard	2	1.06	.35	.03
vehicles * billboard * instruct	2	0.27	.76	.01
vehicles * billboard * age/exp group	4	0.24	.91	.01
vehicles * billboard * instruct * age/exp group	4	0.80	.53	.04
Error(vehicles*billboard)	74			

Grand Mean	**Standard Error**	**95% Confidence Interval**	
		Lower Bound	Upper Bound
0.05	0.00	0.04	0.06

4.3.2 Standard deviation of vertical gaze direction:

Source	*df*	*F*	*p*	η^2
Between subjects				
instruct	1	0.77	.39	.02
age/exp group	2	8.00	.00	.30
age/exp group * instruct	2	2.81	.07	.13
Error	37			
Within subjects				
vehicles	1	4.29	.05	.10
vehicles * instruct	1	0.07	.80	.00
vehicles * age/exp group	2	2.60	.09	.12
vehicles * age/exp group * instruct	2	0.11	.90	.01
Error(vehicles)	37			
billboard	2	3.27	.05*	.08
billboard * instruct	2	1.53	.23*	.04
billboard * age/exp group	4	2.01	.11*	.10
billboard * instruct * age/exp group	4	0.28	.87*	.01
Error(billboard)	74			
vehicles * billboard	2	7.49	.00	.17
vehicles * billboard * instruct	2	0.75	.48	.02
vehicles * billboard * age/exp group	4	1.21	.31	.06
vehicles * billboard * instruct * age/exp group	4	0.89	.47	.05
Error(vehicles*billboard)	74			

* These p values values have been modified using the Huynh-Feldt correction for significant non-sphericity for the variable 'billboard'.

Highest significant interaction is vehicles * billboard:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lead vehicles				
Control site	0.07	0.01	0.05	0.08
Static billboard	0.07	0.00	0.06	0.07
Dynamic billboard	0.06	0.00	0.06	0.07
No vehicles				
Control site	0.06	0.01	0.05	0.07
Static billboard	0.07	0.01	0.06	0.08
Dynamic billboard	0.08	0.00	0.07	0.09

Significant main effect for age/experience group:

Comparison	Mean	Standard Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Probationary	0.09	0.01	0.07	0.10
Fully licensed	0.07	0.01	0.06	0.09
Older	0.04	0.01	0.03	0.06

THE END