MONASH University
Accident Research Centre

RISKS ASSOCIATED WITH IN-VEHICLE TECHNOLOGY USE WHILE DRIVING

Identification of Research and Policy Needs

Kristie L. Young

Michael G. Lenné

Final Report

July 2010

MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE
REPORT DOCUMENTATION PAGE

Report No.	Date	ISBN	ISSN	Pages
Final	July 2010	978-0-7311-9194-9	1835-4815 (online)	41

Title and sub-title:

Risks Associated With In-Vehicle Technology Use While Driving

Author(s):

Kristie L. Young & Michael G. Lenné

Sponsoring Organisation(s):

This project was funded by VicRoads

Abstract:

This report reviews the recent literature on the effects of in-vehicle and portable devices on driving performance and crash risk, including what features and characteristics of these devices pose the greatest crash risk. The review focuses on in-vehicle VDUs and mobile phones, particularly the emerging, multi-function features of these technologies such as navigation/congestion systems, MP3 players and internet/email. The aim of the review is to examine what new research has been conducted in this area since 2007 and discuss what additional information (if any) this new research provides. Topics covered in the report include the effects of technology-related distraction on driver performance and crash risk, as well as the frequency of driver engagement with these technologies. Also discussed are the various strategies being employed to reduce the negative impact of in-vehicle devices on safety, including device placement, methods for interacting with systems and current international distraction policy discussions and directions. The review concludes with a discussion of key knowledge gaps.

Key Words:
Driver distraction; In-vehicle technology; Crash risk; Exposure; HMI design

Monash University Accident Research Centre,
Building 70, Clayton Campus, Victoria, 3800, Australia.
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363
www.monash.edu.au/muarc

Preface

Project Manager / Team Leader:

Dr Michael Lenné

Research Team:

- Ms Kristie Young
- Dr Michael Lenné

Contributorship Statement

Kristie Young conducted the literature searches, identified and reviewed relevant studies and took the lead role in drafting the report.

Michael Lenné scoped and defined the project with the client, provided guidance on research direction and reviewed the draft report.

Acknowledgement

We thank Dr Christina Rudin-Brown for reviewing and providing input to an earlier version of this report.

Contents

Figures

Tables

EXECUTIVE SUMMARY

The last few years have seen an explosion in the number of multi-function in-vehicle and portable devices. A major concern with these systems is the amount of visual and cognitive demand they place on drivers. This report examines the recent literature on the effects of in-vehicle device use on driving performance and crash risk, with a particular focus on the features and characteristics of mobile phone and visual display units that pose the greatest crash risk. The review aims to examine what new research has been conducted in this area since 2007 and discuss what additional information (if any) this recent research provides.

The recent research in this area offers a number of new insights into the effects of in-vehicle devices on driving performance and crash risk and the best methods to collect accurate and detailed distraction data:

- Particularly in the area of mobile phones, recent research has shifted away from establishing the effects of device use on driving, towards identifying and understanding the underlying psychological reasons influencing drivers' willingness to use in-vehicle devices, including personality characteristics and perception of risk. The research focus has also shifted to extend our knowledge of the relative effects of using various in-vehicle devices compared to other distracting activities or forms of driver impairment. The research has also moved beyond just examining the distracting effects of devices for drivers, to identifying the risks that such devices have for other road users, including pedestrians and cyclists.

- The findings from two recent naturalistic driving studies suggest that visually demanding tasks, which require drivers to look away from the roadway for two or more seconds (e.g., dialling and texting), are associated with a higher crash risk than cognitive tasks (e.g., talking on a phone). Tasks that are largely cognitive and allow drivers to keep their eyes on the road, were found to be associated with a smaller increase in crash or near-crash risk in these studies. These findings challenge the results from previous simulator and laboratory studies, which have found that conversing on a mobile phone while driving is as dangerous as the visual manual task of dialling. However, it is important to note that the findings from the naturalistic studies are based on a small sample of drivers and crashes/near-crashes and require replication before firm conclusions can be drawn. A number of larger-scale or more mobile phone focussed naturalistic studies are currently underway or in their planning stages in Europe and the US that may help to provide more insight into the inconsistent findings across studies. However, it likely that the findings of these studies will not be known for a number of years.

- Vehicle manufacturers and system developers are using a number of innovative design approaches for interacting with in-vehicle systems in order to minimise their potential to distract drivers. These include voice-recognition technology, touch screens, tactile interfaces, and steering wheel controls. Research on these interaction methods has found that touch screens are advantageous for integrating multiple systems into one, centralized location, and combining different types of feedback (i.e., auditory-visual or haptic-visual) is likely to enhance the safety features of this interaction method. Voice-based interaction is also likely to be appropriate for completing what would otherwise be long duration, visually demanding tasks, such as address entry, but is unlikely to reduce the distraction imposed by highly complex tasks such as reading or composing emails.

- The limited amount of research available suggests that public transport and particularly heavy vehicle drivers regularly use in-vehicle technologies and may be more vulnerable than passenger vehicle drivers to the negative effects of distraction from these devices due to the higher workload demands placed on them from their job and physical characteristics of the vehicle which make it harder to manoeuvre and also longer to stop, giving drivers less time to react effectively to hazards. Indeed, recent naturalistic studies have found that certain mobile phone activities are associated with relatively higher crash/near-crash risks for heavy vehicle drivers compared to passenger vehicle drivers, which may be due to the higher physical and mental demands of driving a heavy or public transport vehicle.

- There is a movement towards the naturalistic driving methodology as the 'best practice' method for collecting a range of distraction-related data including exposure, driving performance and crash risk data. It is argued that this method has several advantages over more traditional methods, including allowing for the detailed and accurate collection of multiple data sources in a real-world environment.

The review highlighted a number of key gaps in our research knowledge of the risks associated with distraction from in-vehicle technology. The key research needs in relation to in-vehicle technology distraction are summarised briefly below:

- There is a need for more detailed and complete data on drivers' exposure to technology-related distraction. This is particularly the case for new and emerging technologies (e.g., DVD, portable digital music players, email/internet) and driver aides (eco-driving systems, congestion assistants, stop-n-go speed/headway maintenance systems). While surveys are a cost and time efficient method for colleting these data, more objective methods such as naturalistic driving studies are indicated to ensure the collection of completed and accurate data.

- There is a need to better link technology-related distraction to at-fault crashes. This will likely require the collection of such data via police crash report forms, or the conduct of large-scale naturalistic driving or in-depth crash studies. It should be noted, however, that the collection of distraction-related crash data is a difficult undertaking given that many distractions leave no 'trace', and drivers are often unwilling or unable (due to lack of recall) to provide information on any distracting activities they were engaged in prior to the crash.

- There is a need for additional and higher quality research to establish the impact of new and emerging technologies on driving performance (e.g., DVD, portable digital music players, email/internet). A priority for research in this regard is on the use of multi-function 'smart' mobile phones. These devices allow drivers to access a host of functions, including those that were once the domain of on-board systems (e.g., navigation and traveller information), but using much smaller screens, buttons and complex menus that were not necessarily designed for use in-car. Where possible, larger-scale, on-road research programs, such as naturalistic driving studies, should be used to study drivers' use of these technologies and their associated performance degradations under real-world driving conditions.

- Research is needed to examine the distracting effects (if any) of the various driver aides and collision warning systems entering the market in order to support their safe design and implementation.

- Research is required to identify the safest interaction/input method for in-vehicle technologies (e.g., touchpad/screen, voice-based interaction). It is likely that the best interaction method might also differ across driving populations (i.e., older drivers), so it is important for any research conducted in this area to include a range of driver populations.

- In addition to interaction methods, there is a need for research on the ideal placement of portable devices such as multi-function mobile phones in the vehicle. Guidelines exist for the placement of on-board VDUs. However, portable devices represent an additional challenge for drivers given their small displays and buttons and, currently, there is no guidance on which, if any, mounting location(s) facilitate ease of use or minimise distraction.

- Finally, there is a need to explore driver exposure to, and the performance effects and crash risks of, technology-related distraction for commercial heavy vehicle and public transport drivers.

1 INTRODUCTION

Driving is a complex task, requiring a combination of cognitive, physical, sensory and psychomotor skills. Despite the complexity of this task, research shows that drivers regularly engage in various non driving-related activities while driving. In particular, drivers' preoccupation with in-vehicle technologies while driving is becoming more common (NHSTA, 2009). The last few years have seen an explosion in multi-function in-vehicle and portable devices. These devices allow drivers access to a diverse and complex array of functions including email, song lists, navigation and traffic congestion information, and the internet while driving. Such functions are typically accessed from a single on-board visual display unit (VDU) or portable device such as the new 'smart phones'. Given that driving is primarily a visual task, the introduction of such visually demanding devices and features into the vehicle could have major implications for road safety.

Driver distraction can be defined as a diversion of attention away from activities critical for safe driving towards a competing activity (Lee, Young, & Regan, 2009). The extent to which engaging in distracting activities results in a degradation of driving performance depends on a combination of factors, including the demands of the driving task, the demands of the distracter task, and the manner in which the driver allocates their attention between these two tasks (Horrey & Wickens, 2004; Lee, Regan, & Young, 2008; Wickens, 2002, 2008).

This report examines the recent literature on the effects of in-vehicle device use on driving performance and crash risk, with a particular focus on what features and characteristics of these devices pose the greatest crash risk. The aim of the review is to examine what new research has been conducted in this area since 2007 and discuss what additional information (if any) this recent research provides.

The review focuses on in-vehicle VDUs and mobile phones, particularly the emerging, multi-function features of these technologies such as navigation/congestion systems, MP3 players and internet/email. Topics covered in the review include the effects of these devices on driver performance and crash risk, as well as the frequency of driver engagement. Also discussed are the various strategies being employed to reduce the negative impact of such devices on safety, including device placement, methods for interacting with the device and international policy discussions. The review concludes with a discussion of key knowledge gaps and a list of priority research needs.

2 REVIEW OF IN-VEHICLE TECHNOLOGY RISKS

This section reviews what is known about the effects of various in-vehicle technologies on driving performance and crash risk, with a particular focus on mobile phones and Visual Display Units (VDUs). The review is organised so that, where relevant and/or available, earlier (pre-2007) research is first briefly discussed. Then, recent research (2007 onwards) is presented and conclusions drawn about what additional information this newer research adds to our knowledge.

2.1 MOBILE PHONES

The use of mobile phones while driving has been the focus of a large body of research, particularly over the past decade, and is easily the most extensively studied distracting activity to date. This section synthesises what is known about the effects of mobile phone use on driving, including the risks associated with individual phone activities. First, however, mobile phone exposure rates are discussed.

2.1.1 Prevalence of Mobile Phone Use

The popularity of mobile or portable devices, particularly mobile phones, has escalated in the last decade, with the mobile phone market reaching saturation level in Australia (Harpur & Budde, 2008). But how many of these owners actually use their mobile phones while driving? Research suggests that phone use while driving is common and widespread.

Roadside observational surveys conducted between 1999 and 2006 found that between 1.5 and 2% of Australian drivers were using a hand-held mobile phone at any one time (Horberry et al., 2001; Taylor et al., 2003; Taylor et al., 2007). In 2009, a Melbourne-based study found that this figure had increased to 3.4%, while 1.4% of drivers were observed using hands-free phones (Young, Rudin-Brown, & Lenné, 2010).

Mail, telephone and web-based surveys have also shown that mobile phone use is prevalent among drivers, although exposure estimates vary across countries. Up to 40% of Canadian (Beirness, 2002; Laberge-Nadeau et al., 2003) and 30% of Swedish (Thulin & Gustafsson, 2004) drivers admit to using mobile phones while driving. Usage rates in countries such as the United States, Spain, New Zealand and Australia are higher, with around 60% of drivers reporting that they use a mobile phone in their vehicle (Gras et al., 2007; McEvoy, Stevenson, & Woodward, 2006; Stutts, Hunter, & Huang, 2003; Sullman & Baas, 2004; Young & Lenné, 2010). An examination of demographic data from these studies indicate that mobile phone use while driving is particularly prevalent among drivers who are young, inexperienced, travel in urban areas and have high annual mileage rates.

What is particularly concerning among these studies is the high proportion of drivers who use their phones in hand-held mode, even in countries where legislation exists to prohibit this mode of use. Young and Lenné (2010) recently found that over one third (35%) of Victorian drivers who use a phone admit to using it in *hand-held* mode all of the time, while 13% use their phone in both hand-held and hands-free mode. Also, of concern is the high number of drivers who admit to sending and receiving text messages. Young and Lenné also found a high number of young (18-25 yrs) drivers (approx 30%) who regularly (once a day or more) read and/or send text messages while driving. The recent Telstra

'Drive Safe, Phone Safe' is consistent with these findings, with around one third of drivers in their survey reportedly send text messaging when driving (Telstra, 2010).

Much of the previous mobile phone exposure survey has been collected using survey methods, whether mail, telephone or roadside surveys. While they are quick, easy and inexpensive to use, exposure surveys have a number of limitations, including self-reporting bias, low-response rate, sample bias, and observer error (roadside surveys) (Young & Regan, 2008). It is clear that more objective methods are needed, such as naturalistic driving studies, to get a more complete and accurate picture of what activities drivers are engaging in and how frequently and for how long they engage.

2.1.2 The Effects of Mobile Phone Use on Driving and Behaviour

Earlier research examining distraction and mobile phones typically focused on establishing the effects of using a mobile phone on various driving performance measures. A synthesis of this research reveals a long list of driving measures that have shown to be affected by mobile phone use:

- *reduced lateral control (ability to maintain correct lane position)* (Brookhuis, de Vries, & de Waard, 1991; Haigney, Taylor, & Westerman, 2000; Kass, Cole, & Stanny, 2007; Tornros & Bolling, 2005);
- *reduced longitudinal control (ability to maintain an appropriate and predictable speed and headway from lead vehicles)* (Alm & Nilsson, 1995; Patten et al., 2004; Rakauskas, Gugerty, & Ward, 2004; Strayer & Drews, 2004);
- *increased detection and reaction (braking, swerving) times to roadway events, particularly those occurring in the periphery* (Bellinger et al., 2009; Burns et al., 2002; Consiglio et al., 2003; Harbluk, Noy, et al., 2007; Langer, 2005; Lesch & Hancock, 2004; McPhee et al., 2004);
- *increase in missed traffic signals and signs* (Burns et al., 2002; McKnight & McKnight, 1993; Strayer, Drews, & Johnston, 2003; Tornros & Bolling, 2005);
- *impaired visual search patterns and scanning (visual tunnelling to centre roadway)* (Al-Tarawneh et al., 2004; Recarte & Nunes, 2003; Schreiner, Blanco, & Hankey, 2004; Strayer, Cooper, & Drews, 2004);
- *risky decision making (i.e., gap selection when turning)* (Cooper & Zheng, 2002; Cooper et al., 2003); and
- *reduced awareness of surrounding traffic (i.e., reduced situational awareness)* (Harbluk, Noy, et al., 2007; Kass et al., 2007).

The extent to which these driving performance measures are affected by mobile phone use depends, in part, on the specific phone activity being carried out with the phone (e.g. dialling, talking or texting). Comparisons between the effects of talking on a mobile phone while driving and of dialling a phone number while driving have found that there is a different pattern of driving degradation observed across these two phone tasks. That is, rather than one task being deemed more 'distracting' than the other, they appear to affect different aspects of driving or the same aspect differently.

Lateral position measures (lane keeping) appear to be particularly affected by the visual-manual demands of dialling, but less so by the cognitive demands of conversing. Several studies have shown that dialling a mobile phone leads to greater deviation in drivers' lateral position and increased steering wheel movements relative to conversing (Brookhuis et al., 1991; Green, Hoekstra, & Williams, 1993; Horrey, Wickens, & Consalus, 2006; Reed & Green, 1999; Tornros & Bolling, 2005). Lateral control has been shown to be less affected by talking on a mobile phone (Caird et al., 2008). These findings are in-line with other research that has shown that visual-manual tasks increase lane keeping variation (e.g., Greenberg et al., 2003; Zwahlen, Adams, & de Bald, 1988), while moderate cognitive tasks have little effect on lane keeping performance and can even lead to more precise lateral control (Engstrom, Johansson, & Ostlund, 2005; Jamson & Merat, 2005). Dialling affects lateral vehicle control due to biomechanical interference with steering, but also due to the build up of heading errors. When visual attention is diverted from the road, drivers tend to maintain a fixed steering angle and make less micro steering corrections, which can lead to over-corrections, lane weaving and excursions. Cognitive tasks such as conversing are believed to have less of an impact on lane keeping due to the effects of visual tunnelling, whereby driver concentrate their gaze on the centre of the road (Engstrom et al., 2005). Indeed, talking on a mobile phone has been shown to constrain drivers' visual search patterns (e.g., Recarte & Nunes, 2003), and the attentional processing and recall of traffic signs (e.g., Strayer et al., 2003).

Dialling a mobile phone has also been associated with larger reaction times to peripheral stimuli and a greater number of missed traffic signals (Brookhuis, de Vries, & de Waard, 1991; Tornros & Bolling, 2005). In a meta-analysis of the mobile phone literature, Caird et al. (2008) also found that, compared to baseline measures, talking on a mobile phone increased reaction times by 0.33 seconds for cognitive tasks that approximate a cell phone conversation and by 0.14 seconds for naturalistic conversations. Dialling or entering a number had a relatively higher reaction time increase of .36 seconds.

Despite the enormous amount of mobile phone-related research, relatively little of it has focused on the effects of text messaging. Based on the type of task demand (visual-manual) and its relatively longer duration, there is good reason to expect that texting would have a more detrimental impact on driving than dialling and talking. Two recent simulator studies have examined the effects of text messaging on driving. Hosking, Young, and Regan (2009) examined the impact of text messaging on driving performance. Twenty young, novice drivers (less than 6 months of driving experience) were exposed to a number of safety-related events (e.g., a pedestrian appears from behind a car) while sending and reading messages. Both texting activities negatively affected the driver's ability to control lateral position and responses to traffic signs were also significantly impaired. Also, the amount of time that drivers spent looking away from the road was up to four times greater when text messaging than in the baseline condition. Driving speed when texting did not differ from the baseline condition; however, following distance increased.

Drews and colleagues (Drews et al., 2009) extended the findings of Hosking et al., by comparing texting with talking on a mobile phone. They found that texting in a driving simulator resulted in more crashes, slower response rates to brake lights of lead cars, and impaired forward and lateral control than drivers who were talking on a cell phone while driving or drove without texting. The type of texting task also played a role, whereby reading text messages affected braking times more than composing texts. Drews et al. concluded that texting while driving is riskier than talking on a mobile phone because it places additional demands on visual attention that result in participants' switching attention between activities, rather than simultaneously sharing attention between the two tasks as they do when talking.

2.1.2.1 Recent mobile phone research (2007-2010)

While earlier mobile phone research focused on the effects of using a phone on various driving performance measures, research conducted in the last several years has begun to dig deeper, focusing on the underlying psychological reasons influencing drivers' willingness to use mobile phones, including personality characteristics and perception of risk. Recent research has also shifted to examine the effects of mobile phones on road users other than drivers, namely pedestrians and cyclists. Another focus has been on extending our knowledge of the effects of mobile phone use compared to other distracting activities or forms of driver impairment.

In addition to age and gender, research has found a number of personality traits that are associated with an increased willingness to use a mobile phone while driving. Specifically, more frequent rates of mobile phone use while driving is associated with drivers who are more aggressive, prone to (general, day-to-day) accidents, adopt risky driving styles (exceeding speed limit, red-light running, drink driving), more in a hurry, and have a greater number of traffic crashes (Beck, Yan, & Wang, 2007; Chen, 2007). Australian research exploring the underlying psychological factors that influence willingness to use a mobile phone when driving have found that drivers who are frequent phone users have a positive attitude to mobile phone use, believe that others approve of them using their mobile phone while driving, and perceive in-car phone use to have a large time management benefit (Walsh et al., 2008; White et al., 2010). Perceived risk of detection by police and of crashing generally did not influence drivers' intentions to use their mobile phone when driving (Walsh et al., 2008). Over confidence in one's abilities also appears to play a role in willingness to use a phone while driving. Schlehofer and colleagues (In Press) found that, in a sample of US college students, overestimating one's driving performance and overestimating the control one has to avoid negative outcomes were both associated with more frequent mobile phone use while driving. Such findings point to the need for stricter and more vigorous enforcement of mobile phone laws and, potentially, for the use of automated mobile phone detection technology to assist police in this enforcement.

Research has also examined whether and how the perceived riskiness of mobile phone activities affects the frequency of phone use while driving. This research has found that although drivers acknowledge the dangers associated with using a mobile phone when driving, frequency of phone use is generally not influenced by perceived risk (Nelson, Atchley, & Little, 2009; Young & Lenné, 2010). Nelson and colleagues found that although perceived risk lead to a mental struggle over whether to use the phone, it ultimately did not affect their actual behaviour. It was argued that the perceived importance of the call outweighed the perceived risks involved in using the phone. Similarly, Young and Lenné found that although some phone activities were perceived as being extremely dangerous (e.g., text messaging), they were still engaged in by a large proportion of drivers on a regular basis.

Recent research has also sought to extend earlier research comparing the relative performance degradations associated with mobile phone use and other distractions and risky driving behaviours. Following on from earlier work comparing phone and passenger conversations (Consiglio et al., 2003; Crundall et al., 2005; Drews, Pasupathi, & Strayer, 2004; 2008; Laberge et al., 2004), Charlton (2009) systematically compared the driving performance effects and conversation patterns of hands-free mobile phone conversations and in-car and remote passenger conversations. He found that drivers who were conversing on a hands-free phone or with a remote passenger had appreciably poorer speed control when overtaking and slower reaction times to hazards than drivers who were conversing with an in-vehicle passenger. The author concluded that conversation modulation, whereby the conversation partner slowed their talking around hazards and provided alerting comments, was a key factor in maintaining good driving performance. Conversation modulation was found in the in-car passenger conversations and, to a lesser extent, in the remote passenger conversations. It was not present during the mobile phone conversations, where driving performance showed the greatest degradation. In an epidemiological study, McEvoy et al. (2007) also found evidence that conversations on a mobile phone place drivers at a greater risk of crashing (four-fold increase) than passenger presence (two-fold increase).

Rakauskas and colleagues (2008) extended previous work on the relative effects of distraction and alcohol on driving performance by examining the effects of both on driving performance and drivers' coping strategies, such as trying harder, relaxing performance goals or increasing safety margins. They found that drivers use different coping strategies when distracted compared to when intoxicated. When distracted, drivers tended to withdraw attention from all aspects of driving, despite reports that they were attempting to invest more effort into driving. Moderate levels of alcohol, in contrast, affected how drivers' allocated their resources and adjusted their performance targets, whereby they 'shed' lower priority driving tasks to invest more effort in primary driving goals.

Finally, three studies have focused on the effects of mobile phone use on pedestrian behaviour and one on cyclist safety. These studies revealed that pedestrians who were talking on a mobile phone made more unsafe road crossings, evidence by not looking before or during the crossing, crossing more slowly, and crossing when cars are still approaching (Hatfield & Murphy, 2007; Nasar, Hecht, & Wener, 2008). Both studies demonstrate that mobile phone use can reduce pedestrians' awareness of their surroundings, potentially putting them at a greater risk of an accident. In a simulated crossing experiment, Neider et al. (In press) found that, despite taking more time to initiate their crossing, pedestrians were less likely to successfully cross the road when conversing on a mobile phone than when listening to music on an iPod. When using the mobile phone, most of the failures to cross the road successfully resulted from trial timeouts, not collisions, confirming the findings of Hatfield and Murphy and Nasar et al., that pedestrians on mobile phones take longer to complete their crossings than pedestrians who are not distracted or using an iPod.

In a study of Japanese high school students, Ichikawa and Nakahara (2008) found that mobile phone use while riding a bicycle was widespread among the students during their commute to school (up to 87% of students). A higher frequency of mobile phone use amongst the cyclists was found among male students and those who only commuted to school by bicycle. Those students who perceived this activity to be dangerous and those who thought that using a mobile phone while riding is prohibited were less likely to engage in phone use while riding.

Despite the rapid evolution of multi-function or 'smart' mobile phones over the past couple of years, no research, to the knowledge of the authors, has examined the effects or crash risk associated with these new enhanced phone features. Mobile phones now allow drivers access to the internet, email, satellite navigation, digital music lists, personal photos and videos, and games and other applications including entire books. While some of these features have been examined as separate systems (see Section 2.2), their application as part of a portable, hand-held device is likely to place different demands on users given the different interaction modes and screen size used. It is hence important that drivers' use of these multi-function devices is established and the risks associated with their use determined.

2.1.3 Crash Risk Associated with Mobile Phone Use

Early epidemiological studies suggested that using a mobile phone while driving is associated with a four-fold increase in crash risk, and that there is no appreciable difference in crash risk between hand-held and hands-free phones (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997).

More recent research using the naturalistic driving method yields important insights into the risks associated with mobile phone use by light and heavy vehicle drivers under real-world conditions. A combination of data from the naturalistic driving studies conducted by the Virginia Tech Transportation Institute (VTTI) suggests that the crash risks associated with mobile phone use depends on the type of phone activity being carried out (see Table 1). In a sample of light vehicle drivers, Klauer et al. (2006) found that dialling a hand-held device was associated with an almost three-fold increase (odds ratio = 2.79) in crash or near-crash risk, while talking/listening on a hand-held device was associated with a relatively smaller increase in risk (odds ratio = 1.29). In a sample of 258 commercial and heavy vehicle drivers, Olson et al. (2009) found an almost six-fold increase in crashes or near-crashes for dialling a mobile phone and a twenty-three-fold increase for text messaging. Talking/listening on a phone was not associated with an increased crash risk. The relatively higher crash/near crash risks for heavy vehicle compared to light vehicle drivers for visual-manual tasks (e.g., dialling) may be due to the higher physical demands of driving a heavy vehicle.

The findings from these two naturalistic studies combined suggest that it is the visual phone tasks, which require drivers to look away from the roadway (e.g., dialling and texting) that are associated with the greatest risk. The cognitive distraction associated with talking or listening on a mobile phone, tasks that allow drivers to keep their eyes on the road, were associated with relatively smaller increases in crash or near-crash risk compared to visually demanding tasks such as dialling and text messaging. These findings challenge results from simulator and laboratory studies, which suggest that conversing on a mobile phone while driving is as dangerous as the visual manual task of dialling (e.g., Beede & Kass, 2006; Strayer et al., 2003). It is important to note, however, that a number of simulator and laboratory-based studies have also found higher performance degradations for dialling versus conversing on a phone (e.g., (Brookhuis et al., 1991; Green, Hoekstra, et al., 1993; Horrey et al., 2006; Reed & Green, 1999; Tornros & Bolling, 2005). Also, the findings from the naturalistic studies are based on a small sample of drivers and crashes/near-crashes and require replication before firm conclusions can be drawn. Clearly this is an area in need of further research to determine the underlying reasons for the inconsistency in results.

Table 1 Crash risk (odds ratio) associated with various mobile phone activities for light and heavy vehicle drivers (adapted from Klauer et al., 2006; Olson et al., 2009)

Mobile Phone Task	Crash/Near-Crash Risk Increased by
Light Vehicles	
Dialling mobile phone	2.8
Talking/listening to mobile phone	1.3
Reaching for Object (i.e. electronic device)	1.4
Heavy Vehicles	
Dialling mobile phone	5.9
Talking/listening to mobile phone	1.0
Use/reach for electronic device	6.7
Text message	23.2

Note: An odds ratio of 1 indicates that there is no increase in the outcome (crash) occurring associated with that activity. An OR greater than 1 indicates that the odds of crashing when engaged in the associated activity is higher than it would be if not engaged in that activity.

2.2 VISUAL DISPLAY UNITS

Driving is widely acknowledged as being a primarily visual task (e.g., Spence & Ho, 2009). It comes as little surprise then, that the introduction of multi-functional visual display units (VDUs) into the vehicle has raised safety concerns among researchers and road safety authorities. The systems that are associated with some form of VDU can be broadly categorised into two classes - driver aides (e.g., navigation and collision warning) and information and entertainment systems (e.g., DVD, TV, Email), collectively referred to as 'infotainment' systems. The follow sections discuss what is currently known about the effects of these systems on driving and, where known, their crash risks.

2.2.1 Satellite Navigation Systems

Much of the satellite navigation research was conducted in the late 1990's and into early part of last decade. Some recent work (post 2006) has been conducted on navigation systems, although this research has examined destination entry only and has tended to be primarily focused on other issues such as driving test validation; examining navigation systems as a secondary issue (e.g., Harbluk, Burns, et al., 2007; Harbluk, Mitroi, & Burns, 2009).

2.2.1.1 Earlier research on destination entry

Satellite navigation systems are popular with motorists. These systems have been fitted to vehicles as on-board devices for more than a decade, but are now increasingly being replaced by portable models, typically those available through mobile phone applications. Indeed, by one estimate, at the end of 2009, 25.9 million people worldwide were estimated to be active users of GPS navigation on their mobile phones (Canalys, 2010, cited in Nokia, 2010). Despite their increasing popularity, no research, to the knowledge of the authors, has examined the distraction associated with aftermarket and portable navigation systems brought into the vehicle. Research on the systems has, to date, focussed on dedicated systems built into the vehicle by Original Equipment Manufacturers (OEMs).

Many of the functions on modern navigation systems take longer to complete and require more frequent and longer eye glances to the device than conventional vehicle controls such as using the indicators or headlights. Of primary concern for distraction is the task of entering destination information. Depending on the type of system and how the information is entered (manual entry or voice-activation), entering destination details can take up to nine minutes to complete (Farber, Foley, & Scott, 2000). Despite the long entry times, some researchers argue that the associated glance behaviours (short, frequent glances) and total eyes-off-road-time are still within the guidelines of safe operation (Chiang, Brooks, & Weir, 2004).

Tijerina and colleagues (1998) compared the distracting effects of entering destination information navigation systems, with two other common in-vehicle tasks - dialling a hand-held mobile phone and tuning the radio. They used four commercially available navigation systems that differed in their entry method: three involved visual-manual destination entry, while the fourth involved only voice input and output. They found that, compared to the two comparison tasks, entering destination details using any method was associated with longer completion times, longer eyes-off-road times, longer and more frequent glances to the device, and a greater number of lane excursions. The systems that required drivers to manually type in part of the address and then make a selection from a scrolling list had a longer completion time (118 seconds) than systems that required drivers to select from scrollable lists. The use of voice-activation technology reduced some of the detrimental effects observed, particularly lane excursion and eyes-off-road time, but not to the level of the two comparison tasks. Later studies by Nowakowski et al. (2000) and Tsimhoni et al. (2004) support these findings. Tsimhoni et al., for example, found that when drivers entered addresses into a navigation system using a keyboard, their lateral control, including lane position variation and number of lane departures, was significantly worse than when addresses were entered using a voice-activated interface.

2.2.1.2 Recent research on destination entry (2007-2010)

Recent research on destination entry is relatively limited. Research by Harbluk and colleagues (2007) has found, however, that both manual and speech-based entry methods degraded driving performance compared to baseline, but that the speech-based input method had substantially longer task completion times than manual entry. Further work by Harbluk and colleagues (2009) has confirmed the long completion times for destination entry (up to 90 seconds).

2.2.1.3 Research on guidance instructions

Once destination information has been entered, the navigation system issues direction instructions. The form of these instructions varies widely across systems: information can be presented on a visual display and/or via voice guidance. In the case of visual displays, information can be presented as a holistic route map or as a turn-by-turn display (Srinivasan & Jovanis, 1997; Tijerina et al., 2000).

Research has sought to determine which guidance modes impose the least amount of demand on drivers. Navigation systems that present navigation instructions using voice output are less distracting and more usable than systems that only present the information visually on a display. Furthermore, navigation systems that provide visual turn-by-turn instructions, rather than presenting holistic route information (i.e., complete maps), are less distracting to the driver and present the safest means of navigation, particularly when coupled with voice-activation (Dingus et al., 1995; Srinivasan & Jovanis, 1997). These studies also demonstrated that well-designed route guidance systems were less distracting than using a paper map.

2.2.2 Other Driver Aides

A range of driver information and support systems are now available or entering the vehicle market that promise drivers access to real-time information ranging from upcoming traffic conditions, accidents or roadwork ahead, weather conditions, fuel prices to advice regarding how efficiently the vehicle is being driven, and warnings regarding imminent collisions, speed violations and lane departures. Research on these types of driver aides has focused on issues such as how they reduce fuel or trips times or improve driving behaviour and help to avoid collisions and traffic violations. Very little research exists on whether or how these systems distract drivers, although some information exists on the workload demands associated with their use, which can have implications for distraction given that high workload leaves less spare attention available for dealing with competing tasks. Given the recent emergence of such systems on the market, the workload research in this area has been published in the last two to three years. This research is summarised below.

A study by Brookhuis and colleagues (Brookhuis et al., 2009) examined the impact of a congestion assistant on driving behaviour, acceptance and workload. The congestion assistant comprised three aspects: congestion information and warning, an active accelerator pedal and a ‘stop & go’ system, which takes over longitudinal control (speed and headway) of the car in a traffic jam. They found that the congestion assistant improved safety by reducing speed on approach to traffic congestion and enhanced travel efficiency. Of relevance here, however, is that the congestion assistant decreased driver mental workload while in congestion, but there was a potential for the systems to increase workload on approach to congestion.

The safety benefits and potential distraction and workload issues of an in-vehicle tunnel warning system were examined by Vashitz et al. (2008). They examine driving performance, distraction (glances to display) and workload (heart rate variability) while driving in a simulated tunnel environment with no information system and two alternative information interfaces: a highly informative display and a minimal information display. The high information display contained extra elements such as excessive speed warning and location information for any hazards in the tunnel. Use of both information displays led to improved speed control, lower speeds, longer headways, but poorer lane stability compared to no display. There were no significant differences between the high and minimal information displays on these driving measures and neither display led to an increase in workload. The high information display did, however, receive a higher number of glances than the minimal display, suggesting that it may pose a greater level of visual distraction. The study authors concluded that the level of distraction impose was relatively minor; however, a full eye glance analysis, including glance duration and total eyes-off-road time should be conducted before firm conclusions can be drawn about the distracting effects of such systems.

Another set of driver aides that are gaining increased attention are eco-driving systems. The goal of eco-driving systems is to change driving style in order to reduce fuel consumption and vehicle emissions. These systems exists as prototypes in many forms ranging from those that use on-board systems to control aspects of driving and provide the driver with little information on their driving efficiency, to those systems that offer information via a visual display (either in real-time or post-drive) on driving efficiency and give advice on how to improve this (e.g., when to change gear, reduce acceleration and braking hardness). Those eco-driving systems that offer information and advice in real-time are of concern here, because they have the potential to visually distract drivers given the vast amount of information they provide (see Figure 1). Not surprisingly, research into these devices has focused on their effectiveness in reducing fuel consumption and vehicle emissions. No published research, to the knowledge of the authors, has systematically examined if and how these systems distract drivers, although large-scale research projects are currently underway to examine these issues (e.g., http://www.foot-lite.net; Young, Birrell, & Stanton, 2009).

***Figure 1** The visual display of the 'Econav' system showing, for example, information on ideal gear (top right) acceleration and speed*

The distracting effects of many in-vehicle information systems (IVIS) are well established, with numerous studies demonstrating that mobile phones, voice-based email systems and satellite navigation systems can distract drivers (Bayly, Young, & Regan, 2008; Chen, Chang, & Doong, 2005; Drews & Strayer, 2008; Gelau, Stevens, & Cotter, 2004). The distracting effects of Advanced Driver Assistance Systems (e.g., Intelligent Speed Adaptation, Forward Collision Warning), however, are less well understood. Although much research has focused on refining the type and timing of driver support warnings and information, very little is known about whether these technologies, particularly those that are designed to capture a driver's attention at critical moments, actually distract drivers from focusing on the most safety-critical information or delay drivers from taking evasive action (e.g., by looking at the warning display for guidance rather than at an approaching vehicle). As the number and complexity of advanced driver support systems entering vehicles increase, issues regarding driver distraction and appropriate Human Machine Interface (HMI) design and integration will become more critical. It is essential for research to be conducted to establish the level of demand and potential distraction imposed by such systems.

2.2.3 Audio-Visual Display Units

In-vehicle audio-visual entertainment systems, including DVD/TV players, are emerging devices that are proving to be popular among motorists. These systems may be either fixed into the vehicle by vehicle manufactures or brought into the vehicle as portable systems. Fixed systems are typically mounted to the rear of the front seats or from the vehicle's ceiling, for viewing by rear-seat passengers, while portable devices may be used by any vehicle occupant in any position (not necessarily legally), and may not always be secured or positioned correctly.

Given their relatively recent emergence on the commercial market, the effects of audio-visual devices have not yet been widely explored. The handful of studies that have examined these devices have focused on the effects of both viewing the devices and listening to the devices placed in rear seats. One study has also examined the effects of manipulating system controls (e.g. loading a disc, pausing, scanning). Furthermore, these studies have all investigated DVD players, not portable televisions.

2.2.3.1 Earlier research on audio-visual displays

An early study by Kircher et al. (2004) investigated the driving performance of eight drivers in a simulator while they watched a DVD on a screen mounted on the centre console. Drivers completed drives in urban and rural environments, at speeds ranging from 50 to 90 km/h. Watching the DVD while driving generally had no effect on mean speed, speed variance, braking reaction time or perceived subjective workload, although, in higher speed conditions (90km/h), mean headway increased by 16.10 metres and average minimum headway increased by 0.26 seconds. In addition, reaction time to a peripheral detection task increased by up to 135 milliseconds, depending on the speed condition. The increase in headway was interpreted by the authors to be a compensatory behaviour.

2.2.3.2 Recent research on audio-visual displays (2007-2010)

Much of the research on audio-visual displays has been published in the last two to three years and a large portion of it has been conducted in Australia. Legislation in Australia prohibits any system that is not a driver's aide from having visual displays mounted within the driver's field of view. This legislation is primarily designed to prevent visual and physical distraction. However, it is reasonable to expect that drivers may be cognitively distracted by these entertainment systems even if the driver cannot see the screen, as the stimulus is incomplete without the visual display and may therefore require increased attention to follow it. As such, research has also focused on the effects of simply listening to audio-visual devices placed in the rear seat. White et al. (2006) examined the effects of both rear seat or front seat audio-visual configurations. The front-seat system included both visual and auditory stimuli, while the rear-seat configuration only included auditory stimuli from the DVD. A total of 48 participants drove in a no-DVD condition, and either the rear seat or front seat configuration. Presence of the DVD was associated with shorter headway distances in the order of two metres and reductions in speed of almost 2 km/h. An increase in perceptual reaction time was observed for the front-seat condition (0.25 seconds), but this effect was not found for the rear-seat (listening only) condition. Findings from another simulation study by Hatfield and Chamberlain (2008a) also found little evidence that simply listening to an audio-visual system degrades driving performance. Their results found that auditory output from an audio-visual unit was no more distracting than listening to the car radio and showed few differences from driving with no secondary task.

A recent test-track study went beyond the effects of watching and listening to audio-visual systems to also examine how manipulating these devices can affect driving. Funkhouser and Chrysler (2007) measured the driving behaviour of nine participants as they completed five laps of a test-track, while watching a DVD, listening to the DVD, and manipulating the system controls. All of the driving performance measures recorded showed degradation for at least one of the DVD conditions although the small sample size meant that few significant differences were found. When watching or manipulating the DVD, drivers were slower and made fewer detections during rear and forward detection tasks and also applied the brakes for a greater proportion of driving time; however, these affects were not significant. Average lateral accelerations were higher for the manipulating, listening and watching conditions, however only one significant effect was found: between the manipulating and one baseline conditions. Significantly lower average speeds (1.8 km/h) were observed for the watching condition compared with the control, while the listening and operating conditions were also slower but not significant.

The potential for audio-visual entertainment units to distract the drivers of other vehicles was explored by Hatfield and Chamberlain (2008b). In the context of existing legislation that prevents a driver from viewing a DVD player within their own vehicle, they explored the effects on driving performance of a visual display observable through the rear window of another vehicle. Simulated driving performance was found to be impaired by the presence of a display that was set up simulate it being visible through the rear of a car in a neighbouring lane. Impairments were observed in the form of reduced mean speeds, greater lane position deviation on curves, slower deceleration when a pedestrian stepped onto the roadway and a tendency to drive more toward the road edge on curves (which may result in more run-off road crashes). These effects were only observed when the driver was instructed to attend to the DVD display in the other vehicle.

A concern with the audio-visual studies reviewed is that all were conducted in simulated or test track environments. These environments differ from on-road environments in terms of their driving complexity and drivers' resource allocation strategies and, as such, the effects of the devices on driving performance could be underestimated. A goal for further research is to examine the effects of audio-visual units in an on-road environment where the driving demands are higher and more complex, before firm conclusions can be drawn about the impact of rear-seat audio-visual systems on driver distraction. Furthermore, in all studies the drivers' recall of the audio and visual materials was not examined to ensure that they were indeed attending to the systems while driving. In any distraction research it is important to examine performance on the secondary task in addition to the driving task to determine the extent to which drivers are attending to and prioritising each task. This appears particularly important in light of Hatfield and Chamberlain's (2008b) findings that the effects of viewing a DVD screen were only found when drivers were explicitly instructed to attend to the screen.

2.2.4 Internet and Email

Only two known earlier studies have examined the effects on driving performance of retrieving, reading and responding to email messages (Jamson et al., 2004; Lee et al., 2001). These studies revealed that interacting with a speech-based email system increases drivers' reaction time to a braking lead vehicle by up to 30 percent, reduces the number of corrective steering wheel movements made and also increases drivers' subjective workload. Drivers do, however, appear to compensate for the increased workload associated with using an email system by adopting longer following distances to vehicles ahead.

To the knowledge of the authors, no research has examined the distracting effects of accessing the myriad of visual and auditory information available through the internet. The internet is now more accessible than ever in the vehicle, thanks to portable devices such as Personal Digital Assistants (PDAs) and smart phones. Several vehicle manufactures and software companies are now also actively marketing in-vehicle internet accessibility (see web links below). It is therefore clear that research is needed on the potentially distracting nature of internet access in vehicles to inform both the design of these systems and potential regulations regarding their fitment and use.

http://media.ford.com/article_display.cfm?article_id=31705

http://www.audi.com/com/brand/en/company/news/models_and_services.detail.2009~12~the_new_audi_a8__0.html

http://social.telematicsupdate.com/weekly-brief/intel-and-google-bring-web-dashboard-motorola%E2%80%99s-new-phone-does-backflip-korean-plug-cof

2.2.5 Digital Music Players

Again, given their recent emergence into the market, research examining the effects of portable music systems on driving has been conducted in the last two to three years. Digital music players are becoming increasingly popular among motorists. Of Victorian drivers aged 18 to 25 years who own an MP3 player, 40 percent admitted to using it while driving (Young & Lenné, 2010). These devices allow drivers access to a greater range of personalised music than existing auditory entertainment systems (e.g., car radios and CD players), and provide the option of searching extensive libraries of music, photos and videos. Other audio files such as 'podcasts' and 'e books' can also be accessed on these devices. Portable music players may be listened to using headphones or connected to the vehicle's speaker system. Trends in on-board and portable system integration, means that MP3 systems are now also available on modern vehicles as part of their on-board multi-function information systems. The distraction potential of these devices is considerable, given the high level of visual demand and time required to navigate through complex menu structures and lists that are often thousands of items long. The portable variants of these devices can also be placed (often unsecured) anywhere in the vehicle.

A handful of simulation studies have investigated the effects on driving performance of interacting with MP3 players in their portable form (i.e., iPods) (Chisholm et al., 2007; Chisholm, Caird, & Lockhart, 2008; Crisler et al., 2008; Salvucci et al., 2007). Selecting items (and watching videos) on an MP3 player resulted in greater lateral deviation from the centre line, however a reduction in car-following speed was believed to compensate for the impaired lateral performance (Salvucci et al., 2007). Listening to songs or podcasts was not associated with changes in either lane position deviation or vehicle speed. Chrisler et al. (2008) also found that manipulating an iPod resulted in significant decrements in lane-keeping performance and significant increases in speed variability. Furthermore, more complex MP3 interactions (those involving more than two steps) have been associated with increases in performance response time and frequency of collisions, as well as the number and duration of glances inside the vehicle (Chisholm et al., 2007).

Chisholm and colleagues (2008) have also examined the effects of repeated iPod interactions on driving performance to determine if practice leads to a decrease in performance decrements. Over the course of the six experimental sessions, driving performance improved in all conditions, including the iPod conditions. A decrease in perception-response times was associated with practice, although driving performance while interacting with the iPod did not return to baseline levels even with increased practice.

A recent study by Williamson et al. (In Preparation) examined the effects on driving, usability and subjective workload of interacting with an on-board MP3 player. They had drivers search for specific songs from scrollable lists using a touch screen interface while performing the Lane Change Test. Performance of the music selection tasks significantly increased drivers' subjective workload and led to a range of driving degradations including increases in mean lane deviation and lane excursions and a decrease in correct lane changes made. There was also evidence that drivers' subjective workload increased when performing the music selection tasks.

Two studies have examined pedestrian crossing behaviour while listening to iPods (Nasar et al., 2008; Neider et al., In press). Both studies found that pedestrians made more successful crossings when listening to an iPod than when conversing on a mobile phone. Indeed, both studies found that the crossing behaviour of pedestrians using iPods did not differ significantly from pedestrians who were not engaging in any secondary tasks.

Given the relatively recent introduction of digital music devices into the vehicle cockpit, their impact on driving performance and crash risk is not yet well understood. The effects of portable music players, even when integrated into the HMI of the vehicle, are likely to be different from those deriving from driver use of most current-generation fixed auditory entertainment systems (e.g. CD players and radios), as they involve scrolling and selecting through numerous levels of a hierarchical menu structure. Furthermore, as suggested by Salvucci et al.[5], the greater level of visual attention required to operate an iPod (or similar device) renders them difficult to operate compared with other devices, such as mobile phones, which have greater tactile feedback in their buttons and controls and, thus, may facilitate "blind" operation.

2.3 DISTRACTION IN PUBLIC TRANSPORT AND HEAVY VEHICLES

Of the plethora of distraction-related research conducted in the last decades, the majority has focussed on drivers of private passenger vehicles. However, it is reasonable to expect that distraction also represents a significant problem within the public transport and commercial vehicle sectors (i.e., bus and heavy vehicle driving). This assumption is made on the basis that drivers who are working might be exposed to a range of additional distractions deriving from work-related technology (e.g., CB radios, text-based messaging, ticketing machines), and such drivers may feel under pressure to use these devices more frequently due to work demands (Llaneras, Singer, & Bowers-Carnahan, 2005; Pettitt, Burnett, & Stevens, 2005). Further, public transport and commercial vehicle driving are examples of high-stress tasks, characterised by high workloads and often conflicting demands. Indeed, simply the physical attributes of many public transport and commercial vehicles imposes a greater level of demand on the driver to maintain vehicle control than do passenger vehicles.

Taken together, the combination of high workload and the performance of multiple additional activities can make public transport and heavy vehicle drivers more vulnerable to the negative effects of distraction. This section reviews what is known about distraction in these two transport sectors.

2.3.1 Commercial (Heavy) Vehicle Sector

Research examining driver distraction within the commercial transport sector has focus on the extent to which drivers engage in distracting activities and the crash risks associated with these activities. This research has largely been carried out in the United States. Research examining the effects of distracting activities on driving performance measures is very limited.

Research examining heavy vehicle driver engagement in distracting activities has found that distraction is widespread among this driving population. Barr and colleagues (2003) conducted an exploratory analysis of naturalistic driving study data that was designed to gather information related to driver distraction among truck drivers. In total, 121 hours of naturalistic video data (using 6 truck drivers) were analysed, resulting in the identification of 4,329 'distracting events'. Drivers were engaged in potentially distracting activities for approximately 52% of the time that they spent driving (63.1 hours out of a total of 121 hours driving time). The most commonly occurring distracting events involved non-technology based activities (e.g., scratching, eating, drinking, smoking). Distracting activities that were found to reduce the amount of time that drivers spent looking at the road ahead included tuning the radio, conversing with a passenger and conversing on a mobile phone.

Further, survey research in Demark focusing on the use of mobile phones, found that more than 99% of heavy vehicles drivers used a mobile phone while driving (Troglauer, Hels, & Falck, 2006). More frequent phone use was associated with longer driving hours, younger driver age, and more frequent stops.

A number of studies in the US have also examined the crash and near-crash risk of the various distracting activities performed by heavy vehicle drivers. Bunn et al. (2005) conducted a retrospective review of commercial motor vehicle collision data from the Kentucky Collision Report Analysis for Safer Highways (CRASH) database for incidents occurring between 1998 and 2002. They found that fatigue and distraction were both strongly associated with a fatal outcome in commercial vehicle collisions. They found that, when other contributing factors (e.g., age and restraint) were controlled for, drivers who were distracted or inattentive were three times more likely to be involved in a fatal crash than drivers with 'other human factors' listed as a cause of the collision.

A naturalistic driving study of 41 long-haul truck drivers examined the role of distraction in heavy vehicle crashes and near-crashes (Hanowski, Perez, & Dingus, 2005). Crash and near-crash data was examined from almost 140,000 miles of driving data. During the data collection period, 2737 'critical incidents', which were made up of crashes, near-crashes and crash-relevant conflicts, were recorded. Of these critical incidents, driver distraction contributed to 178 (6.5%) of them. 'Looking outside distractions' were associated with the highest number of critical incidents in the truck drivers, followed by reaching to the floor and then looking at instrument panel. Looking at, talking on, or adjusting the CB radio also contributed to a number of critical incidents.

The data from Hanowski et al.'s study was combined with data from another large-scale naturalistic truck study by Blanco et al. (in press) to conduct a detailed investigation of driver distraction amongst commercial heavy vehicle drivers and its contribution to crashes and near-crashes (Olson et al., 2009). Combined, the data sets include 203 commercial vehicle drivers, seven trucking fleets, 16 fleet locations and approximately 3 million miles of driving and video data. Analysis of these data identified 4,452 safety-critical events: 21 crashes, 197 near-crashes, 3,019 crash-relevant conflicts, and 1,215 unintentional lane deviations. Of the 4,452 safety-critical events, 81.5 percent had some type of driver distraction listed as a potential contributing factor. Although distraction was found to be a factor in *all* crashes, the authors offer a number of caveats, including crashes being a rare occurrence and checking mirrors being included, something which heavy vehicle drivers are trained to do often. Odds ratio analyses were conducted to identify tasks that were high risk (i.e., had an increased likelihood of involvement in a safety-critical event compared with baseline). These odds ratios are presented in Table 2.

As displayed, complex tasks and those that require a large amount of visual attention were associated with the highest safety-critical event risk. Text messaging was by far the riskiest activity engaged in, with drivers being 23 times more likely to be involved in a safety-critical incident compared with when not engaged in this activity. Of note among the findings, is that some of the cognitive tasks, such as conversing on a hand-held phone did not elevate safety-critical event risk. Tasks such as conversing on a CB-radio or hands-free phone were even associated with a reduced risk of being involved in a safety-critical event. The authors hypothesised that these tasks did not increase risk because they do not require drivers to take their eyes off the roadway, thus increasing their chances of avoiding an incident. The authors did note, however, that this hypothesis does not consider 'gaze concentration' or 'visual tunnelling' that has been found to occur with the performance of cognitively demanding tasks, nor does it consider that these tasks might be degrading performance in other ways (e.g., speed and lateral control).

It is also important to note that, as discussed in Section 1.1.3, a comparison of Olson et al.'s (2009) data with that of Klauer et al. (2006), revealed that some distracting tasks, typically visual-manual tasks (e.g., dialling), had relatively higher crash/near-crash risks for heavy vehicle drivers compared to light vehicle drivers (see Table 1). This increased crash/near-crash risk for heavy vehicle drivers might be due to the higher physical demands of driving a heavy vehicle, leaving these drivers with less capacity to perform these tasks without severely degrading their driving performance. Further research that systematically compares the effects of distracting activities on light and heavy vehicle drivers is needed to confirm this hypothesis.

Table 2 Crash risk (odds ratio) associated with various distracting activities for heavy vehicle drivers (adapted from Olson et al., 2009)

Task	Odds Ratio	95% CI
Complex Tertiary Task		
Text message on cell phone	**23.24***	9.69 - 55.73
Other—Complex *(e.g., cleaning side mirror, rummaging through a grocery bag)*	**10.07***	3.10 – 32.71
Interact with/look at dispatching device	**9.93***	7.49 – 13.61
Write on pad, notebook, etc.	**8.98***	4.73 – 17.08
Use calculator	**8.21***	3.03 – 22.21
Look at map	**7.02***	4.62 – 10.69
Dial cell phone	**5.93***	4.57 – 7.69
Read book, newspaper, paperwork, etc.	**3.97***	3.02 – 5.22
Moderate Tertiary Task		
Use/reach for other electronic device	**6.72***	2.74 – 16.44
Other—Moderate *(e.g., opening a pill bottle to take medicine, exercising in the cab)*	**5.86***	2.84 – 12.07
Personal grooming	**4.48***	2.01 – 9.97
Reach for object in vehicle	**3.09***	2.75 – 3.48
Look back in Sleeper Berth	**2.30***	1.30 – 4.07
Talk or listen to hand-held phone	1.04	0.89 – 1.22
Eating	1.01	0.83 – 1.21
Smoking-related behaviour—reaching, lighting, extinguishing	**0.60***	0.40 – 0.89
Talk or listen to CB radio	**0.55***	0.41 – 0.75
Look at outside vehicle, animal, person, object, or undetermined	**0.54***	0.50 – 0.60
Talk or listen to hands-free phone	**0.44***	0.35 - 0.55
Simple Tertiary Task		
Put on/remove/adjust sunglasses or reading glasses	**3.63***	2.37 - 5.58
Adjust instrument panel	**1.25***	1.06 - 1.47
Remove/adjust jewellery	1.68	0.44 - 6.32
Other—Simple (e.g., opening and closing driver's door)	2.23	0.41 - 12.20
Put on/remove/adjust hat	1.31	0.69 - 2.49
Use chewing tobacco	1.02	0.51 - 2.02
Put on/remove/adjust seat belt	1.26	0.60 - 2.64
Talk/sing/dance with no indication of passenger	1.05	0.90 - 1.22
Smoking-related behaviour—cigarette in hand or mouth	0.97	0.82 - 1.14
Drink from a container	0.97	0.72 - 1.30
Other personal hygiene	**0.67***	0.59 - 0.75
Bite nails/cuticles	**0.45***	0.28 - 0.73
Interact with or look at other occupant(s)	**0.35***	0.22 - 0.55
Secondary Tasks		
Look at left-side mirror/out left window	**1.09***	1.01 – 1.17
Look at right-side mirror/out right window	0.95	0.86 – 1.05
Check speedometer	**0.32***	0.28 – 0.38

Asterisks/Bold indicates a significant odds ratio.
95% CI = 95% Confidence Intervals

2.3.2 Public Transport Sector

Distraction research within the public transport sector is relatively limited and has been focused primarily on bus operations. Chen and colleagues (2006) used a simulator experiment to investigate the effects of using a mobile phone and a wireless communication device (similar to a CB radio) on bus driver performance. They found that both the hand-held and hands-free communication devices increased the bus drivers' response times to sudden events (e.g. a lead vehicle braking suddenly). However, the hand-held device increased lane position deviation to a greater extent than the hands-free mobile phone.

Salmon et al. (2009) investigated the presence and nature of bus driver distraction at a major Australian public transport provider. The findings suggest that there are a number of sources of distraction that could potentially distract bus drivers while driving, including those that derive from the driving task, and those that derive from the additional requirements associated with bus operation. In terms of technology-related sources of distraction, they found a range of devices used by bus drivers that can create a distraction, including mobile phones, the radio, the broadcast radio and handset, and the ticket machine. Apart from being distracted by passengers' technology-based devices, driver engagement with these technology-based sources all represent violational activity on the part of the driver (i.e., activities prohibited by company policy, rules and regulations).

3 DISCUSSION OF REVIEW FINDINGS AND DISTRACTION MANAGEMENT STRATEGIES

3.1 SYNTHESIS OF REVIEW FINDINGS

Technology-based distraction has been estimated to account for at least 15 – 20% of all distractions identified through crash-report studies and about one third of all distractions identified through the 100-car study (Gordon, 2009). It is also possible, based on the studies reviewed, to draw conclusions about which in-vehicle technologies and which specific functions of these pose the greatest risk for safety. Table 3 summarises the research reviewed in terms of the proportion of drivers engaging with various in-vehicle technologies and the crash risks associated with them. This table is useful as it provides information on two levels: first, it allows us to draw conclusions about the in-vehicle technologies that pose the greatest danger to drivers and, second, it highlights where gaps in our knowledge exist. Both of these areas are discussed, but first, it is important to define the crash risk terms used.

Odds Ratios (OR) provide information on the odds of an outcome (crash) occurring in one group (distracted driver) compared to the odds of the same event happening in another group (attentive driver). An odds ratio of 1.0 means that the odds of having a crash while performing a distracting activity is no different to the odds of having a crash while not performing that distracting activity. An odds ratio greater than 1.0 means that the odds of crashing when distracted are higher than when not distracted. The population attributable risk (PAR) percentage is the percentage of crashes and near-crashes occurring in the population at-large that are directly attributable to each of the listed activities. The PAR estimates take into account driver exposure to the activity, or the amount of time spent performing the activity, as well as the odds ratio. As such, the size of the OR and the PAR can vary dramatically if a highly risky activity is engaged in infrequently and vice versa. For example, it can be seen that text messaging has a very high OR (23.2), but leads to a safety-critical event in only approximately 0.7% percent of the population, because this activity is engaged in infrequently.

Based on an examination of Table 3, preliminary conclusions can be made about what in-vehicle technologies pose the greatest danger to drivers. For those activities with an associated OR, it can be seen that activities which require a high amount of visual attention (i.e., for driver to take their eyes off the road) have a higher risk than tasks with low visual demand. These risky visual activities include text messaging and dialling/answering a mobile phone. It is important to note that although text messaging has a low associated PAR in the table, this figure was based on a sample of US truck drivers, who may differ from private vehicle drivers in terms of their frequency of texting. In private vehicle drivers and in countries like Australia, where texting has been shown to be engaged in by a majority of drivers in some age groups, it is likely that the PAR for this activity will be much higher. Tasks that are largely cognitive or require minimal visual attention, such as talking on a mobile phone, have relatively lower ORs. However, these tasks still pose a risk to the population as a whole because drivers' exposure (frequency and duration) to them is relatively high. These findings highlight that it is always important to consider both the absolute risk associated with a particular activity as well as exposure to this activity when determining overall risk.

For many of the in-vehicle technologies listed in Table 3, their crash risk is unknown. Extrapolating the findings discussed above, however, it is reasonable to expect that those technologies or individual functions that require drivers to remove their eyes form the roadway for extended periods of time will pose a greater risk than those that do not. Thus, entering address details into a satellite navigation system is likely to pose a greater threat to safety than listening to voice guidance instructions. Likewise, scrolling through long lists of songs on digital music players is likely to pose a greater risk than simply listening to these devices. Of course, further research is needed to confirm these hypotheses for the specific technologies mentioned, but they do highlight the importance of examining systems at an individual component level rather than as a whole, as it may only be some and not all features of a system that pose a crash risk. They also indicate the need to focus policy development on those technologies or features that impose a high level of visual demand on drivers.

The blank cells in Table 3 highlight where gaps in our knowledge exist. Apart from mobile phones, very little is known about the risks associated with many in-vehicle devices as a whole, let alone their individual system functions or characteristics. Information on driver exposure is similarly lacking for some technologies. As a priority, it is important for research to establish the crash risks associated with the use of satellite navigation and portable digital music players given their popularity among drivers. It is acknowledged that this is no easy task, as determining crash risk requires the detailed and accurate collection of driving performance, crash and distraction exposure data. It will also be important for research to track how many drivers own and are using in-vehicle email and internet systems and driver aides as these systems increase in popularity over the next few years.

Table 3 Summary of driver engagement in and the crash/near crash risks associated with various in-vehicle technology based distractions

Distracting Activity	**% of Drivers Engaging in Activity**		**Crash/Near Crash Risk**	
	Surveys	Naturalistic Driving Studies	Odds Ratio	Population Attributable Risk
Phone Use (undefined)[1]	30.0 - 80.0%	34.0%	9.3	
Talking on Hand-Held Phone			1.04 – 4.9	0.2 - 3.6%
Talking on Hands-Free Phone			0.44 – 3.8	
Dialling/Answering Mobile Phone		15.7 – 27.1%	2.8 - 5.9	2.5 - 3.6%
Text Messaging	12.0 - 64.3%		23.2	0.7%
Satellite Navigation	8%*			
Radio/CD/Cassettes	95.0%	90.0%	0.6^ - 2.3†	0.2%
Portable Digital Music Player	40.7%			
DVD/TV	< 1.0%			
Email/Internet				
Use/reach for other electronic device (e.g. PDA, laptop)	4.2%		6.7	0.23%
Driver Aides *(eco-driving, ITS)*				

[1] Study did not specify phone type or activity.
*Of sat nav owners † Inserting/Retrieving CD ^ Adjusting radio

3.2 MANAGING THE RISKS OF IN-VEHICLE TECHNOLOGY THROUGH DESIGN

3.2.1 Device Placement

A range of human factors guidelines exist that provide guidance on the safe design and placement of in-vehicle VDUs. The guidelines of relevance to this report include: *The European Statement of Principles* (European Commission, 2005), *AAM Guidelines* (Alliance of Automobile Manufacturers, 2006), *JAMA Guidelines* (JAMA, 2004), *UN/ECE Guidelines* (UNECE, 1998), *TRL Guidelines* (Stevens et al., 2002), *UMTRI Guidelines* (Green, Levison, et al., 1993), and the *Battelle Guidelines* (Campbell et al., 2007).

These guidelines have been assembled based on the findings from a vast array of laboratory, simulation and instrumented vehicle studies and are designed to minimise the level of demand or distraction that information systems impose on drivers. The guidelines all vary in length, with some providing only general design principles and others containing very specific details. Each set of guidelines offer a host of advice on in-vehicle VDU design, including the levels and prioritisation of information/warnings, the amount and type of visual information (i.e., icons vs. text, colour, size and font), warning/information timing, input and output modalities and device placement. For the purposes of this report, only the guidelines on VDU placement will be examined.

In terms of VDU placement, a synthesis of the guidelines suggests that in-vehicle VDUs:

- should be located such that the driver has to move his/her eyes as little as possible to extract information. To achieve this, VDUs should be aligned as closely as possible to the forward view in order to reduce glance times. The device should ideally be located within 15 degrees of the driver's normal line of sight, and should not exceed 30 degrees south. Recommended placement of VDUs that include navigation information is on top of the centre console or on a Heads-Up Display (HUD);
- should be located so that commonly used displays, or those that are critical, are closer to the drivers' line of sight than other displays (in the case of multiple displays or split displays).
- should not adversely affect or interfere with other critical system components or primary driving controls; and
- should be within easy reach of the driver so that no stretching or leaning is required to manipulate controls. The device controls should also be designed so that the driver can keep one hand on the steering wheel at all times.

While the authors are not aware of any specific research examining the placement of portable devices such as mobile phones in vehicles, progress has taken place on portable device integration, particularly through the eSafety Nomadic Device Forum (Rieinhardt & Jendrzok, 2009). One objective of this forum was to identify areas in the vehicle for the safe mounting of portable devices and promoting the creation of commonly accepted and standardised mountings or docking stations for in-vehicle integration of portable devices. They recommend that portable device design and placement follow the European Statement of Principles (2005) guidelines. Based on a review of manufacturer mounting instructions on portable device placement, this forum has recommended: *"Until more sophisticated future fixation solutions are available nomadic device manufacturers should recommend to their customers to fix a nomadic device on the left (right in Australia) lower* *corner of the windscreen or for cars with fixed side windows (MPV, etc.) on this side windscreen"* (Rieinhardt & Jendrzok, 2009). To the knowledge of the authors, this placement advice has not been empirically tested. Indeed, there exists very little research on the least distracting placement of various portable technologies and whether, given their relatively small size, safe placement differs from on-board (fixed) devices.

3.2.2 Interaction Methods

In addition to device placement, vehicle manufacturers and system developers are using a number of innovative design approaches for interacting with in-vehicle systems in order to minimise their potential to distract drivers. Certain system control types (i.e., push buttons) have been found to be more suitable than other input controls (i.e., touch screens) for some in-vehicle system functions or operations (Rogers et al., 2005). Hence, it is important to ensure that the methods used to interact with in-vehicle devices are compatible with the tasks being performed in terms of ease of use, fast, error-free completion times, minimal eyes-off-road-time, and minimal interference with driving. The interaction design approaches of most relevance to the technologies reviewed in this report include voice-recognition technology, touch screens, tactile interfaces, and steering wheel controls. The advantages and disadvantages of these design approaches in terms of minimising distraction are discussed in the following sections.

3.2.2.1 Voice Recognition/Activation

A major concern with in-vehicle technology is that drivers spend large periods of time with their eyes off the road and their hands off the steering wheel while interacting with a system. Given the visual input channel is already largely occupied with the driving task, many designers believe that using another modality, such as speech, to interact with in-vehicle systems may result in less interference with the driving task. As a result, many manufacturers and system designers have, or are in the process of, developing voice-activated systems, which allow drivers to operate systems using speech input and output.

Research on this technology has generally found that, while the use of voice recognition technology to interact with in-vehicle devices reduces visual distraction, it is by no means a solution to driver distraction. Although drivers do not have to remove their eyes off the road or their hands off the steering wheel, they still need to generate the correct command and interpret auditory output, which can be cognitively distracting, particularly for long or complex tasks.

As discussed, early research using voice activation/output for inputting address details into navigation systems or for guidance instructions has found that this interaction method does not produce the same level of performance degradation, particularly in terms of lane excursion and eyes-off-road time, than keyboard entry or visual guidance instructions (Nowakowski et al., 2000; Srinivasan & Jovanis, 1997; Tijerina et al., 2000; Tsimhoni et al., 2004).

More recent research has examined the use of voice-based interaction with a wider array of in-vehicle systems, including audio systems, in-vehicle computers and portable devices such as phones and PDAs (Maciej & Vollrath, 2009; McCallum et al., 2004; Ranney, Harbluk, & Noy, 2005; Sodnik et al., 2008). Like the navigation research, these studies have found that using voice activation and output to interact with in-vehicle technology results in fewer driving impairments than does visual-manual interaction (e.g., using buttons and dials). Specifically these studies found that voice-based systems had lower eyes-off-road time, lower reaction times, greater lateral control and lower subjective workload, than visual-manual systems. However, although associated with better driving performance, voice-based systems in all studies were not equivalent to baseline (no distraction) conditions (expect where driving conditions were easy), suggesting that while they offer some advantages, voice interaction can still impose a cognitive distraction resulting in impaired driving. Studies by Lee et al. (2000) and Jamson et al. (2004) confirm this. They found that using a speech-based interface to perform email tasks led to impaired driving performance, with drivers showing a 30 percent increase in reaction times to a lead braking vehicle and higher subjective workload. Further research has also found that as the complexity of the speech-based messages increases, drivers' cognitive workload also increases (Lai et al., 2001). Thus, it may be that highly complex tasks such as emailing pose a level of cognitive distraction that cannot be overcome with the use of voice-based interfaces.

There are also a number of technical challenges associated with voice-based technology which can undermine its safety benefits and lower the acceptability of such systems among drivers. One of the biggest challenges facing voice recognition systems is external noise from the vehicle, passengers, and the outside environment, which can lower the recognition rate of systems. This may lead to drivers having to repeat commands or the system interpreting a command incorrectly. Another challenge is improving "speaker independence" or the ability of the system to recognise different accents or pronunciations across drivers, which can also lower the recognition rate. Finally, voice-recognition systems must be able to recognise specific commands from speech spoken naturally by drivers, rather than only be able to response to exact one or two word commands.

3.2.2.2 Touch Screens and Tactile Interfaces

Screen-based interfaces, such as touch screens or touch pads, have been developed to allow drivers to interact with multiple in-vehicle systems through one interface. Compared to voice-based systems, there has been relatively little research on the safety-implications of using touch screens in cars. An early study (Zwahlen et al., 1988) found that touch screens do not appear to be as safe as knobs and push buttons controls for performing discrete radio (adjusting volume, band, station presets) and climate control tasks (turning heater on, setting temperature and adjusting fan speed). Rogers et al. (2005), however, found that completion times and error rates can be improved if touch screen buttons are grouped close together, were larger in size, and placed in the centre of the screen.

A concern with touch screens is that they are likely to require a large amount of visual attention on the part of the driver to operate given the lack of tactile and kinaesthetic feedback. Hence, drivers are not able to operate in-vehicle systems via touch screens using just the feel and location of the buttons - they are required to look at the screen to locate the appropriate controls (Sasanouchi et al., 2005).

An interaction approach designed to reduce the need for drivers to take their eyes off the road to operate in-vehicle devices are bi-modal touch screens, which combine visual feedback with tactile and haptic feedback (Norberg & Rahe, 2009). Tactile interfaces introduce the sense of touch into the interface so that users are provided with physical feedback sensations such as textures and vibrations. Haptic interfaces combine tactile sensations and kinaesthetic cues, such as position, orientation and resistance of buttons (Christian, 2000). Both types of interfaces are designed to allow users to distinguish between different modes, selections and menus by changing the way they 'feel' rather than just the way they look. Such interfaces are designed to allow drivers to interact with in-vehicle systems largely through their sense of touch, reducing their need to look at the device.

Martens and van Winsum (2001) compared the effect of tactile and speech-based driver support messages on driving performance, workload and acceptability. The results revealed that speech warnings are more effective than tactile warnings at getting drivers to comply with law enforcement warnings (e.g., speed warnings), while tactile warnings were more effective at increasing drivers' safety margin in safety critical situations (e.g., lead vehicle braking suddenly). While there was no difference between the interface types in terms of driver acceptance, the speech messages resulted in an increase in self-reported driver workload from the no warning condition, whereas the tactile messages did not increase workload compared to the control condition.

One concern with tactile interfaces is that drivers are required to learn and memorise what each tactile or haptic sensation means, which in the case of complex systems such as satellite navigation, can prove difficult. Indeed, drivers find such complex systems difficult to operate using only tactile/haptic feedback (Sasanouchi et al., 2005).

3.2.2.3 Steering Wheel Controls

Steering wheel controls have also been developed to operate in-vehicle systems. These controls are designed so that drivers can select system functions while maintaining their driving position and without removing their hands from the steering wheel. Steering wheel buttons are very popular among drivers (Hu et al., 2006), however the limited space on the steering wheel means that the number of functions that can be controlled by steering wheel buttons can be limited. Research examining steering wheel-mounted controls has found that visual distraction and workload is reduced when using controls located on the steering wheel compared to controls located on central instrument panel (centre console) (Itoh et al., 2004; Makiguchi, Tokunaga, & Kanamori, 2003).

3.2.2.4 Summary

Overall, each of the interaction methods reviewed has advantages and disadvantages in terms of safety and practicality. It is, thus, often a difficult choice as to which interaction method is most appropriate for which device. A few general conclusions can be drawn from the literature, however. Discrete manual controls such as push buttons are typically better than other interaction methods for quick, one touch tasks such as on/off. Steering wheel controls, given their close proximity, are likely to be useful for commonly used features such as volume or 'next track'. Touch screens are advantageous for integrating multiple systems into one, centralized location, and the use of bi-modal feedback (i.e., auditory-visual or haptic-visual) is likely to enhance the safety features of this interaction method. Voice-based interaction is likely to be appropriate for completing what would otherwise be long duration, visually demanding tasks, such address entry, but are unlikely to reduce the distraction imposed by highly complex tasks such as reading or composing emails.

3.3 MANAGING THE RISKS OF IN-VEHICLE TECHNOLOGY THROUGH POLICY

Policies to manage driver distraction have been in place for many years. Many of the countermeasures developed have tended to focus on and address the issue at an individual system or activity level. There is now, however, a move to take a broader approach to the understanding and management of distraction. This is reflected in the conduct of large-scale driver distraction inquires and summits being conducted in various countries that bring together a large number of stakeholders to discuss distraction policy approaches ranging from driver education through to legislation, regulation and enforcement, and system and road design.

The Victorian Parliamentary Road Safety Committee was one of the first to initiate a large-scale Inquiry into Driver Distraction, to better understand the nature and extent of the problem and develop a range of appropriate countermeasures. The report on the findings of the inquiry was tabled in Parliament in August 2006, and contains 31 recommendations for addressing driver distraction (Parliament of Victoria, 2006). These recommendations range from developing a better understanding of what distraction is and how many crashes it contributes to, through to the development of a wide range of countermeasures.

Other countries are now following suit. In October 2009, the U.S. Department of Transportation held a summit to determine the best ways to reduce the number of crashes and deaths due to distracted driving. The summit brought together a range of road safety stakeholders and distraction experts and covered topics including the extent and impact of distraction, research findings, and discussion of best practice strategies for managing the issue. In the closing remarks, U.S. Transportation Secretary Ray LaHood announced that the US would pursue three rules to restrict texting and mobile phone use for truck, rail and bus operators:

- Ban text messaging altogether, and restrict the use of cell phones for truck and bus operators;
- Restrict cell-phones and other electronic devices for rail operators; and
- Disqualify school bus drivers convicted of texting while driving from keeping their commercial licenses.

While no official report has been released on the outcomes of the Distracted Driving Summit (John D. Lee, *personal communication*), the US Government has enacted a number of laws that derive specifically from the summit. On October 1, 2009, President Obama signed Executive Order 13513, Federal Leadership on Reducing Text Messaging While Driving, which prohibits all federal employees and contractors from text messaging while driving government vehicles, while driving personal vehicles on government business, or while using government-issued electronic equipment while driving any vehicle anywhere. In January 2010, the texting ban was extended to prohibit texting by drivers of commercial vehicles such as large trucks and buses. The Department of Transport has also launched the educational website distraction.gov (http://www.distraction.gov/), which, in addition to education resources, provides updates on legislation enacted as a result of the summit.

The state of Alabama also held a Distracted Driving Summit on December 3, 2009 (http://www.uab.edu/utc/Distracted_Driving_Summit_Homepage.html). This summit had similar aims as the US summit, but with a particular focus on identifying and reviewing legislative, regulatory and educational approaches for addressing distracted driving in Alabama. As yet, no information has been released on any distraction policies deriving from this summit.

3.3.1 Future Directions for Distraction Policy

As mentioned above, approaches to the management of driver distraction are proposing that policies should be multi-faceted and take a wider behavioural approach rather than an individual technology/activity focus.

At the US Distracted Driving Summit, four underlying messages were promoted in terms of distraction policy development:

- *Policy approaches must be driven by science* - public policy should be guided by and based on sound scientific evidence.
- *Policy approaches must consider future innovation* – to reduce the need for constant re-drafting of policies and legislation as new technology enters the market, but also to ensure that policies do not prohibit the development or use of new in-vehicle technologies or design approaches that may have safety benefits or be able to mitigate the negative outcomes of distraction.
- *Policy approaches must focus on distraction broadly, not just specific technologies* – the focus should be on the broader issue of distracted driving and driver behaviour rather than targeting specific technologies, to promote wider behavioural change rather than simply prohibiting drivers from using a particular device.
- *Policy approaches must be multi-faceted* – there is no one solution. Countermeasures must involve a combination of legislating behaviour, public education and designing smarter and safer technology and roadways.

There was also discussion at the First International Conference on Driver Distraction and Inattention, in Sweden, September 2009, that distraction legislation should focus on impaired driving performance (i.e., poor speed control) rather than attempt to legislate against individual devices and/or activities (http://www.chalmers.se/safer/driverdistraction-en). Examples of such behaviour-based policies would be legislation that focuses on impaired or unsafe driving behaviours such as lane weaving and/or excursions or poor speed control, or regulations that restricts the use of devices that require drivers to remove their eyes of the road for more than two seconds at a time. It is argued that such an approach would be capable of covering a wide range of distracting activities, both technology and non-technology based, and would account for emerging and future technologies that are yet to be introduced in the vehicle, reducing the need for new policies or legislation each time a new system enters the market. It should be noted, however, that these suggested approaches are in their infancy and, thus, exactly what these performance criteria will be and how devices will be assessed against them is not yet clearly understood. It should also be noted that this approach, does not preclude device-specific research from being conducted, as this could still be used to inform the set of design and performance criteria. Another problem with the general impairment approach is that, due to the transient nature of distraction and the fact that it often leaves no trace, it would be difficult for police to accurately link the impaired driving to the driver being distracted (unless police can directly observe the driver engaging in an activity). Clearly further discussion is needed to establish whether such approaches are feasible.

3.4 RESEARCH NEEDS TO SUPPORT DISTRACTION POLICY

It is important for policy makers to have a solid evidence base on which to develop distraction-related policies. This section identifies key gaps in the research knowledge (either due to lack of research or to methodological issues) in relation to distraction from in-vehicle technology and highlights what further research is needed to inform policy development in this area. The research needs identified are based on the review conducted and are complementary to those needs identified at the 2009 US Distracted Driving Summit. A summary of the identified research needs is provided below.

- Data on Australian drivers' exposure to many in-vehicle and portable technologies are very limited or non-existent (see Table 3). First, information on the number of vehicles fitted with various on-board systems is scarce, particularly in Australia. Second, there is very limited information on how many drivers actually use in-vehicle or portable devices while driving, how often they use them, when they use them, and how they interact with them. Such exposure information is an essential first step in determining which in-vehicle and portable technologies pose a potential distraction risk to drivers in Australia. There is therefore a need for research to obtain more detailed and complete exposure data to technology-related distraction. While surveys are a cost and time efficient method for colleting exposure data, more objective methods such as naturalistic driving studies are indicated to ensure the collection of completed and accurate data.

- There is also a lack of data on the crash risks and number of crashes attributable to many existing and new in-vehicle technologies (e.g., satellite navigation, digital music players, DVD/TV; see Table 3). In order to better target distraction policy there is a need for research to better link technology-related distraction to at-fault crashes. This will likely require the collection of such data via police crash report forms, or the conduct of large-scale naturalistic driving or in-depth crash studies. It should be noted, however, that the collection of distraction-related crash data is a difficult undertaking given that many distractions leave no 'trace', and drivers are often unwilling or unable (due to lack of recall) to provide information on any distracting activities they were engaged in prior to the crash.

- There is a need for additional and higher quality research to establish the impact of new and emerging technologies on driving performance (e.g., DVD, portable digital music players, email/internet). A priority for research in this regard is on the use of multi-function 'smart' mobile phones. These devices allow drivers to access a host of functions, including those that were once the domain of on-board systems (e.g., navigation and traveller information), but using much smaller screens, buttons and complex menus that were not necessarily designed for use in-car. What research does exist on new and emerging devices is largely laboratory or simulator-based, typically has small, homogenous samples and many lack secondary task performance data, which is necessary to determine how drivers prioritise attention across the driving and secondary tasks (performance trade-offs). Driving simulators offer an ideal environment to conduct this type of research and to examine performance trade-offs but, where possible, larger-scale research programs, such as the naturalistic driving studies mentioned above, should be used to study the performance degradations under real-world driving conditions.

- The distracting effects of driver aides are poorly understood. Little is known about whether such technologies, which are designed to increase safety and mobility, may actually distract drivers from focusing on the most safety-critical information or delay drivers from taking evasive action (e.g., by looking at the system for guidance rather than at an approaching vehicle). Just like infotainment systems, as the number and complexity of driver support systems increases, issues regarding driver distraction and appropriate Human Machine Interface (HMI) design and integration will become more critical. Thus research is needed, in the first instance, to examine the distracting effects of the various driver aides and collision warning systems entering the market in order to support their safe design and implementation.

- Research is required to identify the safest interaction/input method for in-vehicle technologies (e.g., touchpad/screen, voice-based interaction). While a range of studies already exist on the various interaction methods, it is often difficult to determine which method is likely to be most appropriate for a specific in-vehicle or portable device. It is likely that the best interaction method might also differ across driving populations (i.e., older drivers), so it is important for any research conducted in this area to include a range of driver populations.

- In addition to interaction methods, there is a need for research on the ideal placement of portable devices such as multi-function mobile phones in the vehicle. Guidelines exist for the placement of on-board VDUs. However, portable devices represent an additional challenge for drivers given their small displays and buttons and, currently, there is no guidance on which, if any, mounting location(s) facilitate ease of use or minimise distraction.

- Finally, only limited information exists in terms of the exposure, performance effects and crash risks of technology-related distraction for commercial heavy vehicle and, particularly, public transport drivers. Given that these drivers often operate under additional stressors and higher workloads than passenger vehicle drivers, the effects of distraction on these driver populations could differ substantially to their light vehicle counterparts. It is therefore important that authorities not rely solely on the results of research with passenger vehicle drivers to inform distraction policy for these driver groups. The propensity of commercial and public transport drivers to engage with in-vehicle technology and its associated effects on their driving and crash risk needs to be established, ideally through the use on on-road studies.

4 REFERENCES

Al-Tarawneh, B.S., Cohen, W.J., Trachtman, D., Krauss, D.A., & Bishu, R.R. (2004). *The effect of hands-free cellular telephone conversation complexity on choice response time in a detection task.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.

Alliance of Automobile Manufacturers. (2006). Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication System. Washington, D.C., USA: Alliance of Automobile Manufacturers (AAM).

Alm, H., & Nilsson, L. (1995). The effects of a mobile telephone on driver behaviour in a car following situation. *Accident Analysis and Prevention, 27*(5), 707-715.

Barr, L.C., Yang, D.C.Y., & Ranney, T.A. (2003). *Exploratory analysis of truck driver distraction using naturalistic driving data.* Paper presented at the Proceedings of the 82nd Annual Meeting of the Transportation Research Board, Washington, DC.

Bayly, M., Young, K., & Regan, M. (2008). Sources of distraction inside the vehicle and their effects on driving performance. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation*. Boca Raton, FL: CRC Press.

Beck, K.H., Yan, F., & Wang, M.Q. (2007). Cell phone users, reported crash risk, unsafe driving behaviors and dispositions: A survey of motorists in Maryland. *Journal of Safety Research, 38*(6), 683-688.

Beede, K.E., & Kass, S.J. (2006). Engrossed in conversation: The impact of cell phones on simulated driving performance. *Accident Analysis & Prevention, 38*(2), 415-421.

Beirness, D., Simpson, H.M., Pak, A. (2002). The Road Safety Monitor - Driver Distraction (pp. 1-20). Ottawa, Ontario: The Traffic Injury Research Foundation.

Bellinger, D.B., Budde, B.M., Machida, M., Richardson, G.B., & Berg, W.P. (2009). The effect of cellular telephone conversation and music listening on response time in braking. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*(6), 441-451.

Brookhuis, K.A., de Vries, G., & de Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention, 23*(4), 309-316.

Brookhuis, K.A., van Driel, C.J.G., Hof, T., van Arem, B., & Hoedemaeker, M. (2009). Driving with a congestion assistant; mental workload and acceptance. *Applied Ergonomics, 40*(6), 1019-1025.

Bunn, T.L., Slavova, S., Struttmann, T.W., & Browning, S.R. (2005). Sleepiness/fatigue and distraction/inattention as factors for fatal versus nonfatal commercial motor vehicle driver injuries. *Accident Analysis and Prevention, 37*, 862-869.

Burns, P.C., Parkes, A., Burton, S., Smith, R.K., & Burch, D. (2002). How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol (pp. 56): TRL Limited.

Caird, J.K., Willness, C.R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. *Accident Analysis & Prevention, 40*(4), 1282-1293.

Campbell, J.L., Richard, C.M., Brown, J.L., & McCallum, M.C. (2007). Crash warning system interfaces: human factors insights and lessons learned (HS 810 697). Seattle, WA: Battelle Center for Human Performance and Safety.

Charlton, S.G. (2009). Driving while conversing: Cell phones that distract and passengers who react. *Accident Analysis & Prevention, 41*(1), 160-173.

Chen, W.H., Chang, S.H., & Doong, J.L. (2005). Effects of IVIS interface workload on driving safety. *Transportation Research Record, 1937*(73-78).

Chen, Y.-L. (2007). Driver personality characteristics related to self-reported accident involvement and mobile phone use while driving. *Safety Science, 45*(8), 823-831.

Chiang, D.P., Brooks, A.M., & Weir, D.H. (2004). On the highway measures of driver glance behavior with an example automobile navigation system. *Applied Ergonomics, 35*(3), 215-223.

Chisholm, S., Caird, J.K., Lockhart, J., Fern, L., & Teteris, E. (2007). *Driving performance while engaged in MP-3 player interaction: Effects of practice and task difficulty on PRT and eye movements.* Paper presented at the 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, Stevenson, Washington.

Chisholm, S.L., Caird, J.K., & Lockhart, J. (2008). The effects of practice with MP3 players on driving performance. *Accident Analysis & Prevention, 40*(2), 704-713.

Christian, K. (2000). Design of haptic and tactile interfaces for blind users. On line paper. Retrieved from http://www.otal.umd.edu/UUGuide/kevin/

Consiglio, W., Driscoll, P., Witte, M., & Berg, W.P. (2003). Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. *Accident Analysis & Prevention, 35*(4), 495-500.

Cooper, P.J., & Zheng, Y. (2002). Turning gap acceptance decision-making: The impact of driver distraction. *Journal of Safety Research, 33*(3), 321.

Cooper, P.J., Zheng, Y., Richard, C., Vavrik, J., Heinrichs, B., & Siegmund, G. (2003). The impact of hands-free message reception/response on driving task performance. *Accident Analysis & Prevention, 35*(1), 23-35.

Crisler, M.C., Brooks, J.O., Ogle, J.H., Guirl, C.D., Alluri, P., & Dixon, K.K. (2008). Effect of wireless communication and entertainment devices on simulated driving performance. *Transportation Research Record: Journal of the Transportation Research Board, No. 2069*, 48-54.

Crundall, D., Bains, M., Chapman, P., & Underwood, G. (2005). Regulating conversation during driving: a problem for mobile telephones? *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(3), 197-211.

Dingus, T., McGehee, D., Hulse, M., Manakkal, N., Mollenbauer, M., & Fleischman, R. (1995). Travtek evaluation task C3 - Camera car study. Iowa City: Performance and Safety Sciences, Inc.

Drews, F.A., Pasupathi, M., & Strayer, D.L. (2004). *Passenger and cell-phone conversations in simulated driving.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.

Drews, F.A., Pasupathi, M., & Strayer, D.L. (2008). Passenger and Cell Phone Conversations in Simulated Driving. *Journal of Experimental Psychology: Applied, 14*(4), 392-400.

Drews, F.A., & Strayer, D.L. (2008). Cellular phones and driver distraction. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation*. Boca Raton, FL: CRC Press.

Drews, F.A., Yazdani, H., Godfrey, C.N., Cooper, J.M., & Strayer, D.L. (2009). text messaging during simulated driving. *Human Factors, 51*(5), 762-770.

Engstrom, J., Johansson, E., & Ostlund, J. (2005). Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 97-120.

European Commission. (2005). European Statement of Principles on the Design of Human Machine Interaction (ESoP 2005). Brussels: European Commission.

Farber, E., Foley, J., & Scott, S. (2000). *Visual attention design limits for ITS in-vehicle systems: The society of automotive engineers standard for limiting visual* *distraction while driving.* Paper presented at the Transportation Research Board 79th Annual General Meeting, Washington, D.C.

Funkhouser, D., & Chrysler, S.T. (2007). Assessing driver distraction due to in-vehicle video systems through field testing at the Pecos research and testing center. Texas, USA: College Station, Texas Southwest Region University Transportation Center.

Gelau, C., Stevens, A., & Cotter, S. (2004). Impact of IVIS on driver workload and distraction: Review of assessment methods and recent findings.

Gordon, C.P. (2009). Crash studies of driver distraction. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation*. Boca Raton, FL: CRC Press.

Gras, M.E., Cunill, M., Sullman, M.J.M., Planes, M., Aymerich, M., & Font-Mayolas, S. (2007). Mobile phone use while driving in a sample of Spanish university workers. *Accident Analysis & Prevention, 39*(2), 347-355.

Green, P., Hoekstra, E., & Williams, M. (1993). On-the-road tests of driver interfaces: Examination of a route guidance system and a car phone (pp. 89). Washington, D.C.: University of Michigan Transport Research Institute.

Green, P., Levison, W., Paelke, G., & Serafin, C. (1993). Suggested Human Factors Guidelines for Driver Information Systems (Technical Report UMTRI-93-21). Ann Arbor, MI: The University of Michigan Transportation Research Institute. (also published as FHWA-RD- 94-087, McLean, VA: U.S. Department of Transportation, Federal Highway Administration, December, 1995).

Greenberg, J., Tijerina, L., Curry, R., Artz, B., Cathey, L., Grant, P., et al. (2003). Evaluation of driver distraction using an event detection paradigm. *Journal of the Transportation Research Board, No 1843*.

Haigney, D., Taylor, R.G., & Westerman, S.J. (2000). Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes. *Transportation Research, Part F 3*, 113-121.

Hanowski, R.J., Perez, M.A., & Dingus, T.A. (2005). Driver distraction in long-haul truck drivers. *Transportation Research, Part F*(8), 441-458.

Harbluk, J.L., Burns, P.C., Lochner, M., & Trbovich, P.L. (2007). *Using the Lane-Change Test (LCT) to Assess Distraction: Tests of Visual-Manual and Speech-Based Operation of Navigation System Interfaces* Paper presented at the Driving Assessment 2007, Stevenson, Washington.

Harbluk, J.L., Mitroi, J.S., & Burns, P.C. (2009). *Three navigation systems with three tasks: using the Lane Change Test (LCT) to assess distraction demand.* Paper presented at the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Big Sky, Montana.

Harbluk, J.L., Noy, Y.I., Trbovich, P.L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. *Accident Analysis & Prevention, 39*(2), 372-379.

Harpur, P., & Budde, P. (2008). Australia - Mobile communications - statistics, trends and forecasts. Bucketty, NSW: BuddeComm.

Hatfield, J., & Chamberlain, T. (2008a). The effect of audio materials from a rear-seat audiovisual entertainment system or from radio on simulated driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 11*(1), 52-60.

Hatfield, J., & Chamberlain, T. (2008b). The impact of in-car displays on drivers in neighbouring cars: Survey and driving simulator experiment. *Transportation Research Part F: Traffic Psychology and Behaviour, 11*(2), 137-146.

Hatfield, J., & Murphy, S. (2007). The effects of mobile phone use on pedestrian crossing behaviour at signalised and unsignalised intersections. *Accident Analysis & Prevention, 39*(1), 197-205.

Horberry, T., Bubnich, C., Hartley, L., & Lamble, D. (2001). Drivers' use of hand-held mobile phones in Western Australia. *Transportation Research, Part F 4*, 213-218.

Horrey, W.J., Wickens, C.D., & Consalus, K.P. (2006). Modeling Drivers' Visual Attention Allocation While Interacting With In-Vehicle Technologies. *Journal of Experimental Psychology: Applied*, *12*(2), 67-78.

Hosking, S., Young, K.L., & Regan, M. (2009). The effects of text messaging on young drivers. *Human Factors, 51*(4), 582-592.

Ichikawa, M., & Nakahara, S. (2008). Japanese high school students' usage of mobile phones while cycling. *Traffic Injury Prevention, 9*, 42-47.

Itoh, K., Miki, Y., Yoshitsuga, N., Kubo, N., & Mashimo, S. (2004). *Evaluation of a voice-activated system using a driving simulator*. Paper presented at the 2004 SAE World Congress, Detroit, Michigan.

JAMA. (2004). Guideline for in-vehicle display systems - Version 3.0. English version, August. 18, 2004. Available at: <http://www.umich.edu/~driving/guidelines.html>. Japan Automobile Manufactures Association.

Jamson, A.H., Westerman, S.J., Hockey, G.R.J., & Carsten, O.M.J. (2004). Speech-based e-mail and driver behaviour: Effects of an in-vehicle message system interface. *Human Factors, 46*(4), 625-639.

Jamson, H.A., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2), 79-96.

Kass, S.J., Cole, K.S., & Stanny, C.J. (2007). Effects of distraction and experience on situation awareness and simulated driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 10*, 321-329.

Kircher, A., Vogel, K., Tornros, J., Nilsson, L., Malmstrom, T., & Ceci, R. (2004). Mobile telephone simulator study (pp. 1-256). Borlange, Sweden: Swedish National Road and Transport Research Centre.

Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., & Ramsey, D.J. (2006). The impact of driver inattention on near-crash/crash risk: an analysis using the 100-Car Naturalistic Driving Study data. Blacksburg, Virginia: Virginia Tech Transportation Institute.

Laberge-Nadeau, C., Maag, U., Bellavance, F., Lapierre, S., Desjardins, D., Messier, S., et al. (2003). Wireless telephones and the risk of road crashes. *Accident Analysis and Prevention, 35*, 649-660.

Laberge, J., Scialfa, C., White, C., & Caird, J. (2004). Effects of passenger and cellular phone conversations on driver distraction. *Transportation Research Record: Journal of the Transportation Research Board, 1899*, 109-116.

Lai, J., Cheng, K., Green, P., & Tsimhoni, O. (2001). *On the road and on the web? Comprehension of synthetic and human speech while driving*. Paper presented at the ACM SIGCHI CHI 2001.

Langer, P., Holzner, B., Magnet, W., & Kopp, M. (2005). Hands-free mobile phone conversation impairs peripheral visual system to an extent comparable to an alcohol level of 4-5g 100ml. *Human Psychopharmacology, 20*, 65-66.

Lee, J.D., Caven, B., Haake, S., & Brown, T.L. (2001). Speech-based interaction with in-vehicle computers: The effect of speech-based e-mail on drivers' attention to the roadway. *Human Factors, 43*, 631-640.

Lee, J.D., Young, K.L., & Regan, M.A. (2009). Defining driver distraction. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver Distraction: Theory, Effects, and Mitigation*. Boca Raton: Florida: CRC Press.

Lesch, M.F., & Hancock, P.A. (2004). Driving performance during concurrent cell-phone use: are drivers aware of their performance decrements? *Accident Analysis & Prevention, 36*(3), 471-480.

Llaneras, R.E., Singer, J.P., & Bowers-Carnahan, R. (2005). Assessment of truck driver distraction problem and research needs. Washington, DC: National Highway Traffic Safety Administration.

Maciej, J., & Vollrath, M. (2009). Comparison of manual vs. speech-based interaction with in-vehicle information systems. *Accident Analysis & Prevention, 41*, 924-930.

Makiguchi, M., Tokunaga, H., & Kanamori, H. (2003). A human factors study of switches installed on automotive steering wheel. *JSAE Review, 24*, 341-346.

Martens, M., & van Winsum, W. (2001). *Effects of speech versus tactile driver support messages on driving behaviur and workload.* Paper presented at the ESV 2001, Amsterdam.

McCallum, M.C., Campbell, J.L., Richman, J.B., & Brown, J.L. (2004). Speech recognition and in-vehicle telematic devices: potential reductions in driver distraction. *International Journal of Speech Technology, 7*, 25-33.

McEvoy, S., Stevenson, M.R., & Woodward, M. (2006). Phone use and crashes while driving: a representative survey of drivers in two Australian states. *Medical Journal of Australia, 185*, 630-634.

McEvoy, S.P., Stevenson, M.R., McCartt, A.T., Woodward, M., Haworth, C., & Palamara, P. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. *BMJ Online,* 5.

McEvoy, S.P., Stevenson, M.R., & Woodward, M. (2007). The contribution of passengers versus mobile phone use to motor vehicle crashes resulting in hospital attendance by the driver. *Accident Analysis & Prevention, 39*(6), 1170-1176.

McKnight, A.J., & McKnight, A.S. (1993). The effect of cellular phone use upon driver attention. *Accident Analysis & Prevention, 25*(3), 259-265.

McPhee, L.C., Scialfa, C.T., Dennis, W.M., Ho, G., & Caird, J.K. (2004). Age Differences in Visual Search for Traffic Signs During a Simulated Conversation. *Human Factors, 46*(4), 674.

Nasar, J., Hecht, P., & Wener, R. (2008). Mobile telephones, distracted attention, and pedestrian safety. *Accident Analysis & Prevention, 40*(1), 69-75.

Neider, M.B., McCarley, J.S., Crowell, J.A., Kaczmarski, H., & Kramer, A.F. (In press). Pedestrians, vehicles, and cell phones. *Accident Analysis & Prevention*.

Nelson, E., Atchley, P., & Little, T.D. (2009). The effects of perception of risk and importance of answering and initiating a cellular phone call while driving. *Accident Analysis & Prevention, 41*(3), 438-444.

Nokia. (2010). New Ovi Maps with free navigation races past 1 million downloads in a week. Nokia Press Relaese, 3 February 2010 Retrieved Accessed 4 February 2010, from http://www.nokia.com/press/press-releases/showpressrelease?newsid=1380128

Norberg, S., & Rahe, U. (2009). *Touchpad as interaction input control for use of in-vehicle infotainment systems*. Paper presented at the First International Conference on Driver Distraction and Inattention, Gothenburg, Sweden.

Nowakowski, C., Utsui, Y., & Green, P. (2000). Navigation system evaluation: The effects of workload and input devices on destination entry time and driving performance and their implications to the SAE recommended practice. MI, USA: The University of Michigan Transport Research Institute (UMTRI).

Olson, R.L., Hanowski, R.J., Hickman, J.S., & Bocanegra, J. (2009). Driver distraction in commercial vehicle operations. Blacksburg, Virginia: Virginia Tech Transportation Institute.

Patten, C.J.D., Kircher, A., Ostlund, J., & Nilsson, L. (2004). Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention, 36*(3), 341-350.

Pettitt, M., Burnett, G., & Stevens, A. (2005). *Defining driver distraction*. Paper presented at the 2005 ITS World Congress, San Francisco, USA.

Rakauskas, M.E., Gugerty, L.J., & Ward, N.J. (2004). Effects of naturalistic cell phone conversations on driving performance. *Journal of Safety Research, 35*(4), 453-464.

Rakauskas, M.E., Ward, N.J., Boer, E.R., Bernat, E.M., Cadwallader, M., & Patrick, C.J. (2008). Combined effects of alcohol and distraction on driving performance. *Accident Analysis & Prevention, 40*(5), 1742-1749.

Ranney, T.A., Harbluk, J.L., & Noy, Y.I. (2005). Effects of voice technology on test track driving performance: Implications for driver distraction. *Human Factors, 47,* 439-454.

Recarte, M.A., & Nunes, L.M. (2003). Mental workload while driving: Effects on visual search, discrimination and decision making. *Journal of Experimental Psychology: Applied, 9*(2), 119-137.

Redelmeier, D.A., & Tibshirani, R.J. (1997). Association between cellular-telephone calls and motor vehicle collisions. *The New England Journal of Medicine, 336*, 453-458.

Reed, M.P., & Green, P.A. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics, 42*(8), 1015-1037.

Rieinhardt, W., & Jendrzok, M. (2009). Nomadic Device Forum. Final (draft) report. Brussels Belgium: eSafety Support.

Rogers, W.A., Fisk, A.D., McLaughlin, A.C., & Pak, R. (2005). Touch a screen or turn a knob: Choosing the best device for the job. *Human Factors, 47*(2), 271-288.

Salmon, P.M., Young, K.L., & Regan, M.A. (2009). Distraction and public transport: case study of bus driver distraction. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver distraction: Theory, effects and mitigation*. Boca Raton, FL: CRC Press.

Salvucci, D.D., Markley, D., Zuber, M., & Brumby, D.P. (2007). *iPod distraction: Effects of portable music-player use on driver performance.* Paper presented at the CHI 2007, San Jose, California.

Sasanouchi, K., Ishiai, Y., Tanaka, T., Yukawa, J., & Hu, A. (2005). *Development of the HMI system that improves the safety and operational convenience by the combination of steering wheel switch and head up display*. Paper presented at the 2005 SAE World Congress, Detroit, Michigan.

Schlehofer, M.M., Thompson, S.C., Ting, S., Ostermann, S., Nierman, A., & Skenderian, J. (In Press). Psychological predictors of college students' cell phone use while driving. *Accident Analysis & Prevention*.

Schreiner, C., Blanco, M., & Hankey, J.M. (2004). *Investigating the effect of performing voice recognition tasks on the detection of forward and peripheral events.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.

Sodnik, J., Dicke, C., Tomazic, S., & Billinghurst, M. (2008). A user study of auditory versus visual interfaces for use while driving. *International Journal of Human-Comupter Studies, 66*, 318-332.

Spence, C., & Ho, C. (2009). Crossmodal information processing in driving. In C. Castro (Ed.), *Human factors of visual and cognitive performance in driving*. Boca Raton, Florida: CRC Press.

Srinivasan, R., & Jovanis, P.P. (1997). Effect of in-vehicle route guidance systems on driver workload and choice of vehicle speed: Findings from a driving simulator experiment (pp. 97-114). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). Design guidelines for safety of in-vehicle information systems. (Project report PA3721/01). Crowthorne, United Kingdom: Transport Research Laboratory.
Strayer, D.L., Cooper, J.M., & Drews, F.A. (2004). *What do drivers fail to see when conversing on a cell phone?* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.
Strayer, D.L., & Drews, F.A. (2004). Profiles in Driver Distraction: Effects of Cell Phone Conversations on Younger and Older Drivers. *Human Factors, 46*(4), 640.
Strayer, D.L., Drews, F.A., & Johnston, W.A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Applied Psychology, 9*(1), 23-32.
Stutts, J., Hunter, W.W., & Huang, H.F. (2003). *Cell Phone Use While Driving: Results of a Statewide Survey*. Paper presented at the Transportation Research Board, Annual Meeting CD-ROM.
Sullman, M.J.M., & Baas, P.H. (2004). Mobile phone use amongst New Zealand drivers. *Transportation Research, Part F 7*, 95-105.
Taylor, D., Bennett, D.M., Carter, M., & Garewal, D. (2003). Mobile telephone use among Melbourne drivers: A preventable exposure to injury risk. *The Medical Directory of Australia, 179*(3), 140-142.
Taylor, D., MacBean, C.E., Das, A., & Rosli, R.M. (2007). Handheld mobile telephone use among Melbourne drivers. *Medical Journal of Australia, 187*(8), 432-434.
Telstra. (2010). Drive Safe, Phone Safe survey Retrieved 29 January 2010, from http://www.telstra.com.au/abouttelstra/media/announcements_article.cfm?ObjectID=46402
Thulin, H., & Gustafsson, S. (2004). Mobile Phone Use while Driving. Conclusions from four investigations. Linkoping, Sweden: Swedish National Road and Transport Research Institute.
Tijerina, L., Johnston, S., Parmer, E., Winterbottom, M.D., & Goodman, M. (2000). Driver distraction with wireless telecommunications and route guidance systems. Washington, DC: National Highway Traffic Safety Administration.
Tijerina, L., Parmer, E., & Goodman, M. (1998). *Driver workload assessment of route guidance system destination entry while driving: A test track study.* Paper presented at the 5th ITS World Congress, Seoul, Korea.
Tornros, J.E.B., & Bolling, A.K. (2005). Mobile phone use - Effects of handheld and handsfree phones on driving performance. *Accident Analysis & Prevention, 37*, 902-909.
Troglauer, T., Hels, T., & Falck, C.P. (2006). Extent and variations in mobile phone use among drivers of heavy vehicles in Denmark. *Accident Analysis & Prevention, 38*, 105-111.
Tsimhoni, O., Smith, D., & Green, P. (2004). Address Entry While Driving: Speech Recognition Versus a Touch-Screen Keyboard. *Human Factors, 46*(4), 600.
UNECE. (1998). Guidelines for the design and installation of information and communication systems in motor vehicles. Annex 16 to consolidated resolution on the construction of vehicles (R. E. 3). Available at: http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29re3.html: United Nations Economic Commission for Europe.
Vashitz, G., Shinar, D., & Blum, Y. (2008). In-vehicle information systems to improve traffic safety in road tunnels. *Transportation Research Part F: Traffic Psychology and Behaviour, 11*(1), 61-74.
Walsh, S.P., White, K.M., Hyde, M.K., & Watson, B. (2008). Dialling and driving: Factors influencing intentions to use a mobile phone while driving. *Accident Analysis & Prevention, 40*(6), 1893-1900.

White, C., Fern, L., Caird, J., Kline, D., Chisholm, S., Scialfa, C., et al. (2006). *The effects of DVD modality on drivers' performance*. Paper presented at the 37th Annual Conference of the Association of Canadian Ergonomics, Banff, Canada.

White, K.M., Hyde, M.K., Walsh, S.P., & Watson, B. (2010). Mobile phone use while driving: An investigation of the beliefs influencing drivers' hands-free and hand-held mobile phone use. *Transportation Research Part F: Traffic Psychology and Behaviour, 13*(1), 9-20.

Williamson, A., Young, K.L., Lenné, M., & Navarro, J. (In Preparation). Music selection using a touch screen interface: Effect of auditory and visual feedback on driving performance and usability. *Submitted to International Journal of Vehicle Design*.

Young, K.L., & Lenné, M.G. (2010). Driver engagement in distracting activities and the strategies used to minimise risk. *Safety Science*, *48*, 326-332.

Young, K.L., & Regan, M.A. (2008). Driver Distraction Exposure Research: A Summary of Findings. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver distraction: theory, effects and mitigation*. Boca Raton, FL: CRC Press.

Young, K.L., Rudin-Brown, C.M., & Lenné, M.G. (2010). Look who's talking! A roadside survey of drivers' cell phone use. *Traffic Injury Prevention, 11*(6), 555-560.

Young, M.S., Birrell, S.A., & Stanton, N.A. (2009). *Design for smart driving: a tale of two interfaces.* Paper presented at the Engineering Psychology and Cognitive Ergonomics, 8th International Conference, EPCE 2009, San Diego, CA, USA.

Zwahlen, H.T., Adams, C.C., & de Bald, D.P. (1988). Safety aspects of CRT touch panel controls in automobiles. In A. G. Gale, et al. (Ed.), *Vision in Vehicles II* (pp. 335-344). Netherlands: The North Holland Press.