Vägverket

PUBLICATION NO. 2007:35

ANALYSIS OF THE LITERATURE

THE USE OF MOBILE PHONES WHILE DRIVING

Document title: Analysis of the Literature: The Use of Mobile Phones While Driving
Publication no.: 2007:35
Date of issue: 2007-04-17
Issued by: Vägverket
Reference: Christopher Patten
ISSN no.: 1401-9612

Title:

Analysis of the literature: The use of mobile phones while driving

Authors:
Charlotte L. Brace, Kristie L. Young and Michael A. Regan
Human Factors and Simulation Group, Monash University Accident Research Centre (MUARC), Australia

Sponsoring Organisation:
Swedish Road Administration (Vägverket)

Abstract:
The objectives of this report were to examine the effects of hands-free and hand-held mobile phone use on driving performance and to examine the relative effects of hands-free versus hand-held mobile phones on driving. The research reviewed indicates that use of mobile phones can have a significant impact on a number of safety-critical driving performance measures. Using a mobile phone while driving can distract drivers visually, physically, and/or cognitively. Research to date shows a four-fold increase in crash risk with mobile phone use, regardless of hand-held or hands-free mobile phone application. In particular, the distraction caused by conversing on mobile phones while driving has been shown to impair a driver's ability to maintain an appropriate speed, throttle control and lateral position on the road. It can also impair drivers' visual search patterns, reaction times, and decision-making processes. Moreover, these impairments have been demonstrated for both hand-held and hands-free phones, refuting the belief held by many drivers that conversing on hands-free phones is safer than conversing on hand-held phones. Regardless of whether the phone is hands-free or hand-held, drivers are forced to remove their eyes from the road and their hands from the wheel to reach for the phone and initiate a connection by either dialling a number or answering an incoming call. Hand-held phones have the additional physical distraction of requiring the driver to drive one handed while holding the phone to their ear during a conversation. Many factors moderate the effect of mobile phone use on driving performance including: exposure to phone use, phone design, driving and phone task demands and driver characteristics. Initial economic cost-benefit analysis suggests that the value of preventing crashes caused by mobile phone use while driving is approximately equal to the value of the calls that would be eliminated by a ban.

Key Words:
Driving, mobile phone, cellular phone, hand-held, hands-free, road safety, distraction, driver distraction, distracted driving, safety.

www.monash.edu.au/muarc

Monash University Accident Research Centre,
Building 70, Clayton Campus, Victoria, 3800,
Australia.
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363

CONTENTS

INTRODUCTION

Any activity that distracts the driver from the primary driving task has the potential to compromise safety and increase crash risk. In recent years the popularity of mobile telephones has escalated. As more mobile phones proliferate the market, the road safety community has become increasingly aware of the potential for these devices to distract drivers and compromise safety. In response to the growing use of mobile phones among drivers, a large and rapidly growing body of research has examined the impact of mobile phones on driving performance. Using a mobile phone while driving can distract drivers visually, physically, and/or cognitively. That is, it can induce drivers to take their eyes (visual distraction) and minds off the road (cognitive distraction) and their hands off the steering wheel (physical interference). The forms of distraction arising from phone use have potential to degrade driving performance and increase crash risk.

The Swedish Road Authority (SRA) recognises the importance of better understanding the impact mobile phone use can have on driving performance and safety and has requested that MUARC review the literature pertaining to use of mobile phones while driving. The SRA is particularly interested in comparing the conclusions deriving from recent research findings with those deriving from an earlier review published by the SRA (Patten, Ceci, Malmstrom & Rehnberg, 2003). Key conclusions deriving from the earlier SRA report are included in Appendix 1.

OBJECTIVES

The review aimed to compare the conclusions deriving from recent research findings with those from the earlier review published by the SRA (Patten et al., 2003). The objectives were to:

1. Examine the effect of hands-free and hand-held mobile phones on normal driving.

2. Examine the effect of hands-free versus hand-held mobile phones on normal driving.

APPROACH

A review of the scientifically published literature has been undertaken to assess the current state of knowledge with regard to the effects of various mobile phone tasks and complexity levels on various driving performance parameters and crash risk.

Databases (Compendex, Engineering, Psychology, PsychInfo, ScienceDirect, Transport) and Google were searched for relevant literature published between 1 January 2003 and 26 October 2006 using keyword searches (adapted as appropriate to the specification of each database/search) in the study title/text (#1 "Mobile Telephone"; #2 "Driving"). Reference lists were scanned and searches included abstracts, grey literature and unpublished data to retrieve as much relevant information as possible published in the English language. Earlier literature reviews were also consulted. Research published since 2003 has been listed in Appendix 2. The recent studies which examined the effect of: using mobile phones whilst driving compared to normal driving, or; using hands-free mobile phones compared to using hand-held mobile phones whilst driving compared to normal driving, have been discussed in the report. After discussion of the relevant research findings, a conclusion of the aggregated research is presented.

DISCUSSION OF FINDINGS

The research studies can be grouped into those that examined:

1. the prevalence and patterns of mobile phone use while driving;
2. the impact of mobile phone tasks on (simulated, instrumented or naturalistic) driving performance;
3. the epidemiological impact of mobile phone use on crash risk; and
4. the impact (cost-benefit) of legislation banning mobile phone use while driving.

SECTION 1: PREVALENCE AND PATTERNS IN MOBILE PHONE USE

Mobile phones were introduced in the mid-1980s and in the last two decades their ownership and use has increased dramatically. Mobile phone ownership at the end of 2005 was at near saturation levels in many areas of the world – most notably in East Asia, as over 90% of all households in South Korea, Japan and urban China own at least one mobile phone (ipsosinsight, 2006). Western European markets rank second collectively in mobile phone prevalence, with roughly 80% of all households owning a wireless handset (ipsosinsight, 2006). In North America, prevalence of mobile ownership is slightly less robust: in the U.S., three in four households own a mobile phone, while just over 60% of Canadian households own a mobile phone today (ipsosinsight, 2006). The popularity of mobile phones is a result of the communication and flexibility that they facilitate and the personal safety issues that they overcome. Interestingly, the design of mobile phones is also evolving, with more functions being added to an increasingly "miniaturised" handset. In themselves, miniaturisation and increased function might make the phone more difficult to use while driving as more concentration may be required.

As more mobile phones and other portable devices, such as PDAs, proliferate the market, the road safety community has become increasingly aware of the potential for these devices to distract drivers and compromise safety. In response, a large and rapidly growing body of research has examined the impact of mobile phones on driving performance. This knowledge is limited, however, to that relating to use of the device to converse and, to a far lesser extent, to send text messages. At present, the effect on driving performance of using mobile phones to access emails and the internet and to perform other functions has not, to the knowledge of the authors, been studied.

Although there are many statistics about the number of people owning mobile phones, in a road safety context, there is very little reliable information available about the frequency of their use whilst driving. Estimates of the use of mobile phones while driving come from self-report studies, observational studies or police crash records, each of which has limitations. With their increasing ownership, research has suggested that an escalating number of drivers use mobile phones while driving (both hand-held and hands-free). From examining a range of studies, it has been summarised that the vast majority of drivers (60-70%) report using their mobile phones whilst driving "at least sometimes" (Dragutinovic & Twisk, 2005), and estimates of use are as high as 99% within some user groups (Troglauer, Hels & Christens, 2006). Recent analysis suggests that mobile phone use while driving has more than doubled between 2001-2005 (Eby, Vivoda & St. Louis, 2006). Poysti, Rajalin and Summala (2005) revealed with the use of a survey that 81% of drivers used their phones in the car at least sometimes, with 9% using it for over 15 minutes a day. No quantitative data on the prevalence of hands-free mobile phone usage could be obtained. It is far more difficult to accurately determine the proportion of drivers at any one time who use hands-free mobile phones, as drivers who are observed to be talking could be talking to themselves, singing or talking to an unseen passenger.

Interestingly, White, Eiser and Harris (2004) found in Britain that using hand-held mobile phones was perceived as being one of the riskiest activities to perform while driving. However, they also found, amongst the same cohort, that the risks of using a hands-free mobile phone were perceived as being relatively small. Lesch and Hancock's (2004) research findings suggested that many drivers may not be aware of their decreased driving performance whilst using mobile phones.

Recent findings have also indicated that young drivers and the male gender use their phones more often than older drivers or women (Sullman & Bass, 2004; Poysti et al., 2005), which endorses the findings of earlier studies and is particularly concerning as young drivers are far more likely to be involved in road crashes than drivers in other age categories.

SECTION 2: THE IMPACT OF MOBILE PHONE TASKS ON DRIVING TASKS

Much work has been conducted to examine the impact of using a mobile phone on the driving task. This section outlines the main types of research studies that have investigated this issue, and their strengths and limitations, prior to an overview of the various studies (including meta-analyses and reviews) and the key findings. Factors that influence the effect of mobile phone use on driving are also summarised.

2.1 Study Design

The quality and realism of research studies vary dependent on the methods used and the conditions under which they have been performed. Research studies that have investigated the impact of mobile phone use on driving can be categorised into simulated, instrumented (on-road, test-track), or naturalistic, dependent on the context of the research.

The strength of experimental (simulated or instrumented) studies is that both the driving task and the mobile phone task can be scrupulously defined and monitored. However, the main limitations of these types of studies is that they can vary in how realistically they portray real-world driving and behaviour (i.e. phone use); the small numbers of participants may be influenced by the knowledge that their behaviour is being observed; and learning effects are rarely accounted for (McCartt, Hellinga & Bratiman, 2006). Research conducted in instrumented vehicles on public roads would be expected to have more validity than that conducted in simulators or on test tracks. Naturalistic driving is the situation most similar to a real-world context. This is when driver behaviour is recorded during a period of normal driving and detailed real-world information on the patterns, contextual circumstances, and effects of drivers' phone use are collected (McCartt et al., 2006). However, these experiments are particularly costly and participants may again be influenced by the knowledge that their behaviour is being observed. Additionally, they are less well controlled and there may be confounding variables that affect the results. However, this approach is as realistic and comparative as possible and provides depth and understanding that cannot be otherwise obtained.

The different research contexts are further impacted upon by other aspects of the research design (e.g. task complexity, driving environment, driver characteristics etc.). These are discussed in the following sub-sections.

2.2 Factors That Influence the Effect of Mobile Phone Use on Driving Performance

Phone task

Dialling and Answering

A number of studies have examined the effect on driving performance of manually dialling numbers on hand-held phones. Far fewer studies have examined the impact of answering the phone on driving performance. Manually dialling numbers on hand-held and hands-free phones has been shown to have a large negative effect on a number of safety-critical driving performance measures. The nature and extent of this effect can vary depending on a number of factors, including the phone design and level of integration in the vehicle (e.g. fully integrated controls with steering wheel mounted controls versus cradle held phones mounted on the dashboard).

Recent research confirms earlier findings that dialling either a hands-free or a hand-held phone can have serious consequences for driving performance (Mazzae, Ranney, Watson & Wightman, 2004; Schreiner, Blanco & Hankey, 2004; Tornros & Bolling, 2005). Schreiner and colleagues examined the effects of phone dialling tasks using hand-held and hands-free phones on the ability to detect forward and peripheral events. They found that reaction times to visual events increased when using a hand-held phone to dial phone numbers and that older drivers missed a greater number of these events when dialling when using both hand-held and hands-free phones, but particularly when using the hand-held phone. Drivers also spent less time looking at the roadway and the speedometer when using the hand-held phone to dial numbers. In a driving simulator study, Tornros and Bolling found evidence that dialling numbers on a phone can impair driving performance to a greater extent than conversing on a phone. Reaction times to peripheral targets increased by 270 milliseconds when dialling, regardless of whether the phone was hand-held or hands-free, compared to an increase of 159 milliseconds in reaction time when conversing on a phone. Drivers also missed 13 percent more targets when conversing and 24 percent more targets when dialling on either phone type. Finally, participants in Mazzae et al.'s study rated dialling either a hand-held or hands-free phone as much more difficult than conversing on a phone while driving.

Very few studies have examined the task of answering mobile phones while driving and none of these has directly examined the impact of answering the phone on driving performance. Patten, Kircher, Ostlund and Nilsson (2004) had participants answer a phone in either hand-held or hands-free mode and hold a conversation. However, the authors did not distinguish between answering the phone and holding a conversation in the results of their study. Mazzae et al. (2004) had participants dial numbers, answer incoming calls and engage in conversation on hand-held and hands-free phones while driving in a simulated environment. They did not specifically examine the effect of answering the phone on driving performance; however, they did report results on how long it took drivers to answer the phone when driving. Results revealed that drivers answered the console mounted hands-free phone faster (5.25 secs) than a hand-held phone (10.28 secs) or a headset hands-free phone (10.25 secs).

Several studies have examined the effect on driving performance of dialling numbers using hands-free phones. However, no studies, to the knowledge of the authors, have examined the impact on driving performance of answering hands-free phones. Overall, the research suggests that dialling numbers on hands-free phones has less of an impact on driving than does dialling on a hand-held phone, and that the use of voice-activation can further reduce the impact of hands-free dialling.

Conversing

Numerous studies have examined the effect of conversing on a hand-held phone on driving behaviour and safety (Consiglio, Driscoll, Witte & Berg, 2003; Matthews, Legg & Charlton, 2003; Strayer, Drews & Johnston 2003; Horrey & Wickens 2004; Strayer & Drews 2004; Shinar, Tractinsky & Compton, 2005; Tornros & Bolling 2006). The results of these studies provide evidence that conversing on a hand-held or a hands-free phone can have adverse effects on driving performance. More specifically, holding a conversation on a hands-free or hand-held phone can significantly impair drivers' ability to maintain their speed and position on the road, increase their reaction time to hazardous events by up to 50 percent or result in drivers failing to detect traffic signals and hazards at all. Increases in subjective mental workload, frustration and perceived time pressure have also been reported.

As discussed in the sub-sections below, a growing number of research studies have revealed that it is not just the physical distraction of handling the phone that presents a potential safety hazard, but also the cognitive distraction of being engaged in a conversation. Hands-free mobile phones were developed in an effort to reduce, or even eliminate, the physical distraction caused by handling the phone while driving (Wheatley, 2000). However, while hands-free phones do reduce the need for drivers to hold or physically manipulate the phone, as with hand-held phones they still impose a cognitive distraction on drivers. Indeed, many studies have found that using a hands-free phone while driving to converse is no safer than using a hand-held phone, discussed in a later sub-section.

Much of the recent research on mobile phone distraction now seeks to establish the impact of cognitive distraction on various measures of driving performance and examine whether and how the level of this distraction, as determined by the complexity or emotionality of the phone conversation, influences driver behaviour. As with hand-held phones, holding a conversation on a hands-free phone impairs a driver's ability to control and maintain an appropriate speed and their position on the road, increases their reaction time to hazardous events, results in a greater number of failures to detect traffic signals and hazards, impairs visual search patterns, reduces the amount of time spent scanning the periphery for hazards, and increases subjective mental workload, frustration and perceived time pressure (Al-Tarawneh, Cohen, Trachtman, Krauss & Bishu, 2004; Consiglio et al., 2003; Patten et al., 2004; Rakauskas, Gugerty & Ward, 2004). However, the extent to which driving performance is affected by either hands-free or hand-held phone conversations is determined by the difficulty or emotionality of the conversation. The impact of conversation difficulty on driving performance is discussed in a following sub-section.

Text Messaging

Only a limited amount of research has been conducted on the distracting effects of sending or receiving text messages while driving. An Australian survey, conducted by Telstra, found that 58 percent of drivers aged 17 to 29 years regularly read text messages while driving and 37 percent send text messages when driving (Telstra, 2004). Such a high prevalence of text messaging while driving is disturbing, given that the physical interface and visual and cognitive distraction associated with text messaging while driving is likely to be greater than that associated with simply talking on a hand-held phone (Direct Line, 2002).

To the knowledge of MUARC, only two published studies have investigated the impact of text messaging on driving. A small-scale simulator study conducted in Sweden by Kircher, Vogel, Tornros, Nilsson, Patten, Malmstrom and Ceci (2004) found that *retrieving* text messages increased braking reaction times to a motorcycle hazard, but little else. Most recently, MUARC conducted a simulator study to examine the effects of both sending and retrieving text messages on the driving performance of young novice drivers (Hosking, Young & Regan, 2005). The study found that retrieving and, in particular, sending text messages adversely affects driving performance. When sending and retrieving text messages, the amount of time drivers spent with their eyes off the road increased by 400 percent. Lane position variability also increased when text messaging and drivers made 28 percent more lane excursions and 140 percent more incorrect lane changes when retrieving and sending text messages. The results did, however, reveal that drivers attempted to compensate for these impairments in their driving by increasing the distance between themselves and the vehicle ahead. Drivers did not, however, reduce speed.

Type of phone used

The cognitive, physical or visual demands that a secondary task places on the driver will have a significant influence on the degree to which performance of the task will distract drivers. Tasks that place little demand on drivers may be able to be effectively time-shared with the driving task, resulting in little or no degradation in driving performance. In terms of mobile phones, one factor that influences task demand characteristics is the physical design and type of the mobile phone.

Numerous studies have sought to examine the relative effects of hand-held and hands-free mobile phones on driving performance. Research findings have typically revealed that, although the physical distraction associated with handling the phone can present a significant safety hazard, when dialling for instance, the cognitive distraction associated with being engaged in a conversation can also have a considerable effect on driving. Indeed, many studies have found that hands-free phone use has a similar impact on driving as using a hand-held phone (Consiglio et al., 2003, Matthews et al., 2003; Strayer et al., 2003; Mazzae et al., 2004; Strayer, Drews & Crouch, 2006). Horrey and Wickens' (2004) meta-analysis of 16 studies did not find any difference in effect between hand-held and hands-free mobile phone use.

Research by Strayer and colleagues (2003; 2006) found that when drivers were engaged in a phone conversation using either a hand-held or hands-free phone, they demonstrated similar driving deficits, including being more likely to miss, or respond slower, to simulated traffic signals than when not conversing on a mobile phone. Research by Matthews et al. (2003) and Mazzae et al. (2004) has also revealed that conversing on a mobile phone while driving imposes an increased workload on drivers regardless of the phone type used (hand-held or hands-free) and that drivers tended to overestimate the ease of using hands-free phones while driving.

The observed similarity in impact on driving performance between hand-held and hands-free mobile phone conversations is consistent and calls into question driving regulations that prohibit hand-held mobile phones and permit hands-free mobile phones, as it can be suggested that such regulations are unlikely to eliminate the problems associated with using cell phones while driving (Strayer et al., 2006). With respect to mobile phone use, it is apparent that the safest course of action is not to use a mobile phone while driving.

Research has also sought to establish whether various types of hands-free phone devices differentially affect driving performance. Matthews et al. (2003) found that using a phone with a personal hands-free kit (ear-piece) led to lower reported levels of mental workload and higher levels of conversation intelligibility than using a phone with an external speaker. However, Mazzae et al. (2004) found that it took drivers longer to answer the phone when using a phone equipped with a headset (10.25 seconds) than a phone with a cradle-mounted speaker (5.25 seconds). It is important to note that, in both studies, the hands-free phones were less of a distraction than hand-held phones when dialling and answering calls.

Time spent engaging in mobile phone use

The degree to which a mobile phone distracts a driver is a function of the absolute level of distraction brought about by use of the phone and the amount of driving time the driver is exposed to the device. Very few studies have attempted to quantify the amount of time drivers spend engaging in distracting activities. Only one such study has been published: a US study by Stutts, Feaganes, Rodgman, Hamlett, Meadows & Reinfurt (2003). The "100-Car Naturalistic Driving Study" (Neale, Dingus, Klauer, Sudweeks & Goodman, 2005; Klauer, Neale, Dingus, Ramsey & Sudweeks, 2006) also sought to obtain exposure data for a number of driving activities including engaging in distracting activities, however, this data has not been published to date.

Although there were limitations with the potential effects on driver behaviour from being observed, Stutts et al. (2003) revealed that drivers only spent 1.3 percent of the time interacting with a mobile phone. Drivers were generally more likely to engage in secondary activities while the vehicle was stationary, suggesting that drivers do tend to engage in distracting activities at "safer" driving times (e.g., low traffic density). It was found that engaging in distracting activities while the vehicle was moving negatively affected driving performance.

Complexity of mobile phone task

Another factor, often closely linked to interface design that can influence the distraction potential of mobile phones is the type and complexity of the phone task engaged in. For example, the level of difficulty or emotionality of a phone conversation can affect the cognitive demands that the task places on the driver and hence it's potential to distract them from the driving task.

Researchers have sought to establish whether and how various levels of cognitive distraction, as determined by the complexity or emotionality of the phone conversation, can differentially affect driver behaviour. Recent research examining the relative effects of conversation complexity on the detection and response time to targets supports earlier findings. A study by Al-Tarawneh and colleagues (2004) found that driver response times to visual targets were significantly higher when engaging in a complex phone conversation (recalling information provided earlier by an experimenter) than when engaging in a simple conversation (short simple questions about their day) or no conversation. Patten et al. (2004) also found that drivers took longer to react to a peripheral detection task when they were involved in a complex conversation requiring them to solve arithmetic problems, than when they were having a simple conversation requiring them to repeat back single digits spoken by the experimenter. However, Treffner and Barrett (2004) were unable to reveal a linear relationship when investigating four differing levels of conversation complexity and suggested that it may not be the degree of difficulty of the conversation but the conversation itself that affects driving (Treffner & Barrett, 2004). This result may have been due to limitations in the study design; for example, the measure of performance may not have been sensitive enough to detect differences between the levels of conversation complexity, or the taxonomy of conversation complexity used may not have been broad enough to capture a range of complexity levels.

One concern that has been raised with research examining the use of mobile phones while driving has been the use of artificial mathematical or verbal tasks to simulate phone conversations. Some studies have required participants to solve mathematical problems (Patten et al., 2004) while others have used verbal recall or recognition tasks that require listening to sentences, remembering elements of the sentences, and then repeating the words or making some sort of decision about the words (Mazzae et al., 2004). While these tasks may be practical to implement, the extent to which they are representative of typical phone conversations and the demands associated with these is questionable. In response, a number of studies have since used naturalistic phone conversations to measure the effects of mobile phone use on driving performance (Rakauskas et al., 2004; Shinar et al., 2005). The results revealed that, although the use of the phone degraded driving performance, the level of conversation difficulty did not differentially affect driving performance in terms of mean speed, speed or steering variability, or subjective mental workload (Rakauskas et al., 2004). One explanation why this study failed to demonstrate an affect of conversation difficulty when numerous others have done so may be that naturalistic conversations require less cognitive effort than the verbal reasoning and mathematical tasks used in previous studies and, thus, are less sensitive to effects of increasing difficulty. Shinar et al. (2005) found that performing a maths operation task degraded driving performance to a greater extent than engaging in an emotionally involving conversation. These results would suggest that studies that have used maths or verbal tasks might have over-estimated the adverse effects of mobile phone conversation on driving performance. An alternative explanation is that the two complexity conditions used did not differ enough in difficulty to reveal any differential effects on driving performance. These studies highlight the need for research to utilise more ecologically valid tasks to examine the effects of performing a secondary task on driving.

Driving task demands

The demands of the driving task itself, such as increases in traffic density and the complexity of the traffic environment, can also influence the distracting effects of mobile phone use (Strayer et al., 2003). The use of mobile phones on a quiet country road may have a considerably different affect on driving performance than mobile phone use in a busy urban environment, where the driving task places greater demand on the driver, leaving less spare cognitive capacity available for the performance of secondary tasks. A number of studies have examined the interaction between mobile phone use and the complexity of the driving environment (Strayer et al., 2003; Horberry, Anderson, Regan, Triggs & Brown, 2006).

Using a driving simulator, Strayer et al. (2003) found that conversing on a hands-free mobile phone while driving led to an increase in reaction times to a lead braking vehicle and this impairment in reaction time became more pronounced as the density of the traffic increased. One interesting aspect of this finding is that neither the test car nor the lead vehicle interacted with the additional vehicles on the road, suggesting that simply increasing the perceptual complexity of the road environment can intensify the distracting effects of engaging in a phone conversation while driving.

Research by Horberry and colleagues (2006), however, failed to reveal any interaction between the complexity of the driving environment and conversing on a hands-free mobile phone. They manipulated the complexity of the driving environment by increasing the number of billboards and advertisements placed on the roadside and the number of buildings and on-coming traffic. Participants drove along the simple and complex driving environment while interacting with the mobile phone and while not performing any secondary task. Results revealed that interacting with the mobile phone affected driving performance, by decreasing mean speed, increasing speed variability and decreasing responses to a pedestrian hazard. However, no interaction between the distracter task and environment complexity was revealed, suggesting that driving performance while interacting with a mobile phone was not further degraded by increased complexity in the traffic environment. One reason why Horberry and colleagues failed to find that a more complex driving environment further degraded driving performance when using a phone, when other studies have found such an effect, may be the type of objects they used to increase the complexity of the environment. Horberry et al. used objects that were not central to the driving task to increase the complexity of the drives, such as billboards and buildings, whereas other research has tended to increase the complexity of the driving environment by manipulating objects central to driving such as other traffic and the difficulty of the driving terrain. It is possible that increasing the number of objects that are not central to the driving task has little effect on increasing the demands of the driving task because drivers simply ignore environmental features not essential to the driving task when under increased load (e.g. when performing a secondary task).

Driver characteristics

Age and experience

There is a large body of evidence that driver age and driving experience can influence the relative distracting effects of mobile phones, with recent studies continuing to back up earlier findings (McPhee, Scialfa, Dennis, Ho & Caird, 2004; Schreiner et al., 2004; Shinar et al., 2005). Research has consistently found that older drivers have a decreased ability to share their attention between two concurrent tasks due to their decreased visual and cognitive capacity and, hence, they may be more susceptible to the distracting effects of using a mobile phone while driving than younger drivers.

Similarly, young novice drivers, who have less driving experience, may also be relatively more vulnerable to the effects of distraction than experienced drivers. It is widely recognised that inexperienced drivers often lack the driving skills necessary to operate and manoeuvre a vehicle using only minimal cognitive resources and, therefore, do not have sufficient spare cognitive capacity to devote to secondary non-driving tasks (Regan, Deery, & Triggs, 1998; Williamson, 1999). Thus, it may be more difficult for the inexperienced driver to divide their attention appropriately between the phone and driving tasks, potentially degrading their driving performance.

Recent work (Hosking et al., 2005) that examined the effects of sending and retrieving text messages on the driving performance of young novice drivers (aged 18 to 21 years) revealed that retrieving and, in particular, sending text messages had a detrimental effect on a number of safety critical driving measures. Specifically, when text messaging, the drivers' ability to maintain their lane position and to detect and respond appropriately to traffic signs was significantly reduced. In addition, drivers spent up to four times longer with their eyes off the road when text messaging, than when not text messaging. Despite these degradations in driving performance and legislation banning the use of hand-held phones while driving, a large proportion of the drivers reported that they regularly use hand-held phones while driving for talking and text messaging.

Recent research provides more evidence that older drivers are relatively more susceptible to the effects of in-vehicle distraction than their younger counterparts (Schreiner et al., 2004) and less accurate and slower at identifying target signs in a traffic scene when engaging in a simulated conversation (e.g., listening to and answering questions about a short paragraph) (McPhee et al., 2004). However, a study by Strayer and Drews (2004) failed to find any age-related differences in driving performance degradation when engaged in phone conversations. They found that the distracting effects of mobile phone conversations on driving performance were equivalent for younger and older drivers. One explanation for this inconsistent finding is that the performance of older drivers was compared to that of young, inexperienced drivers aged 18 to 25, rather than middle-aged or more experienced drivers, and these younger drivers may also be particularly susceptible to the effects of distraction. Indeed, research by Shinar et al. (2005) has demonstrated that both older (60 to 71 years) and young inexperienced (18 to 22 years) drivers' driving performance was more negatively affected by phone conversations than middle-aged drivers'.

Despite the observed age-related decrements in dual task performance in many driver distraction studies, research has also shown that older drivers engage in self-regulatory behaviour, such as slowing down or avoiding the use of mobile phones while driving, in order to compensate for their greater performance decrements. Horberry et al. (2006), for example, found that the driving performance of drivers aged over 60 years was relatively more degraded when interacting with a mobile phone than younger drivers, but that the older drivers attempted, either consciously or unconsciously, to compensate for this degradation by reducing their speed. Whether these compensatory behaviours are sufficient to offset the degradation in their driving performance and reduce their crash risk, however, should be the focus of future research.

Learning effects

With respect to learning effects, a criticism of research examining the impact of mobile phone use on driving is that, in many studies, the effects of in-vehicle device use on driving performance are only examined on a limited number of trials or drives. Participants are not usually given the opportunity to interact with the device over a number of trials and, therefore, any learning effects, whereby drivers learn to effectively time-share the non-driving and driving tasks, are not usually assessed. A recent study by Shinar and colleagues (2005) examined whether repeated experience conversing on a mobile phone led to a learning effect, whereby drivers became better able to share the phone and driving tasks, thus reducing the effects of the secondary task on driving performance. As expected, the use of the mobile phone had a negative impact on driving performance, with drivers displaying lower mean speeds and greater speed and steering variability. However, over the course of the five sessions, the negative effects of the phone tasks on driving performance diminished, such that, on several of the driving measures, there was no difference between performance in the distraction and no-distraction conditions. The results of this research suggest that those studies which examine the effects of mobile phone use over a limited number of trials and/or use artificial and demanding phone tasks, such as mathematical solving tasks, may be overestimating the detrimental effects of mobile phone use on driving performance.

With respect to the role that experience plays in moderating mobile-phone-induced dual-task interference, Strayer et al. (2006) found that participants' self-reported estimates of the amount of time that they usually spent driving while using a mobile phone suggested there was no evidence that practice improved driving performance. The authors suggest that this is not surprising given the cognitive requirements of the two activities, since both naturalistic conversation (i.e. responding to different people on different topics etc.) and driving (i.e. reacting to unpredictable events on the road etc.) place ever-changing context-dependent demands on the individual. Clearly, further research is needed in this area before any firm conclusions can be drawn.

Gender

Gender differences in drivers' exposure to, and ability to cope with, distraction have been under-examined in the literature, compared to other driver characteristics such as age and driving experience. The results regarding the effects of gender on distraction exposure and distractibility are mixed. Sullman and Baas (2004) found that males reported that they use mobile phones more often when driving than females, while Wogalter and Mayhorn (2005) found that a greater number of females reported using mobile phones while driving. Differences between these studies may result from age-related differences in the samples surveyed. Sullman and Bass' participant sample was older by an average of 10 years, than Wogalter and Mayhorn's sample and these age differences may influence the use of phones while driving across genders. In terms of gender differences on driving performance, some recent studies have found that distraction has a greater impact on the driving performance of female drivers than males (Cooper, Zheng, Richard, Vavrik, Heinrichs & Siegmund, 2003; Hancock, Lesch & Simmons, 2003), while other studies have found no gender differences in the effects of distraction (McKnight & McKnight, 1993; Reed & Green, 1999; Strayer & Johnston, 2001). Again, age differences between the study samples may be driving the discrepancies in the results. Those studies that found gender effects tended to have an older participant sample than those studies that found no effects. Indeed, Hancock et al. (2003) found an interaction between age and gender, whereby no differences in the effect of distraction were found between younger male and female drivers, but that distraction had a greater effect on older female drivers than on older males.

Behaviour (self-regulation)

One fundamental question regarding the effect of mobile phones on driving performance is whether and how drivers self-regulate their driving in order to compensate for the decrease in attention to the driving task. Surprisingly, very little research has been conducted to specifically address this issue. Rather, research has focused on identifying the particular performance impairments associated with the use of mobile phones. It is important to recognise, however, that not all changes in driving performance associated with mobile phones are indicative of driver impairment, and research suggests that drivers can and do engage in a range of conscious and unconscious compensatory behaviours in order to attempt to maintain an adequate level of safe driving while using a phone (Haigney, Taylor & Westerman, 2000).

Compensatory or adaptive behaviour can occur at a number of levels ranging from the *strategic* (e.g., choosing not to use a mobile phone while driving) to the *operational* level (e.g., reducing speed) (Poysti et al., 2005). At the strategic level, drivers can choose to moderate their exposure to risk by choosing not to use a mobile phone while driving. At the operational level, several studies have shown that drivers attempt to reduce workload and moderate their exposure to risk while interacting with mobile phones. They do this through a number of means: decreasing speed (Rakauskas et al., 2004); increasing their following distance (Strayer & Drews, 2004; Strayer et al., 2003); changing the relative amount of attention given to the driving and phone tasks in response to changes in the road environment (Brookhuis, de Vries & de Waard, 1991); and accepting a temporary degradation in certain driving tasks (e.g., checking mirrors and instruments less frequently) (Brookhuis et al., 1991; Harbluk, Noy, Trbovich & Eizenman, 2007).

Several on-road and simulator studies have found that drivers tend to decrease their mean speed when using a mobile phone. In a simulator study, Rakauskas and colleagues (2004) reiterated earlier research findings when they found that drivers' mean speed decreased and their speed variability increased while carrying out a naturalistic conversation on a mobile phone. An increase in following distance is another compensatory behaviour that has been displayed by drivers while they are interacting with in-vehicle devices, an increase that was particularly pronounced under high traffic density conditions (Strayer et al., 2003). It has also been found that drivers' following distance to a lead vehicle can increase by up to 12 percent when drivers are conversing on a hands-free mobile phone under simulated driving conditions (Strayer & Drews, 2004). Earlier work has also shown that drivers paid less attention to other traffic (as measured by the frequency of checking the rear-view and side mirrors) on a quiet motorway while engaging in a mobile phone conversation, but that engaging in the phone task did not alter the amount of attention they paid to other traffic on a busy ring-road (Brookhuis et al., 1991). Thus, it appears that the amount of attention drivers are willing to allocate to the performance of a secondary task is situation dependant and may change across driving environments and task types.

Tornros and Bolling (2006) found that conversation reduced driving speed regardless of traffic environment during hand-held phone use, whereas for hands-free mode, speed was reduced only in 2 environments (rural, 90km/h environment; urban complex environment). This reduced driving speed can be interpreted as an attempt to compensate for the increased mental workload. The increased compensatory effort whilst using a hand-held mobile phone might be because drivers underestimate the risk associated with conversation when using a hands-free mobile phone while driving. Alternatively it might be that the drivers using a hand-held mobile phone in this study needed to slow down more to reach a comfortable or acceptable level of mental workload than when using a hands-free mobile phone.

Interestingly, after examining mobile phone driving performance in a simulator and drivers' self-perception of their own performance, Strayer et al. (2006) suggested that drivers may not be aware of their own impaired driving as there appeared to be a 'disconnect' between drivers perceived and actual performance. This has serious implications for safety on the road and needs to be bridged with education and awareness raising.

2.3 Mobile Phone Use versus Other Distractions and Influences on Driving

Some work has been conducted to examine how the use of mobile phones while driving compares to other distractions and the influence of alcohol on driving.

Consiglio et al. (2003) examined five conditions using a low-fidelity driving simulator. In the control condition, participants did not view, handle or use a mobile phone. In the experimental conditions participants listened to music played on a radio, engaged in paced, relaxed conversation with a researcher (who played the role of a right-rear seated vehicle passenger), engaged in paced, relaxed conversation with a researcher whilst using a hand-held mobile phone, and engaged in paced, relaxed conversation with a researcher whilst using a hands-free mobile phone (i.e. headset). The use of either type of mobile phone caused reaction time to slow by 19% compared to the control condition. Conversation with a passenger caused reaction time to slow by 16% compared to the control condition. The use of a hand-held mobile phone and the use of a hands-free mobile phone produced nearly identical performance decrements. Listening to the radio did not significantly cause reaction time to slow compared to the control condition. The results of the study suggest that the use of mobile phones while driving is no worse than other distractions routinely faced by drivers, such as conversing with passengers. These findings have been further strengthened by Horrey and Wickens' (2004) meta-analysis of 16 studies which did not find any difference in effect between mobile phone and passenger conversations.

However, Crundall, Bains, Chapman & Underwood (2005) examined how conversation is regulated between two people and compared drivers using a hands-free mobile phone to hold a conversation with another individual and when conversations were held between a driver and a passenger in the (same) vehicle. Both driver and passenger participants had an average of five years of driving experience since passing the driving test. Participants drove their own vehicle along the experimental route whilst conducting a conversation (verbal task) with their passenger or a non-passenger via a mobile phone. The verbal task was presented as a game between the two individuals who were conversing. For each conversation condition, a different topic was picked at random (e.g. television, music). For each topic, 7 keywords were listed. The non-driver had to engage the driver in conversation relative to the topic and the non-driver scored one point for each word on the list that the driver said. The driver scored two points for guessing what the keywords were, but only if the driver said it out loud. These rules encouraged the driver to converse and the non-driver to embed the keywords into general conversation so that the driver would not be aware of what they were. Normal in-car conversations were suppressed during the most demanding urban roads, suggesting that both drivers and passengers suppress conversations when the demands of the road become too great. During a mobile telephone conversation, the non-drivers' made more utterances (i.e. were not suppressed) than they would with a normal in-car conversation. This was because the non-drivers were not in the vehicle and were unaware of the demands of the road. The results demonstrate the potential problem that when using hands-free mobile phones while driving, the non-driver is unaware of the demands of the road on the driver, and does not compensate for the environmental conditions. This may result in increased driver distraction and a subsequent detrimental effect on safety. However, it should also be noted that there are different types of passengers, including those with little or no understanding of driving, or for the varying complexities of the driving task (e.g. young or intoxicated passengers, who also do not compensate for the environmental conditions). These groups of passengers were not examined in this study.

Additional work by Hunton and Rose (2005) that examined the effects of conversation mode on driving performance also supports the suggestion that mobile phone and in-vehicle passenger conversations are different and that mobile phone conversations consume more attention and interfere more with driving than passenger conversations. The authors suggest that mobile phone conversations lack the non-verbal cues available during close-contact conversation and conversation participants expend more cognitive resources to compensate for the lack of such cues.

Rakauskas, Ward, Bernat, Cadwallader, and De Waard (2005) compared driver performance while conversing on a hands-free cell phone to conditions of operating common in-vehicle controls (e.g., radio, fan, air conditioning) and alcohol intoxication (BAC 0.08). In addition, the study examined the combined effects of being distracted and being intoxicated given that there may be a higher risk of a crash if the driver engages in a combination of risk factors.

The study found that distraction from in-vehicle tasks resulted in the most impairment. Indeed, secondary-task distraction resulted in more impairment than did alcohol intoxication. Not only were significant distraction effects more numerous than for the effects of intoxication, but specific comparisons demonstrated that intoxicated drivers were less impaired than sober drivers when distracted. In this study, alcohol caused drivers to be more cautious when crossing through traffic, as intoxicated drivers waited for larger gaps and chose gaps with larger safety margins. However, it was reported that these same drunk drivers had more than twice the number of total collisions with other vehicles. It appeared that although intoxication caused drivers to be more cautious on this event, it did not improve their ability to safely control their vehicle and navigate through traffic. This finding was confirmed during the pullout-event results, where intoxicated drivers displayed quicker movement times than sober drivers, similar to the performance observed while drivers were completing the secondary-tasks, suggesting that drivers' resources were overloaded. Moreover, it was reported that participants might have found it easier to compensate for alcohol impairment than for the secondary-tasks. That is, they may have found it easier to compensate for the general impairment from alcohol as opposed to the unavoidable hindrance of taking one's eyes away from the roadway and removing one's hands from the steering wheel.

Unlike alcohol intoxication, Rakauskas et al. (2005) suggested that the distraction tasks interfered with specific resources (e.g. visual processing, manual response). The authors acknowledged that the amount of impairment from resource competition may have been greater than the (generic) impairment of all resources by alcohol. Thus, drivers seemed to be better able to compensate for their intoxication than they were able to detect and compensate for their distraction. In addition, drivers seemed to be better able to compensate for the resources demanded by the mobile phone task (primarily auditory in nature: listening and verbally responding) than those demanded by the in-vehicle task (visually searching for input and then visually looking and manually manipulating controls while responding). This suggests that looking away from the visual scene greatly hinders one's ability to maintain safe driving behavior. Notably, sober drivers interacting with in-vehicle tasks were often more impaired than drunk drivers without any secondary-task. This is consistent with the inherent greater conflict for visual input, spatial processing, and manual output resources shared by both driving and the in-vehicle tasks.

Strayer et al.. (2004; 2006) conducted research to provide a direct comparison of the driving performance of a mobile phone driver and a drunk driver in a controlled laboratory setting. They found that when drivers were conversing on either a hand-held or a hands-free mobile phone, their braking reactions were delayed and they were involved in more traffic accidents than when they were not conversing on a mobile phone. The impaired reaction of mobile phone drivers makes them less likely to travel with the flow of traffic which has implications for increasing overall traffic congestion (Strayer et al., 2006). By contrast, when drivers were intoxicated they exhibited a more aggressive driving style, following closer to he vehicle in front of them and applying more force when braking. It was noted by the authors that the study was conducted in the daytime and used daytime driving conditions. The majority of fatal accidents on US highways occur at night time in dark conditions and include other confounding variables, e.g. fatigue, visibility. In the study, participants were well-rested, potentially lowering the relative risks, with results giving a better case scenario than real life.

These studies support earlier findings (e.g. Redelmeier and Tibshirani, 1997; Burns, Parkes, Burton, Smith, & Burch, 2002). It can be concluded that when driving conditions and time on task are controlled for, the impairments associated with using a mobile phone while driving can be as profound as those associated with driving while drunk. However, it has been identified that the mechanisms underlying the impaired driving in the alcohol and mobile phone conditions differ, as, in the case of mobile phone driving, impairments appear to be attributable to the diversion of attention from the processing of information necessary for safe operation of a vehicle (Strayer et al., 2003, 2006), although these impairments are transient. By contrast the effect of alcohol can be persistent for longer periods, as well as being systemic and leading to chronic impairment (Strayer et al., 2006).

SECTION 3: THE IMPACT OF MOBILE PHONE USE ON CRASHES AND CRASH RISK

3.1 Crash Studies

In contrast to the detailed figures about mobile phone ownership, the collection of information about mobile phone involvement in road crashes is neither widespread nor particularly systematic, which makes it difficult to estimate the danger of mobile phone use in vehicles. For example, the presence or use of a mobile phone in a vehicle is not recorded in most countries. Even when this information is recorded drivers may be reluctant to report the truth due to potential prosecution. Therefore, it can be suggested that there is a serious problem of under-reporting regarding road crashes involving mobile phones. Although there is not enough information available to understand the real risk related to the use of a mobile phone while driving, recent epidemiological studies suggest that drivers using a mobile phone when driving are more at risk of having a road crash (Laberge-Nadeau, Maag, Bellavance, Lapierre, Desjardins, & Messier, 2003; McEvoy, Stevenson, McCartt, Woodward, Haworth, Palamara & Cercarelli, 2005; Glaze & Ellis 2003; Gordon, 2005; Neale et al., 2005; Klauer et al., 2006).

Glaze and Ellis (2003), in a study conducted for Virginia Commonwealth University, used crash records collected by troopers during 2002 to determine the most common sources of driver distraction contributing to crashes in Virginia. Glaze and Ellis found that passengers were the most common source of distraction, accounting for 8.7 percent of all distractions, while devices such as pagers and technologies, were the least common source of driver distraction (0.1 percent of distractions). Using a mobile phone was found to account for 3.9 percent of all reported distractions.

Laberge-Nadeau and colleagues (2003) studied whether an association exists between mobile phone use and risk of being involved in a road crash. A total of 36,078 drivers completed a survey regarding driving habits, crash history within the preceding 24 months and mobile phone use. Data from the survey were correlated with mobile and driving records and analysed to establish if there is a link between mobile phone use while driving and crashes. The findings revealed that, for drivers who use mobile phones while driving, the risk of being involved in an injury crash and all crash types is 38 percent higher than it is for non-users. However, when all confounding variables (e.g., kilometres driven per year) were accounted for, this increased risk decreased to 1.11 and 1.2 for male and female mobile phone users, respectively.

Gordon (2005) completed a study examining the role of distraction in crashes in New Zealand. The study aimed to provide detailed information on the role of various internal and external distractions, including mobile phones, that contribute to crashes. Two approaches have been used to examine the crash data. In the first, crash data from 2002 to 2003, based on driver distraction factor codes, has been summarised and categorised into types of distractions deriving from inside and outside the vehicle. The second approach involved a review of individual traffic crash reports for distraction-related crashes in New Zealand between 2002-2003 – to provide a comparison with the factor codes utilised in the first approach and to allow for a more detailed breakdown of driver distraction in terms of the objects, behaviours, typical crash movements and other factors involved. Results revealed that driver distraction (both internal and external) contributed to 10 percent of all police-reported casualty crashes occurring in New Zealand in 2002 and 2003 and that internal driver distractions (i.e., caused by activities or objects within the vehicle) were a contributing factor in 44 percent of these distraction-related crashes. In relation to the role of mobile phone use in crashes, Gordon found that, in 2002 and 2003, telecommunication devices (including mobile phones, pagers and radio-telephones) were identified as a source of distraction in approximately 12 percent of all internal distraction-related crashes. The majority (93 percent) of the telecommunication devices involved in the telecommunication-related crashes were mobile phones. Of all the telecommunication-based crashes, 40 percent involved the driver reacting to an incoming call or message, 35 percent involved the driver conversing on the phone or sending a text message, and 15 percent involved the driver searching for, or replacing, the phone or pager.

McEvoy et al. (2005) conducted an Australian study on the impact of mobile phone use on crash risk. Participants were 456 drivers in Western Australia aged 17 years and above who owned or used mobile phones and had been involved in a road crash necessitating hospital attendance between April 2002 and July 2004. The researchers ascertained drivers' use of the mobile phone at the estimated time of the crash and on trips at the same time of day in the week before the crash. They also interviewed the drivers in hospital and examined phone company records of drivers' phone use during this period.

Driver's use of a mobile phone up to 10 minutes prior to a crash (and also up to 5 minutes before the crash) was associated with a four-fold increase in the likelihood of having a crash resulting in hospital attendance. Importantly, crash risk was raised regardless of whether the phone was hand-held or hands free. There was a 3.8 times increase in the likelihood of having a crash causing injury for hands-free phones, and a 4.9 times increase for the hand-held phone. The increased risk was similar in men and women and in drivers aged less than 30 years and 30 years and above. The sample size was not large enough to assess whether different types of hand-free phones might have been safer than other types. A third of calls before crashes and on trips during the previous week were reportedly on mobile phones.

The 100-Car Naturalistic Driving Study is the first instrumented vehicle study undertaken with the primary purpose of collecting large-scale naturalistic driving data (Dingus et al., 2006; Klauer et al., 2006; Neale et al., 2005). The instrumented vehicles collected, from 241 drivers over a 12 to 13 month period, about 2,000,000 vehicle miles of driving data. Drivers involved in the study ranged in age from 18 to 55+ years. Most drove between 0 and 9,000 miles, and about 12 percent drove more than 21,000 miles. The study revealed a wealth of data on the role of driver distraction in crashes, near crashes and incidents that required an evasive manoeuvre. In total, there were 69 crashes, 761 near crashes and 8,295 incidents.

The results revealed that 78 percent of the crashes and 65 percent of the near crashes involved driver inattention as a contributing factor. Secondary task distraction was found to be the largest of four sub-categories of inattention identified from analysis of the data (the other three categories were "fatigue", "inattention to the forward roadway" and "non-specific eye glance"). The sources of distraction that contributed to the greatest proportion of near-crashes were, in descending order, wireless devices (primarily mobile phones), passenger-related tasks (primarily conversations) and internal distractions (manipulating or locating miscellaneous objects not related to wireless devices, in-vehicle systems, passengers or eating/drinking or smoking, such as animals, insects, reading). These three sources of distraction also contributed to the greatest proportion of crashes however, internal distraction accounted for a slightly higher proportion of crashes than wireless devices and passenger-related tasks (Dingus et al., 2006). Dingus et al. (2006) found that 93 percent of crashes with a lead vehicle (rear-end crashes) involved inattention as a contributing factor. Wireless devices (mainly mobile phones but including PDAs) were the most frequent contributing factor, followed by passenger-related distraction and then internal distractions. The trend was similar for near crashes.

Of all of the crash data reported, the data from the Klauer et al. (2006) study are likely to be the most accurate data, given that it enabled the most accurate assessment to be made of the contributing role of distraction to crashes, near misses and incidents. Given that the data collection instrumentation was unobtrusive, the authors argue that driver awareness of the instrumentation was out of mind and that the behaviours and performances observed were typical of normal driving. Klauer et al. (2006) further analysed the driver inattention data from the 100-car study to estimate the relative crash and near-crash risk for each of the four types of driver inattention. The results of these analyses are reported in the following section on crash risk.

3.2 Crash Risk (Epidemiological) Studies

Epidemiological research seeks to establish whether exposure to a particular variable is a risk factor for the development or occurrence of another variable. In the case of driver distraction, epidemiological research has been used to determine if using a mobile phone while driving increases the risk of being involved in a traffic crash. It is important to note upfront, that epidemiological research identifies 'associations' between factors; it does not indicate causality of an accident (e.g., that mobile phone use *causes* road crashes) and should not be interpreted as such.

There are a variety of epidemiological study designs, but the ones most often used in driver distraction research are the case-control and case-crossover studies. In case-control studies, a group of people who, for example, have been involved in a traffic crash (cases) are compared to people who have not (controls). Each case is matched to a control, who is similar to the case on potentially confounding variables such as age and gender. The proportion of cases who were using a mobile phone at the time of their crash is then determined. The proportion of controls who were also using a mobile phone while driving at the time of the case's collision is also determined. If a greater proportion of cases than controls were on the phone at the time of the crash, then it is concluded that using a mobile phone increases crash risk. Case-crossover studies are similar to case-control studies, except that in case-crossover studies, the cases serve as their own control. Therefore, potentially confounding factors such as age and personality are eliminated.

Laberge-Nadeau and colleagues (2003) studied whether an association exists between mobile phone use and risk of being involved in a road crash. A total of 36,078 drivers completed a survey regarding driving habits, crash history within the preceding 24 months and mobile phone use. Data from the survey was correlated with mobile and driving records. The findings revealed that, for drivers who use mobile phones while driving, the risk of being involved in an injury crash and all crash types is 38 percent higher than it is for non-users. However, when all confounding variables (e.g., kilometres driven per year) were accounted for, this increased risk decreased to 1.11 and 1.2 for male and female mobile phone users, respectively.

Wilson, Fang, Wiggins and Cooper (2003) used an epidemiological approach to examine the relationship between collision and violation involvement of drivers who use mobile phones. Their findings suggest that mobile phone use while driving is associated with an increased risk of at-fault crashes and rear-end collisions and that this user population is in general, a group of 'riskier drivers' than people who do not use a mobile phone while driving.

McEvoy and colleagues (2005; McEvoy, Stevenson, Woodward, in press) recently completed a case-control study in Perth, Western Australia, to examine the role of self-reported driver distraction in serious road crashes resulting in hospital attendance. The cases were drivers aged 17 years or over who had been involved in a road crash requiring attendance at a hospital emergency department. Controls were drivers aged 17 and above who had not been involved in a crash. Structured interviews were conducted to determine the prevalence and types of distracting factors reported by drivers who were involved in crashes, and the role of driver distraction in serious road crashes. There were 1367 participants in the study (274 cases and 1096 controls). McEvoy et al. (in press) found that 14 percent of cases reported that a distraction had contributed to the crash that resulted in hospital attendance. The categories of distraction reported included passenger distractions, internal cognitive distractions, physical distractions and external distractions. Being distracted while driving was found to increase the risk of having a serious crash by almost 3 times.

McEvoy et al. (2005) also conducted a study specifically on the impact of mobile phone use on crash risk. Participants were 456 drivers in Western Australia aged 17 years and above who owned or used mobile phones and had been involved in a road crash necessitating hospital attendance between April 2002 and July 2004. The researchers ascertained drivers' use of the mobile phone at the estimated time of the crash and on trips at the same time of day in the week before the crash. They also interviewed the drivers in hospital and examined phone company records of drivers' phone use during this period. Driver's use of a mobile phone up to 10 minutes prior to a crash was associated with a four-fold increase in the likelihood of having a crash resulting in hospital attendance. Importantly, crash risk was raised regardless of whether the phone was hand-held or hands free. There was a 3.8 times increase in the likelihood of having a crash causing injury for hands-free phones, and 4.9 times increase for the hand-held phone. The increased risk was similar in men and women and in drivers aged less than 30 years and 30 years and above. The sample size was not large enough to assess whether different types of hand-free phones might have been safer than other types and whether text messaging was more risky than conversing on a hand-held phone.

As part of the 100-Car Naturalistic Driving Study, Klauer et al. (2005) calculated the relative crash/near-crash risk associated with engaging in various inattention-related activities, including engaging in various secondary tasks. Crash risk estimates were calculated for 3 types of secondary tasks: complex tasks (tasks involving multiple steps, buttons presses or glances away from the road); moderate tasks (tasks requiring at most two button presses or glances away from the road); and simple tasks (tasks requiring none or only one button press or glance away from the road). The results revealed that drivers who engage in complex secondary tasks while driving are around 3 times more likely to be involved in a crash or near-crash, while drivers who are engaged in moderate secondary tasks are around 2 times more likely to be involved in a crash or near-crash. The odds ratios for simple secondary tasks indicated that these tasks do not significantly alter the likelihood of crash or near-crash involvement. Table 1 displays the risk of being involved in a crash or near-crash for various types of secondary tasks. A number of tasks were associated with increased crash risk: reaching for a moving object is the secondary task associated with the highest crash/near-crash risk, followed by looking at an external object, reading, applying makeup and dialling a hand-held device. Secondary tasks including handling a CD, talking/listening to hand-held device, insect in vehicle and reaching for object all had odd ratios greater than 1.0, however, their lower confidence limits were below 1.0, indicating that these tasks may not increase crash/near-crash risk.

Hand-held device use, (mainly mobile phone use) was the most frequent type of secondary task engaged in during the 100-car study. Talking/listening to a hand-held device was associated with a greater number of incidents than dialling a hand-held device. Dialling and conversing on a hand-held device each contributed to 3.6 percent of crashes and near-crashes. Although dialling and conversing on a hand-held device were shown to contribute to the same proportion of crashes in the 100-car study, dialling was found to increase crash risk, but conversing was found to have no significant affect on crash risk. One explanation for this finding is that drivers were conversing on hand-held devices a much larger proportion of time than they were dialling a hand-held device. Thus, the percentage of crashes and near-crashes that were attributable to these two activities was similar due to the fact that dialling was *more* dangerous but was performed less frequently, whereas conversing was *less* dangerous but performed more frequently.

Table 1. Odds ratios point estimates to assess the likelihood of combined crash (N = 49) or near-crash (N = 439) involvement when engaging in secondary tasks.

Type of Secondary Task	Odds Ratio
Reaching for a moving object	8.82
Insect in vehicle	6.37
Looking at external objects	3.70
Reading	3.38
Applying make-up	3.13
Dialling hand-held device	2.79
Inserting/retrieving CD	2.25
Eating	1.57
Reaching for non-moving object	1.38
Talking/listening to hand-held device	1.29
Drinking from open container	1.03
Other personal hygiene	0.70
Adjusting radio	0.55
Passenger in adjacent seat	0.50
Passenger in rear seat	0.39
Combing hair	0.37
Child in rear seat	0.33

Source: Klauer et al. (2006).

SECTION 4: THE IMPACT OF LEGISLATION BANNING MOBILE PHONE USE WHILE DRIVING

4.1 Behavioural Impact

In recent times, legislation has been established to ban the use of hand-held mobile phones while driving. Information on countries that have banned the use of a mobile phone when driving unless used with some form of hands-free kit is available from www.cellular-news.com (although the accuracy of this information has not been verified). Due to the recency of the legislation and the limitations of the methodologies used to establish frequency of phone use, it has been difficult to establish firm patterns of behavioural change as a result of modifications in the law. However, some recent investigations have generally suggested that banning the use of hand-held mobile phones initially lowers the rate of hand-held mobile phone use while driving (by up to 50%), before figures subsequently rise back up to pre-legislation levels (McCartt and Geary 2004; Johal, Napier, Britt-Compton & Marshall, 2005; Rajalin, Summala, Poysti, Anteroinen & Porter, 2005; Hussain, Al-Shakarchi, Mahmoudi, Al-Mawlawi & Marshall, 2006). The reasoning behind this subsequent rise and return to pre-legislation levels may be two-fold: enforcement - after a brief period of compliance, drivers are judging that the risk of getting caught is minimal, hence returning to using hand-held mobile phones while driving; and publicity - after a reduction in the publicity about the risks of mobile phone use while driving drivers may be forgetting or demoting these risks (Hussain et al., 2006).

4.2 Economic Impact

Very few studies have attempted to explore the economic implications of banning the use of mobile phones while driving. Two early studies (Hahn & Tetlock, 1999; Redelmeier & Weinstein, 1999, cited in Cohen & Graham, 2003), attempted to quantify the monetary benefits associated with a ban on mobile phones and the monetary costs associated with the loss of consumer convenience in being able to use the devices while driving. Both studies concluded that a ban on the use of mobile phones would not be economically efficient. The Hahn and Tetlock benefit-cost analysis estimated that a ban on mobile phones would result in a societal loss of US $23 billion annually (costs of US $25 billion and benefits of US $1.2 billion). The cost-effectiveness analysis conducted by Redelmeier and Weinstein estimated that the cost per quality adjusted life year (QALY) saved would be US $300,000. However, in a more recent study (Cohen and Graham, 2003), the key assumptions for the two earlier studies were revised so that they were consistent, reflected the latest information available, and assumed a ban on the use of both hand-held and hands-free mobile phones. They concluded that the estimated net benefit of a ban on mobile phone use while driving (in the US) was close to zero; that is, the value of preventing crashes caused by mobile phone use while driving is approximately equal to the value of the calls that would be eliminated by a ban.

CONCLUSIONS

OVERVIEW

Mobile phone use is a continuously increasing phenomenon particularly with the widening availability of continually evolving technologies and applications (e.g. text messaging, Internet access, cameras, calendars and email etc.) combined with standard telephone functions. Research findings reported to date show a four-fold increase in crash risk with mobile phone use, regardless of hand-held or hands-free mobile phone application. High and ever-increasing mobile phone ownership and use while driving combined with its impact on crash risk result in mobile phones being a large road safety concern.

Using a mobile phone while driving can distract drivers visually, physically, and/or cognitively. Physical and visual distraction is particularly pronounced when operating a hand-held phone, but can also occur when using a hands-free phone. Regardless of whether the phone is hands-free or hand-held, drivers are forced to remove their eyes from the road and their hands off the wheel to reach for the phone and initiate a connection by either dialling a number or answering an incoming call. Hand-held phones have the additional physical distraction of requiring the driver to drive one handed while holding the phone to their ear during a conversation. Cognitive distraction can result from the driver being startled by the initial ringing of the phone or from the conversation itself. While cognitive distraction occurs during any conversation, it is particularly pronounced while conversing on a mobile phone, as the sound quality and reception can vary throughout the conversation and drivers may struggle to hear the person on the other end of the line. Regardless of whether the phone is hand-held or hands-free, there is strong evidence that the actual task of conversing on the phone, whether it be listening or talking, while driving places significant cognitive demands on drivers and distracts them from concentrating on the safe operation of the vehicle and any hazards arising in the road environment. Experimental evidence shows that mobile phone conversations while driving, regardless of whether they are conducted on hand-held or hands-free devices, affect measures of driving performance. Collectively, the literature to date has shown that using a mobile phone while driving can:

- impair or improve your ability to maintain the correct lane position;
- impair your ability to maintain an appropriate and predictable speed;
- result in longer reaction times to detect and respond to unexpected events;
- result in drivers missing traffic signals;
- result in harder and later braking;
- reduce the functional visual field of view, which has been shown to be correlated with increased crash involvement;
- result in longer or shorter following distances to vehicles in front;
- result in people accepting gaps in traffic streams that are not large enough;
- increase mental workload, resulting in higher levels of stress and frustration;
- encourage people to look straight ahead rather than scanning around the road ahead; and
- reduce drivers' awareness of what is happening around them in time and space (i.e., reduced situational awareness).

The dangers of mobile phone use relative to other important crash risks (e.g., alcohol intoxication) have also been examined and it can be concluded that when driving conditions and time on task are controlled for, the impairments associated with using a mobile phone while driving can be as profound as those associated with driving while intoxicated by alcohol.

Whether and how the nature of driving performance is affected by mobile phone use depends, in part, on the type of mobile phone being used (e.g., hand-held or hands-free, and the degree of integration) and the specific activity being carried out with the phone (e.g. dialling, talking or sending/reading SMS messages). Other factors which moderate the effect of mobile phone use on driving performance include: exposure to phone use, phone design, driving and phone task demands and driver characteristics.

Research has shown that the design of the phone, the complexity and/or emotionality of the phone conversation or message, the complexity of the driving environment and driver characteristics, such as age and driving experience level, can all influence the potential for phone tasks to distract drivers. There is evidence to suggest that the driving performance of older and younger drivers is particularly affected by mobile phone use while driving.

Some research suggests that the impact of talking on a mobile phone on driving performance is similar to that of holding a conversation with a passenger. However, more work needs to be done in this area to examine what occurs in practice because other research has suggested that because passengers are aware of the road environment, they will generally let the conversation lapse during a dangerous driving situation. A person conversing with a driver on a mobile phone, however, is not aware of potential hazards and they will often continue to talk, distracting the driver at critical moments. There may also be social pressures to maintain a telephone conversation despite the presence of potential hazards as well as difficulties with conversation clarity due to signal strength. The evidence is therefore currently inconclusive on this matter.

Mobile phone use also often involves the performance of secondary tasks that may further distract the driver. Therefore, the distracting effects of using mobile phones while driving may extend beyond the actual operation of the phone itself.

Existing research suggests, however, that drivers often engage in a range of compensatory strategies in an attempt to maintain an acceptable level of driving performance while interacting with mobile phones. These compensatory strategies range from not using a phone while driving, to reducing speed, maintaining larger following distances, or altering the relative amount of attention allocated to each task at any given time depending on the demands of each task.

Few studies have reported detailed data on the frequency of crashes in which mobile phone use is a contributing factor. However, initial economic cost-benefit analysis suggests that the value of preventing crashes caused by mobile phone use while driving is approximately equal to the value of the calls that would be eliminated by a ban. Where legislation is put in place to ban the use of mobile phones while driving, enforcement needs to be effective, targeted, consistent and continuous. It is clear that enforcement is difficult and work is required in this area to develop effective countermeasures, especially for hands-free phones. It is apparent that new technologies may aid with this important process. There is a also need for high quality crash data which allows for the independent verification of mobile phone use to continuously evaluate their epidemiological impact on crash risk. There are few reliable estimates regarding the proportion of crashes attributable to mobile phone use. Better data would assist road authorities in monitoring the impact of legislation on population behaviour and give a more reliable indication of mobile phone usage rates while driving.

Regardless of legislation and its impact on behaviour, it is inevitable that mobile phones will still be used by some road users, regardless of whether it is legal or not. Indeed, research suggests that bans on mobile phone use do not affect long-term behaviour and need sustained and consistent enforcement and publicity. Therefore, it is important that mobile phones are ergonomically designed to accommodate driver limitations and capabilities so that any negative effects on driving performance that they might induce, such as distraction, are minimised.

Although most road crashes are due to a combination of risk factors (Stutts et al., 2001) and people regularly engage in a wide variety of multitasking activities when they are behind the wheel (Strayer et al., 2006), little research to date has considered the risk of mobile phone use in combination with other risk factors. This suggests that much of the research in this area is based on best-case scenarios, as real-world driving can be full of unknown and unexpected risk factors, dependent on task, context, behaviour and coincidence. Therefore, it is probable that many of the studies presented in the literature are underestimating the impact of mobile phone use while driving because they have rarely examined it in combination with a multitude of other influences.

While the effects of both phone types on performance are well documented and generally similar, their effects on safety outcomes are less well understood. This is because we know little about how drivers self-regulate in the real world, and the data on the involvement of phone distraction in police-reported crashes (with the exception of the epidemiological data) is relatively irregular.

REVIEW AND COMPARISON OF SRA (2003) FINDINGS

The key findings of the previous report published by the SRA (Patten et al., 2003) are outlined in the statements in Figure 1 (as per Appendix 1):

> Driving performance is impaired considerably when the driver speaks on a mobile phone whilst driving on simulated rural roads and in built up areas.
>
> When using a mobile phone (whether hand-held or hands-free), compared to driving without using a mobile phone, reaction times are longer, and more signals are missed.
>
> The disruptive effect of making a phone call cannot be fully eliminated by using a hands-free mobile phone system due to cognitive distraction.
>
> There is evidence of compensatory behaviour with the use of hand-held mobile phones (reduced speed with the use of hand-held mobile phones compared to hands-free mobile phones).
>
> No clear effects on driving performance were found regarding the receiving of text messages.

Figure 1. Key findings from the SRA Report (Patten et al., 2003)

It can be suggested from the complementary evidence presented in this new review that the SRA's 2003 conclusions are still valid, except the final point, as text messaging has now been found to be detrimental to driving performance. This new review has also brought to light the more recent research findings published since 2003, particularly for specific mobile phone tasks, which are summarised in Table 3. In relation to the SRA's earlier conclusions, these new findings specifically demonstrate that:

i. Using a mobile phone while driving is associated with a four-fold increase in crash risk.

ii. Using a mobile phone while driving can distract drivers visually, physically and cognitively.

iii. Manual touch dialling is associated with:
    a. A decrease in speed using either phone type.

b. An increase in speed variability when using hand-held mobile phones.
c. An increase in lateral position deviation for both phone types.
d. An increase in drivers' reaction time for both phone types.
e. An increase in missed signals for both phone types.
f. A decrease in eyes on road and on speedometer for hands-free phone use.

iv. Voice-activated dialling is associated with:
   a. An increase in reaction time.
   b. An increase in missed signals by older drivers.
   c. A similar glance pattern as when not using a mobile phone.

v. Simple conversation is associated with:
   a. A reduction in speed when using either type of phone.
   b. An increase in following distance for hands-free phones.
   c. An increase in reaction time with either type of phone.
   d. An increase in missed signals with either type of phone.
   e. An increase in subjective mental workload with both types of phone.

vi. Complex conversation is associated with:
   a. A decrease in speed with both types of phone.
   b. A decrease in steering variability with both types of phone.
   c. An increase in following distance with both types of phone.
   d. An increase in reaction time with both types of phone.
   e. An increase in the acceptance of more unsafe gaps with the use of hands-free phones.
   f. An increase in missed signals with both types of phone.
   g. An increase in subjective mental workload with both types of phone.

vii. Retrieving text messages is associated with:
   a. No change in speed.
   b. An increase in variation of lane position.
   c. An increase in braking reaction times.
   d. An increase in eyes off road time.

viii. Sending text messages is associated with:
   a. No change in speed.
   b. An increase in variation of lane position.
   c. An increase in eyes off road time.

ix. The impairments associated with mobile phone use can be as profound as those associated with driving while intoxicated by alcohol.

REVIEW OF OBJECTIVES

The objectives of this report were to:

1. Examine the effect of mobile phones (hands-free and hand-held) on normal driving.

The research reviewed indicates that use of mobile phones can have a significant impact on a number of safety-critical driving performance measures. In particular, the distraction caused by conversing on mobile phones while driving has been shown to impair a driver's ability to maintain an appropriate speed, throttle control and lateral position on the road. It can also impair drivers' visual search patterns, reaction times, and decision-making processes. Moreover, these impairments have been demonstrated for both hand-held and hands-free phones, refuting the belief held by many drivers that conversing on hands-free phones is safer than hand-held phones.

2. Examine the relative effect of hands-free *versus* hand-held mobile phones on normal driving.

Experimental evidence shows that mobile phone conversations while driving, regardless of whether they are conducted on hand-held or hands-free devices, affect measures of driving performance. Regardless of whether the phone is hands-free or hand-held, drivers are forced to remove their eyes from the road and their hands from the wheel to reach for the phone and initiate a connection by either dialling a number or answering an incoming call. Hand-held phones have the additional physical distraction of requiring the driver to drive one handed while holding the phone to their ear during a conversation.

Table 3. Summary of the Impact of Mobile Phone Tasks on Driving Performance

Performance / Phone Task	Speed Maintenance and Control	Lateral Position	Following Distance	Reaction Time	Gap Acceptance / Risk Taking	Missed Signals	Visual Scanning	Subjective Mental Workload
Dial – Manual touch	HH & HF: Mean speed decreased when dialling on either phone type, but especially when using hands-free phone (Tornros & Bolling, 2005). HH: Speed variability increased when dialling (HF not tested) (Reed & Green, 1999).	HH & HF: Lateral lane position deviation increased when dialling on either phone type (Tornros & Bolling, 2005). HH: Lane keeping performance reduced and steering wheel angle variability increased when dialling (HF not tested) (Reed & Green, 1999).	-	HF: Brake response times increased by 0.18 secs (HH not tested) (Lesch et al., 2004). HF: Reaction time to visual events increased (HH not tested) (Schreiner et al., 2004). HH & HF: Reaction times to peripheral targets increased by 270msecs when dialling on either phone type (Tornros & Bolling, 2005). HH: Reaction times were increased (HF not tested) (Hancock et al., 2003).	-	HF: Drivers stopped less at red traffic signals when using the phone (HH not tested) (Lesch et al., 2004). HH: Older drivers missed a greater number of events when dialling (HF not tested) (Schreiner et al., 2004). HH & HF: Drivers missed 13% more targets when conversing on either phone type (Tornros & Bolling, 2005).	HH: Drivers looked less at the roadway and speedometer with phone use (HF not tested) (Schreiner et al., 2004).	HH & HF: HH rated most difficult to use and the cradle-mounted hands-free the easiest to use (Mazzae et al., 2004). HH & HF: Drivers found conversing more mentally demanding than dialling (Tornros & Bolling, 2005).
Dial - Voice activated	-	-	-	HF: Reaction time to visual events increased only for older drivers (HH not tested) (Schreiner et al., 2004).	-	HF: Older drivers missed a greater number of events when dialling (HH not tested) (Schreiner et al., 2004).	HF: Produced similar glance patterns as no mobile phone free driving (HH not tested) (Schreiner et al., 2004).	-
Receive call - Manual	-	-	-	-	-	-	-	-
Receive call - Voice activated	-	-		-	-	-	-	-
Converse - simple conversation	HH & HF: Mean speed reduced when conversing for both phone types, but more so when using HF. Standard deviation of speed increased when using HH phone only (Burns et al., 2003). HF: No difference in mean speed. Standard deviation of speed decreased when using phone (HH not tested) (Horberry et al., 2006). HF: Mean speed reduced when using the phone and speed variability increased (HH not tested) (Rakauskas et al., 2004). HH: The use of a HH mobile phone slowed speed (Patten	HH & HF: no difference (Burns et al., 2003). HF: Steering variability increased when using the phone (but not statistically significant) (HH not tested) (Rakauskas et al., 2004). HH & HF: Drivers made a greater number of off-road excursions when using the hand-held phone compared to the hands-free (Haigney et al., 2000). HF: Steering variability decreased (HH not tested) (Shinar et al., 2005).	HH & HF: no difference (Burns et al., 2003). HF: Following distance increased when conversing by 12% (HH not tested) (Strayer & Drews, 2004). HF: Following distance increased when conversing (HH not tested) (Strayer et al., 2003).	HH & HF: Reaction time to road signs increased (Burns et al., 2002). HH & HF: The use of either type of mobile phone use caused RT to slow by 19% (Consiglio et al., 2003). HF: Drivers reduced their speed less in response to a pedestrian crossing the road when on the phone (HH not tested) (Horberry et al., 2006). HH & HF: The use of either type of mobile phone slowed reaction times to peripheral targets, especially for complex conversations (Patten et al., 2004).	-	HH & HF: The number of road signs missed increased (Burns et al 2002). HH & HF: Drivers made fewer correct responses to targets when conversing on either type of phone (Patten et al., 2004). HF: Drivers correctly detected fewer road objects when conversing (HH not tested) (Strayer et al., 2004). HH & HF: Drivers missed a greater number of simulated traffic signals when using either phone type (Strayer et al., 2003).	HF: There were no differences in eye fixations on objects when conversing (HH not tested) (Strayer et al., 2004).	HH & HF: Mental effort ratings increased when using both phone types (but highest for HF) (Burns et al., 2003). HF: Workload increased when using phone (HH not tested) (Horberry et al., 2006). HF: Phone use increased mental workload (HH not tested) (Rakauskas et al., 2004). HH & HF: Both types of phone increased workload but HF produced the lower level of workload (Matthews

	et al., 2004). HF: The use of a HF mobile phone increased speed, although not significantly (Patten et al., 2004). HF: Approach speed to obstacles reduced when conversing (HH not tested) (Treffner & Barrett, 2004). HF: There was no difference in mean speed (HH not tested) (Strayer & Drews, 2004). HH & HF: Mean speed and speed variability reduced when using either phone type (Haigney et al., 2000).			HF: Drivers commenced braking and steering control actions closer to the corner when conversing (HF not tested) (Treffner & Barrett, 2004). HF: Reaction times to a braking lead car increased by 18% (HH not tested) (Strayer & Drews, 2004). HH & HF: Reaction times to simulated traffic signals increased by 50msecs (Strayer et al., 2003). HF: Brake reaction times increased by 179msecs when conversing (HH not tested) (Strayer et al., 2003). HF: No significant difference in reaction time to visual stimuli (HH not tested) (Al-Tarawneh et al., 2004).				et al., 2003).
Converse - complex conversation	HF: Mean speed reduced when using the phone and speed variability increased (HH not tested) (Rakauskas et al., 2004). HH: The use of a HH mobile phone slowed speed (Patten et al., 2004). HF: The use of a HF mobile phone increased speed, although not significantly (Patten et al., 2004). HF: Approach speed to obstacles reduced when conversing (HH not tested) (Treffner & Barrett, 2004). HH: Mean speed reduced when conversing on a hand-held phone (Tornros & Bolling, 2005). HF: Mean speed did not change when conversing on a hands-free phone (Tornros &	HF: Steering variability increased when using the phone (but not statistically significant) (HH not tested) (Rakauskas et al., 2004). HH & HF: Lateral lane position deviation decreased when conversing on either phone type (Tornros & Bolling, 2005). HH & HF: Drivers made a greater number of off-road excursions when using the hand-held phone compared to the hands-free (Haigney et al., 2000). HF: Steering variability decreased (HH not tested) (Shinar et al., 2005).	HF: Following distance increased when conversing by 12% (HH not tested) (Strayer & Drews, 2004). HF: Following distance increased when conversing (HH not tested) (Strayer, et al., 2003).	HF: Peripheral vision reaction time increased by 0.4 secs when conversing (HH not tested) (Langer et al., 2005). HF: Reaction time to traffic signals increased when conversing (HH not tested) (McPhee et al., 2004). HH & HF: The use of either type of mobile phone slowed reaction times to peripheral targets especially for complex conversations (Patten et al., 2004). HF: Drivers commenced braking and steering control actions closer to the corner when conversing (HF not tested) (Treffner & Barrett, 2004). HH & HF: Reaction times to peripheral targets increased by 159msecs when conversing on either phone type (Tornros & Bolling, 2005). HF: Reaction times to a braking	HF: Accepted more unsafe gaps between traffic. HH: not tested. (Cooper & Zheng, 2002) HF: Drivers accepted smaller gaps when on phone (HH Not tested) (Cooper et al., 2003).	HF: Drivers stopped at red signals a greater number of times when using the phone (HH not tested) (Cooper et al., 2003). HH & HF: Drivers made fewer correct responses to targets when conversing on either type of phone (Patten et al., 2004). HH & HF: Drivers missed 24% more targets when dialling on either phone type (Tornros & Bolling, 2005). HH & HF: Drivers missed a greater number of simulated traffic signals when using either phone type (Strayer et al., 2003). HH & HF: More signals were missed during phone conversation in all types of traffic environments tested (Tornros & Bolling, 2006).	HF: No difference in visual search patterns (HH not tested) (McPhee et al., 2004).	HF: Phone use increased mental workload (HH not tested) (Rakauskas et al., 2004). HH & HF: Drivers found conversing more mentally demanding than dialling (Tornros & Bolling, 2005).

	Bolling, 2005). HF: There was no difference in mean speed (HH not tested) (Strayer & Drews, 2004). HH & HF: Mean speed and speed variability reduced when using either phone type (Haigney et al., 2000). HH: Speed was reduced during phone conversation in all types of traffic environments tested (Tornros & Bolling, 2006). HF: Speed was reduced during phone conversation in more complex types of traffic environments tested (Tornros & Bolling, 2006).			lead car increased by 18% (HH not tested) (Strayer & Drews, 2004). HH & HF: Reaction times to simulated traffic signals increased by 50msecs (Strayer et al., 2003). HF: Brake reaction times increased by 179msecs when conversing (HH not tested) (Strayer et al., 2003). HF: No significant difference in reaction time to visual stimuli (HH not tested) (Al-Tarawneh et al., 2004). HH & HF: Reaction time was slower during phone conversation in all types of traffic environments tested (Tornros & Bolling, 2006).				
Retrieve text message	Speed did not change when text messaging (Hosking et al., 2006).	Lane position variability increased when text messaging (Hosking et al., 2006).	Drivers increasing the distance between themselves and the vehicle ahead when retrieving text messages (Hosking et al., 2006).	Retrieving text messages increased braking reaction times to a motorcycle hazard (Kircher et al., 2004).	-	When retrieving text messages, the amount of time drivers spent with their eyes off the road increased by 400 percent (Hosking et al., 2006).	-	-
Send text message	Speed did not change when text messaging (Hosking et al., 2006).	Lane position variability increased when text messaging (Hosking et al., 2006).	Drivers increasing the distance between themselves and the vehicle ahead when sending text messages (Hosking et al., 2006).	-	-	When sending text messages, the amount of time drivers spent with their eyes off the road increased by 400 percent (Hosking et al., 2006).	-	-

HH = Hand-held, HF = Hands-free.

“Converse” means that participants were required to both talk and listen.

“ – “ means that the performance variable has not been studied for the task.

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.

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.

Burns, P. C., Parkes, A., Burton, S., Smith, R.K., & Burch, D. (2002). *How dangerous is driving with a mobile phone? Benchmarkng the impairment to alcohol*. Report 547. TRL Limited, Crowthorne.

Cohen, J. T. and Graham, J.D. (2003). A Revised Economic Analysis of Restrictions on the Use of Cell Phones While Driving. *Risk Analysis*, *23*(1), 5-17.

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 and Prevention*, *35*, 495-500.

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 and Prevention*, *35*, 23-35.

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

Dingus, T. A., Klauer, S.G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., & Knipling, R.R. (2006). *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment.* Virginia Tech Transportation Institute, Blacksburg, Virginia.

Direct Line (Motor Insurance). (2002). *The Mobile Phone Report: A report on the effects of using a hand-held and a hands-free mobile phone on road safety.* Direct Line Insurance. Croydon, United Kingdom.

Dragutinovic, N. & Twisk D. (2005). *Use of mobile phones while driving - effects on road safety. A literature review.* R-2205-12. SWOV Institute for Road Safety Research, The Netherlands.

Eby, D. W., Vivoda, J. M., & St. Louis, R. M. (2006). Driver hand-held cellular phone use: A four-year analysis. *Journal of Safety Research*, *37*(3), 261-265.

Glaze, A. L., & Ellis, J.M. (2003). *Pilot study of distracted drivers*: Survey and Evaluation Research Laboratory, Virginia Commonwealth University Center for Public Policy.

Gordon, C. (2005). *A preliminary examination of driver distraction related crashes in New Zealand.* Paper presented at the International Conference on Driver Distraction, Sydney.

Hahn, R.W., & Tetlock, P.C. (1999). *The economics of regulating cellular phones in vehicles*. Washington, DC: American Enterprise Institute-Brookings Joint Centre for Regulatory Studies.

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.

Hancock, P. A., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accident Analysis & Prevention, 35*(4), 501-514.

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, 372-379.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185-191.

Horrey, W. J., & Wickens, C.D. (2004). Cell phones and driving performance: A meta-analysis. *Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, Louisiana.

Hosking, S., Young, K., & Regan, M. (2005). *The effects of text messaging on young novice driver performance.* Report prepared for the NRMA by Monash University Accident Research Centre, Clayton, Victoria.

Hunton, J., & Rose, J.M. (2005). Cellular telephones and driving performance: The effects of attentional demands on motor vehicle crash risk. *Risk Analysis, 25*(4), 855-866.

Hussain, K., Al-Shakarchi, J., Mahmoudi, A., Al-Mawlawi, A., & Marshall, T. (2006). Mobile phones and driving: a follow-up. *J Public Health, 28*(4), 395-396.

Ipsosinsight (2006). From: http://www.ipsosinsight.com/pressrelease.aspx?id=3049 (accessed 28 Nov 2006).

Johal, S., Napier, F., Britt-Compton, J., & Marshall, T. (2005). Mobile phones and driving. *Journal of Public Health, 27*, 112-113.

Kircher, A., Vogel, K., Tornros, J., Nilsson, L., Patten, C., Malmstrom, T., & Ceci, R. (2004). *Mobile telephone simulator study*: Swedish National Road and Transport Research Centre.

Klauer, S. G., Neale, V.L., Dingus, T.A., Ramsey, D., & Sudweeks, J. (2005). Driver inattention: A contributing factor to crashes and near-crashes. *Paper presented at the Human Factors and Ergonomics Society 49th Annual Meeting,* Orlando, Florida.

Laberge-Nadeau, C., Maag, U., Bellavance, F., Lapierre, S. D., Desjardins, D., Messier, S., & Saidi, A. (2003). Wireless telephones and the risk of road crashes. *Accident Analysis & Prevention, 35*(5), 649-660.

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

Matthews, R., Legg, S., & Charlton, S. (2003). The effect of cell phone type on drivers' subjective workload during concurrent driving and conversing. *Accident Analysis & Prevention, 35*(4), 451-457.

Mazzae, E. N., Ranney, T.A., Watson, G.S., & Wightman, J.A. (2004). *Hand-held or hands-free? The effects of wireless phone interface type on phone task performance and driver preference.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.

McCartt, A., Hellinga, L., & Bratiman, K. (2006). Cell Phones and Driving: Review of Research. *Traffic Injury Prevention, 7*(2), 89-106.

McCartt, A. T., & Geary, L. L. (2004). Longer term effects of New York State's law on drivers' handheld cell phone use. *Injury Prevention, 10*(1), 11-15.

McEvoy, S.P., Stevenson, M.R., McCartt, A.T., Woodward, M., Haworth, C., Palamara, P., & Cercarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. *British Medical Journal, 331*;428-432.

McEvoy, S.P., Stevenson, M.R., & Woodward, M. (in press). The prevalence of, and factors associated with, serious crashes involving a distracting activity. *Accident Analysis and Prevention,* In Press.

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), 674-685.

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

Neale, V. L., Dingus, T.A., Klauer, S.G., Sudweeks, J., & Goodman, M (2005). An overview of the 100-car naturalistic study and findings. *Presented at the 19th International Technical Conference on Enhanced Safety of Vehicles (ESV),* Washington DC.

Patten, C.J.D., Ceci, R., Malmstrom, T; Rehnberg, K (2003). *The use of mobile phones in road traffic: SNRA inquiry into the use of mobile phones and other IT systems while driving*. Publication 2003:91. SNRA, SE-781 87 Borlange, Sweden.

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.

Poysti, L., Rajalin, S., & Summala, H. (2005). Factors influencing the use of cellular (mobile) phone during driving and hazards while using it. *Accident Analysis & Prevention, 37*(1), 47-51.

Rajalin, S., Summala, H., Poysti, L., Anteroinen, P., & Porter, B.E. (2005). In-car cell phone use and hazards following hands free legislation. *Traffic Injury Prevention, 6*, 225-229.

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

Rakauskas, M., Ward, N, Bernat, E, Cadwallader, M, & De Waard, D. (2005). *Driving Performance During Cell Phone Conversations and Common In-Vehicle Tasks While Sober and Drunk*. University of Minnesota HumanFIRST Program.

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.

Redelmeier, D.A. & Weinstein, M.C. (1999). Cost-effectiveness of regulations against using a cellular telephone while driving. *Medical Decision Making, 19,* 1-18.

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.

Regan, M.A., Deery, H. & Triggs, T. (1998). Training for Attentional Control in Novice Car Drivers (pp. 1452 - 1456). *In the Proceedings of the 42nd Annual Meeting of the Human Factors and Ergonomics Society (Volume 2).* Chicago, Illinois.

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.

Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention, 37*(2), 315-326.

Strayer, D. L., & Drews, F.A. (2004). Profiles in driver distraction: Effects of cell phone conversations on younger & older drivers. *Human Factors, 46*(4), 640-649.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell Phone-Induced Failures of Visual Attention During Simulated Driving. *Journal of Experimental Psychology: Applied*, *9*(1), 23-32.

Strayer, D. L., Drews, F.A., & Crouch, D.J. (2006). A Comparison of the Cell Phone Driver and the Drunk Driver. *Human Factors, 48*(2), 381.

Strayer, D. L., & Johnston, W.A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science, 12*(6), 462-466.

Stutts, J., Feaganes, J., Rodgman, E., Hamlett, C., Meadows, T., & Reinfurt, D. (2003). *Distractions in everyday driving*. Washington, D.C.: AAA Foundation for Traffic Safety.

Sullman, M. J. M., & Bass, P.H. (2004). Mobile phone use amongst New Zealand drivers. *Transportation Research, Part F 7,* 95-105.

Telstra. (2004). *Young motorists miss the safe driving message.* Telstra News Release. www.telstra.com.au/newsroom.

Tornros, J., & Bolling, A. (2006). Mobile phone use - effects of conversation on mental workload and driving speed in rural and urban environments. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(4), 298-306.

Tornros, J. E. B., & Bolling, A. K. (2005). Mobile phone use--Effects of handheld and handsfree phones on driving performance. *Accident Analysis & Prevention*, *37*(5), 902-909.

Treffner, P. J., & Barrett, R. (2004). Hands-free mobile phone speech while driving degrades coordination and control. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(4-5), 229-246.

Troglauer, T., Hels, T., & Christens, P. F. (2006). Extent and variations in mobile phone use among drivers of heavy vehicles in Denmark. *Accident Analysis & Prevention, 38*(1), 105-111.

Wheatley, D. J. (2000). *The driving need for human factors in the car of the future*: Motorola Labs.

White, M. P., Eiser, J.R., & Harris, P.R. (2004). Risk perceptions of mobile phone use while driving. *Risk Analysis*, *24*(2), 323-334.

Williamson, A. (1999). *Young drivers and crashes: Why are young drivers over-represented in crashes? Summary of the issues*. Paper prepared for the Motor Accidents Authority of NSW, Sydney, Australia.

Wilson, J., Fang, M., Wiggins, S., & Cooper, P. (2003). Collision and violation involvement of drivers who use cellular telephones. *Traffic Injury Prevention*, *4*(1), 45-52.

Wogalter, M. S., & Mayhorn, C.B. (2005). Perceptions of driver distraction by cellular phone users and nonusers. *Human Factors*, *47*(2), 455-467.

APPENDIX 1 - Key findings from the SRA/Vägverket report (Patten et al. 2003)

- Driving performance is impaired considerably when the driver speaks on a mobile phone whilst driving (p12) on simulated rural roads and in built up areas (p15).
- When using a mobile phone (whether hand-held or hands-free), compared to driving without using a mobile phone (p14):
  - Reaction times are longer, and;
  - More signals are missed.
- The disruptive effect of making a phone call cannot be fully eliminated by using a hands-free mobile phone system (p11) due to cognitive distraction.
- There is evidence of compensatory behaviour with the use of hand-held mobile phones (reduced speed with the use of hand-held mobile phones compared to hands-free mobile phones) (p15).
- No clear effects on driving performance were found regarding the receiving of text messages.

APPENDIX 2 - Mobile Phone Use While Driving: The Scientifically Published Studies Issued Since 2003

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.

Amado, S., & Ulupinar, P. (2005). The effects of conversation on attention and peripheral detection: Is talking with a passenger and talking on the cell phone different? *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(6), 383-395.

Anttila, V., & Luoma, J. (2005). Surrogate in-vehicle information systems and driver behaviour in an urban environment: A field study on the effects of visual and cognitive load. *Transportation Research, Part F 8*, 121-133.

Atchley, P., & Dressel, J. (2004). Conversation limits the functional field of view. *Human Factors, 46*(4), 664-673.

Barkana, Y., Zadok, D., Morad, Y., & Avni, I. (2004). Visual field attention is reduced by concomitant hands-free conversation on a cellular telephone. *American Journal of Ophthalmology, 138*(3), 347-353.

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.

Blanco, M., Biever, W. J., Gallagher, J. P., & Dingus, T. A. (2006). The impact of secondary task cognitive processing demand on driving performance. *Accident Analysis & Prevention, 38*(5), 895-906.

Cohen, J. T. & Graham, J.D. (2003). A Revised Economic Analysis of Restrictions on the Use of Cell Phones While Driving. *Risk Analysis, 23*(1), 5-17.

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 and Prevention, 35*, 495-500.

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 and Prevention, 35*, 23-35.

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. A., Klauer, S.G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J., & Knipling, R.R. (2006). *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment.* Virginia Tech Transportation Institute, Blacksburg, Virginia.

Dragutinovic, N. & Twisk D. (2005). *Use of mobile phones while driving - effects on road safety. A literature review.* R-2205-12. SWOV Institute for Road Safety Research, The Netherlands.

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.

Eby, D. W., & Vivoda, J. M. (2003). Driver hand-held mobile phone use and safety belt use. *Accident Analysis & Prevention, 35*(6), 893-895.

Eby, D. W., Vivoda, J. M., & St. Louis, R. M. (2006). Driver hand-held cellular phone use: A four-year analysis. *Journal of Safety Research, 37*(3), 261-265.

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

Glaze, A. L., & Ellis, J.M. (2003). *Pilot study of distracted drivers*: Survey and Evaluation Research Laboratory, Virginia Commonwealth University Center for Public Policy.

Gordon, C. (2005). A preliminary examination of driver distraction related crashes in New Zealand. *Paper presented at the International Conference on Driver Distraction*, Sydney, Australia.

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, 347-355.*

Green, P. (2004). Driver distraction, telematics design, and workload managers: Safety issues and solutions. *Paper presented at the Convergence International Congress and Exposition on Transportation Electronics*, Detroit, Michigan.

Gugerty, L., Rakauskas, M., & Brooks, J. (2004). Effects of remote and in-person verbal interactions on verbalization rates and attention to dynamic spatial scenes. *Accident Analysis & Prevention, 36*(6), 1029-1043.

Hancock, P. A., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accident Analysis & Prevention, 35*(4), 501-514.

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, 372-379.*

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

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185-191.

Horrey. (2006). Modeling Drivers' Visual Attention Allocation While Interacting With In-Vehicle Technologies. *Journal of Experimental Psychology. Applied, 12*(2), 67-78.

Horrey, W. J., & Wickens, C.D. (2004a). *Cell phones and driving performance: A meta-analysis.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.

Horrey, W. J., & Wickens, C.D. (2004b). Driving and side task performance: The effects of display clutter, separation, and modality. *Human Factors, 46*(4), 611-624.

Horrey, W. J., Wickens, C.D. (2004c). The Impact of Cell Phone Conversations on Driving: A Meta-Analytic Approach. Technical Report AHFD-04-2/GM-04-1. *Technical Report AHFD-04-2/GM-04-1. General Motors Corporation, MI, USA*.

Horrey, W.J, Wickens, C.D. (2006). Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors, 48*(1), 196.

Hosking, S., Young, K., & Regan, M. (2005). *The effects of text messaging on young novice driver performance.* Report prepared for the NRMA by Monash University Accident Research Centre, Clayton, Victoria.

Hunton, J., & Rose, J.M. (2005). Cellular telephones and driving performance: The effects of attentional demands on motor vehicle crash risk. *Risk Analysis, 25*(4), 855-866.

Hussain, K., Al-Shakarchi, J., Mahmoudi, A., Al-Mawlawi, A., & Marshall, T. (2006). Mobile phones and driving: a follow-up. *J Public Health, 28*(4), 395-396.

Jahn, G., Oehme, A., Krems, J.F., & Gelau, C. (2005). Peripheral detection as a workload measure in driving: Effects of traffic complexity and route guidance system use in a driving study. *Transportation Research, Part F 8*, 255-275.

Jamson, A. H., & 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 8*, 79-96.

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.

Johal, S., Napier, F., Britt-Compton, J., & Marshall, T. (2005). Mobile phones and driving. *Journal of Public Health, 27*, 112-113.

Kawano, T., Iwaki, S., Azuma, Y., Moriwaki, T., & Hamada, T. (2005). Degraded voices through mobile phones and their neural effects: A possible risk of using mobile phones during driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(4-5), 331-340.

Kircher, A., Vogel, K., Tornros, J., Nilsson, L., Patten, C., Malmstrom, T., & Ceci, R. (2004). *Mobile telephone simulator study*: Linköping : Swedish National Road and Transport Research Institute (VTI).

Klauer, S. G., Neale, V.L., Dingus, T.A., Ramsey, D., & Sudweeks, J. (2005). *Driver inattention: A contributing factor to crashes and near-crashes.* Paper presented at the Human Factors and Ergonomics Society 49th Annual Meeting.

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.

Laberge-Nadeau, C., Maag, U., Bellavance, F., Lapierre, S. D., Desjardins, D., Messier, S., & Saidi, A. (2003). Wireless telephones and the risk of road crashes. *Accident Analysis & Prevention, 35*(5), 649-660.

Lai, F., & Carsten, O. (2003, 7-10 September). Safety implications of driver dual-task performance. *Paper presented at the Vision in Vehicles 10*, Granada, Spain.

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., & Strayer, D.L. (2004). Preface to the special section of driver distraction. *Human Factors, 46*(4), 583-586.

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

Levy, J., Pashler, H., & Boer, E. (2004). *Vehicle breaking is slower under dual-task conditions: Evidence for "central" interference.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting, New Orleans, Louisiana.

Liu, B.-S., & Lee, Y.-H. (2006). In-vehicle workload assessment: Effects of traffic situations and cellular telephone use. *Journal of Safety Research, 37*(1), 99-105.

Liu, Y.-c. (2003). Effects of Taiwan in-vehicle cellular audio phone system on driving performance. *Safety Science, 41*(6), 531-542.

Ma, R., & Kaber, D.B. (2005). Situation awareness and workload in driving while using adaptive cruise control and a cell phone. *International Journal of Industrial Ergonomics*, 35, 939-953.

Ma, R., Sheik-Nainar, M.A., & Kaber, D.B. (2005). Situation awareness in driving while using adaptive cruise control and a cell phone. *Paper presented at the Human Factors and Ergonomics Society 49th Annual Meeting.*

Manser, M. P., Ward, N.J., Kuge, N., & Boer, E.R. (2004). Influence of a driver support system on situation awareness and information processing in response to lead vehicle braking. *Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, Louisiana.

Matthews, R., Legg, S., & Charlton, S. (2003). The effect of cell phone type on drivers subjective workload during concurrent driving and conversing. *Accident Analysis & Prevention, 35*(4), 451-457.

Mazzae, E. N., Ranney, T.A., Watson, G.S., & Wightman, J.A. (2004). Hand-held or hands-free? The effects of wireless phone interface type on phone task performance and driver preference. *Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, Louisiana.

McCallum, M. C., Campbell, J.L., Richman, J.B., Brown, J.L., & Wiese, E. (2004). Speech recognition and in-vehicle telematics devices: Potential reductions in driver distraction. *International Journal of Speech Technology, 7*(1), 25-33.

McCartt, A., Hellinga, L., & Bratiman, K. (2006). Cell Phones and Driving: Review of Research. *Traffic Injury Prevention, 7*(2), 89-106.

McCartt, A. T., Braver, E.R., & Geary, L.L. (2003). Drivers' use of handheld cell phones before and after New York State's cell phone law. *Preventative Medicine, 36*, 629-635.

McCartt, A. T., & Geary, L. L. (2004). Longer term effects of New York State's law on drivers' handheld cell phone use. *Injury Prevention, 10*(1), 11-15.

McCartt, A. T., Hellinga, L.A., & Geary, L.L. (2006). Effects of Washington, D.C. law on drivers' hand-held cell phone use. *Traffic Injury Prevention, 7*, 1-5.

McDougall. (2006). Searching for Signs, Symbols, and Icons: Effects of Time of Day, Visual Complexity, and Grouping. *Journal of experimental psychology: Applied, 12*(2), 118-128.

McEvoy, S.P., Stevenson, M.R., McCartt, A.T., Woodward, M., Haworth, C., Palamara, P., & Cercarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. *British Medical Journal, 331*;428-432.

McEvoy, S.P., Stevenson, M.R., & Woodward, M. (in press). The prevalence of, and factors associated with, serious crashes involving a distracting activity. *Accident Analysis and Prevention,* In Press.

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), 674-685.

Merat, N., Anttila, V., & Luoma, J. (2005). Comparing the driving performance of average and older drivers: The effect of surrogate in-vehicle information systems. *Transportation Research, Part F 8*, 147-166.

Monk, C. A., Boehm-Davis, D.A., & Trafton, J.G. (2004). Recovering from interruptions: Implications for driver distraction research. *Human Factors, 46*(4), 650-663.

Neale, V. L., Dingus, T.A., Klauer, S.G., Sudweeks, J., & Goodman, M (2005). *An overview of the 100-car naturalistic study and findings.* Presented at the 19th International Technical Conference on Enhanced Safety of Vehicles (ESV), Washington DC.

Neyens, D. M., & Boyle, L. N. (2007). The effect of distractions on the crash types of teenage drivers. *Accident Analysis & Prevention, 39*(1), 206-212.

Olsen, E. C. B., Lerner, N., Perel, M., & Simons-Morton, B.G. (2005). In-car electronic device use among teen drivers. *Paper presented at the Transportation Research Board Meeting*, Washington, D.C.

Patten, C., Ceci, R., Malmstrom, T; Rehnberg, K. (2003). The use of mobile phones in road traffic: SNRA inquiry into the use of mobile phones and other IT systems while driving. *Publication 2003:91. SNRA, SE-781 87 Borlange, Sweden.*

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.

Patten, C. J. D., Kircher, A., Ostlund, J., Nilsson, L., & Svenson, O. (2006). Driver experience and cognitive workload in different traffic environments. *Accident Analysis & Prevention, 38*(5), 887-894.

Piechulla, W., Mayser, C., Gehrke, H., & Konig, W. (2003). Reducing drivers' mental workload by means of an adaptive man-machine interface. *Transportation Research, Part F 6*, 233-248.

Poysti, L., Rajalin, S., & Summala, H. (2005). Factors influencing the use of cellular (mobile) phone during driving and hazards while using it. *Accident Analysis & Prevention, 37*(1), 47-51.

Rafaely, V., Meyer, J., Zilberman-Sandler, I., & Viener, S. (2006). Perception of traffic risks for older and younger adults. *Accident Analysis & Prevention, 38*(6), 1231-1236.

Rajalin, S., Summala, H., Poysti, L., Anteroinen, P., & Porter, B.E. (2005). In-car cell phone use and hazards following hands free legislation. *Traffic Injury Prevention, 6*, 225-229.

Rakauskas, M., & Ward, N. (2005). Behavioural effects of driver distraction and alcohol impairment. *Paper presented at the Human Factors and Ergonomics Society 49th Annual Meeting.*, Orlando, Florida.

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

Rakauskas, M., Ward, N, Bernat, E, Cadwallader, M, & De Waard, D. (2005). Driving Performance During Cell Phone Conversations and Common In-Vehicle Tasks While Sober and Drunk. *University of Minnesota HumanFIRST Program.*

Regan, M., Young, K & Johnston I. (2005). *MUARC Submission to the Parliamentary Road Safety Committee Inquiry into Driver Distraction.* Parliamentary Road Safety Committee, Melbourne, Australia.

Reyes, M. L., Lee, J.D. (2004). The influence of IVIS distractions on tactical and control levels of driving performance. *Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting*, New Orleans, Louisiana

Roberts, S. (2003). *Computer use in automobiles: Safety and usability issues*: Human Oriented Technology Lab.

Rosenbloom, T. (2006). Driving performance while using cell phones: an observational study. *Journal of Safety Research, 37*(2), 207-212.

Sagberg, F., & Bjornskau, T. (2006). Hazard perception and driving experience among novice drivers. *Accident Analysis & Prevention, 38*(2), 407-414.

Salvucci, D. D. (2005). Modeling tools for predicting driver distraction. *Paper presented at the Human Factors and Ergonomics Society 49th Annual Meeting*, Orlando, Florida.

Santos, J., Merat, N., Mouta, S., Brookhuis, & de Waard, D. (2005). The interaction between driving and in-vehicle information systems: Comparison of results from laboratory, simulator and real-world studies. *Transportation Research, Part F 8*, 135-146.

Sayer, J. R., Mefford, M.L., Shirkey, K., & Lantz, J. (2005, 27-30 June, 2005). Driver distraction: A naturalistic observation of secondary behaviours with the use of driver assistance systems. P*aper presented at the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Rockport, Maine, USA.

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.

Seo, D. C., & Torabi, M. R. (2004). The impact of in-vehicle cell-phone use on accidents or near-accidents among college students. *Journal of the American College of Health, 53*(3), 101-107.

Sheridan, T. B. (2004). Driver distraction form a control theory perspective. *Human Factors, 46*(4), 587-599.

Shinar, D., Tractinsky, N., & Compton, R. (2005). Effects of practice, age, and task demands, on interference from a phone task while driving. *Accident Analysis & Prevention, 37*(2), 315-326.

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. (2004a). Profiles in driver distraction: Effects of cell phone conversations on younger & older drivers. *Human Factors, 46*(4), 640-649.

Strayer, D. L., & Drews, F.A. (2004b). 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 Experimental Psychology: Applied, 9*(1), 23-32.

Strayer, D. L., Drews, F.A., & Crouch, D.J. (2006). A Comparison of the Cell Phone Driver and the Drunk Driver. *Human Factors, 48*(2), 381.

Strayer, D. L., Drews, F.A., Albert, R.W., & Johnston, W.A. (2003). *Cell phone induced perceptual impairments during simulated driving*, from http://ppc.uiowo.edu/driving-asse...ent%20Papers/03_Strayer_David.html

Stutts, J., Feaganes, J., Reinfurt, D., Rodgman, E., Hamlett, C., Gish, K., & Staplin, L. (2005). Drivers' exposure to distractions in their natural driving environment. *Accident Analysis and Prevention, 37*, 1093-1101.

Stutts, J., Feaganes, J., Rodgman, E., Hamlett, C., Meadows, T., & Reinfurt, D. (2003). *Distractions in everyday driving*. Washington, D.C.: AAA Foundation for Traffic Safety.

Sullman, M. J. M., & Bass, P.H. (2004). Mobile phone use amongst New Zealand drivers. *Transportation Research, Part F, 7*, 95-105.

Tay, R., & Knowles, D. (2004). Driver inattention: Drivers' perception of risks and compensating behaviours. *IATSS Research, 28*(1), 89-94.

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.

Tornros, J., & Bolling, A. (2006). Mobile phone use - effects of conversation on mental workload and driving speed in rural and urban environments. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(4), 298-306.

Tornros, J. E. B., & Bolling, A. K. (2005). Mobile phone use--Effects of handheld and handsfree phones on driving performance. *Accident Analysis & Prevention, 37*(5), 902-909.

Townsend, M. (2006). Motorists' use of hand held cell phones in New Zealand: An observational study. *Accident Analysis & Prevention, 38*(4), 748-750.

Treffner, P. J., & Barrett, R. (2004). Hands-free mobile phone speech while driving degrades coordination and control. *Transportation Research Part F: Traffic Psychology and Behaviour, 7*(4-5), 229-246.

Troglauer, T., Hels, T., & Christens, P. F. (2006). Extent and variations in mobile phone use among drivers of heavy vehicles in Denmark. *Accident Analysis & Prevention, 38*(1), 105-111.

Tsimhoni, O., Smith, D., & Green, P. (2004). Address entry while driving: Speech recognition versus a touch-screen keyboard. *Human Factors, 46*(4), 600-610.

Victor, T. W., Harbluk, J.L., & Engstrom, J.A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research, Part F 8*, 167-190.

Ward, N., Shankwitz, C., Gorgestani, A., Donath, M., de Waard, D., & Boer, E. (2006). An evaluation of a lane support system for bus rapid transit on narrow shoulders and the relation to bus driver mental workload. *Ergonomics, 49*(9), 832-859.

White, M. P., Eiser, J.R., & Harris, P.R. (2004). Risk perceptions of mobile phone use while driving. *Risk Analysis, 24*(2), 323-334.

Wikman, A., & Summala, H. (2005). Aging and time-sharing in highway driving. *Optometry & Vision Science, 82*(8), 716-723.

Wilson, J., Fang, M., Wiggins, S., & Cooper, P. (2003). Collision and violation involvement of drivers who use cellular telephones. *Traffic Injury Prevention, 4*(1), 45-52.

Wogalter, M. S., & Mayhorn, C.B. (2005). Perceptions of driver distraction by cellular phone users and nonusers. *Human Factors, 47*(2), 455-467.

This page has intentionally been left blank.

Swedish Road Adminstration
Society and Traffic
781 87 Borlänge.
www.vv.se. vagverket@vv.se.

Vägverket