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Driver distraction: A review of the literature

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Approximately one quarter of vehicle crashes in the United States are estimated to result from the driver being inattentive, or distracted. As more wireless communication, entertainment and driver assistance systems proliferate the vehicle market, the incidence of distraction-related crashes is expected to escalate. In North America, Europe and Japan, driver distraction is a priority issue in road safety. However, the significance of driver distraction as road safety issue has only recently been recognised in Australia. This paper provides a review of current research on in-vehicle driver distraction, focusing on mobile phone use in particular, given that this device has received the greatest attention in the driver distraction literature. The review discusses the effect of in-vehicle devices on driving performance. Issues addressed include: the adaptive strategies drivers adopt in order to maintain their driving performance while distracted at an adequate level; under what conditions these adaptive strategies can fail; and how driving performance is affected when they do. Also examined is whether, and to what degree, these degradations in driving performance translate into an increased crash risk. In the final section of the paper, recommendations for future research are provided.

Introduction

Driving is a complex task, requiring the concurrent execution of various cognitive, physical, sensory and psychomotor skills. Despite these complexities, it is not unusual to observe drivers engaging in various non driving-related activities while driving. These activities range from conversing with passengers and listening to the radio, to applying make-up and even reading. With the advent of wireless communication (e.g., mobile phones), more sophisticated entertainment systems and the introduction of technologies such as route navigation and the Internet into vehicles, preoccupation with electronic devices while driving is also becoming increasingly common (Regan, 2004a; 2004b; 2004c). Any activity that competes for the driver’s attention while driving has the potential to degrade driving performance and have serious consequences for road safety.

Research by the National Highway Traffic Safety Administration (NHTSA) estimates that driver inattention, in its various forms, contributes to approximately 25 percent of police-reported crashes. Driver distraction is one form of driver inattention and is claimed to be a contributing factor in over half of inattention crashes (Stutts, Reinfurt, Staplin, & Rodgman, 2001; Wang, Knipling, & Goodman, 1996). However, as more wireless communication, entertainment and driver assistance systems proliferate the vehicle market, it is likely that the rate of distraction-related crashes will escalate.

This paper provides a review of the current literature on driver distraction, focussing specifically on in-vehicle distraction; that is, distraction caused by activities or objects inside the vehicle rather than those outside the vehicle. Also, given that relatively little research has been conducted on the potentially distracting effects of in-vehicle devices other than mobile phones and route guidance systems (e.g., email and the Internet), the paper focuses primarily on research pertaining to these two devices. The review discusses the effect of in-vehicle devices on driving performance. In particular, it the focus is on the adaptive strategies drivers adopt when using devices in order to maintain their driving performance at an adequate level, under what conditions these adaptive strategies can fail and how driving performance is affected when they do. In the final section of the paper, recommendations are provided for managing and minimising the risks associated with driver distraction. First, however, the nature of driver distraction is briefly discussed.

The nature of driver distraction

When driving, drivers must continually allocate their attentional resources to both driving and non-driving tasks. Because many aspects of the driving task become automated with experience, drivers are often capable of dividing their attention between concurrent tasks without any serious consequences to driving performance or safety. Drivers are also capable of adapting their driving to meet the demands of the driving environment or compensate for a decrease in attention to the driving task (e.g., reducing speed or refraining from performing risky manoeuvres such as overtaking) (Haigney, Taylor & Westerman, 2000; OECD, 1990). Drivers can, however, be ‘distracted’ by an activity or event to the extent that they no longer allocate sufficient attention to the driving task and their driving performance is compromised. In this sense, driver distraction results when drivers’ normal cognitive processes (i.e., attention-sharing) and adaptive strategies fail and drivers are no longer able to adequately divide their attention between the driving and secondary tasks and maintain driving performance at a satisfactory level. Distraction can occur either because the secondary task is so complex or compelling that drivers fail to allocate (or prioritise) sufficient attention to driving, or because the demands of the driving task are so high that they do not allow the performance of a secondary task at any level.

Despite the proliferation of research into driver distraction in the past few years, there is currently no universally agreed upon definition of driver distraction. The definitions of driver distraction found in the literature range from “driver distraction occurs when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver’s shifting attention away from the driving task.” (Treat, 1980, p. 21) to “a shift in attention away from stimuli critical to safe driving toward stimuli that are not related to safe driving” (Streff & Spradlin, 2000). While these definitions agree that distraction involves a shifting of attention away from the driving task, they fail to address the fact that not *all* events or objects that divert attention from the driving task are going to create a distraction. A definition of distraction should encompass the qualification that distraction occurs when drivers attend to other, non-driving tasks or events to the degree that they fail to allocate sufficient attention to the driving task and their driving performance is degraded. In other words, if there is no negative effect of the secondary task on driving performance or control, then distraction has not occurred. To this end, driver distraction may be defined as occurring when a driver’s attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object to the extent that the driver is no longer able to perform the driving task adequately or safely.

The above definition, however, does not take into account other forms of interference that occur when secondary tasks are performed concurrently with the driving task. Research has typically categorised distraction into four distinct types: visual, auditory, biomechanical (physical) and cognitive distraction. Visual distraction occurs when the driver neglects to look at the road and instead focuses his/her visual attention on another target for an extended period of time. Auditory distraction occurs when the driver focuses their attention on auditory signals rather than on the road environment. Biomechanical or physical distraction occurs when drivers remove one or both hands from the steering wheel for extended periods of time to physically manipulate an object, and cognitive distraction includes any thoughts that absorb the driver's attention to the point that they are no longer able to navigate through the road environment safely.

What form of interference will lead to the greatest degradation in driving performance has been the topic of debate. According to Wickens' multiple resource theory, if two tasks, performed concurrently, compete for similar cognitive, perceptual or motor resources then dual-task interference occurs (Wickens, 2002). Given that driving is primarily a visual-spatial-manual task, then, according to multiple resource theory, tasks that have visual inputs and require a manual response should cause greater dual-task interference and, hence, greater reductions in driving performance, than auditory or cognitive distraction. There is some evidence supporting this theory in the literature (e.g., Hurwitz & Wheatley, 2002; Tijerina, Palmer & Goodman, 1998). However, as Wickens (2002) states, just because two concurrent tasks utilise different resources does not mean that they will not cause *any* dual-task interference, particularly if the demands of one or both tasks are high. Indeed, as discussed in the review, there is now ample evidence, especially in relation to mobile phone conversations, that tasks involving auditory inputs and speech responses can interfere with the driving task and impair performance (Haigney et al., 2000; Matthews, Legg & Charlton, 2003; Patten, Kircher, Ostlund & Nilsson, 2004; Strayer & Drews; 2004; Treffner & Barrett, 2004).

Review of the literature

The popularity of mobile or portable devices, particularly mobile phones, has escalated in recent years, with approximately 80 percent of Australians currently owning a mobile phone (Allen Consulting Group, 2004). As more in-vehicle and portable devices proliferate the market, there has been growing concern regarding the safety implications of using such devices while driving. In response, a large and rapidly growing body of research has examined the impact of devices, particularly mobile phones, on driving performance (Young, Regan & Hammer, 2003).

Compensatory behaviour

One fundamental question regarding the effect of in-vehicle devices on driving performance is whether and how drivers self-regulate their driving to compensate for any 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 in-vehicle devices. It is important to recognise, however, that not all changes in driving performance associated with non-driving tasks are indicative of driver impairment, and research suggests that drivers do engage in a range of conscious and unconscious compensatory behaviours in order to attempt to maintain an adequate level of safe driving (Haigney et al., 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, Rajalin & Summala, 2005). At the highest level, drivers can choose to moderate their exposure to risk by choosing not to engage in a potentially distracting task while driving. Research has shown, for example, that older drivers' driving performance is impaired to a greater degree than younger drivers when using a mobile phone and this results in compensatory behaviour at the highest level; many older drivers choose not use a mobile phone while driving (Alm & Nilsson, 1995; Lamble, Rajalin & Summala, 2002).

At the operational level, several studies have shown that drivers attempt to reduce workload and moderate their exposure to risk while interacting with in-vehicle devices. They do this through a number of means: decreasing speed (Alm & Nilsson, 1990; Burns, Parkes, Burton, Smith & Burch, 2002; Haigney et al., 2000; Rakauskas, Gugerty & Ward, 2004), increasing inter-vehicular distance (Jamson, Westerman, Hockey & Carsten, 2004; Strayer & Drews, 2004; Strayer, Drews & Johnston, 2003), changing the relative amount of attention given to the driving and non-driving tasks in response to changes in the road environment (Brookhuis, de Vries & de Waard, 1991; Chiang Brooks & Weir, 2001), and accepting a temporary degradation in certain driving tasks (e.g., by checking mirrors and instruments less frequently) (Brookhuis et al., 1991; Harbluk, Noy & Eizenmann, 2002).

Several on-road and simulator studies have found that drivers tend to decrease their mean speed when engaging in a secondary task. In a simulator study, Haigney et al. (2000) examined the effects on driving performance of engaging in a mobile phone task using hand-held and hands-free mobile phones. Thirty participants completed four simulated drives while completing a grammatical reasoning task designed to simulated a mobile phone conversation. The results revealed that mean speed and the standard deviation of accelerator travel decreased while participants were conversing on the mobile phone. More recent research carried out in a driving simulator by Rakauskas and colleagues (2004) also found that drivers' mean speed decreased and their speed variability increased while carrying out a naturalistic conversation on a mobile phone.

Research examining the effects on driving performance of interacting with other in-vehicle devices also provides evidence that drivers tend to reduce speed when using in-vehicle devices. Chiang et al. (2001), for example, found that drivers decreased their speed when entering destination details into a route navigation system, while Horberry, Anderson, Regan, Triggs and Brown (in press) found that drivers' mean speed decreased while they were interacting with an in-car entertainment (radio and CD-player) system.

The observed reductions in speed while engaging in a secondary task could be the result of drivers modifying their performance goals and accepting a sub-optimal level of driving performance, or the result of drivers simply allocating too much attention to the secondary task and insufficient attention to the primary driving task. Both of these explanations can have road safety implications, resulting from the driver either not allocating sufficient resources to the driving task and, hence, any potential hazards in the road environment, or because the driving performance standard that they are willing to accept may be below that needed for safe driving in certain situations.

An increase in following distance is another compensatory behaviour that has been displayed by drivers while they are interacting with in-vehicle devices. Using a driving simulator, Strayer and colleagues (2003) found that conversing on a hands-free mobile phone while driving led to an increase in following distance from a lead vehicle and this increase was particularly pronounced under high traffic density conditions. Strayer and Drews (2004) also found that drivers' following distance to a lead vehicle increased by 12 percent when drivers were conversing on a hands-free mobile phone under simulated driving conditions. Finally, in a driving simulator study, Jamson et al. (2004) revealed that drivers adopted longer headways from a lead vehicle while processing emails using a speech-based email system. Interestingly, although the drivers in all three studies attempted to compensate for their reduced attention to the roadway by adopting longer following distances, in many cases this increased headway was often inadequate to avoid collisions with other road users.

Another compensatory behaviour drivers have been found to engage in when interacting with in-vehicle devices is to change the amount of attention they allocate to the primary and secondary tasks at any given time in response to changes in the driving environment. Chiang and colleagues (2004), for instance, found that drivers allocated more attention (as measured by duration of glance time) to the roadway and less to entering destination details when driving in a freeway environment than they did when driving in the city. The researchers concluded that the drivers may have viewed the heavier traffic and higher speeds associated with freeway driving as posing a greater safety risk than driving in city traffic and, hence, the drivers reduced the amount of attention they were willing to allocate to the secondary task under such conditions. Research examining the effects of mobile phones on driving performance has also revealed that drivers modify the relative amount of attention they are willing to allocate to the primary and secondary tasks based on current driving conditions. Brookhuis et al. (1991), however, found 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. It thus, 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.

Task demands and driver characteristics: Impact on driver distraction

The research discussed above indicates that drivers are capable of adapting their driving behaviour to meet the increased demands of engaging in non-driving tasks while driving. However, under certain conditions these adaptive behaviours can breakdown, resulting in a significant degradation in driving performance. The potential for a non-driving task to distract the driver is determined by the complex interaction of a number of factors including task complexity, current driving demands, driver experience and skill and the willingness of the driver to engage in the task. A non-driving task that distracts drivers and degrades driving in one situation may not do so in another situation and, similarly, non-driving tasks may differentially affect drivers from different driving populations. Recently, driver distraction research has focused on identifying those conditions under which engaging in secondary tasks while driving is most likely to distract drivers to the extent that their driving performance and safety is compromised. A number of task and driver characteristics that can influence the potential for non-driving tasks to distract drivers have been identified in the literature. These are discussed below.

Secondary Task Demands
The cognitive, physical or visual demands that the non-driving 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 in-vehicle devices, one factor that influences secondary task demand characteristics is the physical design of the in-vehicle device, such as the type of mobile phone or the menu structure of a route navigation system.

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 using a hand-held phone degrades driving performance significantly and, in response, many countries including Australia, Brazil, Italy and England, and several states in the U.S., have prohibited the use of hand-held mobile phones while driving (Goodman et al., 1997; Matthews et al., 2003). Based on the results of numerous studies examining hand-held mobile phones, researchers concluded that the main risk associated with mobile phone use while driving was the physical interference caused by handling and manipulating the phone (Briem & Headman, 1995; Brookhuis et al., 1991). However, as subsequent research discovered, although the physical distraction associated with handling the phone can present a significant safety hazard, the cognitive distraction associated with being engaged in a conversation can also have a considerable effect on driving. Indeed, many studies have found that conversing on a hands-free phone while driving is no safer than using a hand-held phone (Haigney et al., 2000; Matthews et al. 2003; Redelmeier & Tibshirani, 1997; Strayer, Drews, Albert & Johnston, 2003).

A study by Haigney et al. (2000) revealed no safety advantages of hands-free phones over hand-held phones. Using the Aston Driving Simulator, Haigney and colleagues examined the relative effects of hand-held and hands-free mobile phone use on driving performance. Thirty participants (mean age 26.93 years) completed four simulated drives in which they had to deal with incoming calls, using both a hands-free and a hand-held phone. The simulator was fitted with a heart rate sensor to measure deviations from the participants' resting heart rate while using the mobile phones. Results revealed that speed and standard deviation of accelerator pedal travel were lower, and mean heart rate higher during phone use. Moreover, as heart rate increases were not associated with type of phone, the authors concluded that these increases were not related to the physical demands of holding the phone, but rather to the cognitive demands associated with the phone conversation.

Further research by Strayer and colleagues (2003) 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, Ranney, Watson and Wightman (2004) has also revealed that conversing on a mobile phone while driving imposes an increased workload demand on drivers regardless of the phone interface type used (hand-held or hands-free) and that drivers tended to overestimate the ease of using hands-free phones while driving.

Several studies have also sought to examine the relative effects of using different route guidance interfaces on driving performance. The potential for route guidance systems to distract drivers can occur either when they are entering destination details or responding to guidance instructions.

A number of methods exist for entering information into route guidance systems: selecting the required destination from a scrolling list of cities, suburbs and street names; manually typing in the address letter by letter; or using voice input to enter the destination details (Tijerina, Johnston, Parmer, Winterbottom, & Goodman, 2000). The first two methods of data entry are the lengthiest and, thus, are likely to be the most physically and cognitively demanding; however, they are also the most commonly used by drivers. The relative benefits of using voice rather than manual input when operating route guidance systems has become a major focus of research examining the distracting nature of route guidance systems.

Tijerina and colleagues examined the distracting effects of entering destination information into four different route guidance systems requiring different destination entry methods (Tijerina et al., 1998). Three of the systems involved visual-manual destination entry, while the fourth involved voice input and output. The visual attention required to dial a hand-held mobile phone and tune the radio was also assessed for comparative purposes. Sixteen participants drove along a track with traffic lights in an instrumented vehicle. While driving, participants were required to enter destination information into each of the four route guidance systems. Mean glance time at the road and the device, number of lane exceedences and time taken to enter destination information were recorded for each system.

The results revealed that the three visual-manual destination entry systems were associated with longer completion times, longer eyes-off-road times, more frequent glances at the device, and a greater number of lane exceedences compared to the voice activated system. In particular, drivers aged less than 35 years took, on average, over one minute to enter destination information into the systems manually, while drivers aged over 55 took twice as long to perform the same task. The voice activated system, however, was associated with more frequent glances at a card containing the destination details than the visual-manual entry systems. Regardless of the type of route guidance system, the destination entry task took substantially longer to complete than either the mobile phone dialling or radio tuning tasks. The authors concluded that route guidance systems with voice recognition technology are a more viable and safer option than systems that require visual-manual entry (Tijerina et al., 1998). Nevertheless, continuing concerns over the amount of time required to enter destination information, whether manually or by voice-activation, has led some system developers to limit access to certain navigation functions while the vehicle is in motion. In particular, a number of route guidance systems now ‘lock out’ the destination entry function when the vehicle is in motion (Farber, Foley, & Scott, 2000).

Numerous studies have also examined and compared the relative distracting effects of route guidance systems that present navigation information in different forms. One of the most notable of these is the camera car study, conducted by the NHTSA (Dingus, McGeehee, Hulse, Jahns, & Manakkal, 1995). Four different route guidance systems were examined: turn-by-turn guidance screens with and without voice guidance and an electronic route map with and without voice guidance. Two control conditions, written directions and a conventional paper map, were also examined. Thirty participants each drove an instrumented “camera car” while interacting with the various configurations of the route guidance system, the paper map and the written direction list. Of all the systems tested, the electronic route map without voice guidance and the conventional map resulted in the greatest degradations in driving performance. Use of the electronic route map without voice guidance created high visual attention demand, requiring drivers to look at the display longer to retrieve required information and resulted in more braking errors and lane deviations than the other navigation systems. Use of the conventional map also required a large amount of cognitive attention, as evidenced by the high number of abrupt braking manoeuvres and high self-reported workload ratings under this condition. The turn-by-turn guidance screen with voice guidance was associated with the best performance with regard to usability, safety and attentional demand, suggesting that route guidance systems which provide turn-by turn instructions, rather than complex holistic route information, are least distracting to drivers and present the most useable means of navigation (Dingus et al., 1995).

More recently, Srinivasan and Jovanis (1997) used a high fidelity driving simulator to examine the effect on driving performance of interacting with complex route guidance systems. The study sought to determine whether the addition of voice guidance or a turn-by-turn display enhances the usability of route guidance systems. Eighteen participants drove along a simulated network while interacting with four different route guidance systems: head-down electronic route map; head-up turn-by-turn guidance display with head-down electronic map; voice guidance with head-down electronic map and a paper map. Driving speed, workload, navigation errors, and reaction time to external events were measured while interacting with each system. The voice guidance/electronic map system was associated with better driving performance, resulting in the lowest workload ratings, the fastest mean speeds on all road types and the least number of navigational errors. In contrast, the paper map resulted in the lowest mean speeds, the highest workload ratings and the greatest number of navigational errors. The authors hypothesised that lower mean speeds were an indication that the system required more of the driver's attentional capacity, as drivers would drive at slower speeds to compensate for their reduced attention to the roadway. The authors therefore viewed faster mean speeds as better driving performance.

Overall, based on the above research, the potential for an in-vehicle device to distract drivers can be influenced by the design of the interface for the device. With regard to mobile phones, there is evidence that the task of having to physically manipulate the phone does negatively affect driving. However, the task of conversing on the phone has also been shown to have a considerable negative impact on driving performance regardless of the phone type used. In addition, the use of visual-manual entry systems to enter destination information into route guidance systems appears to have a greater effect on driving performance than does the use of voice input technology to perform this task. Similarly, guidance systems that present navigation instructions using voice output appear to be less distracting and more usable than systems that present information via a visual display, especially if the display is a complex map.

Another factor, often closely linked to interface design, that can influence the distraction potential of a secondary task is the complexity of the task. For example, the level of difficultly or emotionality of a phone conversation, or the familiarity of a destination address can affect the cognitive demands that the task places on the driver and hence its potential to distract the driver from the driving task.

In relation to mobile phones, 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. A study by McKnight and McKnight (1993) was one of the first to examine the relative effects of simple and complex phone conversations on a driver's ability to attend to the driving task. They had 150 participants drive a 25 minute simulated drive under five distraction conditions: dialling a mobile phone, holding a simple phone conversation (e.g., discussing what they did for a living), holding a complex phone conversation (e.g., solving maths problems), tuning a radio and no distraction. All three phone conditions led to an increase in failures to respond to traffic situations such vehicles ahead slowing down or pedestrians entering the road, and the complex conversation led to the greatest overall degradation in driving performance.

More recent research examining the relative effects of conversation complexity on the detection and response time to targets also support the results of McKnight and McKnight. A study by Al-Tarawneh and colleagues (2004) found that 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.

Harbluk et al. (2002) also investigated the impact of cognitive distraction on driver's visual behaviour in an on-road experiment. Twenty-one drivers (aged 21 to 43 years) drove an instrumented car along a city test route while carrying out secondary tasks of varying cognitive complexity communicated via a hands-free mobile phone. Participants drove the test route under three conditions: while performing no secondary task; while completing easy addition problems (e.g., 6+9); and while completing complex addition tasks (e.g., 47+38). Measures of visual scanning behaviour (using eye tracking equipment) vehicle control (e.g., braking and longitudinal deceleration) and drivers' subjective assessments of workload, safety and distraction were recorded. Measures of the drivers' visual scanning patterns revealed that as the cognitive complexity of the phone task increased, drivers made significantly less saccadic eye movements (high-speed eye movements which facilitate exploration of the road environment) and spent more time looking centrally and less time looking to the right periphery for impending hazards. Drivers also spent less time checking their mirrors and instruments and many drivers displayed a change in their inspection patterns of their forward view (e.g., spent more time looking up or down). Evidence of an increase in the incidence of hard braking during the complex addition task was also observed. Finally, as the complexity of the addition tasks increased, drivers' perception of workload (recorded using the NASA-TLX), distraction level and perceptions of their driving as being less safe also increased (Harbluk et al., 2002).

One concern that has been raised with previous 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 (Brookhuis et al., 1991; McKnight and McKnight, 1993; 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 (Haigney et al., 2000; Mazzae et al., 2004; Strayer & Johnston, 2001). 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 are now using naturalistic phone conversations to measure the effects of mobile phone use on driving performance (Rakauskas et al., 2004: Shinar, Tractinsky & Compton, 2005). Rakauskas and colleagues (2004) examined the relationship between level of conversation difficulty and driver distraction using a naturalistic conversation task, whereby participants were required to answer easy and difficult questions (e.g., "What are you doing tomorrow?" "Do you think the world will be better or worse in 100 years?") while driving in a simulated driving environment. 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. One explanation why this study failed to demonstrate an effect of conversation difficulty when numerous other 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. Indeed, a study by 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. An alternative explanation is that the two complexity conditions used did not differ enough in difficulty to reveal any differential effects on driving performance.

Another criticism of previous distraction research 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 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 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. Thirty participants carried out two mobile phone tasks (math operation task and emotionally involving conversation) over five driving sessions. 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 math solving tasks, may be overestimating the detrimental effects of mobile phone use on driving performance. Clearly, further research is needed in this area before any firm conclusions can be drawn. However, the study does 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 engaging in non-driving tasks (Strayer et al., 2003). The performance of a non-driving task on a quiet country road may have a considerably different effect on driving performance than performance of the same task 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 the performance of an in-vehicle non-driving task and the complexity of the driving environment (Brookhuis et al., 1991; Horberry et al., in press; Strayer & Johnston, 2001; Strayer et al., 2003).

Strayer and Johnston (2001) examined what additional effect increasing the complexity of the driving environment had on pursuit tracking performance while using a mobile phone. Participants were required to converse on hand-held and hands-free mobile phones while performing an easy, predictable simulated driving task and a difficult, unpredictable driving task. The results revealed that, when using the mobile phone, participants missed almost twice as many tracking targets as when they were not using a mobile phone and that this effect was most pronounced when performing the difficult tracking task.

More recently, 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 times 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.

The impact of adverse weather conditions has also been shown to influence the effect of mobile phone-based distraction on drivers' ability to make safe cross-traffic turning decisions (Cooper & Zheng, 2002). Using a closed-course driving experiment, 39 participants were exposed to approximately 100 gaps between eight vehicles that circled the test circuit continuously. The test circuit was wet for half of the trials. The participants were asked to press down on the accelerator pedal when they felt that it was safe to turn in front of the approaching vehicles (although the test vehicle stayed stationary). For half the trials participants were required to listen and respond to a complex message and for the other half the participants were not distracted. Results revealed that when distracted by the mobile phone task, drivers did not take into account the road surface condition (whether it was wet or dry) when deciding whether to accept or reject a gap. Indeed, on the wet road surface, participants were estimated to have initiated twice as many potential collisions when distracted by the verbal messages. The authors concluded that listening and responding to verbal messages while driving reduces a driver's ability to adequately consider and process all the information necessary for safe decision-making, particularly in adverse driving conditions.

Research by Horberry and colleagues (in press), however, failed to reveal any interaction between the complexity of the driving environment and two in-vehicle distracter tasks: operating an in-car entertainment system 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 entertainment system and mobile phone and while not performing any secondary task. Results revealed that interacting with the entertainment system and 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 tasks and environment complexity was revealed, suggesting that driving performance while interacting with the in-car devices 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 in-vehicle devices, 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 anything not essential to the driving task when under increased load (e.g., when performing a secondary task).

Driver Age and Experience

There is a large body of evidence that driver age and driving experience can influence the relative distracting effects of in-vehicle devices (Lam, 2002; McPhee, Scialfa, Dennis, Ho & Caird, 2004; McKnight & McKnight, 1993; Reed & Green, 1999; Schreiner, Blanco & Hankey, 2004; Shinar et al., 2005). Research has consistently found that older people have a decreased ability to share attention between two concurrent tasks due to their decreased visual and cognitive capacity and, hence, may be more susceptible to the distracting effects of engaging in a secondary task 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 attentional resources and, therefore, do not have sufficient spare attentional 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 non-driving and driving tasks, potentially degrading their driving performance. To this end, a training product, known as DriveSmart, has been developed specifically to train novice drivers' attention sharing ability (Regan, Triggs & Godley, 2000).

An Australian study examined for drivers of different ages, the association between distraction inside and outside the vehicle and the risk of being involved in a crash (Lam, 2002). Fatal and injury crash data collected by New South Wales police during the years 1996 and 2000 was examined and crashes were categorised as resulting from no distraction, or distraction inside or outside the vehicle. In-vehicle distractions included using a hand-held phone, attending to passengers, tuning the radio, adjusting the CD player and smoking. Results revealed that drivers in the 25 to 29 year age group had the highest risk of being involved in a fatal or injury crash while using a hand-held phone of all age groups examined. In contrast, the risk of being involved in a fatal or injury crash resulting from other in-vehicle distractions increased with increasing age. With regard to the finding that 25 to 29 year olds have a greater crash risk when using a mobile phone than other age groups, Lam suggested that this might result from differential exposure to mobile phone use across age groups, rather than differences in attention sharing ability. That is, drivers aged 25 to 29 years may be more likely to use their mobile phone while driving than older drivers and this increased exposure would be expected to heighten their crash risk.

Lam’s (2002) finding that older drivers are more susceptible to the effects of distraction than younger drivers supports the findings of previous research by McKnight and McKnight (1993) and Reed and Green (1999). McKnight and McKnight found that drivers aged 50 to 80 years demonstrated a greater deficit in being able to respond to traffic signals while conversing on a mobile phone than did younger (17 to 25 years) and middle aged (26-49 years) drivers. Drivers in the youngest group also demonstrated a significant decline in responsiveness to traffic signals when they were engaged in a casual phone conversation. Results of a later study by Reed and Green (1999) revealed similar decrements in driving performance with increasing age, whereby the older participants (aged 60+) showed greater decrements in their ability to maintain speed and lane position than the younger participants aged 20 to 30 years.

More recent research provides some evidence that older drivers are relatively more susceptible to the effects of in-vehicle distraction than their younger counterparts. Schreiner and colleagues (2004) found in a closed-course study that older drivers’ (mean age: 57 years) ability to detect forward and peripheral events while concurrently driving and using a voice recognition system to dial phone numbers was impaired compared to their baseline performance. The younger to middle-aged drivers (mean age: 23 years), however, did not demonstrate a performance decrement when interacting with the voice recognition system. Similarly, McPhee et al. (2004) found that, compared to the younger to middle-aged drivers, older adults were 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).

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 older, 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. (in press), for example, found that the driving performance of drivers aged over 60 years was relatively more degraded when interacting with an entertainment system or a mobile phone than younger drivers, but that the older drivers attempted, either consciously or unconsciously, to compensate for this degradation by reducing 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.

Driver Distraction and Crash Risk

A large and fast growing body of evidence shows that interacting with in-vehicle devices while driving impairs driving performance on a number of safety critical measures. But does this degradation in driving performance translate into an increase in crash risk? There has been relatively less research conducted to examine this question, primarily due to reporting and recording issues, and the research that has been conducted has largely focused on the risks associated with mobile phone use.

Using an epidemiological approach, Redelmeier and Tibshirani (1997) examined whether using a mobile phone while driving increases the risk of being involved in a vehicle crash and whether hands-free phones offer any safety advantages over hand-held phones. A total of 699 Toronto drivers who owned a mobile phone and who were involved in a vehicle crash resulting in substantial property damage, but no personal injury, participated in the study. Each driver's mobile phone calls on the day of the crash and in the week prior to the crash were analysed through detailed billing records. The time of each collision was determined through driver statements, police records and call records to emergency services. Case-crossover analysis was used to assess the risk associated with mobile phone use. Results revealed that the risk of being involved in a vehicle crash while using a mobile phone was four times greater than that among the same drivers when they were not using a phone. Moreover, the authors observed no safety advantages of using a hands-free over a hand-held phone while driving and concluded that their results did not support the policy being adopted in many countries of prohibiting the use of hand-held, but not hands-free, mobile phones while driving. However, concerns have been raised by researchers over the validity of Redelmeier and Tibshirani's results, namely that the data method used in the study does not allow for an accurate conclusion to be drawn regarding whether the driver was on the phone at the time of the accident or immediately after the accident occurred; the risk associated with phone use may, thus, have been over-estimated.

Violanti (1998) conducted a case-control study using data from 223,137 crashes occurring between 1992 and 1995 in the US to examine the associations between fatal traffic crashes and the use, or presence in the vehicle, of mobile phones. Information regarding mobile phone use and crash characteristics was compared across fatal and non-fatal crashes. The study found that a mobile phone was present in four percent of the vehicles involved in a fatal crash and, in these crashes, almost eight percent of the drivers were using the phone at the time of the crash. The study also found that drivers who were using a mobile phone were nine times more likely to be involved in a fatal crash than drivers who were not. Simply having a mobile phone in a vehicle was found to be associated with a two-fold increased risk in being involved in a fatal collision.

Stutts et al. (2001) conducted a study for the AAAFTS in which they examined detailed crash records from the Crashworthiness Data System (CDS) collected between 1995 and 1999. This study constituted Phase 1 of a larger project examining the role of distraction in traffic crashes. They found that, of the crashes examined, 8.3% were the result of the driver being distracted by some event, object or activity inside or outside the vehicle. The study also identified the most common sources of distraction that contributed to distraction-related crashes. Distraction outside the vehicle was identified as the contributing factor in 29.4 percent of crashes attributable to distraction. Adjusting the radio, cassette or CD player were the most commonly reported sources of in-vehicle distraction, accounting for 11.4 percent of drivers involved in distraction-related crashes, followed closely by other vehicle occupants

(10.9 percent of drivers). Interestingly, using or dialling a mobile phone was the second least common source of distraction reported by drivers (1.5 percent). However, under-reporting may have attenuated this figure, as use of a hand-held mobile phone is illegal in many U.S. states.

More recently, 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 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., kilometers driven per year) were accounted for, this increased risk decreased to 1.11 and 1.2 for male and female mobile phone users, respectively.

Discussion and conclusions

Emerging entertainment, communication and advanced driver assistance systems have tremendous potential to enhance the safety, mobility and enjoyment of driving. It is important, however, that these systems are ergonomically designed to accommodate driver limitations and capabilities and that any negative effects on driving performance that they might induce, such as distraction, are minimised prior to system deployment. The research reviewed suggests that drivers often engage in a range of compensatory strategies in an attempt to maintain an acceptable level of driving performance while interacting with in-vehicle devices, at least for those devices reviewed. These compensatory strategies range from not using in-vehicle devices while driving, to reducing speed, maintain a larger following distance, or altering the relative amount of attention allocated to each task at any given time depending on the demands of each task. There are however, a number of situations in which these adaptive behaviours can break down, resulting in a significant degradation in driving performance. Research has shown that the design of a device, the complexity and/or emotionality of the secondary task being performed, the complexity of the driving environment and driver characteristics, such as age and driving experience level, can all influence the potential for non-driving tasks to distract drivers. Generally, research has found that as the difficulty of the secondary and/or driving tasks increase, the potential for the task to degrade driving performance also increases. Older drivers and young novice drivers have also been shown to be more susceptible to the distracting effects of engaging in secondary tasks while driving than experienced or middle-aged drivers.

The distraction caused by interacting with in-vehicle devices while driving has been shown to significantly impair a driver's ability to maintain speed, throttle control and lateral position on the road. It can also impair drivers' visual search patterns, reaction times, decision-making processes and can increase the risk of being involved in a collision. Moreover, research findings suggest that drivers are not always aware of the detrimental effects on their driving performance of engaging in secondary tasks (Lesch & Hancock, 2004) and often underestimate the risks involved in performing particular tasks, particularly in relation to their own crash risk relative to their peers (White, Eiser & Harris, 2004).

Further research

Based on the research reviewed, there are a number of priorities for driver distraction research in Australia, which are discussed below. It is important to note that this list is not exhaustive, but derives primarily from the issues discussed in the review.

Exposure to Distraction

- Research is needed to identify what factors motivate or encourage drivers to willingly engage in distracting activities, such as peer-pressure, pleasure, task urgency, personality, age and driving experience.
- Research should also identify what factors discourage drivers from engaging in distracting activities, such as high task demand, poor or complex driving conditions, age and experience.
- Research should attempt to establish how frequently drivers engage in certain distracting activities, how long they typically engage in them, and under what conditions they usually engage in them.
- An inventory of existing and emerging technologies and services which can be accessed on-board the vehicle or through portable devices within the vehicle (e.g., via mobile phones and pocket PCs) should be compiled. The design characteristics (e.g., menu design, inputs/outputs, configurability) of these systems, what driving populations most often use them and whether they use them in the manner intended also need to be established.

Dual-Task Demands and Performance

- Research should examine what compensatory behaviours drivers use to trade-off and maintain an adequate level of driving and secondary task performance and which of these strategies are most effective in minimising driving degradation.
- Research should also establish how the compensatory behaviours adopted to reduce the effects of distraction vary as a function of age, driving experience and different levels of fitness for duty (e.g., fatigued drivers or drivers under the influence of alcohol or drugs).
- The conditions under which compensatory behaviours breakdown leading to driving degradation and/or crashes needs to be established. Also, the conditions under which drivers do not engage at all in compensatory behaviour should be identified.
- There is a need for research to examine the potentially distracting effects of technologies other than mobile phones and route guidance systems (e.g., email, internet, PDA’s, DVD players etc.).
- Further research is needed to obtain information about drivers’ subjective assessments of the degree of distraction imposed by particular devices and their perceived ability to cope with these distractions.
- Further research is also needed to further establish which driver sub-groups may be particularly susceptible to the effects of distraction, such as older drivers, inexperienced drivers and drivers who are fatigued or under the influence of drugs or alcohol.
- Studies examining whether and how training and practice can minimise the interference associated with performing secondary tasks while driving are urgently needed.

Human Machine Interface Design

- Further research is required to establish the most ergonomic way to design in-vehicle devices so that they minimise distraction.

Crash Risk

- Information regarding how the contribution of distraction in road crashes can be most accurately measured (e.g., better police report forms, data event recorders, naturalistic studies) is an important area of future research.
- Further epidemiological research is needed to establish what is the increased crash risk associated with the performance of different activities while driving.
- The driving conditions in which distracted drivers are at greatest risk of being involved in a crash also need to be determined. Also, the interaction between driving conditions, type of technology/activity undertaken and driver characteristics in influencing crash risk need to be examined.

Definition and Measurement of Distraction

- A universally agreed upon operational definition of driver distraction which incorporates all aspects of dual-task interference is needed.
- There is a need to develop a unified model/theory of driver distraction that encompasses the different sources of distraction emanating from within *and* outside of the vehicle.
- A set of standardised experimental protocols are needed to allow for more accurate comparisons of results across studies to be made and to facilitate communication between researchers.
- Research is needed to establish what methods and measurement techniques are most sensitive to the differential effects of in-vehicle technologies on driving performance.
- Research is needed to identify and quantify the distracting effects of objects and events occurring outside the vehicle and further examine whether and how external events combine with internal events to distract the driver.
- Finally, research should attempt, where possible, to utilise ecologically valid distracter tasks rather than artificial tasks which may over-estimate the detrimental effects of particular tasks on driving.

Related Research

- New and existing in-vehicle technologies, even though they might be distracting, have the potential to enhance safety (e.g., by having an alerting affect on drivers who are driving for extended periods or being used to render assistance in a crash), and increase comfort, mobility and productivity if they are well designed and used by appropriately trained drivers. Further research is needed to quantify the positive benefits that derive from these technologies in order to inform public policy.

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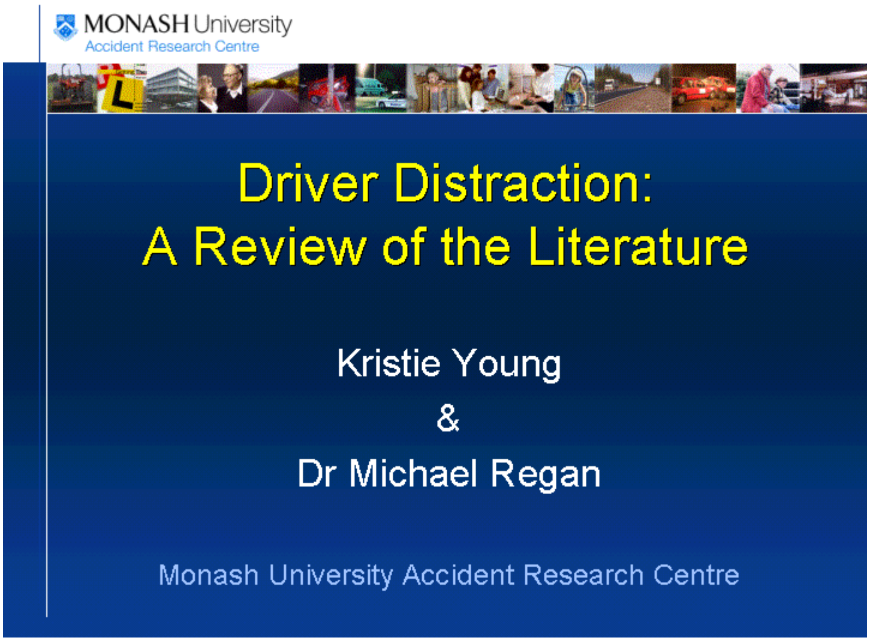
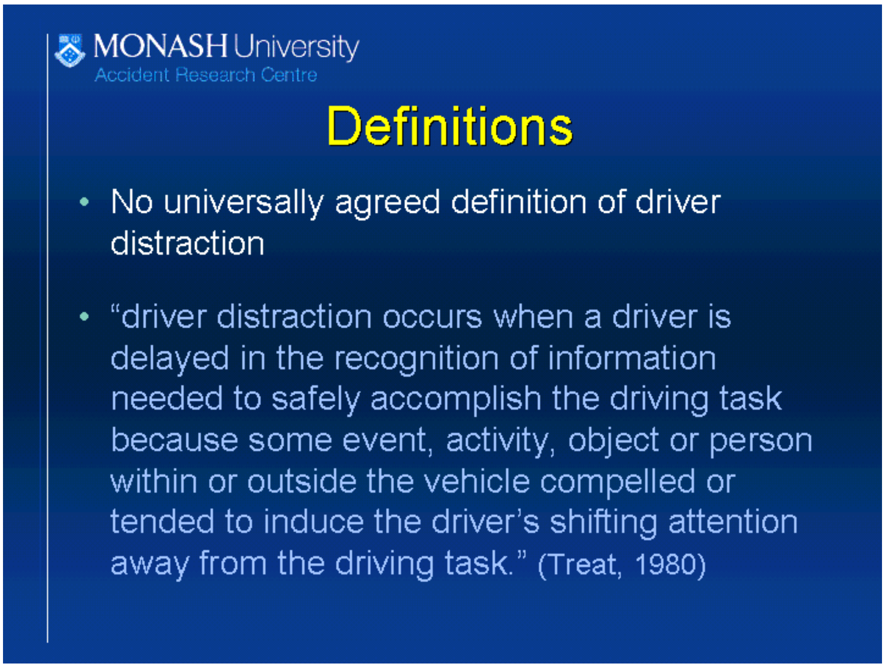
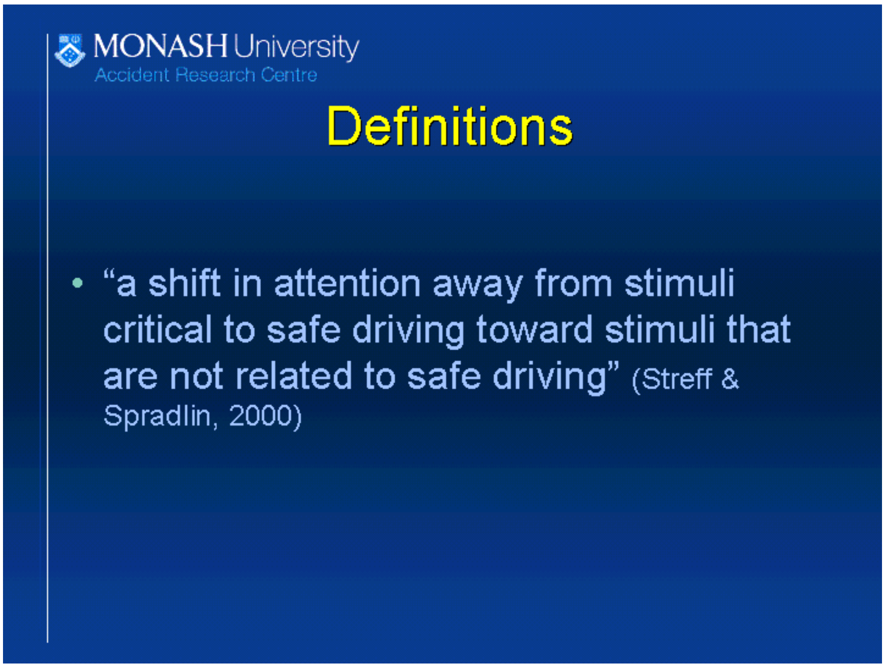
PRESENTATION SLIDES




MONASH University
Accident Research Centre
Definitions
• No universally agreed definition of driver distraction
• "driver distraction occurs when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task." (Treat, 1980)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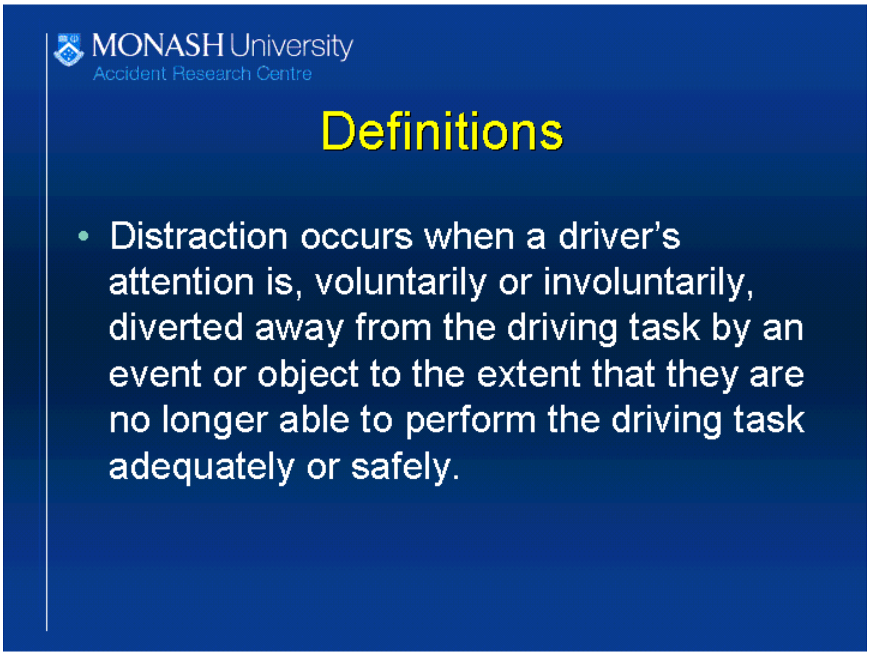
Definitions
• "a shift in attention away from stimuli critical to safe driving toward stimuli that are not related to safe driving" (Streff & Spradlin, 2000)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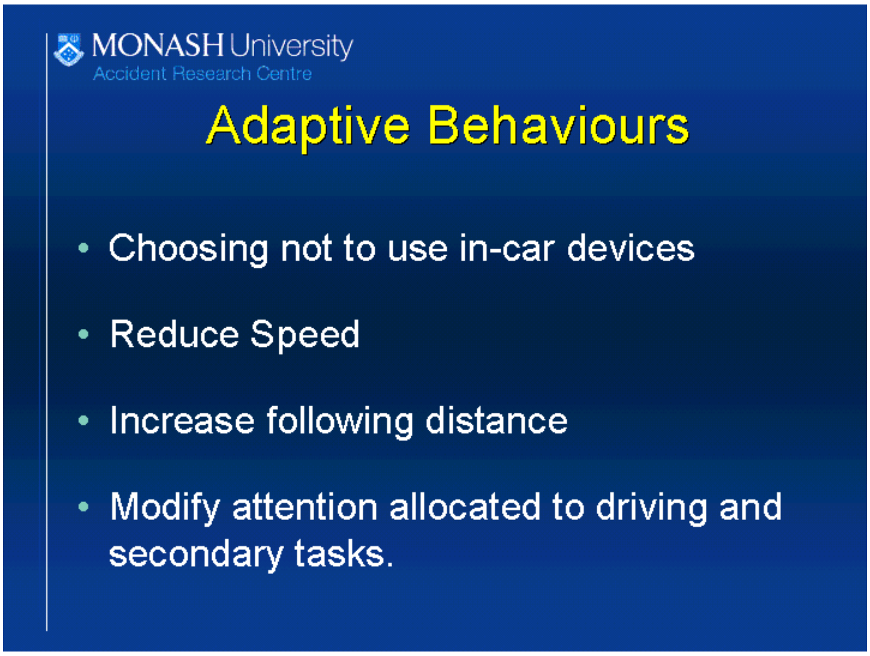
Definitions
Distraction occurs when a driver's attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object to the extent that they are no longer able to perform the driving task adequately or safely.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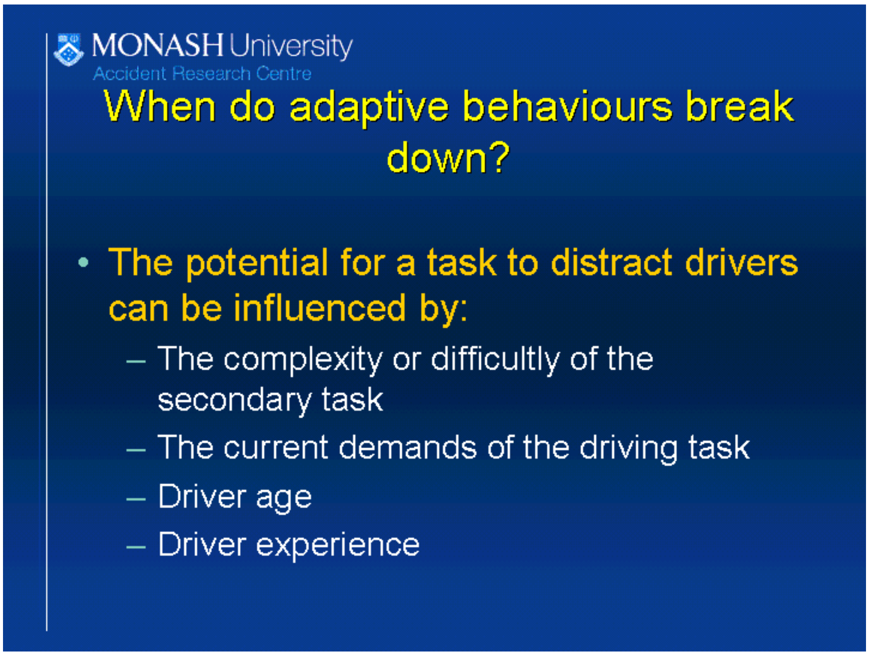
Adaptive Behaviours
Choosing not to use in-car devices
Reduce Speed
Increase following distance
Modify attention allocated to driving and secondary tasks.


MONASH University
Accident Research Centre
When do adaptive behaviours break down?
• The potential for a task to distract drivers can be influenced by:
– The complexity or difficultly of the secondary task
– The current demands of the driving task
– Driver age
– Driver experience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Secondary Task Demands
• Design of Device
– Hand-held vs. hands-free phones
– Visual-manual vs. voice input
• Task Complexity
– Simple vs. difficult conversations
– But, ecological validity of tasks used to measure conversation difficulty are questionable


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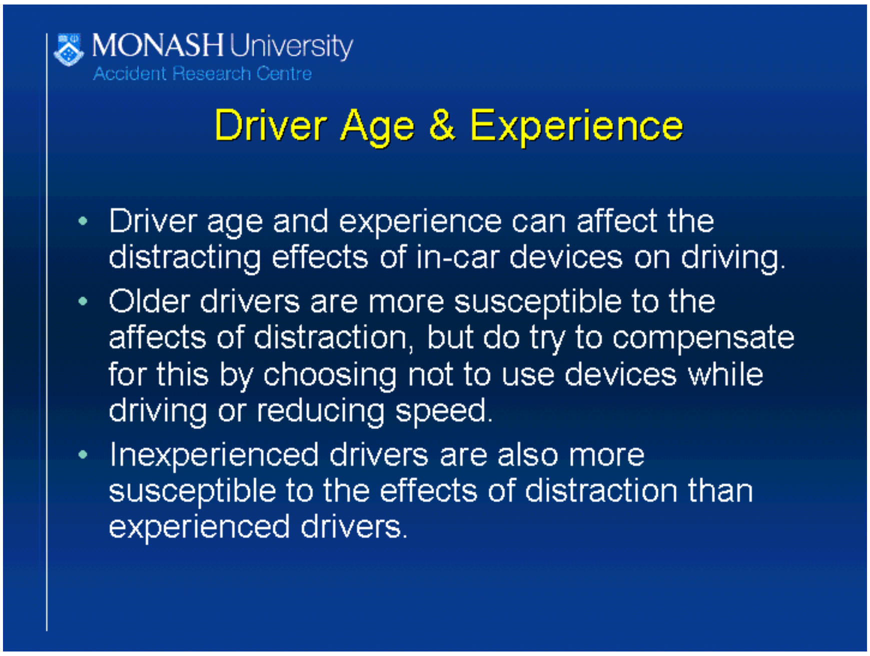
Driving Task Demands
Driving Complexity
Increased traffic
Bad weather conditions
Unfamiliar environment
Difficult driving manoeuvres (e.g., turning right across traffic)
But, factors/objects not central to the driving task have little impact on distraction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Driver Age & Experience
Driver age and experience can affect the distracting effects of in-car devices on driving.
Older drivers are more susceptible to the affects of distraction, but do try to compensate for this by choosing not to use devices while driving or reducing speed.
Inexperienced drivers are also more susceptible to the effects of distraction than experienced drivers.

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Distraction and Increased Crash Risk

- Redelmeier & Tibshirani (1997) found mobile phone use was associated with a four-fold increase in crash risk.
- Violanti (1998) found that mobile phone use increase crash risk by nine times.
- Stutts et al. (2001) found that mobile phones account for 1.5% of all police reported distraction crashes.
- Laberge-Nadeau et al. (2003) found that mobile phone use increased crash risk by 38%

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Summary

- Drivers reduce speed, increase following distance or choose not to use in-car devices to compensate for the distraction associated with in-car devices.
- As complexity of the secondary or driving tasks increase, the potential for secondary tasks to degrade driving also increases.
- Older and inexperienced drivers are more susceptible to the effects of distraction.
- Using in-car devices impairs visual search patterns, reaction times, decision-making processes and the ability to maintain speed and lateral position.
- Also, increases risk of being involved in a crash.


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Further Research
• Research examining in-car devices other than mobile phones.
• What factors encourage and discourage willingness to engage in distracting activities.
• How frequently driver engage in certain activities and under what conditions.
• Further establish what compensatory behaviours drivers engage in when distracted.
• Establish the most ergonomic way to design devices to minimise distraction.
• Further examine crash risk associated with various tasks.
• Universally agreed definition of driver distraction and standardise research protocols.