Driver distraction from in-vehicle sources: a review of TRL research

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Executive summary

Distraction is a significant factor in causing vehicle accidents. However, estimates of the contribution of distraction to accidents vary. Furthermore, as a concept, distraction is not completely understood. Alongside the increasing prevalence of in-vehicle technologies, there has been a research effort to understand the concept of driver distraction and its effects on road safety. TRL has made a significant contribution to research in the area of in-vehicle distraction. This Insight Report summarises research projects since 2002 in this field, which comprised a scoping study, two driving simulator studies and a naturalistic driving study.

During the scoping study of driver distraction, a workshop was held with key UK experts who were identified as being research-active in the field. Distraction was discussed as a concept, and agreement was reached on a UK definition. Notes were produced and circulated among a wider group of UK and non-UK experts for comment.

Two driving simulator studies examined how mobile phone use affected driving performance. These studies found that the effect varied between different measures of driving performance. Drivers spent more time looking directly at the road ahead while using a mobile phone than during normal driving, but this was to the detriment of the usual scanning of instruments and mirrors. Furthermore, reaction times were significantly reduced while holding a mobile phone conversation, even when compared with reaction times when the driver was over the UK legal limit for alcohol consumption.

Mobile phones are only one in-vehicle device that have a distracting effect, and there has arisen the need for a cost-effective yet valid and reliable method of assessing the safety of in-vehicle information systems. TRL's research into Occlusion produced a protocol to define a procedure for the Occlusion technique, and also proposed a demand reference level (DRL) as a criterion for the acceptability of tasks. The DRL enables tasks to be benchmarked against it, but does not necessarily imply that tasks that meet this level are safe for drivers to perform while the vehicle is in motion.

A second aim of the scoping study of driver distraction was to identify specific research needs and propose a programme of research. A broad review of literature was undertaken, and a range of research gaps was identified. These were then grouped to yield a list of 14 main areas, and a group of research-active experts was brought together to discuss these during a workshop. The research gaps identified during this study can be broadly summarised as follows:

- Measuring driving performance degradations from specific current and emerging distractors within and outside the vehicle, with particular emphasis on real-world situations and understanding the associated crash risk.
- Understanding the frequency and duration of drivers' engagement with distractors (including the different functions of in-vehicle systems), their understanding of the risks involved, their attitudes and factors that would motivate them to change their behaviours.
- Understanding the distinction between sensory and perceptual distractors (e.g. "looked but failed to see" accidents).
- Identifying high-risk groups of driver for distraction and the effects of distractors on these groups.
- Developing a standard, meaningful, objective and reliable test procedure and baseline to identify "unacceptable" levels of visual, cognitive and auditory distraction (potentially in real time).
- Identifying best practice to monitor the effects of distracted driving (e.g. accident rates, driver behaviour and attitudes) over time.

These research gaps can be grouped in terms of methodology, and a number of gaps tackled together. Furthermore, exploiting opportunities to collaborate in larger-scale European studies, which enable the sharing of expertise and resources across member states, could be a cost-effective way of conducting some of the research.
Abstract

In 2007, a workshop was conducted at the Department for Transport, and the conclusion was drawn that driver distraction is a significant factor in accident causation, but is neither completely understood nor documented. This Insight Report describes the results of four recent TRL studies in the field of in-vehicle distraction. The scoping study of driver distraction brought together experts in the field to discuss the concept of driver distraction and reach agreement on a definition. The project reviewed observation-based, experimental and opinion-based research and identified a range of research gaps. In terms of experimental research, this Insight Report describes two driving simulator studies that were conducted to examine how mobile phone use affects driving performance. One study showed that reaction times were significantly increased when using a mobile phone compared with a conversation with a passenger, using in-vehicle controls and without any simultaneous tasks. The second study showed that mobile phone use resulted in significantly higher reaction times, even when compared with driving at the UK legal limit for alcohol consumption. Finally, in terms of metrics and measures, this Insight Report describes the research that was carried out in developing the Occlusion Protocol, which is a technique for measuring visual demand.
1 Introduction

Decades of scientific research have shown that distraction is a factor in vehicle-accident causation. It is difficult to agree on a particular figure for the role of distraction in accidents due to the lack of a standard definition of distraction and inconsistent accident reporting (Stevens and Minton, 2001). Nevertheless, it is estimated that distraction is a contributory factor in up to 50% of crashes (Stutts et al., 2001). Results of the 100-car naturalistic driving study undertaken by TRL showed that inattention contributed to 78% of crashes and 65% of near-crashes, with secondary task engagement the greatest source of inattention, accounting for 22% of accidents (Neale et al., 2005; Krauer et al., 2006).

Sources of distraction exist both within and outside the vehicle. Within the vehicle, passengers have been reported as being the greatest single source of distraction, followed by interacting with the radio/music player and handling food, drink and cigarettes (Stevens and Minton, 2001). Notably, drivers are exposed to distractions for different lengths of time. For example, passengers represent a distraction for the entire period they are in the vehicle, whereas adjusting the radio is only a momentary distraction.

The rapid uptake of in-vehicle technologies in recent years may have led to changes in recorded figures of accident causation. It is perhaps the desire to reduce distraction-related accidents, combined with an increase in potential distractors in the driving environment as a result of technological advances, that has driven research in this area over recent years.

TRL has made a considerable contribution to scientific progress in the area of driver distraction and, in particular, distraction from within the vehicle. The aim of this Insight Report is to bring together the results of recent TRL studies related to this topic. These are:

- Defining driver distraction and prioritisation of research gaps (scoping study)
- Distracted driving performance: mobile phone research (driving simulator studies)
- Measuring visual demand: research on the Occlusion technique

Following this, the remainder of the report will discuss the findings from these areas, in the wider context of distraction research.

2 Defining driver distraction

Much research in the area of driver distraction has taken place without there being an agreed definition of the term. Researchers have tended to define the expression in line with their research and underlying assumptions. During a previous Department for Transport (DfT) workshop on driver distraction (Sampson, 2007), concerns were raised about definitions implying particular indicators of distraction, and hence methods of measurement.

In 2007, the DfT commissioned TRL to conduct a scoping study of driver distraction (Basacik and Stevens, 2008). One aim of the study was to prepare a definition of driver distraction and secure at least UK agreement on its adoption. The following subsections summarise the process and findings of that study.

2.1 Method

In order to prepare a definition of driver distraction and secure at least UK agreement on its adoption, the authors consulted influential professionals working in this area. The core group comprised six of the most influential UK experts, later joined by Professor Mike Regan, who has recently edited an international book on driver distraction (Regan et al., 2008). These experts were selected as being research-active in the scientific area of driver distraction:

- Dr Gary Burnett, Nottingham University
- Professor Oliver Carsten, Leeds University
- Mr Mark Fowkes, MIRA
- Dr Terry Lansdown, Heriot-Watt University
- Professor Andrew Parkes, TRL
- Associate Professor Mike Regan, Monash University
- Dr Alan Stevens, TRL

The project team also consulted a wider reference group, which remotely reviewed and commented on outputs from the project. These included:

- Dr Peter Burns, Transport Canada, Canada
- Dr Helen Dudfield, QinetiQ
- Dr Johan Engstrom, Volvo, Sweden
- Mr Rob Gifford, Parliamentary Advisory Council for Transport Safety (PACTS)
- Professor John Groeger, Surrey University
- Dr Joanne Harbluk, Transport Canada, Canada
- Professor Hirano Kawashima, Keio University, Japan
- Professor John Lee, University of Iowa, USA
- Dr Michael Pettitt, University of Nottingham
- Mr John Richardson, Loughborough University
- Professor Neville Stanton, Brunel University
- Professor Geoff Underwood, Nottingham University
- Dr Trent Victor, Volvo, Sweden

To begin the process of defining driver distraction, Basacik and Stevens (2008) compiled a discussion document and circulated it among the core and wider reference groups for comment. The authors used this document as a basis for a subsequent workshop, attended by the core reference group, during which they aimed to reach an agreement on a definition. Dr Alan Stevens acted as expert moderator during this session, and the outcomes were recorded and
sent to members of the core and wider reference groups for comment. The involvement of the core and wider reference groups helped to ensure that the project deliverables were validated and supplemented with additional views.

### 2.2 Workshop outcomes
At the beginning of the workshop, a brief discussion was held as to whether a definition of driver distraction was desirable or necessary. It is clearly not desirable to produce a definition that is so specific that it limits future research efforts, particularly in an area such as driver distraction where much recent research has taken place. The following points summarise the agreements that were reached during the workshop:

- A scientific definition is necessary that is more general than the metrics/indicators but not so broad as to be unfocused.
- Distraction excludes driver fatigue and impairment; these are related but distinct concepts.
- Distraction requires a definable trigger and excludes daydreaming and general internal thoughts.
- It is possible for drivers to be distracted by activities such as navigation, which are part of the driving task. Therefore, there must be a core set of “activities required for safe driving” from which drivers are distracted, with the implication that this requires lateral and longitudinal control of the vehicle in the road and traffic environment (which includes pedestrians and other road users) such that a suitable safety margin is maintained.
- Distraction is a continuous variable. Distraction becomes critical when there is a shortfall between the activities required for safe driving and the resources devoted to it by the driver.
- Drivers can be too distracted and/or driving in an unsafe way even if there is no immediate adverse consequence of the behaviour, such as an actual crash. Safe driving requires more than avoiding crashes, although measuring safe driving is challenging.
- The degree of driver distraction is time varying, as are the demands of safe vehicle control, and unsafe situations can develop rapidly and unexpectedly. All other things being equal, reducing distraction improves the chance of the driver dealing appropriately with an unsafe situation.
- Events, activities, objects and persons only become distracting as a result of a driver’s engagement with them. Their properties determine how distracting they are to a population of drivers.
- Distraction should be considered as arising from both driver-initiated and non-driver-initiated sources.
- Appreciating the different types of distraction may inform future studies, but our current understanding and ability to measure their role is limited.

The workshop agreed on the following definition of driver distraction (Basacik and Stevens, 2008):

### 2.3 Commentary
Many of the agreements reported above require little explanation. However, those relating to the distinction between distraction and inattention, and the argument that there is a core set of activities required for safe driving, necessitate further discussion.

The boundary between distraction and related concepts has remained ill-defined to date. Previously, scientists carrying out research in the field of driver distraction have had to develop operational definitions of the term that would suit the purposes of their research. For example, the US naturalistic driving study (Klauder et al., 2002) grouped fatigued, secondary task demand and general inattention to the road under the single concept of inattention (Lee et al., 2008). This is a pragmatic approach, as it may be difficult to differentiate between inattention and distraction during a naturalistic driving study without access to the subject matter of the driver’s thoughts. Beirness et al. (2002) argue that it is the presence of a triggering event or activity that separates driver distraction from the broader category of driver inattention. Basacik and Stevens (2008) cite the example of a driver who is concentrating hard on distinguishing signage or understanding a complex message; a particular object has triggered a cognitive and perceptual process, which is arguably distracting. Nevertheless, if the thought about the sign were to be followed by other, unrelated thoughts, the authors argue that this would be beyond the realms of distraction. Thus, beyond the cognitive and perceptual processes directly triggered by an event, action, object or person during the driving task, the driver is not considered to be distracted, but rather inattentive.

It is further possible to argue that aspects of the driving task such as route finding can be distracting. A number of models of driving exist, such as Michon’s (1985) hierarchy comprising strategic-, manoeuvring- and control-level activities, and Hollnagel’s (1993) Contextual Control Model (COCOM). These include aspects from general plans about the journey to individual action sequences required for control of the vehicle. Basacik and Stevens (2008) argue that there are a core set of “activities required for safe driving in the road and traffic environment”. They argue that these are primarily monitoring the road environment and activities required for lateral and longitudinal control of the vehicle. The implication is that any competing activities may distract the driver from these core activities. Thus, it seems that elements such as route choice, which is part of the driving task according to

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**Driver distraction**

Diversion of attention away from activities required for safe driving due to some event, activity, object or person, within or outside the vehicle.

**Note 1**: Safe driving requires monitoring of the road and traffic environment (which includes pedestrians and other road users) and control of the vehicle.

**Note 2**: Safe driving also requires an appropriate degree of attention and vehicle control to maintain a reasonable safety margin allowing for unexpected events.

**Note 3**: Types of distraction may be visual, auditory, biomechanical or cognitive, or combinations thereof.
Michon (1985) and Hollnagel (1993), could potentially have an adverse effect on the “core” tasks as defined above.

A final discussion point relevant to the design of the driving environment was that elements in the driving environment only become distracting if the driver engages with them, consciously or unconsciously (Basacik and Stevens, 2008). Engagement can depend on characteristics of the driver, as certain groups may be drawn to engage with certain elements of their environment. On the other hand, elements such as flashing lights may capture a driver’s attention automatically (Wogalter and Leonard, 1999). Thus, decisions taken while designing elements within the driving environment can have an effect on whether groups of driver, or the driving population as a whole, are distracted.

The merit of the agreed definition appears to be that it is general enough to allow new methods and metrics of distraction to be developed and used, while stating high-level characteristics of distractors and the activities required for safe driving. As such, it provides support for distraction research.

### 3 Driving simulator studies

The risks resulting from the use of mobile phones while driving have been a topic of research for over 40 years (e.g., Brown et al., 1969; Independent Expert Group on Mobile Phones, 2000). By the 1990s, research had highlighted the safety problem of using hand-held mobile phones while driving, and some experts believed that removing the handset would solve the problem. Some manufacturers began to investigate integrating well-designed hands-free telephones within their vehicles (Parkes et al., 2007). However, the market evolved in such a way that consumers took advantage of the relatively cheap prices of mobile phone handsets, whereas hands-free kits did not become popular.

It is difficult to determine the exact proportion of accidents that can be attributed to mobile phone use, primarily due to inconsistencies in accident reporting (Stevens and Minton, 2001). Furthermore, mobile phones have only come into widespread use within the vehicle over the last decade, and during this time handsets have evolved in terms of functionality. As a result, it has been difficult to understand how and with what frequency people engage with the technology while driving, and the effects of this behaviour on road safety.

In 2000, the National Highways Traffic Safety Association (NHTSA) held an international online forum on the safety implications of in-vehicle technologies including mobile phones. The data from this forum are likely to be somewhat out of date. However, the following results are of interest in highlighting the problem of engagement with mobile phones while driving:

- 29% (of 573 respondents) responded that they do own a mobile phone but do not use it while driving
- 19% reported that they use a hand-held mobile phone
- 27% reported that they sometimes or frequently receive calls while driving
- 64% had witnessed or experienced a “close call” resulting from a driver (or themselves) using a mobile phone
- 16% had witnessed or experienced a crash as a result of such behaviour

A recent series of observation studies was enhanced by the use of electronic devices sensitive to microwave radiation (TRL, 2006; TRL, 2007). Sample sizes per study included over 80,000 cars and 20,000 other vehicles, such as lorries or vans. The prevalence of mobile phone use for car drivers decreased between September 2006 and August 2007 to 4.4%; for “other drivers”, the overall prevalence for the same time period decreased to 3.0%.

This section presents an overview of the two TRL studies that have provided a context for other research.

#### 3.1 Conversations in Cars Study

Despite a wealth of research showing reduced driving performance and increased crash risk as a result of mobile phone use while driving, a counterargument exists that mobile phones should not be “singled out” by researchers and legislators because their effects are no worse than a number of other distractions within vehicles.

Some research literature can be used to support an argument that, since driving performance is worse while using a hand-held mobile phone, hands-free mobile phone
use is not distracting. However, a growing body of evidence suggests that while hand-held mobile phone use affects the operational control level of the driving task, holding the conversation leads to a decrease in strategic awareness of the driving environment (Parkes and Hooijmeijer, 2000).

A study of mobile phone use while driving (Parkes et al., 2007) compared driving performance while conducting a hands-free phone call with the task of talking to a passenger within the vehicle and carrying out in-car tasks such as adjusting the radio or climate controls of the vehicle. The hypotheses for this study were:

- Driving performance will significantly deteriorate during phone conversation, more so than when performing conventional in-vehicle tasks
- Conversation performance will be poorer over the phone than during conversations with passengers

### 3.1.1 Method

This study examined performance on driving and conversation tasks. There were five different experimental conditions:

- Driving while having a conversation with an experimenter using a hands-free mobile phone
- Driving while having a conversation with an experimenter in the passenger seat
- Driving while adjusting in-vehicle controls
- Driving without any simultaneous tasks
- Conversation only, without the driving task (ie the conversation control)

The experiment required participants to drive a 17 km route in the TRL driving simulator (CarSim). The TRL driving simulator used during these trials consisted of a medium-sized saloon car surrounded by large projection screens giving the driver 210 degrees of horizontal and 40 degrees of vertical forward vision. The screens also allowed normal use of all vehicle mirrors through rear projection screens that span 60 degrees horizontally and 40 degrees vertically.

The simulator vehicle also incorporated hydraulic rams that move the vehicle in order to give the driver motion cues that simulate heave, pitch and roll, which are experienced during normal braking, accelerating and cornering. Feedback through the steering wheel, as well as the provision of car engine, road and external traffic noise, all added to the realism of the driving experience.

The route that participants were required to drive was set up to include sections that would test particular aspects of driving performance. These were:

- a car-following task on a motorway,
- a free drive on a motorway,
- a dual carriageway section with tight curves, where drivers were asked to maintain a constant speed and lane position, and
- a choice reaction time task on a dual carriageway, where drivers were asked to respond to certain traffic signs.

Thirty participants took part in this study. They were all experienced users of mobile phones, aged between 21 and 64 years, and split evenly between genders.

Participants were invited to the laboratory for a pre-trial session during which they were asked to provide some information on their driving history and health, and were briefed on the experimental conditions. However, the description given did not mention the specific aims of the experiment.

Participants were then asked to complete a familiarisation drive in the simulator, during which they had a chance to become comfortable with the controls of the vehicle.

Within a week of their familiarisation drive, participants were asked to return to the laboratory for their trial session. Participants were asked to drive as they normally would and respond to the experimenter’s requests during the drive. The order of treatment conditions was counterbalanced, and after each treatment condition subjective workload measures were taken using the Rating Scale for Mental Effort (Zijlstra and van Doorn, 1985).

The Rosenbaum Verbal Cognitive test Battery (RVCB) was used as a script for the conversations during the experiments. This includes remembering sentence tasks and verbal puzzle tasks, each with items of five levels of difficulty. It measures judgement, flexible thinking and response times (Waugh et al., 2000). The RVCB was used for the mobile phone conversation, the passenger conversation and the conversation control.

For the passenger-conversation condition, the experimenter was seated in the vehicle with the driver. The conversation-only control condition was conducted away from the car in a relaxed seating area with the experimenter.

During a separate drive, passengers were asked to perform a number of in-vehicle tasks. Prior to the drive, all participants were provided with full instructions on how to use the in-vehicle equipment by the experimenter at the side of the vehicle. The participant was also given the opportunity to practice the use of these systems during one section of the control drive. During the control drive and in-vehicle task conditions, the experimenter gave standardised instructions to operate the climate and entertainment controls to the participant over an intercom system installed within the vehicle. During a further drive, participants were asked to drive the same route, but were not given any additional tasks.

A video recording of the participant was taken during the trials. For each of the four elements of the route (ie car following on a motorway, free driving on a motorway, curve negotiation on a dual carriageway and choice reaction time on a dual carriageway), a one-kilometre section was identified and visual behaviour exhibited by participants in this section of road was analysed in detail. Glances to the mirrors, speedometer, climate and entertainment controls or any “other” region inside the vehicle were recorded. Glances were defined as beginning with a movement of the eye away from the road, including dwell time in one of the zones of interest, and ending when the eye started to move to another location. These were categorised in 0.5-second intervals, and results from each of the four elements of the drive were combined to provide a single score for each participant and task condition.

This was supplemented by a battery of questionnaires that investigated aspects of peoples’ mobile phone use, their attitudes towards penalties for being caught while driving and using a mobile phone, their experiences of driving and using a mobile phone and their subjective ratings of the distraction potential of a variety of tasks that people typically perform while driving. The final section of the questionnaire was on conversations with passengers.
3.1.2 Summary of results

Table 1 summarises the statistically significant results that were obtained during this study. Measures of driving performance painted a fairly consistent picture in terms of longitudinal control. Throughout the drives, no headways of less than one second were measured for the participants. Nevertheless, during the control condition there was less variability in headway (indicating more accurate driving) (Figure 1), as well as lower speed deviation and less speed error, than in the mobile phone conversation (which was conducted using a hands-free kit), passenger-conversation and in-vehicle task conditions (Figure 2).

Drivers selected a higher speed around curves in the control condition, suggesting that they may have been attempting to compensate for secondary task demands during the other conditions (Figure 3). However, the lack of a significant difference in speed selection between the other conditions suggests that they did not adjust their speed for the differing demands of these secondary tasks.

During the two conversation conditions, participants exhibited better lane keeping than during the control and in-vehicle task conditions (Figure 4). One explanation for the counterintuitive results of this study may be that drivers adopted a higher speed during the control condition, making the vehicle more difficult to control, and spent more time looking away from the road during the in-vehicle task condition.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Task</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation of time headway</td>
<td>Car following on motorway</td>
<td>Significant contrasts between the control and passenger-conversation condition, and control and in-vehicle task condition, with the control condition consistently showing a lower standard deviation of lane position.</td>
</tr>
<tr>
<td>Mean speed</td>
<td>Curve negotiation on dual carriageway</td>
<td>Significant main effect of condition. Mean speed significantly higher in the control condition than in the passenger-conversation, in-vehicle task and hands-free conditions.</td>
</tr>
<tr>
<td>Speed error</td>
<td>Curve negotiation on dual carriageway</td>
<td>Speed error significantly lower in the control condition than in the passenger-conversation, in-vehicle task and hands-free conditions.</td>
</tr>
<tr>
<td>Number of lane errors</td>
<td>Curve negotiation on dual carriageway</td>
<td>Significantly fewer errors in the passenger-conversation condition than in the control and in-vehicle task conditions.</td>
</tr>
<tr>
<td>Standard deviation of mean speed</td>
<td>Choice reaction time on dual carriageway</td>
<td>Significant main effect of condition. Standard deviation of mean speed on the dual carriageway was significantly lower in the control condition than in the passenger-conversation, in-vehicle task and hands-free conditions.</td>
</tr>
<tr>
<td>Lane position</td>
<td>Choice reaction time on dual carriageway</td>
<td>Significant main effect of condition on lane position errors. Significantly more errors in the in-vehicle task condition than in the control, passenger-conversation and hands-free conditions.</td>
</tr>
<tr>
<td>Standard deviation of lane position</td>
<td>Choice reaction time on dual carriageway</td>
<td>Significant main effect of condition. Standard deviation of lane keeping was significantly lower in the two conversation conditions than in the control and in-vehicle task conditions.</td>
</tr>
<tr>
<td>Median reaction times (mean times skewed)</td>
<td>Choice reaction time on dual carriageway</td>
<td>Significant main effect of condition. Reaction times significantly slower in the hands-free condition than in the in-vehicle task, passenger-conversation and control conditions. Reaction times on the control drive were also significantly faster than during the in-vehicle task condition.</td>
</tr>
<tr>
<td>Missed targets</td>
<td>Choice reaction time on dual carriageway</td>
<td>Significant main effect of condition, with significantly fewer misses in the control drive than in any other condition.</td>
</tr>
</tbody>
</table>

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Reaction times were in the expected pattern: they were slower when a secondary task was present than in the control condition (Figure 5). Talking on a hands-free mobile phone was associated with the slowest reaction times. Furthermore, the greatest number of missed targets occurred during the hands-free condition. The in-vehicle task condition yielded the second-largest number of missed targets, and this was followed by the passenger-conversation condition.

The analysis of visual behaviour showed that scanning was affected by the presence of secondary tasks (Table 2). Overall, the number of glances to mirrors was low. However, this could be a result of low traffic density in the simulator environment. Participants glanced at the speedometer almost half as many times during the conversation tasks compared with the control and in-vehicle task conditions. Thus, participants seemed to be less able to monitor in-vehicle displays when conducting a conversation. Another interesting visual behaviour exhibited was that participants spent a larger percentage of time looking at the road in the mobile phone conversation condition than the control condition, but a lower percentage of time looking ahead in the in-vehicle task condition than in the control. Thus, it seems that the secondary task of adjusting climate and entertainment systems requires visual attention, which is diverted away from the road. On the other hand, the conversation tasks interfere with the driver’s monitoring of the vehicle.

Results for subjective workload (Table 3) repeated the pattern of reaction time, with hands-free conversations being rated highest in terms of workload, followed by the in-vehicle task and passenger-conversation conditions.

Measures of conversation performance showed that driving interferes with the conversation tasks, and that performance was usually worst when talking on a hands-free mobile phone. Analysis of the questionnaire results showed that all of the participants claimed to be regular users of mobile phones, but generally felt that they should not be used while driving. Deterrents ranging from penalties to police cautions were suggested. Three participants had a hands-free kit fitted, although this was not found to be an influence on the performance of this group. The questionnaire also presented participants with a list of tasks that people typically carry out while driving, and asked them to rate how distracting they thought these tasks were. Responses suggested that sending text messages and reading maps were the two most
distracting in-vehicle tasks on the list. Talking to a passenger was rated as being less distracting than talking on a hands-free mobile phone or adjusting a radio.

### 3.1.3 Discussion

The finding that engagement with a secondary task results in poorer performance on the driving task is consistent with other research in the area of driver distraction, and can be seen as an indication of additional workload.

The initial prediction was that the different experimental conditions would affect driving performance to a different extent. For speed control and headway, this was not found to be the case. However, lane keeping was found to be improved during the conversation tasks. This may be a result of reduced speed during these conditions, despite instructions to drive at a constant speed of 60 mph. On the other hand, this phenomenon may also be the result of drivers realising the effect that the conversation was having on their performance and making a conscious decision to concentrate harder on their driving. While this experiment cannot distinguish between these explanations, it does highlight that different aspects of driving can be affected differently by secondary tasks.

The safety implications of these findings are complex. Based on measures of speed and tracking accuracy, it is not possible to conclude that mobile phone use while driving is unsafe. Nevertheless, reaction times were affected more seriously by using a hands-free mobile phone than during any other condition. Arguably, reactions govern most aspects of driving, and become even more important during complex driving scenarios.

The subjective workload measures were consistent with the driving performance results in that participants rated the control condition as requiring the least mental effort and the hands-free condition as requiring the most.

Analysis of visual behaviour produced the expected result that operating climate and entertainment controls required the diversion of visual behaviour away from the road when compared with the control condition. On the other hand, the conversation tasks were shown to increase the amount of time spent looking ahead when compared with the control condition. However, this was to the detriment of normal scanning of vehicle instruments, and was not accompanied by quicker or more accurate responses to traffic signals. One explanation might be that the cognitively demanding conversation task interferes with visual scanning in such a way that drivers do not actively search the visual scene as they might do under normal conditions. This is consistent with studies that have found reduced situational awareness as a result of mobile phone use while driving (Parkes and Hooijmeijer, 2000).

Analysis of conversation performance showed that this was worse when driving. This demonstrates interference between two cognitively demanding tasks, and is consistent with previous research. However, the performance differences between the hands-free and passenger-conversation conditions are interesting, as the driver’s physical task of controlling the vehicle was not directly influenced (as it would have been if a hand-held mobile phone were used) and the conversation task was the same in both conditions. It must be concluded that an aspect of the situation affected performance on this task. The following are candidates’ explanations for this phenomenon:

- An emotive response to the hands-free conversation or hands-free system
- Adjustments made to the conversation by the passenger in response to the driving environment

The following provide theoretical support for this occurrence:

- Intimacy model (Argyle and Dean, 1965)
- Formality model (Morley and Stephenson, 1969)
- Social presence model (Short et al., 1976)
- Cluelessness model (Rutter et al., 1981)
These models argue that if participants in a conversation are visually separated from one another, the conversation style becomes more impersonal as a result of fewer natural cues. Furthermore, there may be increased pressure to respond when on the phone compared with sitting next to the person with whom the conversation is being conducted. Social impact theory (Latane, 1981) would support the argument that the passenger would exert more social influence than a remote participant in the conversation, and this would affect the level of demand experienced by the driver. It is thus clear that talking on a phone, even via a hands-free kit, is not equivalent to talking to a passenger. The quality of information exchange is reduced when talking over a hands-free kit, and is likely to be particularly pronounced in complex driving situations. There are, therefore, business and safety implications for companies that currently allow or expect their employees to use mobile phones for work while driving.

3.2 Alcohol Benchmarking Study

Burns et al. (2002) compared the performance decrements experienced when driving while holding hand-held or hands-free mobile phone conversations with performance decrements experienced when driving under the influence of alcohol. The following subsections summarise their report.

The experimental hypotheses were that driving performance deteriorates more with hand-held phones than hands-free phones, and that some measures of driving performance while talking on a hand-held phone will be significantly worse than driving while impaired by alcohol (Burns et al., 2002).

3.2.1 Method

The experiment required participants to drive a 17 km route in the TRL driving simulator. The route was designed to include sections that would test particular aspects of the participants’ driving performance. These were:

- a car-following task on a motorway,
- a free drive on a motorway,
- a dual carriageway section with tight curves, where drivers were asked to maintain a constant speed and lane position, and
- a choice reaction time task on a dual carriageway, where drivers were asked to respond to certain traffic signs.

This study comprised five experimental conditions:

- Driving while having a conversation with an experimenter using a hand-held mobile phone
- Driving while having a conversation with an experimenter using a hands-free mobile phone
- Driving with a blood alcohol level over the UK legal limit (80 mg/100 ml)
- Driving without any simultaneous tasks
- Conversation only, without the driving task (i.e., the control)

The study was conducted with 20 experienced drivers and the sample was split evenly between genders. Participants were aged between 21 and 45 years and were all regular mobile phone users.

Participants were invited to the laboratory for a pre-trial session during which they were asked to provide some information on their driving history and health, and were briefed on the experimental conditions. However, the description given did not mention the specific aims of the experiment. Participants’ heights and weights were measured and they were then asked to complete a familiarisation drive in the simulator during which they had a chance to become comfortable with the controls of the vehicle.

The test was completed during two visits to the laboratory (i.e., one with and one without alcohol consumption). During each visit, the route was driven three times. During one visit, participants were first breath tested and then drove while using a hand-held mobile phone, a hands-free mobile phone and with neither. The RVCB was used as a script for the conversations during both experiments. This includes remembering sentence tasks and verbal puzzle tasks, each with items of five levels of difficulty. It measures judgement, flexible thinking and response times (Waugh et al., 2000). The conversation-only control was conducted away from the car in a relaxed seating area with the experimenter.

During the alcohol visit, participants were breath-tested before being asked to consume a drink that contained a measured amount of alcohol with a disguising mixer, or a placebo drink that looked and tasted similar. Participants were supervised by a researcher during the ten minutes in which they were asked to consume their drink.

The Widmark Formula (Watson et al., 1980) was used to measure the correct amount of alcohol to moderately impair each participant (80 mg/100 ml), based on their age and weight. The average dosage for males was approximately five units of alcohol, while for females it was approximately three units of alcohol.

After consuming their drink, participants were asked to wait for 20 minutes, and then commenced driving for about 45 minutes. Thus, they were driving for between 20 and 65 minutes after dosing. The effects of alcohol tend to appear after ten minutes and peak at approximately 40 to 60 minutes. Furthermore, before each drive, participants were breathalysed to ensure that they were over the legal limit.

The simulator provided data on participants’ lateral control of the vehicle (lane departures, standard deviation of lane position and root mean square error (RMSE) from lane centre), longitudinal control (mean speed, standard deviation of speed, RMSE from a speed of 60 mph, standard deviation of time headway, RMSE from target following distance, time headway, minimum time headway) and reactions (reaction time to warning signs, missed warning signs and false alarms to warning signs). These data were supplemented by video and audio recordings of the conversation tasks, which were analysed for duration, errors, pauses and failures. A battery of questionnaires was also analysed for participants’ mobile phone use, attitudes towards penalties and self-reported mental effort.

3.2.2 Summary of results

The study analysed variables relating to driving task performance (primary task) as well as performance on the conversation task (secondary task performance). Tables 4 and 5 summarise the results.

Measures of primary task performance tended to indicate better performance under the normal driving condition.
when compared with either of the mobile phone conditions or the alcohol condition. However, on a number of driving performance measures the use of mobile phones had more of a detrimental effect than alcohol.

In particular, the study showed that participants drove significantly slower when using a hand-held or hands-free mobile phone than during the normal driving condition, even when they were asked to maintain a set speed (Figure 6). Although faster driving is normally associated with increased risk, reduced speed while using a mobile phone is a fairly consistent finding in mobile phone research (eg Tornros and Bolling, 2006). This may indicate that drivers find it difficult to cope with the demands of the mobile phone conversation while driving, and choose a lower speed to decrease the demands of the driving task.

When using a hand-held mobile phone, participants demonstrated a higher standard deviation of speed and speed error compared with all other conditions. Thus, speed control is significantly worse when driving using a hand-held mobile phone, even when compared with the alcohol condition.

### Table 4 Effects on primary task performance (Burns et al., 2002)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Section of route</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean speed</td>
<td>Motorway</td>
<td>Significant main effect of condition. Drivers with hand-held mobile phones drove significantly slower than during the alcohol drive.</td>
</tr>
<tr>
<td></td>
<td>Curves</td>
<td>Drivers drove closest to the target speed during the control drive, exceeded it in the alcohol drive and drove slower when using a mobile phone (hand-held or hands-free). When using a hand-held mobile phone they drove significantly slower than during all other conditions.</td>
</tr>
<tr>
<td></td>
<td>Dual carriageway</td>
<td>Significant main effect of condition. Significantly slower when using a hand-held mobile phone than during all other conditions.</td>
</tr>
<tr>
<td>Standard deviation of speed</td>
<td>Curves</td>
<td>Significant main effect of condition. Speed was significantly more variable when using a hand-held phone than during all other conditions.</td>
</tr>
<tr>
<td>RMSE from 60 mph</td>
<td>Curves</td>
<td>Significant main effect of condition. Performance significantly worse when using a hand-held mobile phone than during all other conditions.</td>
</tr>
<tr>
<td>Lane-keeping performance</td>
<td>Dual carriageway</td>
<td>Lane keeping significantly less steady when under the influence of alcohol than during all other conditions.</td>
</tr>
<tr>
<td>Reaction times</td>
<td>Dual carriageway</td>
<td>Significant main effect of condition. Significantly slower when using a hand-held mobile phone than in normal driving and alcohol conditions. Also significantly slower when using a hands-free mobile phone than in normal driving and alcohol conditions. Significantly slower in the alcohol condition than normal driving.</td>
</tr>
<tr>
<td>Missed signs</td>
<td>Dual carriageway</td>
<td>Significant main effect of condition. Significantly more misses for the hands-free and hand-held conditions than in normal driving. Significantly more misses when using a hands-free mobile phone than in the alcohol condition.</td>
</tr>
<tr>
<td>False alarms</td>
<td>Dual carriageway</td>
<td>Significant main effect of condition. Significantly more false alarms with hands-free condition than normal driving, and significantly more false alarms with hands-free or hand-held conditions than alcohol.</td>
</tr>
</tbody>
</table>

### Table 5 Effects on secondary task performance (Burns et al., 2002)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Task</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective workload</td>
<td>Throughout</td>
<td>Rated highest for the hand-held mobile phone condition and lowest for the control, with a significant main effect. Alcohol and normal driving rated as requiring significantly less mental effort than driving with a hand-held or hands-free mobile phone.</td>
</tr>
<tr>
<td>Rate of talking</td>
<td>Throughout</td>
<td>Significant main effect of condition. Rate of talking significantly faster in the control condition than either phone condition, but no differences between the phone conditions.</td>
</tr>
<tr>
<td>Number of pauses</td>
<td>Remembering sentences</td>
<td>Significantly fewer pauses in the control condition than either phone condition. Significantly fewer pauses in the hand-held condition than hands-free.</td>
</tr>
<tr>
<td>Number of pauses</td>
<td>Monologue</td>
<td>Significantly fewer pauses in the control condition than either phone condition. Significantly fewer pauses in the hand-held condition than hands-free.</td>
</tr>
<tr>
<td>Number of correct responses</td>
<td>Throughout</td>
<td>Significantly more correct responses in the control condition than either of the two phone conditions, and significantly more correct responses in the hands-free condition than hand-held.</td>
</tr>
<tr>
<td>Mean response time</td>
<td>Repeating sentences</td>
<td>Time to answer was significantly less in the control conversation than the hand-held or hands-free conversations. Time was also significantly less when using a hand-held phone than in the hands-free condition.</td>
</tr>
<tr>
<td>Mean response time</td>
<td>Verbal puzzles</td>
<td>Time to answer significantly less in the control condition than either phone condition.</td>
</tr>
</tbody>
</table>
Conversely, a higher standard deviation in lane position was recorded during the alcohol condition than during all other conditions.

Under the alcohol condition, reaction times were significantly slower than under the normal driving condition (Figure 7). However, reaction times were significantly worse when using a mobile phone than when under the influence of alcohol. Drivers using mobile phones also responded to the wrong warnings significantly more often than when under the influence of alcohol, and missed significantly more of the target warnings.

Performance on the conversation tasks was significantly affected by the driving task during this study. Compared with a control conversation held in the waiting room, participants spoke more slowly, took longer pauses and made more errors in the conversations while driving. These results could suggest that while driving, the cognitive demands of the mobile phone conversations were too demanding to be conducted at the participant’s normal standard of conversation. Results were mixed when hand-held and hands-free conditions were compared: participants showed poorer performance on sentence repetition when using a hands-free phone, but better performance on verbal puzzles and monologues.

### 3.2.3 Discussion

Most mobile phone studies have been successful in showing performance decrements while driving and holding a mobile phone conversation when compared with normal driving performance. However, the message that performance is worse than normal is not a powerful one. This study has compared driving performance while using mobile phones with driving performance while under the influence of alcohol (the latter being considered by society to be “dangerous”).

The study has shown that drivers show significantly poorer speed control, hazard detection and reaction times when holding a mobile phone conversation than when impaired by alcohol. The consequence of being drunk is that skills associated with perception, attention, attentional shift, working memory, motor co-ordination, reaction time and rate of information processing are compromised (Moskowitz and Burns, 1990). As a result, drivers with a blood alcohol content of more than 0.08% have four to five times greater risk of being involved in a crash (Vinson et al., 1995). The implication of this study is that driving while holding a mobile phone conversation is unsafe, and more so than driving above the permitted alcohol limit.

The finding that drivers are more likely to miss hazard warnings completely when driving while using a mobile phone is perhaps more significant than the possibility of a delayed reaction (McKnight and McKnight, 1991), as the road environment may be designed to tolerate some delays in responding to hazards.

It is difficult to draw any conclusions about crash risk as a result of using mobile phones while driving, for the following reasons:

- Alcohol is likely to affect driving performance for the duration of the trip, while mobile phone use would only affect performance for the duration of the conversation.
- At a population level, exposure to mobile phones while driving is likely to be different from exposure to drink driving.
- Usage patterns are likely to be different for alcohol and mobile phones, with alcohol being more widely consumed late at night and at weekends, whereas phones can be used at any time. This would have an effect on crash type and severity.

During this study, alcohol was used as a benchmark. However, there is a possibility that alcohol may impair driving in a different way to mobile phone use. The study results showed that mobile phone use affected performance on primary and secondary tasks. On the other hand, alcohol consumption affected performance on the primary task (by acting as a central nervous system depressant), even though the driver was theoretically able to fully concentrate on driving.

A further criticism of the study may be that the conversation tasks used were more difficult than typical in-car conversations, and lasted for the duration of the drive.
However, the study also excluded some aspects of mobile phone use that may be particularly distracting, eg dialling the number or searching the address book, answering and terminating the call. The study did show that using a hands-free mobile phone was better than using a hand-held phone. However, performance was still more impaired when using a hands-free mobile phone than during alcohol consumption. Therefore, the safest approach seems to be to switch mobile phones off when driving.

3.3 Commentary

As aspects of the driving task such as changing gear become more automatic, drivers may choose to allocate their spare attentional capacity to secondary tasks such as mobile phone conversations (Basack and Stevens, 2008). When the demands of either the driving task or secondary task become too high, performance decrements can occur in either or both tasks. The results of the two mobile phone studies summarised above provide support for this argument.

The finding that engagement with a secondary task results in poorer performance in the driving task is consistent with other research in the area of driver distraction. Reduced speed while using a mobile phone was also observed in other studies (Haigney et al., 2000) and the increase in the variability of speed is also consistent with findings of other studies (Reed and Green, 1999; Rakauskas et al., 2004). One interpretation of this is that secondary tasks require the participants to divert some of their attention away from driving, whereas in the control condition their attention is focused on the primary task of driving. Analysis of speed control and car-following performance found no significant differences between hand-held mobile phone, passenger-conversation and in-vehicle conditions. While this could be taken as an indication that these secondary tasks were equally distracting, other performance measures indicate that this is not the case (Parkes et al., 2007).

It is also unlikely that talking on a mobile phone improves lane keeping; indeed, this finding is inconsistent with other studies, which have found increases in the variability of steering wheel angle (Green et al., 1993), increases in lateral position variability (Reed and Green, 1999; Beede and Kass, 2006) and decreases in tracking accuracy (Surface Transportation Technical Group, 2002) when using a mobile phone. Rather, the reduced variability in lane position is probably a result of the reduced speeds selected by participants in the conversation conditions (Parkes et al., 2007). The participants in both studies were instructed to maintain a speed that would be challenging given the curvature of the road. Consequently, the results cannot be interpreted to mean that talking on a mobile phone leads to more suitable speed selection. Another explanation of the improvements in lane keeping could be that participants appreciated the effects of driving while using a mobile phone and concentrated more on the driving task (Parkes et al., 2007). The results of these studies cannot be used to support one explanation over the other. However, it is possible to conclude that different measures of driving performance are affected differently when secondary tasks are introduced.

These study results showed that reaction times were also affected by secondary tasks. In fact, reactions were most seriously affected by mobile phone use (Burns et al., 2002; Parkes et al., 2007). This is a significant finding, particularly given that reaction times influence whether or not the driving task can be carried out safely, and play an even greater role in complex road situations. Other studies have also shown poorer reactions while using a mobile phone. Increases in instances of hard braking (Harbluk et al., 2002; Liu and Lee, 2005; Hancock et al., 2003) and driving through stop signs and collisions (Kass et al., 2007) have been found to increase when drivers have held a mobile phone conversation while driving. One study found that participants responded to a change in the speed limit 200 m later when driving while holding a mobile phone conversation compared with a control drive (Parkes and Hooijmeijer, 2000). Because the simulated route in this experiment did not contain as many complex situations as would be expected in the real world, it could be argued that the effects of using a mobile phone would be greater, eg when navigating around busy city centres with dense traffic and complex junctions.

The subjective workload ratings suggested that participants found the control condition least demanding (Burns et al., 2002; Parkes et al., 2007). The passenger-conversation and in-vehicle conditions were more demanding than the control, and the hands-free condition was rated as being the most demanding during the Conversations in Cars Study, whereas in the Alcohol Benchmarking Study the alcohol and normal driving conditions were rated as requiring less mental effort than using a hand-held or hands-free mobile phone while driving. In this sense, this measure supports the argument presented to explain the driving performance results. Other studies have also shown increases in subjective workload ratings (Lesch and Hancock, 2004; Harbluk et al., 2002; Parkes et al., 1991) when using a mobile phone while driving.

Analysis of visual behaviour produced the expected result that operating climate and entertainment controls diverted visual behaviour away from the road when compared with the control condition (Parkes et al., 2007), while the conversation tasks increased the amount of time spent looking ahead when compared with the control condition. This was to the detriment of normal scanning of vehicle instruments, and was not accompanied by quicker or more accurate responses to traffic signals. This phenomenon has been observed during other research (Harbluk et al., 2002). One explanation might be that the cognitively demanding conversation tasks interfere with visual scanning in such a way that drivers do not actively search the visual scene as they might do under normal conditions. Bowyer et al. (2007) found a physiological explanation: that conversation on a mobile phone activated language-specific areas of the brain, but also damped brain activity in the right superior parietal and visual regions. This is consistent with studies that have found reduced situational awareness as a result of mobile phone use while driving (Parkes and Hooijmeijer, 2000).

Analysis showed that conversation performance was worse when driving (Burns et al., 2002; Parkes et al., 2007).
This demonstrates interference between two cognitively demanding tasks, and is consistent with previous research. However, the performance differences between the hands-free and passenger-conversation conditions are interesting, as the drivers’ physical task of controlling the vehicle was not directly influenced (as it would have been if a hand-held mobile phone were used) and the conversation was the same in both conditions (Parkes et al., 2007). It must be concluded that an aspect of the situation affected performance on this task.

This section has presented two studies conducted at TRL, which have shown the disadvantages of conducting a mobile phone conversation while driving. The repeated-measures design of both studies adds weight to the results by reducing the potential for confounding variables. Nevertheless, some criticisms can be made.

Firstly, neither of the studies examined a wide range of driving scenarios, and in particular complex driving tasks such as navigating junctions (Parkes et al., 2007). It is possible that the effects of mobile phone use are more pronounced in such conditions, and it would be interesting to study whether the demands of the simultaneous tasks would exceed drivers’ capabilities in such situations.

Secondly, while in both experiments the hands-free and passenger conversations were conducted in a similar way, a number of variables were changed simultaneously for the control conversation, which was held in a different environment to the other conditions (Parkes et al., 2007; Burns et al., 2002). It is possible that this may have had an effect on conversation performance. However, the conclusion remains that the dual task element is a major influence on performance. Furthermore, it is possible to argue that the RVCB may not be equivalent to normal conversation. Research has been conducted to compare driving performance when carrying out two different types of conversation. Participants were found to exhibit poorer driving performance when a mathematical operations conversation was used compared with an emotional conversation task (Shinar et al., 2005). Nevertheless, the RVCB did provide a means of comparing performance across a number of different conditions, and strengthened the argument that any differences observed could not be a result of the test material being different.

Thirdly, it was not possible to identify which aspect of each condition produced the effect. For example, was it an emotive reaction to the system or the social power of the passenger that produced the differences in performance, or do alternative explanations exist?

When taken on its own, the Conversations in Cars Study shows an effect of dual tasks on performance. It also confirms the findings of other experiments, particularly in terms of visual behaviour and speed choice, showing that driving while using a mobile phone increases the cognitive demand placed on the driver in such situations. However, from this study alone it is not possible to conclude that driving while using a mobile phone is dangerous. The strength of the Alcohol Benchmarking Study is that it shows poorer driving performance while using a mobile phone when compared with being over the UK legal limit for alcohol consumption. Thus, it shows that the distraction caused by a mobile phone conversation is more dangerous than what is accepted by society as being an unsafe act: driving while drunk.

The authors of both studies make a number of recommendations for future research. In particular, altering the driving scenario to include more complex tasks is suggested, to explore the safety implications of using a mobile phone in more complex driving situations. Furthermore, research into a more realistic conversation task is recommended, so that future studies can measure the effects of more natural conversations on the driving task.

Despite these increases in mental workload and the performance decrements discussed above, a recent study has also found that over the course of five sessions, drivers displayed significant improvements in most measures of driving performance (Shinar et al., 2005). This suggests a learning effect of driving and using a mobile phone, and that the real impact of using a mobile phone while driving may depend on the level of experience the driver has in carrying out these two tasks simultaneously. This study does not, however, show that driving performance would reach “safe” levels with practice. Furthermore, the argument that drivers should practice unsafe acts to improve their ability to multitask by driving, and put other road users at risk while doing so, is a weak argument indeed. Clearly, the safest option is to resist using mobile phones while driving.

Research findings have made it clear that the use of mobile phones while driving can lead to decreased driving performance. However, it has also been found that subjects’ perception of their driving performance is unrelated to, and at times converse to, actual decrements in their performance while using a mobile phone (Horrey et al., 2007). This may suggest that drivers themselves are poor judges of their performance decrements while driving.
4 Measuring visual demand: Occlusion

In addition to mobile phones, there is now a wide variety of in-vehicle information systems (IVIS) available to the driver. This has brought about the need for a method to assess the consequences of these systems on driver performance. Several methods have been proposed, such as vehicle simulators, road studies, the lane-change task (Mattes, 2003), the 15-second rule (Green, 1999; Green, 2000) and the IVIS Human–Machine Interaction (HMI) Safety Checklist developed by TRL for the Department of the Environment, Transport and the Regions (DETR) (Stevens et al., 1999). These methods vary in their reliability, validity, expense and requirement for subjective assessments. Therefore, the pressing need for a technique that is economical, reliable and valid is clear. The Occlusion technique was identified by TRL as a method that appears to satisfy these criteria. Indeed, recent research by Gelau et al. (2009) reported observing internal consistencies of 0.90 with Occlusion.

Commissioned by the DfT, TRL sought to develop a robust distraction-measurement protocol, based on a recent International Standard for Occlusion, ISO 16673:20072. The stand-alone research project took an independent and critical view of all of its provisions, taking the form of the largest-ever research project using the Occlusion technique (as of 2007), and the publication of a protocol for the technique designed to complement ISO 16673:2007. The Occlusion Protocol was to be developed from the experiences gained from the research project described in this section. Furthermore, the research project sought to propose criteria for the acceptability of various tasks. Therefore, not only was a well-defined Occlusion technique developed, but recommendations for “cut-off” points of the values of distraction quantified by this technique were proposed to aid in the identification of suitable and non-suitable IVIS.

The Occlusion technique seeks to assess the demand of visual or visio-manual interfaces by intermittently obstructing the driver’s field of view. Generally, Occlusion accomplishes this by using a pair of goggles that intermittently turn opaque – the Plato goggles (Figure 8). Drivers are typically asked to perform a series of tasks and the time they take to accomplish them is measured. The performance measures obtained are total shutter open time (TSOT) and a resumability ratio (R). TSOT is the cumulative length of time that it takes to complete a task, excluding periods when the task is occluded. For example, for a task that takes 15 seconds in total and uses a cycle of 1.5 seconds occluded and 1.5 seconds unoccluded, the cumulative length of time for which the shutter is open is 7.5 seconds (TSOT = 7.5 seconds). R is the ratio of the duration of TSOT to the total task time unoccluded (TTT\textsubscript{unoc})2. It is proposed that R can be used as an indication of how resumable a task is, with ratios of less than 1 being preferred.

The greater the demands required by a task, the higher the TSOT. Furthermore, as a task becomes more difficult to resume after interruptions, its R also increases. There is some debate as to the value of R as a performance measure. In particular, Transport Canada (2006) expressed concern that it was unclear what R was measuring; the link between resumability and safety has not been established. The first work package (WP) of the TRL research project examined the differences in R across age categories.

4.1 Research project

This project had two key objectives. Firstly, the project aimed to identify the issues required to establish an effective Occlusion Protocol for the assessment of IVIS. Secondly, the project sought to “propose criteria for the acceptability of different tasks”. These criteria would consist of a DRL for Occlusion, against which any IVIS task could be judged. In other words, the project would not only clarify the procedure for the Occlusion technique described in International Standard ISO 16673:2007, but also suggest the levels at which tasks completed under the technique should be considered to be acceptable or unacceptable. This would help inform DfT policymakers and others regarding which IVIS tasks should not be undertaken while driving.

The research was divided into five WPs, each designed to address a particular issue of importance in the project:

- WP 1: Age experimental study
- WP 2: Consideration of different IVIS tasks and expert evaluation
- WP 3: Benchmarking different IVIS tasks to performance measures (lane-change task) and other impairment-inducing factors (alcohol)
- WP 4: Protocol repeatability
- WP 5: Developing a demand reference level (DRL)

4.2 Work package 1: age experimental study

4.2.1 Background

It is of key importance to identify a low-cost technique to determine the minimum number of participants required for an Occlusion study. Reducing inter-participant variability is a primary means by which the number of participants required for any experiment can be minimised. Perhaps the most significant source of variability in Occlusion performance is age. International Standard ISO 16673:2007 specifies that 20% of participants should be over 50. The primary aim of this WP was to examine whether this requirement was optimal, or whether another selection criterion would be equally valid, but produce less variability and thus require fewer participants.

The secondary aim of this WP was to investigate the effects of requiring that 20% of participants were over 50. Due to the

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greater variability present among older participants, it is quite possible that researchers or developers using the International Standard independently with varying samples based on age, but the same systems/tasks, would come to markedly different conclusions.

4.2.2 Method
Sixty participants were recruited, distributed across six age categories (10 per category, as follows: 17–26; 27–36; 37–46; 47–56; 57–66; 67–76) and split evenly between genders.

Four tasks were selected as examples that would be likely to be considered acceptable, unacceptable or somewhere in-between. Definitions of the tasks and their predicted acceptability (based on their TSOT and R scores) can be seen in Table 6.

After five training sessions with the IVIS, participants completed five occluded and five “static” (ie unoccluded) attempts at each task (for a total of 40 experimental repeats).

4.2.3 Results
The results were analysed in several stages, the most important of which were:

- Analysis of differences in TSOT between age categories and tasks
- Analysis of differences in R between age categories and tasks
- Effect of randomly including 20% of older drivers within the total participant sample (as per the International Standard)

Table 7 shows the mean TSOT(s) and R values for each of the four tasks.

4.2.3.1 TSOT and age
When the discrepancies between each age group within each task were examined, more differences began to emerge. A general upward trend for TSOT was observed as age categories increased. Figure 9 demonstrates this upward trend across the tasks and age categories. For each task, a repeated-measures ANalysis Of Variance test (ANOVA) was performed and, while there were a few exceptions, generally older age groups were found to have significantly higher TSOT scores and higher variability. Note, the higher variability in the older age groups was an important finding for the definition of the Occlusion Protocol’s sampling recommendation.

4.2.3.2 R ratio and age
Similar analyses were performed on the data obtained for R. As can be seen in Table 8, all R values obtained were less than 1. The implications of this are that all four tasks would have been deemed acceptable with the criterion proposed.
by the Driver Metrics Workshop (2007) of acceptable tasks; namely, those with an R value of less than 1 are “resumable” and therefore acceptable. This adds weight to the view of Transport Canada (2006) that R is not a useful metric if it is agreed that some of the tasks were clearly unacceptable. ANOVAs computed on these data (the large majority of which failed to reach significance) suggest that the upward trend in TSOT by age category was not replicated with the R data. However, similarly to the TSOT data, greater variability in results was observed as the age categories increased for the R data.

4.2.3.3 Sampling strategies
Following these analyses, the effects of following the International Standard recommendation that 20% of participants should be aged over 50 were examined. Specifically, it is possible to ask the question “What is the magnitude of the effect of randomly including 20% of older drivers within the total participant sample?” This was investigated by comparing the results obtained between two groups of ten participants, the first being a randomly selected sample of participants following the ISO guidelines (ie 20% being over 50) and the second being a random sample of all participants, regardless of age. Ten samples of both strategies were compiled.

Figure 10 demonstrates the differences in TSOT obtained for both sampling strategies for all ten samples of each strategy. Casual inspection of Figure 10 suggests that the variability of participants selected using the ISO selection guidelines is somewhat lower than the entirely random sample. However, a t-test computed on these data did not find a significant difference between the two sampling strategies (t = 1.68, df = 18, p = 0.11). This pattern was largely replicated with the R ratio data, and again, a t-test revealed no significant difference between the methods (t = -0.79, df = 18, p = 0.94).

4.2.3.4 Gender comparison
Finally, a comparison of the TSOT results was made for male and female participants. The results of t-tests performed on the data showed no gender effects for any of the four tasks. This implies that an experimenter in a future Occlusion study does not generally need to control for gender.

4.2.3.5 Learning effects
The International Standard recommends that, following training, participants undergo five trials with and without the Occlusion goggles. To ensure that the participants’ performance did not significantly change across the five trials, the data were examined for learning effects. ANOVAs were computed on the data and the results were mixed. For Tasks 1 and 2, no learning effects were revealed. However, for Tasks 3 and 4 the ANOVAs did produce significant differences (mean square = 399.46, df = 4 and p < 0.01 for Task 3; MS = 215.78, df = 4 and p = 0.02 for Task 4).

It must be noted that participants on average became slower rather than faster. Therefore, although there are some significant differences within the order for this task, participants did not get quicker (ie display learning through improved performance times). The precise reason that they became slower is unknown, but it may be in part due to a vigilance decrement (as they were undertaking an experiment that took one hour overall).

4.2.4 Key implications
The key implications are:

- Older participants showed a greater spread of scores (especially for TSOT).
- To obtain minimal inter-subject variability, an experiment should ideally use younger and/or middle-aged participants.
- Gender does not appear to be a significant factor in Occlusion performance.

Table 8 R value by age category and task

<table>
<thead>
<tr>
<th>Age category</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>17–26</td>
<td>0.86</td>
<td>0.74</td>
<td>0.61</td>
<td>0.81</td>
</tr>
<tr>
<td>27–36</td>
<td>0.77</td>
<td>0.75</td>
<td>0.65</td>
<td>0.73</td>
</tr>
<tr>
<td>37–46</td>
<td>0.89</td>
<td>0.76</td>
<td>0.73</td>
<td>0.83</td>
</tr>
<tr>
<td>47–56</td>
<td>0.84</td>
<td>0.88</td>
<td>0.75</td>
<td>0.89</td>
</tr>
<tr>
<td>57–66</td>
<td>0.92</td>
<td>0.90</td>
<td>0.69</td>
<td>1.04</td>
</tr>
<tr>
<td>67–76</td>
<td>0.80</td>
<td>0.86</td>
<td>1.20</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Figure 10 Mean TSOT(s) by sample number
The data sampling recommendation in International Standard ISO 16673:2007 may be unnecessary as the results found that there was no overall difference in either TSOT or R due to the sampling strategy used.

Using subjects aged over 67 would increase the variability of the sample, so should be avoided.

It does not seem that learning occurred through the trials on any task, and that the practice sessions given are enough for a participant to reach the top of the learning curve. As such, the results imply that the practice sessions and experimental order outlined in the International Standard are sufficient.

### 4.3 Work package 2: consideration of different IVIS tasks and expert evaluation

The aim of this WP was to help understand the characteristics of IVIS tasks that are overly distracting. This was achieved in three stages:

- An expert-opinion/heuristic analysis conducted at a two-day workshop with staff from TRL and the University of Nottingham.
- A “keystroke-level” task analysis of each task to quantify how long completion of the four IVIS tasks should theoretically take, and to compare findings with the data obtained in WP 1.
- Ratings of tasks considered to be socially acceptable gathered from the same 60 participants who completed WP 1.

#### 4.3.1 Expert opinion

The expert-opinion/heuristic analysis panel identified positive, negative and neutral features of each of the four tasks used in WP1 (Horberry et al., 2007, p. 26). As can be seen in Table 9, the number of positive features declined as task number increased and the number of negative features increased as task number increased. Therefore, the expert panel identified not only those features that were potentially problematic, but also ranked the tasks in order of difficulty (this ranking was the same as predicted in WP 1).

#### 4.3.2 Keystroke-level task analysis

The keystroke-level task analysis model is usually used to make predictions of task performance time by expert users on routine system tasks. The technique involves decomposition of a task into primitive actions, known as operators; examples of this include pressing a key or button or movement of a hand between input devices. Based on that, total time taken for an “expert performer” is calculated.

The keystroke-level task analysis was used to predict and explain the TSOT and R values that were experimentally produced in WP 1. A detailed description of the analysis of each can be found in Horberry et al. (2007). The results of the keystroke-level task analysis can be summarised as follows:

- Keystroke-level task analysis modelled TSOT performance well for Tasks 1 and 2.
- Keystroke-level task analysis indicated that the differences between Tasks 1 and 2 were largely due to the number of stages involved in the interaction.
- Keystroke-level task analysis indicated the importance of system response time (ie waiting for information to appear) on the R ratio. However, further work would be required to model this accurately.
- Keystroke-level task analysis showed that the theoretical task-completion times (both static and occluded) were closely linked to the results obtained from WP 1 for two of the four IVIS tasks. This does not, of course, directly imply that only a keystroke-level task analysis is sufficient to demonstrate which IVIS tasks may be acceptable, as it was not a good predictor for the other two IVIS tasks.

#### 4.3.3 Social acceptability

All 60 participants from WP 1 were asked to answer two questions for all four tasks. These questions were:

1. Do you believe drivers should be able to carry out this task while driving?
2. Would you consider carrying out this task while driving?

Both questions produced an overall similar pattern of results, but there was a tendency for drivers to judge that they may personally carry out the tasks even though such tasks may not be appropriate for drivers in general. Furthermore, as the task number increased, the degree to which the behaviour was deemed acceptable rapidly diminished. Finally, younger drivers generally rated the tasks as more socially acceptable than the older drivers.

#### 4.3.4 Key implications

The findings of WP 2 identified aspects of tasks that may distract or lack usability, how socially acceptable the tasks were and the relationship between theoretical models of performance and real-world data.

These factors contributed to valuable insights, which were used to satisfy the project’s two main objectives: the production of a comprehensive Occlusion Protocol, and the development of a DRL.

### 4.4 Work package 3: benchmarking different IVIS tasks to performance measures (lane-change task) and other impairment-inducing factors (alcohol)

This WP was designed to aid the selection of an appropriate DRL by examining participant performance of the four IVIS tasks under two conditions other than Occlusion: a performance measure (lane-change task, or LCT); and an impairment-inducing factor (alcohol).

<table>
<thead>
<tr>
<th>Task</th>
<th>Positive features (score of +1)</th>
<th>Negative features (score of -1)</th>
<th>Overall score (positive minus negative scores)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>14</td>
<td>9</td>
<td>+5</td>
</tr>
<tr>
<td>Task 2</td>
<td>8</td>
<td>7</td>
<td>+1</td>
</tr>
<tr>
<td>Task 3</td>
<td>3</td>
<td>11</td>
<td>-8</td>
</tr>
<tr>
<td>Task 4</td>
<td>3</td>
<td>12</td>
<td>-9</td>
</tr>
</tbody>
</table>
4.4.1 Lane-change task and alcohol
One additional method for the evaluation of visual demand from an IVIS is the LCT. This method measures performance while completing an IVIS task using a low-fidelity driving simulation (Figure 11).

Participants were required to change lane as directed by signs at the side of the road while completing the four IVIS tasks. Performance was measured as the difference between actual lateral lane position and a hypothetical optimal lane positioning. This is illustrated in Figure 12.

Participants completed six conditions: a control condition; one condition for each of the four IVIS tasks; and an alcohol condition. In the alcohol condition, participants were given an alcoholic drink and this produced a mean intoxication of 38.7 µg per 100 ml of breath (range 29–50 µg).

ANOVA computed on the results of the LCT suggested that the IVIS tasks decreased driving performance significantly more than the control and more than the alcohol condition. There was no significant difference in performance between the four IVIS tasks.

When comparing the results of the LCT and the Occlusion data from WP 1, it can be seen that, unlike Occlusion, the LCT failed to differentiate between the four IVIS tasks. This suggests that the LCT is not sufficiently sensitive to distinguish between the tasks, whereas the expert panel and keystroke-level model in WP 2 predicted differences that the Occlusion technique corroborated in WP 1.

4.4.2 Key findings
Several key findings were produced in WP 3:
- All four of the IVIS tasks were found to impair performance significantly more than driving at the UK legal alcohol limit (it is important to note that alcohol has other negative effects on performance beyond impaired lane positioning, such as an increase in risk-taking behaviours).
- IVIS tasks take longer to complete when performed when a participant is also completing the LCT.
- All four IVIS tasks produced similar levels of impairment when completing the LCT.
- The LCT seems to be a less sensitive measure for detecting performance differences than Occlusion.

4.5 Work package 4: protocol repeatability
This analysis was performed at the University of Nottingham and consisted of a comparison of the university’s results from an Occlusion study using the same protocol as that developed at TRL (Horberry et al., 2007). This was undertaken to ensure the protocol was repeatable, reliable and valid. In general, the results showed the protocol to be so. However, an addition to the protocol was identified due to the importance of the technical environment in which the task is performed. For example, differences in the scrolling speeds of the IVIS tasks were observed between studies. The cause of this was identified as differences in the programming languages used. Therefore, the protocol was amended to highlight the importance of controlling for the effects of technical systems, which may produce differences between otherwise identical trials.

4.6 Work package 5: developing a demand reference level (DRL)
The final WP aimed to identify an appropriate DRL to be used by the DfT and others to rate the demand level of devices, tasks or functions that are presented to drivers.

It should be explained that the DRL should not be considered to be a recommendation of a safe/unsafe threshold level because:
• The demands of the driving task vary such that there are no absolutely “safe” situations in which secondary in-vehicle tasks can be carried out; in very demanding driving conditions, a brief glance away from the road scene could precipitate an accident.
• Different drivers have different capabilities for undertaking primary driving and secondary information tasks, resulting in different performance and safety levels.
• Distraction (and reduction in safety) results from a driver’s engagement with the secondary task and different drivers have different strategies; an extreme example would be a driver that decides not to use an in-vehicle device, thus reducing its distraction to zero.

Rather, the DRL should be viewed as an appropriate level by which the demand of a device/task can be assessed, or a target that can be incorporated into the design process of a new technology.

4.6.1 Method
Direct measurements of driving safety are problematical as there are no widely agreed measurement scales or limits representing safe driving. Therefore, the DRL was informed by scientific research, social acceptability and commercial considerations. These methods were:
1) a meta-analysis of literature review data,
2) personal contact with Occlusion experts in the USA, Japan, Canada and Germany at an International Standards meeting (ISO TC22 SC13 WG8),
3) experimental work conducted by TRL and the University of Nottingham concerning age (WP 1),
4) the social acceptability and keystroke-level model from WP 2,
5) a comparison of impairment of visual demand from using an IVIS with impairment caused by alcohol intoxication at the socially agreed UK limit (WP 3),
6) the results of the reliability analysis from WP 4, and
7) knowledge of the way in which industry uses design guidelines for the development of new IVIS.

4.6.2 The demand reference level (DRL)
The proposed DRL is based on the Occlusion parameter TSOT. Given the unclear pattern for R from the results of this study, and the general lack of international support for its use, it was decided that R should not be used in the DRL but should nevertheless be included in the protocol, and it is suggested that this be reported by experimenters.

As TSOT scores are typically skewed (there is a minimum time within which any task can be completed, but not a maximum), it was felt that the DRL including reference to the 85th percentile as a fixed mean would be a poor representation of the data. A typical distribution is presented in Figure 13. Figure 13 also shows the presence of a “spread zone”. This can be thought of as similar to a standard deviation term, but one more appropriate for a skewed distribution of values. Specifically, this spread is calculated as:

$$\text{Spread} = \frac{(85\text{th percentile} - \text{mean})^2}{\text{Mean}}$$

As demonstrated in Figure 13, if we used the mean (or, indeed, 85th percentile) alone it would not adequately account for the spread of scores, so the spread is a valuable statistic, especially when only a low number of participants are used for Occlusion testing. But it is still simple to calculate, as it requires only two values: the mean and the 85th percentile.

Given that the data are skewed, purely using standard deviation as a spread is not appropriate.

Therefore, the DRL proposed is that the mean plus the “spread” must be less than eight seconds, or:

$$\text{Mean} + \frac{(85\text{th percentile} - \text{mean})^2}{\text{Mean}} < 8.0 \text{ seconds}$$

When this DRL was applied to the data obtained in WP 1, only Task 1 met the level, with a mean TSOT score of 7.9 seconds. This was just below the cut-off level of 8.0 seconds. Tasks 2, 3 and 4 took between 11.4 and 13.9 seconds, well above the “acceptable” DRL.

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**Figure 13** Typical distribution of TSOT for a task
4.6.3 Key implications

The DRL proposed has been informed by many converging data sources and it represents a reasonable criterion to assess if an IVIS presents an acceptable level of visual demand when driving.

The Occlusion Protocol and the DRL defined here allow manufacturers, researchers and regulators to both undertake repeatable Occlusion research and to compare the visual demand from using an IVIS with a DRL. This process can be used both for original manufacturer fitted equipment and for nomadic and other off-the-shelf systems.

An IVIS task that meets the DRL does not necessarily imply that it is “safe” for a driver to perform while a vehicle is in motion, but it does suggest the visual demand required during the interaction is within a benchmark limit. As such, the DRL is a guideline rather than an absolute limit, and it is recommended that more DRL data are collected on as many common IVIS tasks as possible to further support the value proposed. This can only occur over time as use of the Occlusion method becomes more widespread.

5 Research gaps

The previous sections have highlighted a small number of recent research projects that have taken place in the field of driver distraction; in particular, to agree a UK definition of driver distraction, to highlight the effects of mobile phone use on driving performance and to develop a method for measuring visual demand. Nevertheless, there is a need for further distraction research.

A further aim of the scoping study of driver distraction described in Section 2 was to identify research gaps in the field of driver distraction (Basacik and Stevens, 2008). The following subsections describe the method used to achieve these aims, and the findings. The focus of the summary presented below will be on in-vehicle distractions.

5.1 Method

A second workshop was organised with the experts mentioned in Section 2. Its aim was to:

• confirm that the reference group is content that the important research gaps have been identified,
• discuss specific research needs, projects and priorities, and
• formulate recommendations for a programme of future research and ways to monitor changes in the impact of driver distraction on road traffic accidents.

In advance of the second workshop, the research gaps identified in the distraction review document were categorised and refined into 14 main areas. These formed the basis of an exercise in which members of the core and wider reference groups were asked to allocate a budget of 500 "research points" to these research gaps with the strategic aim of reducing distraction-related accidents. This helped to produce a list of research gaps in order of point allocation, and formed the basis of the discussion in the second workshop.

During a workshop attended by the core reference group, the research gaps were discussed in total research point order. For each, an attempt was made to cover:

• the potential impact of the research topic,
• suggested methodology,
• dependencies and/or collaboration needs, and
• resources and timescale required.

Notes from this workshop were produced and circulated, and commented upon by the core and wider reference groups. These form the basis for the findings presented in the next section.

5.2 Results

Thirteen of the research gaps identified prior to the workshop are relevant to the research area of in-vehicle distraction.

These are listed below.

A) Measuring driving performance degradations caused by people and other non-technical distractors within the vehicle, in real situations.

B) The relative effects on driving performance and interaction effects of distractors, including current and emerging technologies.

C) Measuring the effects of different IVIS interface designs on driving performance (including modality/multimodality, layout, menu complexity).
D) The cumulative and interactive distracting effects of a combination of in-vehicle technologies (including task switching).

E) The frequency and duration of drivers' actual use of the different functions of in-vehicle technologies (eg texting, internet, email functions of mobile phones) and of multiple functions or technologies, and the impact of this on risk during real-world driving.

F) Understanding the distinction between sensory and perceptual distractors (eg "looked but failed to see" accidents).

G) Identification of high-risk groups for distraction (eg elderly drivers, business drivers, younger drivers) and the effects of distractors on these groups.

H) Drivers' knowledge of the effects of distracted driving, their attitudes towards engagement with distractors and factors that would motivate drivers or different groups of driver to change their behaviour.

I) The relationship between the findings of experiments (in terms of driving performance degradations) and actual near-miss or crash rates due to distractors.

J) Quantification of the role of distraction (or individual distractors) in accident causation based on existing crash data, hence the cost to society of distracted driving and related crashes.

K) The development of a standard, meaningful, objective and reliable test procedure and baseline to identify "unacceptable" levels of visual distraction (potentially in real time).

L) The development of a standard, meaningful, objective and reliable test procedure and baseline to identify "unacceptable" levels of cognitive and auditory distraction (potentially in real time).

M) The identification of best practice to monitor the effects of distracted driving (eg accident rates, driver behaviour and attitudes) over time.

Figure 14 was presented at the beginning of the workshop to depict how the research gaps fit within the area of driver distraction. The main elements of the figure are drivers, distraction sources and activities during driving. The various research gaps are identified by a capital letter in bold (see corresponding list above) and are grouped according to the particular aspect of distraction that they aim to address (eg measuring demand, driver engagement).

Annex B illustrates the methodologies that could be used to address each of these research gaps.

Collaboration with industry (vehicle and IVIS manufacturers) was identified as being desirable for research gaps B, C, D, I, K and L. In addition, for a small number of research gaps, collaboration with the police (research gap J) and fleet managers (research gaps G, I and M) was discussed as a possibility. For research gaps D and E, it was proposed that working with European partners and funding could increase the cost-effectiveness of the studies, particularly if the chosen methodology involved naturalistic driving.

In addition, during the workshop, experts identified five further areas for research. These comprised:
- the effects of distraction due to insufficient information to carry out the driving task effectively,
- developing training programmes and monitoring their effects on driver distraction,
- driver self-regulation (how drivers compensate for the current and anticipated effects of distraction),
- long-term effects of using in-vehicle systems (eg reliance) and distraction-mitigation strategies, and
- crash configuration/accident scenarios where distraction is over-involved as a causal factor.

It was noted that some of the original research gaps could be extended to include aspects of these additional research areas. For example, the effects of training on driver distraction and the long-term effects of using in-vehicle systems could be...
5.3 Research programme

Some time was then spent discussing how these research gaps may be turned into a research programme. The following recommendations were made:

- It may be possible to group the research gaps by methodology, and tackle multiple gaps at the same time.
- It may be possible to group the research gaps in terms of which mitigation strategies they support.
- It may be beneficial to characterise the nature of the problem in the first instance, through accident studies, and surveys/focus groups on perceptions and attitudes. Work could include elements of research gaps F, H and I. Focus groups could be used to inform survey questions, and to explore survey results.
- The NHTSA Driver Distraction Internet Forum (National Highways Traffic Safety Association, 2000) is an example of a discussion/survey mechanism that reached a large audience; this format of study could be considered.
- It is important to identify, at an early stage, developments that bring about a change in the nature and types of potential distractions (eg new technologies inside and outside the vehicle) and form a strategy to tackle the potential effects of these.
- Naturalistic driving studies are being planned across Europe, and many of these started in 2008. European projects draw upon expertise across European countries and allow research costs to be shared by member states. By contributing to this work, it may be possible to ensure that additional data are collected to fill the research gaps discussed during this workshop.

5.4 Summary

This workshop discussed a range of research gaps that had been identified during the literature review, in terms of impact, methodology, resources, timescales, dependencies and collaboration needs.

In terms of mitigating against distraction, the need for clear messages to the public that are easy to understand and a methodology for evaluating and monitoring effects were identified.

The workshop concluded that there was some overlap between some of the research gaps in terms of scope and methodology. Furthermore, some of the research gaps will require significant investment and/or participation in larger-scale studies (eg naturalistic driving, at a European level). It was emphasised that exploiting opportunities to collaborate in larger pieces of work would be more beneficial in understanding the phenomenon than carrying out small-scale projects.

6 Conclusion

This Insight Report has summarised the findings of TRL's recent studies in the field of in-vehicle distraction. The scoping study of driver distraction resulted in agreement on a UK definition of driver distraction. The Conversations in Cars and Alcohol Benchmarking studies focused on driver distraction by mobile phone use, and analysed a wealth of task performance variables. The conclusion of these studies was that talking on a mobile phone is a demanding task that has an impact on driving performance. In fact, driving performance while using a mobile phone is worse than when driving while over the UK legal limit for alcohol consumption.

Both the Conversations in Cars and Alcohol Benchmarking studies used a driving simulator in order to assess participants’ driving performance under a variety of task conditions in order to evaluate the relative risks of driving while using a mobile phone. While this is a well-established approach in assessing driving performance, it is also important to acknowledge that, given the plethora of potentially distracting in-vehicle systems becoming available to the driver, a more economical, yet valid and reliable, method of assessing in-vehicle distractions would be welcome. TRL’s research on the Occlusion technique focused on identifying a DRL, based on converging data sources, which would be used to detect whether an IVIS presents an acceptable level of visual demand while driving. Even though holding a mobile phone conversation is more likely to be a cognitive distraction than a visual distraction, it is important to recognise that alternative features of mobile phones such as text-messaging services, internet browsing and email functions, as well as other in-vehicle systems, can invite visual interaction. Thus, the benefits of research into the Occlusion technique are apparent.

Nevertheless, driver distraction remains a topic that is not fully understood. The scoping study of driver distraction has identified that further research is necessary in order to appreciate the mechanisms of driving performance decrements as a result of distraction, how these then affect road safety and the role of distraction in accident causation. Additionally, it is recommended that research could focus on driver attitudes towards distractors and their actual patterns of engagement with sources of distraction.
Acknowledgements

The work described in this Insight Report was carried out in the Human Factors and Simulation Group of the Transport Research Laboratory.

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Annex A: Full text of the Occlusion Protocol

A.1 Introduction
This Occlusion Protocol was developed within a joint TRL and University of Nottingham project for the UK Department for Transport (DfT), based on the ISO Standard 16673:2007 (Road vehicles – Ergonomic aspects of transport information and control systems – Occlusion method to assess visual demand due to the use of in-vehicle systems standard).

Occlusion is a measurement procedure for assessing visual demand due to the use of visual or visual manual interfaces available to the driver while a vehicle is in motion. The Occlusion method assesses the visual demand and interruptability of a task using a means for intermittent viewing of the in-vehicle system (e.g., IVIS). Visual Occlusion helps identify designs which require long single glance durations to assimilate information necessary to complete a task.

This protocol has been developed to extend the ISO Standard and to help ensure that there is consistency between assessment sites. It also acts as a reference tool for experimenters conducting Occlusion studies.

The language adopted is less formal than that of a standard. When “should” is used in this protocol it means that the item is part of the protocol (rather than being “optional”). When “shall” is used this indicates that the step is also part of the ISO Standard.

A.2 Set-up
A.2.1 Environment for testing
The in-vehicle information system (IVIS) under investigation should be operational and fitted to a vehicle, simulator buck, or laboratory mock-up in a design which duplicates the intended location of the interface in the vehicle. (Note, this need not necessarily be done in a vehicle.) The exact geometry of the equipment should be recorded; this could include digital photographs of the set-up and measurements of the subtended visual angle of the IVIS display. While using the Occlusion Protocol to test prototypes, care should be taken to ensure that placement of the IVIS system matches the location of its planned use.

If a car is used it should be placed within an uncluttered and distraction-free environment. Areas that have a large volume of people traversing them should be avoided.

The area should be subject to a full risk assessment prior to the commencement of testing, with any issues or anticipated problems kept in mind at all times.

It is advisable, due to weather issues, that the testing is conducted indoors. Safety concerns associated with vehicles indoors involving, for example, flammable liquids and batteries should be addressed prior to testing.

If used, a vehicle should not be cluttered with extraneous equipment. There should be easy ingress and egress for the participant from the driver’s side, and for the experimenter from the passenger’s side.

When wearing the Occlusion goggles, the ocular illumination levels experienced by participants in the vision and Occlusion intervals should be comparable so that dark/light adaptation of the participants’ eyes is not necessary during the trials.

A.2.2 IVIS equipment
The equipment used will be strongly dependent on the research question. A number of issues that should be considered in the placement of in-vehicle equipment are:

• handedness of participants,
• the position of the equipment in a vehicle that would be being used on the road,
• potential variability in results depending on whether the vehicle was left or right hand drive,
• obstructions to the view of equipment by the participant, and
• viewing angle and control placement relationship should be maintained.

In addition to following experimental set-up and analysis procedures outlined in this protocol, a key point is to carefully record everything. For example, it is useful to obtain photographic evidence of the placement of the equipment for future reference.

When investigating prototypes, care should be taken to ensure IVIS system performance is consistent regardless of the hardware platform used or networking conditions experienced; in other words, the speed of the trials must be consistent and recorded if comparisons are to be made between tasks or across studies. Exactly how this speed will be recorded will depend on the nature of the task, e.g., time taken for 30 data points to scroll across the screen. Likewise, the size of the prototype display should be recorded and held as constant as possible.

A.2.3 Occlusion equipment
The Occlusion procedure approximates the driver looking back and forth between the forward driving scene and an in-vehicle interface, looking at each for a brief period of time. Intermittent viewing of an interface can be provided by various means, but this protocol uses goggles only.

During the Occlusion interval, neither the interface displays nor controls shall be visible, but operation of the controls shall be permitted (though most input to the interface might occur when vision is available). This protocol simulates drivers glancing at both the road and the IVIS to enter information via a manual control or extract information from the IVIS.

A.2.4 Occlusion software
There are a number of different versions of Occlusion software available and they vary concerning details they record. Some software will record the Occlusion metric TSOT (which will be fully defined later in this protocol). Other software does not directly record TSOT or TTT, so this must be recorded by the experimenter. The most basic option for doing this is to use a stopwatch and record from the time the experimenter commences the Occlusion trial until the time that the participant has completed the trial and confirms this by stating “done”.

4 Horberry et al. (2007a).
A.3 General experimental design issues

A.3.1 Task protocol
A task protocol is a detailed study design that includes all the steps required to be undertaken by the experimenter and the instructions to participants for a particular task that is being tested. The task protocol needs to be specific enough in its instruction to participants that if a number of different experimenters are involved each participant would have a similar experience. The instruction should be standardised and can be presented either orally or in written form. The display and controls of the interface should be visible during instruction. If requested by the participant, the instruction shall be repeated to them. An example instruction sheet with phrasing is shown in Appendix 1; such a sheet should be drawn up in advance. Notes should be made by the experimenter on any mistakes or difficulties experienced by the participant with the task or with the Occlusion goggles.

It is important to consider the technical environment and performance speed in which a task is implemented to enable evaluation teams to make meaningful cross-study comparisons. For example, the language in which a task is written should be selected carefully to ensure that a consistent speed of display is possible.

A.3.2 Vision and Occlusion intervals
The vision interval shall be 1.5 seconds and the Occlusion interval shall be 1.5 seconds.

Periods of vision and Occlusion shall automatically occur without interruption until the task is completed or the trial is terminated. Thus, the pacing of the Occlusion intervals is controlled by the system, rather than the participant.

A.4 Task timing
In practice, assessment trials often involve multiple experimenters. This is acceptable; however, care should be taken when stopping and starting each of the tasks, to ensure consistency between multiple experimenters. Ensure that the participant is in a standard “starting position”, eg they have their hands placed on their laps before the trial is started.

Figure 1 shows a timeline of the Occlusion cycles for a given task. When timing the trials, it is imperative that the experimenter is as accurate as possible. If the trial is using Occlusion software that does not time the trial, then the experimenter should use a stopwatch. The stopwatch should be started at the beginning of the first vision interval after the instructions and stopped immediately after the participant has said “done”\(^5\). Ensure that the participant is very clear that they must say “done” as soon as they complete the trial and not before or after. This point is very important for accurate timing.

A.5. Specific experimental design issues

A.5.1 Selection of tasks
The Occlusion procedure is not appropriate for tasks shorter than about five seconds (unoccluded), because there would not be enough shutter open and closed periods during Occlusion trials. In this case, the resolution of the technique is inadequate for the IVIS tasks to be evaluated reliably.

For each task being studied there should be five variations/trials (for example, a task of entering a point of interest into an IVIS would use different points of interest for each variation). This ensures that a fair assessment is made of each task. However, it is important that each trial variation is consistent with the others so that the trials can be directly compared to calculate the Occlusion measures \((TTT_{unoc}, TSOT\) and \(R\)). It is also important that the trials within the unoccluded experiment are comparable to the trials within the occluded experiment (see the “Experimental plan” section below).

\(5\) Participants failing to report “done” at the end of a trial should be considered, for example by also defining when a task is formally completed and using this when “done” is not reported. However, as much as possible requiring participant to say “done” should be required.
A.5.2 Participants
Data from 20 participants is required. Each should be between 17 and 66 years old.

A.5.3 Selection
The participants shall be licensed drivers for the class of vehicle being studied (car, van, HGV, etc.). Persons who have specific technical knowledge or familiarity about the driver interface being studied shall not be included as test participants. These should be excluded using a suitable questionnaire such as in Appendix 2. Furthermore, care should be taken to recruit representative users who are unlikely to be subject to bias (for example, close co-workers may not be suitable).

A.5.4 Data recorded
The age of the participants shall be recorded. Other relevant characteristics of the participants should also be recorded. Depending on the exact purpose of the study, these may include:
- Gender. Obtaining an equal gender balance is not necessary for all studies and in some studies might create an artificial sample (e.g. with truck drivers, who are predominantly male). However, gender should be noted.
- Licence type(s) held.
- Years since gaining first driving licence.
- Average number of miles/kilometres driven per annum.
- General experience of using technology (see Appendix 2 for a suitable questionnaire).

A.6 Trial procedure
A.6.1 Experimenter familiarity
To ensure that the experimenter(s) are familiar with the experiment it is important that sufficient pilot studies and practice are undertaken. This is particularly important to help minimise variation when more than one experimenter is involved (especially if timing is recorded manually).

A.6.2 Introducing Occlusion and the experimental set-up to participants
Before training on the Occlusion procedure, the Occlusion goggles need to be introduced to the participant. The participant should be briefed on the use of the goggles and their purpose and importance within the trial. The participant should be asked to wear the goggles when they are flashing occluded to unoccluded. The experimenter should check that the participant is content to carry on with the trial before any task introduction or training is commenced.

A.6.3 Participant familiarity with equipment
Each participant should be given a general introduction to the equipment used in the trial. If a vehicle is being used, they should be shown how to manoeuvre themselves into a comfortable posture. Reference should also be made to the in-car equipment and further adjustments should be made if they cannot comfortably use the equipment (e.g. if using a PDA or other nomadic device, ensure that the participant can reach the equipment comfortably).

A.6.4 Task introduction
It is important that before the participant begins training they understand how to complete the task. A simple explanation from the experimenter or a spoken run-through of the procedure to complete the task will aid the understanding of the participant and help them to complete the task. It is imperative to explain to the participant any of the functions that they might use to complete the task.

A.6.5 Participant training
Participants shall be told that they may operate the controls during an occluded period. The tasks should be demonstrated, then five practice trials should be undertaken by each participant. The participant should be required to successfully complete a task without intervention from the experimenter.

At least two of these practice trials should use the Occlusion procedure. Any data to be viewed or entered for the specific tasks in practice trials should be different from that in test trials but equivalent in difficulty. The aim should be for each practice trial to be properly completed using the designated method; the experimenter should aim to ensure appropriate completion of the task by providing coaching or assistance if the participant is having problems. If participants cannot successfully complete the practice task unaided by the experimenter at least once in five trials, then the interface design and training protocol should be reviewed.

The participant shall be instructed to say “done” at the moment he or she believes that the task is completed.

A.6.6 Test trials
After training, each participant should be tested individually. As each trial is completed, the participant should be given the next variation. Coaching should not be provided during test trials but feedback on errors is permitted when a trial is completed; for example if the experimenter recognised an aspect of the task that the participant was continually completing incorrectly. In such a situation, the experimenter may give an example of an alternative option to aid successful completion of the task. Any additional input by the experimenter within the trial should be noted. The success criteria for the task must be determined beforehand. “Successful” or “not successful” completion of the task should be recorded for each trial according to whether the success criteria were met.

As described in section A.5.1 above, for each task, every participant should be asked to complete five variations/trials.

A.6.7 Experimental plan
The experimental plan shall be designed to avoid treatment order bias. To reduce such bias, alternate the experimental conditions between participants; this is shown in Figure 2 below.

---

6 Although the ISO Occlusion Standard recommends that two of the ten participants employed should be aged above 50 years, the results of a recent experiment (Horberry et al., 2007b) suggest that including subjects over 67 years may increase the variance of the sample. As such, unless there is a particular reason to focus on older aged drivers, it is recommended that the participants used are aged from 17 to 66 years old.

7 Horberry et al. (2007b) demonstrated that there is not a significant difference in Occlusion results between males and females.
Both TSOT and R are calculated in this protocol. Measurement of R requires a comparison of occluded and unoccluded (static) measurements (i.e., performance with and without the Occlusion goggles, respectively). An experimental plan should be designed to avoid carry-over or training effects between the conditions (Figure 2). If more than one task is being evaluated then additional counterbalancing will be required. The plan should also ensure that instructions to participants are identical and that tasks are of equivalent difficulty; Appendix 1 describes an example of this.

### A.7 Exclusion of trials

There may be occasions when a trial has to be excluded:

- When a participant refuses to complete a trial.
- When a participant says he or she is done with a trial but they are not (either because they have fundamentally misunderstood the task or have not completed the trial).
- When the experimenter judges that the participant cannot successfully complete a trial in spite of multiple efforts.
- Where a calculated TSOT value is an outlier (i.e., more than four times the mean $TTT_{Unoccl}$ for all trials completed by that participant).

In such instances, the result shall be documented and that trial excluded from the analysis. When calculating Occlusion parameters with such a reduced data set, care should be taken to ensure means are based on the total number of correctly completed trials; variations which were not completed must be entered as a missing case and not zero (or means will be calculated incorrectly, for example).

### A.8 Calculation of Occlusion metrics

Definitions of $TTT_{Unoccl}$, $TTT_{Occl}$, and TSOT are shown below and the methods for calculating TSOT and R are described. Appendices 3 and 4 show an example spreadsheet and graphs.

#### A.8.1 $TTT_{Unoccl}$ definition

The total task time unoccluded ($TTT_{Unoccl}$) shall be determined as follows:

- **Start**: Timing starts at the end of the task instruction.
- **End**: Timing ends when the instructed task has been completed and the participant says he or she is “done”.
- **Duration**: Tasks are timed from start to end without interruption, including errors.

#### A.8.2 $TTT_{Occl}$ definition

The total task time in occluded conditions ($TTT_{Occl}$) shall be determined as follows:

- **Start**: Timing starts at the end of the task instruction, with the beginning of the first vision interval.
- **End**: Timing ends when the instructed task has been completed and the participant says he or she is “done”.
- **Duration**: Tasks are timed from start to end without interruption, including errors.

#### A.8.3 TSOT definition

The total shutter open time (TSOT) shall be determined as follows:

- **Start**: Timing starts at the end of the task instruction, with the beginning of the first vision interval (Figure 1).
- **End**: Timing ends when the instructed task has been completed and the participant says he or she is “done”.
- **Duration**: Tasks are timed from start to end without interruption, including errors.

---

8 Unlike the ISO Occlusion Protocol, where the R measure is optional. This protocol includes measurement of R even though the R value is not used to calculate the demand reference level.

9 An outlier is not specifically defined in the ISO Standard, instead it more generally mentions excluding data where the TSOT value was more than four times the mean $TTT_{Unoccl}$ for all trials completed by that participant. This protocol has adapted this data exclusion criteria as the outlier definition. Therefore any TSOT value that is more than four times the mean $TTT_{Unoccl}$ for all trials completed by that participant is both considered as an outlier and is excluded from the analysis.

10 The ISO Standard also allows for other methods to be used. The method recommended here is undoubtedly the most simple to apply. (The most accurate method would require calculating the time elapsed in the last vision interval, subtracting that from the $TTT_{Occl}$ before performing the calculation and then adding it back to the result at the end. However, the small additional accuracy is considered superfluous.)
A.8.4 R value definition
The R value, or resumability ratio, is the ratio of the duration of the total shutter open time (TSOT) to the total task time unoccluded (TTT\textsubscript{Unoccl}), ie TSOT/(mean)TTT\textsubscript{Unoccl}\textsuperscript{11}.

A.8.5 Calculating TSOT
As shown in Equation 1, to calculate TSOT from TTT\textsubscript{Occl} divide TTT\textsubscript{Occl} by 3 (one cycle of Occlusion) and then multiply this value by 1.5 (time the shutter is open in one cycle of Occlusion):

\[ TSOT = \frac{TTT_{Occl}}{3} \times 1.5 \]  

(Equation 1)

As shown in Equation 2, TSOT for each participant should be calculated by using the overall mean TTT\textsubscript{Occl} of the five trials completed (or all the trials completed, if less than five). Refer to Appendix 3 for a worked example.

Overall mean TSOT value = \frac{\sum (TSOT\textsubscript{ni})}{N} \hspace{1cm} \text{Where TSOT\textsubscript{ni} is each of the mean values for TSOT for each participant and N is the number of participants.}  

(Equation 2)

If valid data are obtained from N participants, the following summary statistics should be reported for each task:

a) Mean of the N values of TSOT
b) 85th percentile of the cumulative distribution function of the N values of TSOT

A.8.6 Calculating R
The R value is the ratio of the duration of the total shutter open time (TSOT) to the total task time unoccluded (TTT\textsubscript{Unoccl}). TTT\textsubscript{Unoccl} for one participant is the mean of the five (or actual number of successfully completed) trials.

As shown in Equation 3, the R value for each participant for each task should be calculated by dividing the mean TSOT by the mean value for mean TTT\textsubscript{Unoccl}. Refer to Appendix 3 for a worked example.

\[ R = \frac{TSOT}{TTT_{Unoccl}} \]  

(Equation 3)

As shown in Equation 4, when calculating the overall mean R for a task, take the sum of the mean value of R per participant and divide this by the number of participants.

Overall mean R value = \frac{\sum (R\textsubscript{ni})}{N} \hspace{1cm} \text{Where R\textsubscript{ni} is each of the mean values for R for each participant and N is the number of participants.}  

(Equation 4)

When valid data are obtained from N participants, the mean of R (see Equation 4 above) should be reported. However, given the lack of international agreement about R, it does not form part of the demand reference level assessment (see below). The diagnostic value of R is the subject of much debate, and there is a view amongst some researchers that R > 1 is unacceptable. However, until this debate is satisfactorily concluded, the demand reference level proposed here does not include an R component.

A.9 Comparison of Occlusion metrics to the demand reference level
A demand reference level (DRL) has been recommended based on TSOT (Horberry et al., 2007b). The DRL is based on the mean TSOT and the spread (uncertainty) within the distribution of scores.

As shown in Equation 5, using obtained TSOT values, the measure of spread (S) used is based on the 85th percentile and the mean of the TSOT distribution:

\[ S = \frac{(85th \text{ percentile} - \text{mean})^2}{\text{Mean}} \]  

(Equation 5)

As shown in Equation 6, using obtained TSOT values, the proposed method for calculating DL\textsubscript{Occl} is:

\[ \frac{\text{Mean} + (85th \text{ percentile} - \text{mean})^2}{\text{Mean}} \text{ (seconds)} \]  

(Equation 6)

Once the DL\textsubscript{Occl} has been calculated, this value must be then compared to the DRL (see Equation 7).

\[ \frac{\text{Mean} + (85th \text{ percentile} - \text{mean})^2}{\text{Mean}} < 8.0 \]  

(Or simplified is: \text{Mean} + \text{spread} < 8.0)  

(Equation 7)

So for an IVIS task to “meet” the DRL, the DL\textsubscript{Occl} value produced need to be below eight seconds.

Using these values, the process to assess if a task meets the DRL (and is therefore considered to be “acceptable” by these Occlusion criteria) is shown in Figure 3.
A.10 Additional checks on the data

A.10.1 Learning effects

The data for all tasks should be analysed to assess if any learning effects exist.

An ANOVA should be performed on the data to see if there are any significant differences between the five trials and therefore a potential learning effect. If significant differences are found in the overall ANOVA, a series of post-hoc pairwise comparisons can be performed to assess where specific differences may exist. If learning effects are found, then the training regime should be questioned.

A.10.2 Overall trial position

A comparison should be made to assess if the results obtained for the occluded section of the trial are significantly different depending on whether they were undertaken before or after the unoccluded trials. Both mean TSOT and R values per participant should be examined. T-tests should be employed to analyse the differences between the two groups (the Occlusion results obtained either before or after the unoccluded trials), and the significance level of 0.05 should be used to assess if statically significant differences exist. If overall trial position effects are found, then the training regime should be questioned. Note, recent UK research by Horberry et al. (2007b) showed no learning or trial position effects using this Occlusion Protocol.

A.11 References


Appendix 1: Example experimental instructions

The experimental instructions presented below were taken from a recent experiment undertaken by TRL and the University of Nottingham for DfT. In this experiment, 60 participants of various age ranges were tested on four different IVIS tasks using the Occlusion Protocol based on the ISO Standard.

**Introduction to vehicle, PDA and screen**

For this trial we are going to be using this vehicle stationed in front of us. I would like you to sit in the driver’s seat and adjust the seat position to your normal driving position. Please ensure that you can reach the PDA from your seated position. If you cannot reach the PDA, please adjust your seat accordingly.

**Assist the participant with this adjustment if necessary.**

For this trial we will be using two pieces of equipment, a PDA or Personal Digital Assistant and an LCD screen. You will be simply required to read information from the LCD screen, and you will be asked to perform two different tasks on the PDA. I will give you full training on how to use the device and how to complete each of the tasks so please do not worry if you have never used one before. This PDA device has a touch screen and it is operated by making light taps on the relevant part of the screen using the pen like this........

**Quick demonstration of how to use the PDA.**

(Within this demonstration ensure that you explain both the erase and back functions.)

For parts of the trials you will be required to wear this set of goggles which will occlude or block your vision for short periods of time. If you normally wear glasses for reading please put them on now. I will demonstrate the Occlusion goggles to you now. Please note that the occluded period is intended to simulate the time that your eyes would be on the road.

**Demonstrate Occlusion goggles on participant.**

We are now ready to begin the study. I will give you specific training before each trial to help you to complete it. Are you happy to continue?

### Training for first trial

**The first trial is going to be entering a destination by selecting a “point of interest”:** We will be using the PDA for this. Route guidance systems have digital maps which store information on local services such as hotels or amusement parks. For the first task I will be asking you to enter into the navigation system on the PDA a specific point of interest. To begin I will show you how to enter “Exeter International Airport”.

**Demonstrate entering Exeter International Airport into PDA.**

(Ensure that you show the participant the erase, back and scrolling buttons.)

Please note that the points of interest appear in proximity to your present location, which at this time is TRL in Crowthorne. Now I am going to give you five attempts to practice entering different points of interest into the PDA. When you have found the point of interest and selected it please say “done”. Please could you keep your hand placed on your lap until I ask you to start. Could you find........

**Assist participant to enter point of interest, dictate if necessary.**

After second attempt – I am now going to ask you to repeat this trial wearing the Occlusion goggles.

**Repeat through five training sessions, two trials unoccluded, three trials occluded. If the participant is not confident after the first two trials, allow up to two more practices and then move on to the three occluded trials. Participant must complete a minimum of two occluded trials before they should move on to the recorded trials.**

### First trial

**OCCLUDED**

Now we will move on to the trial. We are going to begin this trial wearing the Occlusion goggles. I will ask you to enter a point of interest. Again, when you select the point of interest can you please say “done”. Please could you keep your hand placed on your lap until I ask you to start. Could you find........

**Repeat for each point of interest.**

**UNOCCLUDED**

For the second part of this trial I am going to ask you to enter another set of five different points of interest. However, this time you will not be wearing the Occlusion goggles. Again, when you select the point of interest can you please say “done”. Please could you keep your hand placed on your lap until I ask you to start. Could you find........

**Repeat for each point of interest.**
## Training for second trial

The second trial is going to be **entering a destination by address, using the PDA**. This route guidance system enables the user to input an address anywhere in the United Kingdom by entering the desired town, street name and house number. I will give you a number of destinations which I would like you to enter. I will provide you with a town, street name and house number for you to enter into the PDA. I will show you an address card with the correct spelling of each of the addresses on it. Now I will talk you through this example so that you understand how to use the system.

*Show address card of 23 Abingdon Road, Sandhurst.*

Demonstrate entering 23 Abingdon Road, Sandhurst.

(Note, please demonstrate how to use the erase and back functions.)

Now I am going to give you five attempts to practice entering different addresses into the PDA. When you have found the address and select it please say “done”.

Please could you keep your hand placed on your lap until I ask you to start. Could you find…….. *(show and read out address card to participant).*

**Assist participant to enter address, dictate if necessary.**

**After second attempt** – I am now going to ask you to repeat this trial wearing the Occlusion goggles.

Repeat through five training sessions, two trials unoccluded, three trials occluded. If the participant is not confident after the first two trials, allow up to two more practices and then move on to the three occluded trials. Participant **must** complete a minimum of two occluded trials before they should move on to the recorded trials.

## Second trial

**UNOCCCLUDED**

Now we will move on to the trial. We are going to begin this trial without the Occlusion goggles. I will ask you to enter an address. Again, when you select the point of interest can you please say “done”.

Please could you keep your hand placed on your lap until I ask you to start. Could you find…….. *(show and read out address card to participant).*

**Repeat for each address.**

**OCCCLUDED**

For the second part of this trial I am going to ask you to enter another set of five different addresses. However, this time you will be wearing the Occlusion goggles. Again, when you select the address can you please say “done”.

Please could you keep your hand placed on your lap until I ask you to start. Could you find…….. *(show and read out address card to participant).*

**Repeat for each address.**

## Training for third trial

The third trial is going to be **searching for share prices**.

For this task we will be using the LCD screen. When I start the task a single scrolling column of text will appear on the screen, which will include both the share three-letter code and share price. I will ask you to search for a share price by the three-letter code and require you to read out loud the share price of the code in question.

*Demonstrate scrolling share prices.*

Now I am going to give you five attempts to practice reading these values from the screen.

Please could you find……..

**Assist participant to understand task if required.**

**After third attempt** – I am now going to ask you to repeat this trial wearing the Occlusion goggles.

Repeat through five training sessions, two trials unoccluded, three trials occluded. If the participant is not confident after the first three trials, allow up to two more practices and then move on to the two occluded trials. Participant **must** successfully complete two occluded trials.
Third trial

**OCCLUDED**

Now we will move on to the trial. We are going to begin this trial wearing the Occlusion goggles. I will ask you to search for five different share codes in succession. We will begin the trial now with........

*Repeat for each share price.*

**UNOCCLUDED**

For the second part of this trial I am going to ask you to search for another five different share codes. However, this time you will not be wearing the Occlusion goggles.

*Repeat for each share code.*

Training for fourth trial

The fourth trial is going to be searching for share prices.

For this task we will be using the LCD screen. When I start the task three columns of scrolling text will appear on the screen, which will include both the share-three letter code and share price. I will ask you to search for a share price by the three-letter code and require you to read out loud the share price of the code in question.

*Demonstrate scrolling share prices.*

Now I am going to give you five attempts to practice reading these values from the screen.

Please could you find........

*Assist participant to understand task if required.*

*After third attempt – I am now going to ask you to repeat this trial wearing the Occlusion goggles.*

*Repeat through five training sessions, two trials unoccluded, three trials occluded. If the participant is not confident after the first three trials, allow up to two more practices and then move on to the two occluded trials. Participant must successfully complete two occluded trials.*

Fourth trial

**UNOCCLUDED**

Now we will move on to the trial. I will ask you to search for five different share codes in succession. We will begin the trial now with........

*Repeat for each share price.*

**OCCLUDED**

For the second part of this trial I am going to ask you to search for another five different share codes. This time I am going to ask you to wear the Occlusion goggles.

*Repeat for each share code.*
Appendix 2: Example pre-Occlusion questionnaire

(To be completed by experimenter)
Participant number: ___________________ Date of trial: __/__/___

Occlusion study

SECTION A: PERSONAL PROFILE

Note:
• All information on this form is confidential.
• No individuals will be identified.

A1. What was your age at your last birthday?
   _____ years

A2. Are you male or female? (tick)
   □ Male
   □ Female

SECTION B: DRIVER PROFILE

(Please circle the number that you feel is most appropriate)

B1. How many years have you held a full driving licence?
   _____ years

B2. Approximately how many miles have you driven in the last year?
   _____ miles

B3. On how many days do you drive in a typical week?
   Never 1 2 3 4 5 6 7

B4. What type of vehicle(s) do you drive? (tick all those that apply)
   □ Motorcycle
   □ Car
   □ Light goods vehicle
   □ Heavy goods vehicle

B5. In general, do you enjoy driving?
   Completely dislike driving Thoroughly enjoy driving
   1 2 3 4 5 6

B6. How confident do you feel when driving?
   Very unsure Very confident
   1 2 3 4 5 6

SECTION C: EXPERIENCE WITH TECHNOLOGY

C1. How long have you been using a computer for?
   _____ years

C2. How often do you use a computer? (please tick the appropriate box)
   □ Never
   □ 1–3 times per month
   □ 1 time per week
   □ 1–3 times per week
   □ Everyday
C3. How long have you owned a mobile phone for?

___ years

C4. How often do you use a mobile phone? (please tick the appropriate box)

☐ Never  
☐ 1–3 times per month  
☐ 1 time per week  
☐ 1–3 times per week  
☐ Everyday

C5. Have you ever used a navigation device? (please tick the appropriate box)

☐ Yes  
☐ No  
☐ Not sure

C4. How frequently do you use a navigation system whilst driving? (please tick the appropriate box)

☐ Never  
☐ Very infrequently  
☐ Occasionally  
☐ Frequently  
☐ Very frequently

C5. How frequently do you use your stereo whilst driving? (please tick the appropriate box)

☐ Never  
☐ Very infrequently  
☐ Occasionally  
☐ Frequently  
☐ Very frequently
### Key
- \( n \): number of completed trials (normally 5)
- \( N \): number of participants
- \( \Delta \): total Occlusion cycle time
- \( R \): resumability
- \( x \): box reference number

### Notes
1. Time taken for each of the five occluded trials
2. \( \sum \) cells E to I
3. Mean of TSOT scores
4. Spread + mean TSOT
5. Time taken for each of the five unoccluded trials
6. \( \sum \) cells O to S
7. \( \sum \) cells O to 9
8. Time taken for each of the five unoccluded trials
9. Mean of ratios \( \sum R / N \)
10. Example of incomplete trial resulting in \( n = 4 \) with consequent effects on subsequent calculation of average \( TTT_{\text{Occl}} \)
11. Mean of TSOT scores
12. 85th percentile of TSOT scores
13. Obtained \( D_{\text{Occl}} \) fails to meet required DRL
14. Obtained \( D_{\text{Occl}} \) is above required DRL of 8, therefore fails to meet acceptable requirements

### Example of Incomplete Trial
- Example of incomplete trial resulting in \( n = 4 \) with consequent effects on subsequent calculation of average \( TTT_{\text{Occl}} \)

### Example Spreadsheets
- ANX A: FULL TEXT OF THE OCCLUSION PROTOCOL
- ANNEX A: FULL TEXT OF THE OCCLUSION PROTOCOL

### Excel Sheet
- Task X Data
- Raw Data
- Task X Analysis
- Summary
Appendix 4: Example graphs

(a) Example graph to show variability in TSOT by age category and task number

(b) Example graph to show variability in R value by age category and task number

Figure 4 Example graphs based on TRL research study
<table>
<thead>
<tr>
<th>Research gap</th>
<th>Epidemiological approach</th>
<th>Survey/questionnaire</th>
<th>Focus group</th>
<th>Laboratory testing</th>
<th>Simulator study</th>
<th>Track/road trials</th>
<th>Naturalistic driving</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Measuring driving performance degradations caused by people and other non-technological distractors within the vehicle, in real situations</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>B. The relative effects on driving performance and interaction effects of in- and extra-vehicle distractors including current and emerging technologies</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>C. Measuring the effects of different IVIS interface designs on driving performance (including modality/multi-modality, layout, menu complexity)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>D. The cumulative and interactive distracting effects of a combination of in-vehicle technologies (including task switching)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>E. The frequency and duration of drivers’ actual use of the different functions of in-vehicle technologies (e.g., texting, internet, email functions of mobile phones) and of multiple functions or technologies, and the impact of this on risk during real-world driving</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>F. Understanding the distinction between sensory and perceptual distractors (e.g., “looked but failed to see” accidents)</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>G. Identification of high-risk groups for distraction (e.g., elderly drivers, business drivers, younger drivers) and the effects of distractors on these groups</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

This was identified as being a relatively well-researched area. It was therefore thought that the focus should be on the implementation of research findings rather than the identification of a methodology for research.
<table>
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</tr>
</thead>
<tbody>
<tr>
<td>H. Drivers' knowledge of the effects of distracted driving, their attitudes towards engagement with distractors and factors that would motivate drivers or different groups of driver to change their behaviour</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>I. The relationship between the findings of experiments (in terms of driving performance degradations) and actual near-miss or crash rates due to distractors</td>
<td>✓</td>
<td></td>
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<tr>
<td>J. Quantification of the role of distraction (or individual distractors) in accident causation based on existing crash data, hence the cost to society of distracted driving and related crashes</td>
<td>✓</td>
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<tr>
<td>K. The development of a standard, meaningful, objective and reliable test procedure and baseline to identify “unacceptable” levels of visual distraction (potentially in real time)</td>
<td>✓</td>
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<tr>
<td>L. The development of a standard, meaningful, objective and reliable test procedure and baseline to identify “unacceptable” levels of cognitive and auditory distraction (potentially in real time)</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>M. The identification of best practice to monitor the effects of distracted driving (e.g., accident rates, driver behaviour and attitudes) over time</td>
<td>✓</td>
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Driver distraction from in-vehicle sources: a review of TRL research

In 2007, a workshop was conducted at the Department for Transport, and the conclusion was drawn that driver distraction is a significant factor in accident causation, but is neither completely understood nor documented. This Insight Report describes the results of four recent TRL studies in the field of in-vehicle distraction. The scoping study of driver distraction brought together experts in the field to discuss the concept of driver distraction and reach agreement on a definition. The project reviewed observation-based, experimental and opinion-based research and identified a range of research gaps. In terms of experimental research, this Insight Report describes two driving simulator studies that were conducted to examine how mobile phone use affects driving performance. One study showed that reaction times were significantly increased when using a mobile phone compared with a conversation with a passenger, using in-vehicle controls and without any simultaneous tasks. The second study showed that mobile phone use resulted in significantly higher reaction times, even when compared with driving at the UK legal limit for alcohol consumption. Finally, in terms of metrics and measures, this Insight Report describes the research that was carried out in developing the Occlusion Protocol, which is a technique for measuring visual demand.

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