

## **Driver Distraction: A Review of Scientific Literature**

**AUTHORS:** Rachel Goodsell, Mitchell Cunningham,  
Dr Anna Chevalier

**PREPARED FOR:** National Transport Commission

**PROJECT No:** 013817

**February 2019**

# SUMMARY

This report presents the synthesised results of reviews of evidence-based research conducted to address the following four research questions:

1. How does distraction affect safety-related driving performance? Specifically, what does research show about the relationship between cognitive load and safety-related driving performance, including the impact of cognitive load caused by secondary tasks involving interaction with technologies such as (i) mobile phones (handheld or handsfree), (ii) in-built vehicle infotainment systems or (iii) wearable technologies (such as smart watches and smart glasses/goggles)?
2. What does research show about the extent to which driver distraction contributes to road trauma in Australia? What does research show about the impact of driver distraction on crash risk?
3. What does research show about the physiological symptoms and presentations of driver distraction? Are these able to be accurately identified and measured?
  - a) Eye-tracking measures: gaze direction, gaze fixation and percentage of eyelid closure (known as PERCLOS).
  - b) Cognitive load and stress response measures: electroencephalogram (EEG, detecting electrical brain activity), galvanic skin response (detecting electrical resistance of the skin to measure response to emotional stress), and heart rate. A widely used non-physiological measure of cognitive load, the Detection Response Task (DRT), was also reviewed.
4. What guidelines have been developed to reduce any negative impact of human-machine interface (HMI) for in-vehicle technologies on driver performance?

With respect to question 1, this report outlines published empirical evidence demonstrating driver interactions with mobile phones, in-built vehicle infotainment systems, and wearable technologies can significantly degrade driving performance. Across the technologies, research shows visual-manual interactions (e.g., mobile phone texting, manual input of a destination into a navigation system), appear to have a greater potential to interfere with activities critical for safe driving than voice interactions. However, research also found such voice interactions appear to have the potential to degrade driving performance compared to driving while not engaged in a secondary task.

With respect to question 2, relatively little research has been undertaken in Australia linking driver distraction and crashes in the real-world compared to other jurisdictions (e.g., United States of America (USA)). However, the studies undertaken converge in demonstrating driver distraction contributes to safety-critical events (e.g., crashes) on Australian roads. The naturalistic driving studies (NDS) undertaken have been primarily based on the USA and demonstrated visual-manual interactions, particularly those that take eyes off the forward roadway for relatively long durations, are particularly risky (e.g., manual text messaging or dialling a mobile phone). This review of existing research also suggests the link between cognitive load and/or distraction (e.g., due to a mobile phone conversation) and safety risk in the real-world is less clear.

With respect to question 3, a range of physiological indicators may be used to measure visual distraction and/or cognitive load. Eye-glance metrics are considered the most sensitive and robust indicator of visual distraction, specifically off-road glance frequency and duration. Consensus around which physiological indicators may be the most sensitive and robust indicator of cognitive load is lacking. On the other hand, the DRT shows promise as a method for assessing cognitive load. Nevertheless, it is recommended the limitations and concerns raised by researchers about this measure be considered. It is also suggested, to increase the robustness of research findings and to help address issues associated with accurate data collection, more than one measure be utilised in conjunction with each other.

**ARRB – YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION**  
ABN 68 004 620 651

With offices in Brisbane, Sydney, Adelaide, Perth.

National Transport Research Centre and Head Office: 80a Turner St, Port Melbourne, 3207 VIC, Australia  
arrb.com.au

With respect to question 4, several guideline documents exist which provide recommendations on the design of in-vehicle technologies to minimise the potential for driver distraction. The documents originate from various transport and road safety groups both locally (e.g., Monash University Accident Research Centre (MUARC)) and internationally (e.g., Transport Research Laboratory (TRL) and National Highway Traffic Safety Administration (NHTSA)).

## Contents

|       |  |    |
|-------|--|----|
| 1     | INTRODUCTION.....  | 1  |
| 2     | METHOD.....  | 3  |
| 3     | DRIVER DISTRACTION AND DRIVING PERFORMANCE .....   | 4  |
| 3.1   | MOBILE PHONE USE AND SAFETY-RELATED DRIVING PERFORMANCE .....  | 6  |
| 3.2   | IN-VEHICLE INFOTAINMENT SYSTEMS AND SAFETY-RELATED PERFORMANCE .....                                       | 6  |
| 3.2.1 | NAVIGATION.....  | 7  |
| 3.2.2 | MOBILE PHONE INTERACTIONS USING IVISS.....   | 7  |
| 3.3   | WEARABLE TECHNOLOGIES AND SAFETY-RELATED DRIVING PERFORMANCE.....  | 8  |
| 4     | DRIVER DISTRACTION, CRASH RISK AND AND ROAD TRAUMA.....  | 10 |
| 4.1   | SIMULATED DRIVING STUDIES VERSES NDS.....  | 13 |
| 5     | PHYSIOLOGICAL INDICATORS OF DRIVER DISTRACTION AND COGNITIVE LOAD .....                                    | 14 |
| 5.1   | PHYSIOLOGICAL SYMPTOMS AND PRESENTATIONS OF DRIVER DISTRACTION.....  | 14 |
| 5.1.1 | EYE-TRACKING MEASURES.....   | 14 |
| 5.1.2 | ELECTROENCEPHALOGRAM (EEG OR BRAIN ACTIVITY).....  | 15 |
| 5.1.3 | GALVANIC SKIN RESPONSE (GSR).....  | 15 |
| 5.1.4 | HEART RATE .....   | 15 |
| 5.1.5 | ADVANTAGES AND DISADVANTAGES OF PHYSIOLOGICAL INDICATORS OF<br>DRIVER DISTRACTION AND COGNITIVE LOAD ..... | 16 |
| 5.2   | DETECTION RESPONSE TASK.....   | 16 |
| 6     | GUIDELINES TO MINIMISE DRIVER DISTRACTION DUE TO IN-VEHICLE TECHNOLOGY .....                               | 19 |
| 7     | CONCLUSIONS.....   | 22 |
| 7.1   | FINAL KEY POINTS .....   | 23 |
| 8     | REFERENCES.....  | 24 |

## Tables

|  |    |
|--|----|
| TABLE 1. SUMMARY OF CRASH RISK ODDS RATIOS (ORS) ASSOCIATED WITH VARIOUS DRIVER INTERACTIONS (DERIVED FROM DINGUS ET AL., 2016)..... | 12 |
| TABLE 2. GUIDELINE DOCUMENTS ON DESIGN OF IN-VEHICLE SYSTEMS TO MINIMISE DISTRACTION .....   | 19 |

Although the Report is believed to be correct at the time of publication, the Australian Road Research Board, to the extent lawful, excludes all liability for loss (whether arising under contract, tort, statute or otherwise) arising from the contents of the Report or from its use. Where such liability cannot be excluded, it is reduced to the full extent lawful. Without limiting the foregoing, people should apply their own skill and judgement when using the information contained in the Report.

# 1 INTRODUCTION

Safe driving requires a complex amalgamation of behaviours. It requires the driver to successfully perform simultaneously several complex activities including (but not limited to): route finding, route following, controlling speed and lateral position, avoiding collisions, obeying road rules and monitoring the status of vehicle systems (Brown, 1986; Michon, 1985; as cited in Cunningham & Regan, 2018).

Despite the often-significant attentional resources such activities demand, drivers are frequently observed to engage in activities that have potential to divert attention away from activities critical for safe driving. Research indicates humans are typically limited in their ability to perform two or more tasks concurrently or in close succession (Pashler, 1994). Numerous psychological theories account for this based on the limitations of the attentional capacities of humans (Cunningham & Regan, 2018). Driver distraction may be conceptualised as a form of dual-task interference, in which the performance of the primary driving task can be compromised by the concurrent performance of a secondary or competing task.

Empirical research reveals lapses of attention, including driver distraction, play a significant role in road crashes and other critical road safety events both locally (e.g., Beanland et al., 2013) and internationally (e.g., Dingus et al., 2016). In response, there has been an increase in research aimed at shedding light on the mechanisms that underlie driver distraction, understanding its impact on crash risk and driving performance, and informing the development of countermeasures to prevent and mitigate its effects (Regan, Lee, & Young, 2009, as cited in Cunningham & Regan, 2018).

The National Transport Commission (NTC) are reviewing the legislation concerning driver distraction, with respect to future amendments to improve upon the existing legislation. One issue, for example, is the current legislation refers to mobile phones. It may be beneficial to have technology neutral legislation to cover other, more recent and future in-vehicle devices, information systems, wearables and emerging technologies drivers may interact with or which are designed to provide information to drivers.

To oversee this legislative review process, the NTC have convened a National Driver Distraction Working Group to discuss driver distraction research, policy and legislative reform options. The working group

consists of stakeholders from government, enforcement and research agencies. It is anticipated the working group will meet occasionally for approximately one and a half years to explore these issues.

To inform the review, the NTC held a full-day National Driver Distraction Workshop to gather input from a broader range of stakeholders, including representatives from telecommunication, vehicle manufacturing, insurance and research organisations. The workshop was held on Thursday 1 November 2018 at the Port Melbourne Australian Road Research Board (ARRB) office. The aim of the Workshop was to understand:

- what governments across Australia are seeking to achieve with respect to addressing road crashes involving driver distraction
- gaps in knowledge and research related to the impact of driver distraction on casualty crashes
- opportunities to reduce the incidence and severity of crashes involving driver distraction.

Following the workshop, the NTC released an issues paper summarising current understanding of factors that may cause driver distraction and analysing key issues to consider for developing potential solutions.

The NTC will prepare a discussion paper to be released for public consultation in June 2019, which will provide an assessment of the case for action and a range of options for potential solutions.

In November 2019, the NTC is scheduled to prepare a draft policy paper. This paper will involve targeted consultation with the States, territories and industry peak bodies. It is anticipated the NTC will present for consideration draft policy and regulatory recommendations to the Transport and Infrastructure Council in May 2020.

To assist with development of the workshop and inform the legislative review, NTC engaged ARRB to produce this synthesised literature review on in-vehicle driver distraction. The literature review aims to address the following four research questions, developed by ARRB in close consultation with the NTC:

1. How does distraction affect safety-related driving performance? Specifically, what does evidence-

based research show about the relationship between cognitive load and safety-related driving performance, including the impact of cognitive load caused by secondary tasks involving interacting with technologies such as (i) mobile phones (handheld or handsfree), (ii) in-built vehicle infotainment systems or (iii) wearable technologies (such as smart watches and smart glasses/goggles)?

2. What does the research show about the extent to which driver distraction contributes to road trauma in Australia? What about the impact of driver distraction on crash risk?
3. What does the research show about the physiological symptoms and presentations of driver distraction? Are these able to be accurately identified and measured by:
  - a) Eye-tracking measures: gaze direction, gaze fixation and percentage of eyelid closure (known as PERCLOS).
  - b) Cognitive load and stress response measures: electroencephalogram (EEG, detecting electrical brain activity), galvanic skin response (detecting electrical resistance of the skin to measure response to emotional stress), and heart rate. A widely used non-physiological measure of cognitive load, the detection response task (DRT), will also be reviewed.
4. What guidelines have been developed to reduce any negative impact of the human-machine interface (HMI) for in-vehicle technologies on driver performance?

## 2 METHOD

This section outlines the method undertaken for the literature review to address the research questions. The review involved the following activities:

1. A search for peer-reviewed literature using a variety of reference databases. These included, but were not limited to, those accessible through the M.G. Lay library, located at ARRB headquarters in Melbourne. There was no constraint placed on the publication date.
2. General Google searches which were used to obtain non-peer-reviewed monographs, industry-related research reports and unpublished sources ('grey' literature).
3. Depending on the research question, several key search terms were used including: driver distraction, driver inattention, cognitive load, driving performance, crash risk, safety, cognitive load measurement, physiological indicators of cognitive load, in-vehicle technologies, human-machine interface, and design guidelines.
4. An ancestry approach was used to obtain other documents; that is, using the references within the literature to lead the authors to other documents.

5. Relevant literature and documents were selected for review.
6. The literature was reviewed to draw out key information that addressed the four research questions.

Given the breadth of the driver distraction research and the constraints of this project, emphasis was placed on reviewing the latest national and international evidence available on driver distraction at the point of publication to the best of our knowledge. In addition, where possible, reviews included published meta-analyses (i.e., papers providing an aggregate analysis of the findings of multiple studies) and review papers (including systematic literature reviews). Moreover, where the findings from naturalistic driving studies (NDSs) were reviewed, emphasis was placed on more recent and larger-scale analyses of naturalistic driving data (at the time this report was being prepared).

The information from these activities is reported in this document.



### 3 DRIVER DISTRACTION AND DRIVING PERFORMANCE

This section presents the findings from the literature review addressing the first research question:

How does distraction affect safety-related driving performance? Specifically, what does research show about the relationship between cognitive load and safety-related driving performance, including the impact of cognitive load caused by secondary tasks involving interacting with technologies such as (i) mobile phones (handheld or handsfree), (ii) in-built vehicle infotainment systems or (iii) wearable technologies (such as smart watches and smart glasses/goggles)?

Before examining the impact of distraction on driving performance, it is critical to distinguish driver distraction from other, albeit related, constructs.

Driver inattention has been defined as ‘...insufficient, or no attention, to activities critical for safe driving’ (Regan, Hallett, & Gordon, 2011, p. 1775). There are several types of driver inattention (Regan, Hallett, & Gordon, 2011). For example, driver-restricted attention involves insufficient, or no attention, to activities critical for safe driving brought about by something that physically prevents (due to biological factors) the driver from detecting (and hence attending to) information critical for safe driving. As an example, the driver may be having a micro-sleep and, as a result, fail to attend to critical information on the road. Another example is driver-misprioritised attention, defined as inattention brought about by the driver focussing attention on one aspect of driving to the exclusion of another, which is more critical for safe driving.

Driver-diverted attention (or driver distraction) has also been conceptualised as one specific form of driver inattention:

‘...the diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving.’ (Regan, Hallett, & Gordon, 2011, p. 1776).

This ‘competing activity’ or secondary task may be driving-related (e.g., looking at a low-fuel warning light and failing to detect a braking vehicle ahead) or non-driving-related (e.g., looking at a mobile phone

and failing to detect a braking vehicle ahead) (Regan, Hallett, & Gordon, 2011).

The question of how distraction impacts driving performance is broad. Distraction can affect driver behaviour and undermine driving performance in a multitude of ways, and to different extents. Research indicates four primary moderating factors may influence the potential for driver distraction (Young, Regan, & Lee, 2008).

One of these moderating factors, driver characteristics, has been found to influence the extent to which a competing (secondary) activity distracts a driver and impairs driving performance. Age and driving experience are driver characteristics that have been a focus of many distraction studies. For example, Regan et al. (2011) suggested young and/or less experienced drivers may be less able to efficiently (and perhaps safely) timeshare the performance of competing activities with activities critical for safe driving as they have only partially automated driving skills (unlike older and/or more experienced drivers). Testament to this, through data derived from an NDS, Klauer et al. (2014) found the performance of a range of competing activities (e.g., reaching for a mobile phone or another object, eating) increased crash and near-crash risk for novice drivers (defined as drivers who had held a driver’s licence for three or less weeks), but not for more experienced drivers (defined as driver who had held a driver’s licence for a mean duration of 20 years).

Another of these moderating factors, the level of demand of the driving task, has been found to influence the extent to which a competing activity interferes with driving performance. The demand of the driving task may be influenced by factors such as weather conditions (e.g. heavy rain), traffic conditions (e.g. congestion), and road conditions (e.g. narrow roads) (Young, Regan, & Lee, 2008). Generally, the performance of a competing activity will be more likely to impair driving performance when the demand of the driving task is higher.

A third moderating factor, the level of demand of the competing activity, has been found to influence the extent to which it interferes with driving performance. In general, the more demanding the competing activity, the more likely it is to degrade activities critical for safe driving (Young, Regan, & Lee, 2008).



Factors that may influence secondary task demand include its resource compatibility with the driving task (e.g., whether it is visual-manual versus auditory-vocal), its complexity, whether it can be ignored, and how interruptible it is (Regan et al., 2009).

A fourth moderating factor, the ability of the driver to self-regulate their engagement in competing activities, has been found to influence the extent to which it interferes with driving performance. Self-regulation refers to how well a driver can change their behaviour to maintain adequate driving performance in the face of competing tasks (Young & Regan, 2007). It has been proposed self-regulation may be preparatory, which involves a driver preparing themselves a priori for the anticipated effects of potential distraction (e.g., turning off a mobile phone before commencing a drive, in case it rings or pings during the drive). Self-regulation may also be reactive in nature, in which the driver behaves strategically to compensate for the effects of an existing source of distraction (e.g., asking a passenger to stop talking when navigating a busy intersection).

Cunningham and Regan (2018) presented a comprehensive review of such moderating factors of driver distraction.

Reported deficits of driving performance due to secondary task engagement vary widely due to methodological variability between studies but have been found to include degraded lane keeping, poor speed control, increased reaction time to critical road events, missed traffic signals, shorter or longer headway distances, unsafe gap acceptances, reduced situational awareness and poorer visual scanning of the roadway environment in simulator and on-road studies (Bayly, Young, & Regan, 2008; Horberry & Edquist, 2008; Cunningham, Regan, & Imberger, 2017; Caird et al., 2018). Situational awareness refers to a driver's ability to comprehend the immediate surrounding driving environment and related events and process the possible consequences of this situation. The specific types and degree of impairment resulting from secondary task engagement have been found to be influenced by the aforementioned moderating factors (Cunningham & Regan, 2018).

Many of these deficits in driving performance are correlated with a significant crash risk (Dingus et al., 2016). For example, when examined separately to other contributing factors like driver distraction, speeding (i.e., poor speed control) can increase crash risk by 12.8 times or following too closely (i.e., short headway distances) can increase crash risk by

13.5 times (Dingus et al., 2016). The results from this large NDS are described in Section 4.

Given the significant visual demand placed on the driver required for safe driving, visual-manual secondary tasks (e.g., text messaging on a mobile phone) are often regarded as having a particularly high potential to degrade driving performance (Caird et al., 2014; Caird et al., 2018; Cunningham & Regan, 2018). Visually-manually demanding secondary tasks can cause drivers to look away from the forward roadway frequently and for long durations. Currently, we are not aware of any widely agreed definitions as to what constitutes "frequent" or "long" eye-glances. However, in terms of the latter, there exists some literature based on research findings (e.g., Klauer et al., 2006), which is discussed further in Section 4, suggesting eye-glances of longer than 2.0 seconds off the forward roadway are "too" long (e.g., National Highway Traffic Safety Administration, 2012). Driver interactions that divert visual attention away from the forward roadway have been associated with a multitude of impairments in driving performance including large and frequent lane deviations, abrupt steering movements and slow responses to lead vehicles braking in both simulator and on-road studies (Cunningham, Regan, & Imberger, 2017; Dingus et al., 1989; Zhang, Smith, & Witt, 2006), as well as failures in detecting, and increasing reaction time, to safety-critical events on the roadway (Regan, Hallett & Gordon, 2011).

Compared to visual distraction, cognitive distraction ('mind off the road') may be more difficult to detect and measure (as discussed in Section 5). Thus, the effect of cognitively demanding secondary tasks on driving performance tends to be more difficult to research. Nonetheless, like visual-manual tasks, engagement in specific cognitive tasks (e.g., a mobile phone conversation) has been found to undermine a driver's sensitivity to safety-critical cues (e.g., braking of lead vehicles, presence of pedestrians) and traffic signals in the roadway environment, even though a driver's eyes are still on the forward roadway (i.e., inattentive blindness) (Caird et al., 2018; Strayer, Drews & Johnston, 2003; Strayer & Johnston, 2001). In addition, in both simulated and on-road studies, cognitively distracted drivers have been found to have longer gaze fixations and a denser gaze concentration on the centre of the road, which may result in failures to perceive important information in peripheral vision (Caird et al., 2018; Regan, Hallett & Gordon, 2011; Recarte & Nunes, 2003).

Examples of the effects of both visual-manual and cognitive secondary tasks on driving performance will be outlined in this section.

### 3.1 MOBILE PHONE USE AND SAFETY-RELATED DRIVING PERFORMANCE

One of the most widely studied secondary tasks in the driver distraction literature is mobile phone use. With the increasing functionality of smartphones, drivers may be exposed to a plethora of different phone interactions. Depending on the type of interaction (e.g., dialling, texting, conversing), mobile phone use while driving may significantly impair driving performance, particularly those tasks requiring visual-manual interactions. For example, manual text messaging is regarded in the research as one of the most dangerous secondary tasks drivers can undertake while driving. A comprehensive meta-analysis of empirical research demonstrated texting is associated with a multitude of decrements in driving performance including (but not limited to) increased reaction time to hazardous road events, increased lateral variability (e.g., poor lane keeping), increased number of missed traffic signals and driver conflicts, and long glances from the forward roadway (Caird et al., 2014). Manual text messaging is particularly risky as it takes eyes off the road (to look at the phone to type a message accurately), mind off the road (to think about what to text and how), and hand(s) off the wheel (to type) (Hallett, Regan & Bruyas, 2011). There is preliminary research to suggest that writing a text message, in particular, is associated with more marked impairments in driving performance (e.g., increased lateral and longitudinal variability) than reading a text message (Reed & Robin, 2008).

A similar pattern of effects have been observed for social media use on a mobile phone while driving. For example, Basacik et al. (2011) found both manually composing a message and reading a message using social media on a handheld mobile phone was associated with poorer speed maintenance and longer glances off the forward roadway compared with driving while not engaged in a secondary task. Composing a message appears to be particularly detrimental to driving performance, also being associated with poor maintenance of lane keeping position and a 30% increase in reaction time to road events.

Results from a meta-analysis of 43 studies (Simmons, Caird, & Steel, 2017) suggests voice interactions with voice-recognition systems (including mobile phones) such as dialling, texting, or music

selection may be less detrimental to driving performance (e.g., reaction time to critical events, lane positioning and headway) compared with visual-manual interactions with technologies (e.g., involving button pressing, looking at the device). However, despite such advantages, voice interactions are still considered to impose a cognitive load on the driver and be detrimental to driving performance compared to driving without interacting with a system.

Conversing using a mobile phone is another activity that has been studied extensively. A recent and comprehensive meta-analysis examined the effects of mobile phone conversations on driving performance across 93 studies. Results showed phone conversations were associated with significant decrements in driving performance, namely a poorer ability to detect roadway events, delayed reaction time, and an increased number of simulated driving collisions (Caird et al., 2018). Moreover, phone conversations that were more naturalistic (as opposed to more 'cognitive' conversations, such as participants performing a vocal arithmetic task) were shown to be particularly detrimental to driver reaction time. Other properties of the conversation (e.g., duration, time of day) were not examined in this study. However, importantly, Caird et al. (2018) found no difference in the impact on driving performance of handheld compared to handsfree phone conversations. Moreover, while phone conversations have been found to primarily impact driver's ability to detect and react to roadway events, the visual-manual interactions that may precede, and are necessary for, a mobile phone conversation being initiated may be particularly dangerous. For example, dialling a handheld phone has been shown to increase reaction time to road events, degrade lane keeping ability, reduce headway and speed maintenance, and promote increased eyes-off-road time (Caird et al., 2018). In addition, as will be discussed further in the report, merely reaching for the mobile phone has been shown in an NDS to significantly increase crash risk (Dingus et al., 2016).

### 3.2 IN-VEHICLE INFOTAINMENT SYSTEMS AND SAFETY-RELATED PERFORMANCE

Advanced in-vehicle infotainment systems (IVISs) are becoming increasingly ubiquitous in passenger vehicles. These systems may host a range of functions such as navigation, wireless connectivity with mobile phones, text messaging, email, climate control, vehicle diagnostics and, in some situations, warning systems and emergency help systems. This functionality means drivers may be increasingly

exposed to a range of secondary tasks and interactions while driving, which may undermine activities critical for safe driving.

This section outlines the impact on driving performance of several key secondary tasks undertaken by the driver using the IVISs, based on empirical research. These activities are primarily navigation and mobile phone related activities.

### 3.2.1 NAVIGATION

Navigational assistance is a common feature of IVISs. This functionality primarily requires two types of interactions possible while driving. Firstly, drivers are required to input their desired destination and the system will plot the fastest/shortest route to that destination (destination input). Secondly, the system will issue turn-by-turn instructions/directions on how to reach that destination (destination following) (Farber, Foley & Scott, 2000). To date, most research has focused on the former (destination input).

Manual destination input has been found to degrade driving performance. In an earlier on-road study, Dingus et al. (1989) found periods of driving where drivers were manually entering a destination were more likely to involve braking errors (e.g., sudden and erratic braking to hazards and traffic signals) than periods without. This finding has been replicated under the controlled conditions of simulated driving, with studies showing manual destination input (compared to baseline driving) was associated with a range of driving decrements such as increased reaction time to roadway events, greater eyes-off-road time, more frequent glances off the forward roadway and slower speeds (Chiang, Brooks, & Weir, 2001; Maciej & Vollrath, 2009).

A number of both simulator (Maciej & Vollrath, 2009; Tsimhoni, Smith, & Green, 2004) and on-road studies (Tijerina, Parmer, & Goodman, 1998) have investigated the effects of voice input versus manual input of destination on driving performance. The findings of these studies converge in demonstrating manual destination entry is associated with a greater number of driving performance decrements compared with voice input. Manual destination entry is associated with longer completion times for destination entry, longer eyes-off-road times (e.g., 23 seconds mean accumulated eyes-off-road times for voice vs 75 seconds for manual input (Tijerina, Parmer, & Goodman, 1998), more frequent glances at the navigation system itself and a greater number of lane deviations compared with voice destination entry (Maciej & Vollrath, 2009). However, compared to driving while not engaged in a secondary task,

voice input was found to be associated with degraded performance and longer reaction time to road events (Maciej & Vollrath, 2009). This suggests the cognitive component of such voice interactions may impair activities critical for safe driving.

### 3.2.2 MOBILE PHONE INTERACTIONS USING IVISs

Vehicles are increasingly being fitted with IVISs able to wirelessly connect to (or 'pair' with) a driver's mobile phone (typically through Bluetooth). This allows (a) phone functionality and content to be accessed through the vehicle hardware (e.g., accessing/reading text messages on the IVIS screen), and (b) the driver to use the mobile phone handsfree (e.g., compose a text message using voice activation).

Research suggests mobile phone interactions using an IVIS can significantly impair driving performance. For example, in their simulator study, Maciej and Vollrath (2009) found selecting a phone number through the IVIS using voice was associated with poorer reaction time to road events compared to driving while not performing a secondary task. However, it is important to note, initiating a conversation or ending a call using voice input through the IVIS tends to be associated with fewer decrements in driving performance (e.g., better lane keeping ability, faster reaction time to hazards) compared with initiating calls manually through the IVIS (Maciej & Vollrath, 2009).

The benefits of voice input have also been demonstrated in on-road studies. For example, a recent on-road study by Mehler et al. (2016) used a sample of 80 drivers to drive an instrumented vehicle on a highway while initiating mobile phone calls (through the IVIS), either manually or by voice. This research found voice input to initiate phone calls was associated with lower levels of driver cognitive workload (as indicated through subjective ratings), required shorter and fewer glances to be directed to the IVIS (and off the roadway) and could result in better speed maintenance compared to manual initiation. However, this study did not present results comparing driving performance and/or workload between drivers (i) engaged in audio-vocal interactions and (ii) not engaged in a secondary task.

IVISs may also be used to compose text messages. One on-road study was found that examined the impact of composing a text message using voice only (through IVIS) on driving performance compared to conventional manual texting using a smartphone and baseline driving (not involving a secondary task) (Owens, McLaughlin, & Sudweeks, 2011). Compared

to manual smartphone texting, this study found voice texting had a number of benefits, such as less and shorter glances away from the forward roadway and better maintenance of steering behaviours (less rapid steering corrections). However, when compared to baseline driving, voice texting still took eyes off the road more frequently and for longer periods of time.

Taken together, the research suggests voice interactions have some advantages over visual-manual interactions in reducing the visual and manual demand on the driver when using these systems. However, very rarely does voice control eliminate cognitive and visual distraction. Generally, the level of distraction remaining varies according to the function and type of driver interaction involved in performing the task. It seems likely cognitive and visual distraction induced through voice interactions can still impair driving performance compared to driving while not performing a secondary task.

### 3.3 WEARABLE TECHNOLOGIES AND SAFETY-RELATED DRIVING PERFORMANCE

Given the relatively recent introduction of wearable technologies (such as smart watches and Google Glass), there is limited literature examining driver interactions with such technologies and safety-related driving performance.

Only a handful of studies have examined the impact on driving performance of interactions using Google Glass, an optical head-mounted display designed in the shape of a pair of eyeglasses which displays information in a smartphone-like handsfree form (He et al., 2015; Sawyer et al., 2014; Young et al., 2016). Overall, these simulated driving studies found the driving performance impairment caused by voice-activated texting using a head-mounted display appears to be less severe than associated with visual-manual texting using a smartphone (He et al., 2015; Sawyer et al., 2014). However, compared to driving while not engaged in a secondary task, using this device is associated with poorer driving performance (more erratic steering wheel movements (He et al., 2015)). Together, these findings suggest although head-mounted devices may allow drivers to better maintain their visual attention on the forward scene, drivers are not able to effectively divide their cognitive attention across the head-mounted display and the road environment, resulting in impaired driving (Young et al., 2016).

Moreover, only three studies were found that have evaluated the safety of wearing a smart watch (a

mobile device worn on the wrist, typically with a touchscreen interface, with many of the same functionalities as a smartphone) while driving. Giang, Hoekstra-Atwood and Donmez (2014) evaluated six drivers' glance patterns towards a smart watch versus a smartphone during simulated driving. Drivers could choose what device to interact with. The study found drivers responded to the smart watch notification more swiftly than the smartphone. However, the smart watch attracted longer glances to read notifications. A similar simulated driving study by Giang et al. (2015) found drivers glanced more frequently towards the smart watch compared to the smartphone, particularly glances of longer than 2.0 seconds (which are known to be particularly risky (Klauer et al., 2006)). Furthermore, drivers' brake response times were longer when receiving a notification prior to a lead vehicle braking event on the smart watch compared to the smartphone. Despite these findings, the authors noted drivers rated the perceived risk of using a smart watch as similar to using a smartphone.

Most recently, Samost et al. (2015) conducted a simulated driving study to evaluate the extent to which the use of a smart watch to verbally initiate phone calls while driving impacted driver workload (as measured through the detection response task (DRT), which is described in Section 5.2 of this report) and driving performance, relative to visual-manual and audio-vocal (or verbal) call-initiation methods on a smartphone. The study found driver workload was highest for visual-manual smartphone interactions, and comparable between the audio-vocal smart watch and smartphone interactions. Participants engaging in visual-manual smartphone interactions showed more erratic driving behaviour (lane position deviation and major steering wheel reversals) and increased eyes-off-road time compared to those verbally initiating phone calls using the smart watch. However, compared to driving without engaging in a secondary task, the study found audio-vocal interactions using either a smartphone or smart watch significantly increased cognitive load (as evidenced through poorer DRT scores and impaired driving performance and an increased major steering wheel reversal rate). It is important to note such voice interactions can also take drivers' eyes off the road (and therefore pose a significant safety risk), particularly if the driver looks at the interface to ensure accuracy.

Taken together, these findings highlight the risks of some new wearable technologies and the potential for drivers to underestimate the risk associated with using wearable technologies such as smart watches



and smart glasses compared to equally or less distracting technologies such as smartphones. These findings also confirm the increase in workload and impaired driving performance associated with

engaging in audio-vocal interactions with smart technology while driving (as discussed in Section 3.2.2).

## 4 DRIVER DISTRACTION, CRASH RISK AND ROAD TRAUMA

This section presents the findings from the literature review addressing the second research question:

What does the research show about the extent to which driver distraction contributes to road trauma in Australia? What does the research show about the impact of driver distraction on crash risk?

In 2017, there were 1226 road crash deaths across Australia (BITRE, 2018). While the number of these crashes for which driver distraction may be a contributor is currently unknown, research suggests driver distraction is a significant road safety issue in Australia. In New South Wales alone, a recent report by Transport for New South Wales (TfNSW, 2017) suggests, based on information contained in Police crash reports, 9% of all driver involvements in fatal crashes between 2008 and 2016 involved an identified distraction factor. However, distraction-related crashes are likely to be underreported due to several possible reasons (e.g., absence of reliable witnesses in single-vehicle crashes, strong disincentive for self-admission of secondary task engagement, and the difficulty in observing cognitive distraction) (TfNSW, 2017).

The research reviewed in the previous section demonstrates driver interactions with devices (e.g., mobile phones, smart watches) and in-vehicle technologies (e.g., IVISs), particularly visual-manual interactions, can significantly impair driving performance in a number of ways. However, these studies have typically been undertaken in controlled experimental conditions, often employing simulated driving scenarios. Exactly how such driving performance decrements may translate into crash risk and road trauma in the real-world is less understood. Moreover, the contribution of driver distraction to crash occurrence and severity are also less understood because in real-world driving situations it is difficult to measure driver distraction and the moderating factors described earlier (e.g., driver characteristics, the cognitive demand on the driver of the secondary task, the cognitive demand of the driving environment being navigated, and the ability of the driver to regulate their secondary task engagement).

In Australia, only a few studies have examined the link between secondary task engagement and real-world safety risk (Beanland et al., 2013; McEvoy, Stevenson, & Woodward, 2006). The findings from

these studies converge in suggesting driver inattention, including distraction, is a significant contributor to road trauma in Australia (Cunningham & Regan, 2018).

In one of the first large-scale studies examining the link between real-world crashes and distraction in Australia, McEvoy, Stevenson, and Woodward (2006) surveyed 1347 licenced drivers in NSW and Western Australia which investigated (self-reported) prevalence of secondary tasks (mainly using a mobile phone) and adverse outcomes due to distraction. Results suggested, on average, drivers engaged in a distracting activity once every six minutes and one in five crashes was attributed to driver distraction. More recently, the Australian National Crash In-depth Study (Beanland et al., 2013) examined the link between secondary task engagement and crashes using more objective data: analysis of 856 crashes from 2000 to 2011 occurring in NSW and Victoria in which at least one party was admitted to hospital due to crash-related injuries. Of the 340 code-able crashes, the study found 57.6% (196/340) of crashes showed evidence of driver inattention, and driver distraction (as defined earlier in this report), specifically, was evident in 15.9% (54/340) of crashes. The most frequent sources of driver distraction recorded were in-vehicle distractions, such as interactions with passengers and mobile phones; these accounted for 55.3% of driver distraction-related crashes.

Most recently, Young et al. (in press) examined patterns of secondary task engagement (e.g., mobile phone use, manipulating centre stack controls) and safety-related incidents using data from the Australian NDS. The study examined data from 379 drivers, with instrumented vehicles, over a period of four months. On average, drivers engaged in a secondary task every 96 seconds while driving, with those most common including interactions with the centre stack controls (e.g., radio) and controls not critical to driving (e.g., seat belt, mirrors). Most relevant to this section, the results of the study showed a total of 95 (5.9%) of the secondary task events were associated with a safety-related incident (e.g., apparent failure to see traffic lights change from red to green, lane excursions, hard braking). Most of the observed incidents occurred while drivers were engaged in secondary tasks that have demonstrable crash risk. For example, 23.2% of the incidents occurred while the driver was using a mobile phone



(handheld or handsfree), although it is not clear exactly what mobile phone interactions were observed/examined (e.g., dialling vs texting vs conversation). In addition, 20% of incidents occurred while the driver was engaged in personal hygiene tasks (e.g., mirror checking) and 10.5% occurred while drivers were reaching for an object or phone. While informative, this paper did not examine crash risk associated with these driver activities.

Together, these studies demonstrate driver distraction, particularly visually distracting tasks, are a significant road safety issue on Australian roads. These data suggest secondary tasks, particularly those that often require the driver to take eyes off the forward roadway, are dangerous to undertake while driving in the real-world.

The impact of driver distraction on the occurrence of safety-critical events, such as crashes and near-crashes, in the real-world has largely been examined through such NDSs. NDSs typically employ participants to drive their own vehicles as they would day-to-day, instrumented with technology that continuously collects data on driver behaviour, vehicle movements, and sometimes the behaviour of other road users (Grzebieta, 2015). After a period of monitoring (months or years), this methodology allows researchers to examine the flow of events (e.g., reading a text message) directly prior to any safety-critical events (e.g., crashes or near-crashes) (Craft & Preslopsky, 2012). These data allow the formulation of statistical analysis findings such as odds ratios (ORs), which reflect the relative risk of a safety-critical event occurring when the driver engages in some secondary task compared to baseline or undistracted driving (Olson et al., 2009). For example, conversing on a handheld mobile phone has been found to have an OR of 2.2 (Dingus et al., 2016), which suggests drivers are 2.2 times more likely to be involved in a safety-critical event (crash) when conversing on a handheld mobile phone than when driving while not engaging in a secondary task. Some level of variation between safety risk estimates for the same or similar tasks across NDSs is expected due to, for example, differences in study designs, how researchers calculate ORs, and/or moderating factors (e.g., the characteristics of the drivers) in the study sample.

NDSs offer an objective means of assessing the contribution of secondary task engagement to the incidence of safety-critical events in the real-world (Grzebieta, 2015). The NDSs referenced in this section derive primarily from the USA; only one peer-

reviewed publication of findings from an NDS into the impact of driver distraction on safety risk undertaken in Australia was found (Young et al., in press). This study, however, does not provide data pertaining to ORs. Unless specified otherwise, all ORs deriving from various NDSs reported in this section were found to be statistically significant.

Overall, results derived from NDSs suggest the impact of driver distraction on safety risk depends largely on the specific secondary task. For example, using data (crashes only) from over 3500 passenger vehicle drivers (aged 16-98 years) over a three-year period in the US Strategic Highway Research Program 2 (SHRP2) study, Dingus et al. (2016) found a strong association between mobile phone interactions and crash risk. Tasks such as dialling a mobile phone, texting, reaching for a phone, and browsing were found to significantly increase crash risk. These elevated crash risks are not surprising given the decrements in driving performance associated with similar interactions (discussed in Section 3). It is important to also note driver engagement in non-phone tasks were also found to increase crash risk, for example reading/writing, adjusting in-vehicle devices such as the climate control or radio, and interacting with passengers (OR = 1.4) (Dingus et al., 2016). While some of these non-phone-related driver interactions are currently legal (in Australia) to undertake while driving (e.g., adjusting in-vehicle controls such as climate or radio, and interacting with passengers), the findings of Dingus et al. (2016) indicate these activities pose a statistically significantly increased crash risk compared to driving while not engaging in a secondary task. A summary of ORs for secondary activities examined by Dingus et al. (2016) are contained in Table 1.

*Table 1. Summary of crash risk odds ratios (ORs) associated with various driver interactions (derived from Dingus et al., 2016)<sup>1</sup>*

| Driver interaction   | Crash risk (OR) |
|--|-----------------|
| <b>In-vehicle device</b>   |                 |
| In-vehicle device (other; e.g., touchscreen menus)                           | 4.6*            |
| Total in-vehicle device  | 2.5*            |
| In-vehicle climate control   | 2.3*            |
| In-vehicle radio   | 1.9*            |
| <b>Cell phone</b>  |                 |
| Cell dial (handheld)   | 12.2*           |
| Reaching for object (not a cell phone)                                       | 9.1*            |
| Cell text (handheld)   | 6.1*            |
| Cell reach   | 4.8*            |
| Total cell (handheld)  | 3.6*            |
| Cell browse  | 2.7*            |
| Cell talk (handheld)   | 2.2*            |
| <b>Passenger</b>   |                 |
| Adult/teen passenger   | 1.4*            |
| Child rear seat  | 0.5             |
| <b>Other</b>   |                 |
| Reading/writing (includes tablet)  | 9.9*            |
| Extended glance duration to external object (precise duration not specified) | 7.1*            |
| Eating   | 1.8*            |
| Drinking (non-alcohol)   | 1.8             |
| Personal hygiene (e.g., fixing his/her hair and nails)                       | 1.4             |
| Dancing in seat to music   | 1.0             |

One common characteristic of many secondary tasks (such as mobile phone use and interactions with in-vehicle devices), is the performance of these tasks tends to require a diversion of drivers' visual attention away from the forward roadway (towards the secondary task). A number of NDSs have investigated how visual activity away from the forward roadway, independent of what the secondary task was, increases the risk of a safety-critical event. Most notably, using data from the 100-car NDS,

Klauer et al. (2006) analysed the eye-glance data from 69 crashes, 761 near-crashes and 5000 baseline driving segments (not involving near-crashes or crashes) to estimate (using ORs) the relative risk of crashes and near-crashes as a function of the duration of glances off the forward roadway. In the study, eye-glance data were extracted from video data collected from a sample of more than 100 drivers (33% of whom were aged between 18 and 24 years) who drove an instrumented vehicle for 12 to 13 months. The study found glances longer than 2.0 seconds off the forward roadway were associated with a doubling in crash or near-crash risk compared to baseline driving (OR = 2.2). Based on this finding, the NHTSA guidelines on the design of in-vehicle electronic devices recommend using an in-vehicle system should not result in eye glances away from the roadway of greater than 2.0 seconds (NHTSA, 2012).

Of concern for younger novice drivers (defined in this study as having a driver licence for no longer than 3 weeks), the same eye-glance durations of longer than 2.0 seconds has been found to increase crash risk almost four-fold (OR = 3.8) (Simons-Morton et al., 2014). Together, these findings provide an example of the impact driver characteristics (i.e., a moderating factor of driver distraction discussed earlier – in this case, driving experience) may have on the safety risk associated with a driver interaction, such as looking away from the forward roadway.

The more recent SHRP2 NDS by Dingus et al. (2016) (described earlier) suggests extended glance durations to an object external to the vehicle interior (outside the vehicle, although the study does not define these objects further) are associated with a crash risk seven times greater (OR = 7.1) compared to undistracted driving, although what constitutes an 'extended glance duration' in this study was not defined. These findings indicate because driving has a significant visual component, visual-manual tasks that take eyes off the forward roadway are especially dangerous for safe driving.

Given cognitive load and/or distraction may be particularly difficult to measure (as would be required to quantify its association with crash risk), compared to visual distraction, the impact of cognitive tasks on safety risk in the real-world is not as well understood. A cognitive task studied extensively through NDSs is

<sup>1</sup> An asterisk denotes statistical significance (based on 95% confidence intervals) from an OR of 1.0 when compared to driving while not engaged in a secondary task

conversing using a mobile phone. However, although phone conversations have been shown to impair drivers' detection and reaction to roadway hazards (for meta-analysis see Caird et al. (2018)), its impact on safety risk in the real-world remains mixed, with crash risks across NDSs ranging from (statistically significant) ORs of 0.36 to 2.2. For example, several NDSs found talking on a handheld or handsfree mobile phone poses no (statistically significant) increase in safety risk compared to driving without talking or undertaking a secondary task (e.g., Fitch et al., 2013; Klauer et al., 2006, 2014). While a number of other studies (e.g., Fitch, Hanowski & Guo, 2015; Olson et al., 2009) suggest conversing on a handsfree phone may have a 'protective' effect on safety risk (risk of involvement in a safety-critical event) compared to driving without undertaking a secondary task (i.e. be a *lower* safety risk), more recently, Dingus et al. (2016) found conversing on a handheld mobile phone significantly increases crash risk, specifically by 2.2 times compared to driving without undertaking a secondary task. However, in a later stage of reviewing this report, we became aware of a new analysis of NDS data focusing specifically on the association between driver interactions with cognitive tasks and crash risk (Dingus et al., 2019). For conversing on a handheld mobile phone, results indicated this specific activity was not associated with any increase (or decrease) in crash risk compared to model (i.e., attentive, alert, and sober) driving. Together, these conflicting findings indicate, unlike visual-manual secondary tasks that are generally associated with increased safety risk, the impact of cognitive secondary tasks on driving safety in the real-world is not yet well understood.

#### 4.1 SIMULATED DRIVING STUDIES VERSES NDS

When considering the research findings presented in this report, it is important to understand the types of studies from which these findings are derived, and in particular, the distinction, merits and limitations between simulated driving studies and NDSs.

As we saw in Section 3, research examining the link between secondary task engagement and driving performance was primarily undertaken using simulated driving studies. This methodology has a number of advantages, such as the experimental induction of driver distraction without any real safety risk, the controlling of other potentially confounding factors (e.g., driving weather conditions), and allowance of testing in a multitude of driving scenarios and conditions (de Winter, van Leeuwen, &

Happee, 2012). However, interpretation of findings from simulated driving studies should also consider the limitations of this study methodology. Although many advanced driving simulators can be quite sophisticated, they can lack realism and ecological validity. Moreover, under experimental conditions, drivers may behave differently during simulated driving than real world driving conditions (de Winter, van Leeuwen, & Happee, 2012).

NDSs overcome some of the issues associated with simulated driving studies, but also have limitations. Perhaps the most important advantage of the NDS methodology is it yields information about the impact of secondary task engagement on driving behaviour and safety risk in the real-world. However, unlike simulated driving studies, various potentially confounding factors cannot be controlled for in the real-world (e.g., weather or road conditions), which may impact the reliability of results (e.g., ORs) deriving from different NDSs for similar types of driver interactions (e.g., mobile phone conversations). Moreover, similar to simulated driving studies, driver behaviour may be influenced by knowledge of the presence of cameras and other sensors in their vehicles, which may compromise the ecological validity of the findings to an extent. Furthermore, this methodology is often resource demanding, including in relation to sample recruitment, data gathering, data storage, and data analysis (Backer-Grondahl et al., 2009; Regan, Williamson, Grzebieta, & Tao, 2012). Resourcing decisions affecting sample size or length of data collection may impact on the power of the study to determine statistical significance.

Each of these study methodologies has advantages and limitations when investigating the impact of distraction on driving performance and safety. When interpreting findings from the driver distraction literature, the effect of these advantages and limitations should be considered, as these methodological distinctions may partly account for why the impact on driving performance (typically derived from simulators) may not perfectly align with real-world safety risk (derived from NDSs) for a given driver interaction (e.g., for mobile phone conversations).

## 5 PHYSIOLOGICAL INDICATORS OF DRIVER DISTRACTION AND COGNITIVE LOAD

This section presents the findings from the literature review addressing the third research question:

What does the research show about the physiological symptoms and presentations of driver distraction? Are these able to be accurately identified and measured by:

- a. Eye-tracking measures: gaze direction, gaze fixation and percentage of eyelid closure (known as PERCLOS).
- b. Cognitive load and stress response measures: electroencephalogram (EEG, detecting electrical brain activity), galvanic skin response (detecting electrical resistance of the skin to measure response to emotional stress), and heart rate. A widely used non-physiological measure of cognitive load, the detection response task (DRT), will also be reviewed.

### 5.1 PHYSIOLOGICAL SYMPTOMS AND PRESENTATIONS OF DRIVER DISTRACTION

To provide a more nuanced examination of the effects of driver distraction and cognitive load on driving performance and safety, there have been efforts in developing methods to help observe and quantify these phenomena. However, before these are outlined, it is critical to distinguish cognitive workload from driver distraction.

Cognitive workload refers to the level of cognitive resources required to perform a particular task (O'Donnell & Eggemeier, 1986). Workload is related to driver distraction in that exhausted mental resources increase the risk for misallocated attention (i.e. there is a higher chance engagement in a secondary task will interfere with driving performance when a driver is already under a heavy workload) (Engstrom & Victor, 2008). The workload imposed on a driver while driving, and the associated potential for distraction, changes dynamically with the driving situation. Throughout a drive, this may lead to short-duration 'workload peaks' in demanding driving situations (e.g., when negotiating a roundabout), which may coincide with other resource-demanding

tasks (e.g., receiving a text message with an accompanying loud notification). In such high-workload situations, secondary task engagement may have a greater potential to interfere with activities critical for safe driving.

Several objective measures have been used by researchers to determine whether a driver may be distracted or help estimate a driver's level of cognitive workload. One broad class of methods for gauging and quantifying the level of distraction and/or cognitive load is through a range of physiological symptoms exhibited by the driver. These include (but are not limited to) tracking:

- eye movements (which has been used primarily to measure visual distraction, but cognitive load as well)
- measurement of brain activity and waves (cognitive load only)
- heart rate (cognitive load only)
- skin resistance (cognitive load only).

This section outlines each of these measures and their efficacy in detecting and measuring driver distraction and cognitive load. A widely used non-physiological measure of cognitive load, the DRT, is also discussed.

#### 5.1.1 EYE-TRACKING MEASURES

Eye-tracking metrics are consistently reported by researchers to be among the best performing diagnostic metrics for measuring distraction and workload, especially that of a visual nature (Victor, Engström & Harbluk, 2008). These metrics have been shown to be highly sensitive to the demands of visual and auditory in-vehicle tasks as well as driving task demands (Victor, Engström, & Harbluk 2008). Importantly, eye-glance metrics have been found to be associated with real-world crash risk, making them an assessment with good predictive validity. As discussed in Section 4, Klauer et al. (2006) found eye-glance durations of longer than 2.0 seconds off the forward roadway were associated with a doubling in crash and near-crash risk in the 100-car NDS. Eye-glance metrics which have been shown to be particularly sensitive to visual distraction are off-road glance frequency and duration (Victor, Engstrom, & Harbluk, 2008), and this may be gauged through a number of methods, including using eye-tracking



glasses or inferred through analysis of video footage of the driver.

Eye-glance metrics have also been used to infer the level of cognitive load or distraction a driver is experiencing (Marquart, Cabrall, & de Winter, 2015). Metrics shown to be most sensitive to cognitive load and distraction include blink rate (sometimes higher, sometimes lower, when cognitively loaded), pupil size (dilated when cognitively loaded), glance duration to forward roadway (longer when cognitively loaded), a spatial distribution of glances (concentration of glances to forward roadway, and few glances to periphery of roadway, when cognitively loaded – known as ‘gaze concentration’) (for literature review see Marquart, Cabrall, & de Winter (2015)).

A blink-related parameter used in research is PERCLOS (‘percentage of eyelid closure’), defined as the percentage of time the eyelid covers 80% or more of the pupil (Darshana et al., 2014). Although widely used to gauge driver fatigue, research suggests increased PERCLOS may also indicate high driver cognitive load (Marquart, Cabrall, & de Winter, 2015). However, given the close association between high cognitive load and fatigue (Desmond & Hancock, 2001), there may be issues in discriminating between the two driver states (cognitive load and fatigue) based on PERCLOS data alone.

### 5.1.2 ELECTROENCEPHALOGRAM (EEG OR BRAIN ACTIVITY)

An electroencephalogram (EEG) is a non-invasive device which measures brainwaves (by detecting small electrical signals occurring within the brain) through electrodes placed on the scalp (Casson et al., 2008). There are four categories of these brainwaves, ranging from the most activity to the least activity (Fisch & Spehlmann, 1999): beta (occurs when the brain is engaged in a task), alpha (occurs during relaxation), theta (occurs in a fatigued state), and delta (occurs in a sleep state). Research has demonstrated changes in task demand and cognitive load correspond with changes in EEG signals (Ryu & Myung, 2005; Wilson et al., 2009). Some studies have found, as mental fatigue level increases, the relative power of beta, alpha and theta rhythms decrease, and the relative power in delta rhythm increases (Gharagozlou et al., 2015). Most driving-related EEG studies focus on fluctuations in the power of theta (4-8 Hz), alpha (8-13 Hz), beta (13-20 Hz), and delta (0-4 Hz) waves (Lal & Craig, 2002).

### 5.1.3 GALVANIC SKIN RESPONSE (GSR)

Galvanic skin response, (GSR) or electrodermal activity, can also be used to measure cognitive load (Larue, Rakotonirainy, & Pettitt, 2011). GSR refers to the electrical changes in the skin following stimulation of the sympathetic nervous system, (e.g., stress) (Sharma, Kacker, & Sharma, 2016). This stimulation may cause an increase in sweating, thereby lowering skin resistance and increasing conductivity of the skin. Generally, measurement of GSR involves placing two non-invasive electrodes on the hand of the participant and running a small electric current between them to determine electrical resistance. Mehler et al. (2009) found increasing driving task demand (and therefore the cognitive load experienced by the driver) resulted in increased skin conductance (increased sweating) and therefore a stronger GSR response.

The majority of the studies using GSR as an indicator for cognitive load have found an increased GSR in drivers under higher task demand conditions (Brown & Huffman, 1972; Engstrom, Johansson, & Ostlund, 2005; Healey & Picard, 2004; Michaels, 1962; Zeier, 1979). Factors such as greater traffic density, more lanes, manual transmission, driver stress, and real-life driving compared to simulator driving, can increase the driver’s GSR. There is also evidence to suggest electrodermal activity is reduced when drivers are in a state of low cognitive load due to driving in a monotonous road environment (Larue, Rakotonirainy, & Pettitt, 2011).

### 5.1.4 HEART RATE

Paxion, Galy and Berthelon (2014) suggest heart rate metrics may be one of the most sensitive indicators of cognitive load. Studies have found heart rate (number of heart beats per minute) and heart rate variability (variation in time between each heart beat) are sensitive to cognitive load and stress (Mulder, 1988; Wilson & Eggemeier, 1991). Heart rate data are collected using an electrocardiogram (ECG), a non-invasive device that measures electrical activity of the heart using electrodes placed on the human chest (Biel et al., 2001).

Studies by De Waard (1991) and De Waard et al. (1995) were among the first to demonstrate the efficacy of heart rate measures in reflecting the demand of the environment drivers were navigating (and therefore the level of cognitive load they were likely experiencing). For example, De Waard (1991) found driving when demand was relatively high (e.g. when entering a roundabout or conversing on a mobile phone), drivers tended to experience an

increase in heart rate. When demand was relatively low (e.g. driving on a rural two-lane road), drivers tended to experience a reduced heart rate. In addition, heart rate variability has been found to decrease with increasing driving demand (e.g., with heavier traffic density and complexity) (De Waard, 1991). In a more recent study of 49 professional drivers, Jahn et al. (2005) confirmed heart rate was a sensitive indicator of drivers' cognitive workload.

### 5.1.5 ADVANTAGES AND DISADVANTAGES OF PHYSIOLOGICAL INDICATORS OF DRIVER DISTRACTION AND COGNITIVE LOAD

There are several advantages and disadvantages which should be considered before utilising physiological indicators to measure driver distraction and cognitive load (which may lead to driver distraction).

Advantages of using physiological indicators to gauge driver distraction and/or cognitive load include:

- Visual glance metrics have direct links to safety risk, making them an assessment metric with good predictive validity.
- Physiological measures allow for continuous on-line assessment that relatively quickly respond to temporal shifts in visual and cognitive load.
- Physiological measures can be recorded as a baseline.
- Physiological measures can be measured objectively.
- Physiological measures typically provide a fine-grained analysis with a specific sensitivity to different visual and cognitive-load dimensions.

However, there are several important disadvantages of using physiological indicators to gauge driver distraction and/or cognitive load including:

- They often require the use of complex technology for measurement, some of which may be expensive.
- They are not entirely reliable, as factors other than the level of visual or cognitive load imposed on the driver can influence these signals (e.g., signal 'noise' may be related to a driver's reaction to physical exertion, emotional state or ambient lighting), occasionally leading to unclear conclusions (e.g., eye-tracking technology used to measure eye-glance metrics, may be impaired by situational factors such as sun glare) (Paxion, Galy, & Berthelon, 2014). Due to these reasons, it has been recommended more than one physiological metric be utilised to assess driver

distraction to improve the reliability of the measurement (Mehler et al., 2009).

- Some of the technology may be difficult to implement in experimental and real traffic conditions, which may lead to inaccurate or less precise results.
- Study participants may find some of the measurement tools intrusive (e.g., eye-tracking glasses, EEG caps, chest heart rate sensors).
- Individuals may differ in which physiological measures show the most reactivity (Mehler et al., 2009).
- There is the possibility of failing to detect a real phenomenon by only employing one physiological metric (Mehler et al., 2009).

## 5.2 DETECTION RESPONSE TASK

The detection response task (DRT) is another method of gauging cognitive load induced by cognitive secondary tasks (such as a mobile phone conversation). Although this methodology does not measure physiological symptoms of the driver, it is important to highlight in this report as it is currently used internationally, most notably by the AAA Foundation and University of Utah in the USA, to measure the potential for cognitive distraction in new passenger vehicles in on-road studies (see website [here](#) for more information).

The DRT requires drivers to respond to two types of stimuli presented randomly every three to five seconds while driving: a visual stimulus, such as a headset with a light presented in peripheral vision; or tactile stimulus, such as a vibration delivered by a device on the shoulder. Strayer et al. (2014) developed a hybrid version of the DRT in which, every three to five seconds, the test participant receives either a visual or tactile (vibration) stimulus. In this version, the visual stimulus is a circular light source projected onto the windscreen which changes colour (from orange to red) and drivers are required to make a manual response (by touching a button on the steering wheel) when they detect the colour change or vibration (only one button touch is required every three to five seconds).

DRT performance, measured in terms of the number of times the visual or tactile stimulus is correctly detected (hit rate), and response times of these detections, is used to gauge the cognitive load associated with the secondary task being investigated. A poorer DRT performance (as evidenced by a lower hit rate and/or longer reaction time to detect DRT stimuli) suggests the secondary



task being investigated imposes a relatively high cognitive load on the driver.

There are several advantages and disadvantages which should be considered before utilising the DRT to measure cognitive load. Advantages of using the DRT to gauge driver cognitive load include:

- It is standardised through the International Organisation for Standardisation (ISO) (ISO 17488:2016).
- Required equipment is minimal, relatively inexpensive and easy to set up (Victor, Engström, & Harbluk, 2008).
- It can be utilised in both simulated and real-world driving studies (Olsson & Burns, 2000; Victor, Engström, & Harbluk, 2008).
- It has good power to discriminate between different levels of cognitive load (e.g., due to audio-vocal secondary tasks). This is particularly important given the increased voice functionality enabled by a wide range of in-vehicle technologies available today and likely to be implemented in the future. Both hit rate and reaction time derived from the DRT are sensitive to variations in cognitive load (Merat & Jamson, 2008; van Winsum, Martens, & Herland, 1999).
- Poorer DRT performance has been associated with poorer reaction time to braking lead vehicles and longer following distances in simulated driving studies (Strayer et al., 2013, 2014), and a lower probability eye glances would be directed to a location where a hazard was likely to occur in real-world driving conditions (Strayer et al., 2013), suggesting a level of predictive validity (however, the link between cognitive load and crashes in the real-world is unclear).
- Comparable results between simulator and field studies (Olsson & Burns, 2000) suggest the method has good reliability and repeatability.

However, the employment of this method also has a number of disadvantages that should be considered before it is used to measure cognitive load. These include:

- The test can be time-consuming. The University of Utah reported (Prof. David Strayer and A/Prof. Joel Cooper, November 2017, face-to-face communication) that to assess the potential for cognitive distraction while driving a new passenger vehicle using on-road studies, approximately three weeks may be needed per

vehicle for data collection and another week for data analysis.

- Its sensitivity to visual-manual load is questionable and requires further validation (Bruyas & Dumont, 2013).
- The DRT can only probe effects intermittently – every few seconds during engagement in a secondary task. It cannot give an unaltered picture of how attention is allocated during the primary driving task or even moment-to-moment assessment during the period of multitasking itself (Lee et al., 2017).
- The duration of secondary tasks being assessed by the DRT needs to be at least five seconds long as the DRT stimulus is presented every three to five seconds (prohibiting the assessment of shorter tasks).
- It does not account well for how participant drivers may ignore the DRT stimulus or secondary task, and it is unclear from the DRT data how drivers may prioritise their secondary task engagement (e.g., for how long and often drivers look away from the road towards the secondary task) in response to instruction from experimenters (which can impact the DRT score). Therefore, in an attempt to ameliorate such issues, it may be beneficial to use the DRT in conjunction with physiological measures (e.g., eye tracking).
- It is unclear how to meaningfully infer changes in DRT performance and values. For example, what reduction in DRT performance would be concerning from a safety perspective.
- The predictive validity of the DRT is further hampered by the fact it is unclear how cognitive load, which the DRT measures, impacts safety risk in the real world (Engström et al., 2017). As noted earlier in the report (Section 4), there is some research suggesting cognitive loading tasks, such as talking on a mobile phone may reduce crash risk (e.g., Fitch, Hanowski, & Guo, 2015; Olson et al., 2009), while other research suggests driving while engaging in a handheld mobile phone conversation increases crash risk (Dingus et al., 2016). More recent NDS research suggests that conversing on a handheld mobile phone does not pose any difference in crash risk compared to “model driving” (described previously) (Dingus et al., 2019).
- Some researchers argue the DRT is itself another interfering task (e.g., having to respond to DRT stimuli by pressing a button on the

steering wheel) which may impact the validity of results (e.g., inflate the cognitive load assumed to be due to a particular secondary task) (Bruyas & Dumont, 2013; Jahn et al., 2005; Samost et al., 2015; Victor, Engström, & Harbluk, 2008). However, Strayer et al. (2013) have provided preliminary evidence the DRT, itself, does not increase the cognitive load of the driver.

These findings indicate both visual distraction and cognitive load can be estimated using various measures. However, each of these measures have limitations, which can make accurate estimation of visual distraction and cognitive load difficult.

## 6 GUIDELINES TO MINIMISE DRIVER DISTRACTION DUE TO IN-VEHICLE TECHNOLOGY

This section presents findings from the literature review addressing the fourth and final research question:

What guidelines have been developed to reduce any negative impact of HMI for in-vehicle technologies on driver performance?

Not all technologies in new vehicles are equal in terms of their potential to distract. The same technologies are often designed and implemented in very different ways by different vehicle manufacturers. The result of these different design choices is some vehicle cockpits are more demanding of drivers' attention than others, and hence are more likely to distract the driver from activities critical for safe driving.

In response to the heterogeneity across different in-vehicle system designs, several guideline documents have been developed which contain recommendations regarding the physical design of these systems, specifically the HMI, to minimise the potential for driver distraction. In general, the content of these guidelines derives mainly from traditional human factors theory and principles.

The documents, and high-level descriptions of each, are contained in Table 2. The documents are presented from the most recent to the oldest.

Table 2. Guideline documents on design of in-vehicle systems to minimise distraction

| Document title  | Author/affiliations  | Description   |
|---|--|---|
| Human Factors Design Guidance for Level 2 and Level 3 Automated Driving Concepts  | <ul style="list-style-type: none"> <li>Campbell et al. (2018)</li> </ul>                                   | This document may assist manufacturers in minimising the unintended consequences of motor vehicle automation and support designers in creating systems compatible with driver limitations and capabilities. The document aims to provide a clear, relevant and easy-to-use reference of human factors guidance for design and operation of driver vehicle interfaces within Level 2 and Level 3 automated driving environments.   |
| Human Factors Design Guidance for Driver-Vehicle Interfaces   | <ul style="list-style-type: none"> <li>Campbell et al. (2016)</li> </ul>                                   | This document provides human factors design guidance for driver-vehicle interfaces (DVIs). The guidance provided is based on the findings of current research (including both available scientific literature and research being conducted by agencies of the US Department of Transportation), as well as human factors concepts. The design guidance is provided as a complementary resource to other documents and resources, as well as an addition to industry research and existing guidance from the NHTSA. The information in the document may be useful to researchers, designers, original equipment manufacturers (OEMs) and Tier-1 suppliers seeking to ensure the compatibility of DVIs with driver limitations and capabilities.  |
| Cooperative Intelligent Transport Systems (CITS): Targeted Literature Review and Human Machine Interface Guidelines Development | <ul style="list-style-type: none"> <li>Young and Lenné (2014)</li> <li>Confidential to VicRoads</li> </ul> | <p>These guidelines offer advice for the optimal design of ADAS warnings and focus on the visual and auditory presentation of warnings and information to drivers. The guidelines do not cover issues associated with manually interacting with devices.</p> <p>The development of the guidelines was based on best practice knowledge from human factors and driver distraction literature, as well as existing automotive HMI guidelines, which have a significant level of research and development behind them. These included:</p> <ul style="list-style-type: none"> <li>The European Statement of Principles (European Commission, 2008)</li> <li>AAM Guidelines (Alliance of Automobile Manufacturers, 2006)</li> <li>JAMA Guidelines (Japan Automobile Manufacturers Association, 2004)</li> </ul> |

| Document title  | Author/affiliations  | Description  |
|---|--|--|
|   |  | <ul style="list-style-type: none"> <li>▪ TRL Guidelines (Stevens et al., 2002)</li> <li>▪ UMTRI Guidelines (Green et al., 1993)</li> <li>▪ Battelle Guidelines (Campbell et al., 2007)</li> <li>▪ NHTSA Visual-Manual Driver Distraction Guidelines (NHTSA, 2012).</li> </ul> <p>The guidelines comprise five sections: general design principles; visual display; auditory display; multiple warning design and scheduling; and portable device placement.</p>  |
| Visual-Manual Driver Distraction Guidelines for In-vehicle Electronic Devices   | <ul style="list-style-type: none"> <li>▪ National Highway Traffic Safety Administration (2012)</li> </ul>                | <p>The NHTSA guidelines list certain secondary, non-driving-related tasks that, based on NHTSA's research, are believed to interfere with a driver's ability to safely control the vehicle. The guidelines recommend in-vehicle devices be designed so they cannot be used by the driver to perform such tasks while driving. For all other secondary, non-driving-related, visual-manual tasks, the guidelines specify a test method for measuring the impact of task performance on driving safety and time-based acceptance criteria for assessing whether a task interferes too much with driver attention to be suitable to perform while driving. If a task does not meet the acceptance criteria, the guidelines recommend in-vehicle devices be designed so the task cannot be performed while driving. In addition to identifying inherently distracting tasks and providing a means for measuring and evaluating the level of distraction associated with other non-driving-related tasks, these guidelines contain several design recommendations for in-vehicle devices to minimise their potential for distraction.</p>   |
| Development of Technological and Functional Guidelines for the Design of Technologies used in Vehicles  | <ul style="list-style-type: none"> <li>▪ Young, Beanland and Lenné (2012)</li> <li>▪ Confidential to VicRoads</li> </ul> | <p>These advisory in-vehicle design guidelines draw on best practice knowledge from the human factors and driver distraction literature, as well as feedback from industry, HMI experts and road safety stakeholders. The primary purpose of the guidelines was to provide vehicle manufacturers with information and advice necessary to design their devices so that they are less complex, usable and minimise the level of driver distraction deriving from the use of technology while driving.</p> <p>Guidelines consulted to develop this resource include:</p> <ul style="list-style-type: none"> <li>▪ The European Statement of Principles (European Commission, 2008)</li> <li>▪ AAM Guidelines (Alliance of Automobile Manufacturers, 2006)</li> <li>▪ JAMA Guidelines (Japan Automobile Manufacturers Association, 2004)</li> <li>▪ TRL Guidelines (Stevens et al., 2002)</li> <li>▪ University of Michigan Transport Research Institute Guidelines (Green et al., 1993)</li> <li>▪ Battelle Guidelines (Campbell et al., 2007)</li> <li>▪ NHTSA Visual-Manual Driver Distraction Guidelines for In-vehicle Electronic Devices (National Highway Traffic Safety Administration, 2012).</li> </ul> |
| Commission Recommendation on Safe and Efficient In-vehicle Information and Communication Systems: Update of the European Statement of Principles on | <ul style="list-style-type: none"> <li>▪ European Commission (2008)</li> </ul>   | <p>This statement of principles summarises essential safety aspects, from a usability and distraction perspective, to be considered for the HMI for in-vehicle information and communication systems.</p> <p>The principles promote the introduction of well-designed systems into the market, and by taking into account both the potential benefits and associated risks they do not prevent innovation within the industry.</p> <p>The principles apply primarily to in-vehicle information and communication systems intended for use by the driver while the vehicle is in motion, for example navigation systems, mobile phones and traffic and travel information systems. Due to a lack of comprehensive research results and scientific proof, they are not intended to apply to voice-</p>   |

| Document title   | Author/affiliations   | Description   |
|--|---|---|
| Human-Machine Interface.   |   | controlled systems; systems providing vehicle braking stabilisation (such as automatic braking systems and electronic stability control); or system functionality providing information, warnings or support requiring immediate driver action (e.g., collision mitigation systems, night vision), sometimes referred to as advanced driver assistance systems (ADAS). ADAS are fundamentally different and require additional considerations in terms of the HMI. However, some of the principles may provide assistance in designing ADAS.  |
| Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-vehicle Information and Communication System | <ul style="list-style-type: none"> <li>Alliance of Automobile Manufacturers (2006)</li> </ul>       | <p>This statement of principles was developed as a voluntary industry guideline to address essential safety and distraction aspects to be taken into account for the human-machine interface (HMI) for driver interactions with future in-vehicle information and communication systems equipped with visual or manual/visual interfaces. It specifically does not apply to voice-activated systems or to systems using a head-up display.</p> <p>The statement is concerned with the visual-manual interaction of the driver with advanced information and communication systems while the vehicle is in motion. For example (not exhaustive), navigation, phoning, messaging or interactive information services (e.g., weather information from the internet) should be evaluated using the guidelines.</p>  |
| Guidelines for In-vehicle Display Systems (v 3.0)  | <ul style="list-style-type: none"> <li>Japan Automobile Manufacturers Association (2004)</li> </ul> | <p>These guidelines, which cover both usability and distraction-related guidelines, apply to display systems (whether factory-installed or installed by a dealer designated by the vehicle manufacturer) installed in vehicles (not including motorcycles) and located at a position visible to the driver.</p> <p>A 'display system' in the guidelines means a system capable of displaying diagrams, letters, numbers and/or images stored in memory or received through broadcasting or telecommunication. Auditory information provided by a display system is also subject to the guidelines.</p>  |
| Design Guidelines for Safety of In-vehicle Information Systems   | <ul style="list-style-type: none"> <li>Stevens et al. (2002)</li> <li>TRL</li> </ul>                | <p>The objective of these guidelines is to provide manufacturers with a summary of the factors to be considered when designing and writing an IVIS user manual. The guidelines provide a 'user friendly' synthesis of current knowledge, and guidance on where to locate more detailed information. The guidelines suggest the production of information presented to the driver regarding IVIS use should ideally consider: whether an appropriate individual is using the manual; appropriateness of the information presentation method; limiting factors associated with the user population; content of the information presented; and ease with which the information can be accessed and learned.</p>  |
| A Safety Checklist for the Assessment of In-vehicle Information Systems  | <ul style="list-style-type: none"> <li>Stevens et al. (1999)</li> <li>TRL</li> </ul>                | <p>This document contains a safety checklist for assessing in-vehicle information systems (IVIS) against established ergonomic custom and practice. The checklist was developed by the TRL to assess new IVIS before their widespread distribution. The function of the checklist is to provide a structured aid to an expert for the assessment of the safety-related and distraction-related features of the IVIS, to lead assessor(s) to a conclusion whether the IVIS does or does not present safety concerns. It was developed drawing on accepted existing codes of practice and international standards (e.g. ISO, Society of Automotive Engineers (SAE) resources).</p> <p>The checklist assessment form is accompanied by supportive information, which provides greater explanation about the application of the checklist, as well as allowing the assessors to clarify questions and understand the rationale behind them.</p> |

## 7 CONCLUSIONS

This report presents the results of literature reviews conducted to address the following four research questions:

1. How does distraction affect safety-related driving performance? Specifically, what does research show about the relationship between cognitive load and safety-related driving performance, including the impact of cognitive load caused by secondary tasks involving interaction with technologies such as (i) mobile phones (handheld or handsfree), (ii) in-built vehicle infotainment systems or (iii) wearable technologies (such as smart watches and smart glasses/goggles)?
2. What does research show about the extent to which driver distraction contributes to road trauma in Australia? What does research show about the impact of driver distraction on crash risk?
3. What does research show about the physiological symptoms and presentations of driver distraction? Are these able to be accurately identified and measured?
  - a) Eye-tracking measures: gaze direction, gaze fixation and percentage of eyelid closure (known as PERCLOS).
  - b) Cognitive load and stress response measures: electroencephalogram (EEG, detecting electrical brain activity), galvanic skin response (detecting electrical resistance of the skin to measure response to emotional stress), and heart rate. A widely used non-physiological measure of cognitive load, the detection response task (DRT), was also reviewed.
4. What guidelines have been developed to reduce any negative impact of HMI for in-vehicle technologies on driver performance?

With respect to question 1, this report outlines published empirical evidence demonstrating driver interactions with mobile phones, in-built vehicle infotainment systems, and wearable technologies can significantly degrade driving performance. Across the technologies, research shows visual-manual interactions (e.g., mobile phone texting, manual input of a destination into a navigation system), have a greater potential to interfere with activities critical for safe driving than voice interactions. However,

research also found such voice interactions have the potential to degrade driving performance compared to driving while not engaged in a secondary task.

With respect to question 2, relatively little research has been undertaken in Australia linking driver distraction and crashes in the real world compared to other jurisdictions (e.g., USA). However, the studies undertaken converge in demonstrating driver distraction contributes to safety-critical events (e.g., crashes) on Australian roads. The NDSs undertaken have been primarily based on the USA and demonstrated visual-manual interactions, particularly those that take eyes off the forward roadway for relatively long durations, are particularly risky (e.g., manual text messaging or dialling a mobile phone). This review of existing research also suggests the link between cognitive distraction (e.g., due to a mobile phone conversation) and safety risk is less clear.

With respect to question 3, a range of physiological indicators may be used to measure visual distraction and/or cognitive load. Eye-glance metrics are considered the most sensitive and robust indicators of visual distraction, specifically off-road glance frequency and duration. Consensus around which physiological indicators may be the most sensitive and robust indicators of cognitive load has not been established. On the other hand, the DRT shows promise as a method for assessing cognitive load. Some of its main merits relate to the fact it has been widely utilised to assess cognitive load, has been standardised, has been shown to be sensitive to changes in cognitive load, and is currently utilised in the USA for assessing the potential for cognitive driver distraction in new passenger vehicles. Nevertheless, it is recommended the limitations and concerns raised by researchers about this measure be considered. It is also suggested, to increase the robustness of research findings and to help address issues associated with accurate data collection, more than one measure be utilised in conjunction with each other.

With respect to question 4, several guideline documents exist which provide recommendations on the physical design of in-vehicle technologies to minimise the potential for driver distraction. The documents originate from various transport and road safety groups both locally (e.g., MUARC) and internationally (e.g., TRL and NHTSA).



It is envisaged the outputs of this literature review may assist with the development of the NTC's National Driver Distraction project, and stimulate discussions regarding driver distraction research, policy and legislative reform options.

## 7.1 FINAL KEY POINTS

To complement the conclusions made in this section, the following key points were drawn from the literature reviews conducted for this project. However, these do not constitute a full understanding of the complexity and diversity of the material presented within this report:

- Driver distraction and inattention remain significant road safety problems in Australia and many other countries.
- The distraction potential of an individual driver engaging with a secondary task may be influenced by a complex interaction of moderating factors (e.g., driver characteristics, driving demand).
- There are several methods to estimate whether a driver is visually distracted or under a high

cognitive load. However, each of these methods have limitations that may affect the validity and reliability of these estimates.

- Engagement in secondary tasks which take a driver's 'eyes off the road' appear to be particularly hazardous. Glances off the forward roadway of greater than 2.0 seconds have been associated with a two-fold increase in crash risk. However, this associated crash risk may be influenced by moderating factors such as driving experience.

Driver interactions with the vehicle's in-built HMI may pose a high risk for driver distraction. Several HMI-design guidelines have been produced to provide guidance about the physical design considerations of the HMI of in-vehicle technologies in an attempt to minimise their potential to produce driver distraction. In general, the content of these guidelines derive mainly from traditional human factors theory and principles.

## 8 REFERENCES

- Alliance of Automobile Manufacturers (AAM) 2006, *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication System*, Alliance of Automobile Manufacturers (AAM) Washington, D.C., USA.
- Basacik, D, Reed, N, & Robbins, R 2011, 'Smartphone use while driving: A simulator study', report no. PPR592, TRL, Wokingham.
- Bayly, M, Young, K & Regan, M 2008, 'Sources of distraction inside the vehicle and their effects on driving performance', In MA Regan, JD Lee & KL Young (Ed.), *Driver distraction: Theory, effects and mitigation*, CRC Press, Boca Raton, FL.
- Beanland, V, Fitzharris, M, Young, K & Lenne, M 2013, 'Driver inattention and driver distraction in serious casualty crashes: Data from the Australian National Crash In-depth Study', *Accident Analysis & Prevention*, vol. 54, pp. 99-107.
- Biel, L, Pettersson, O, Philipson, L & Wide, P 2001, 'ECG analysis: a new approach in human identification', *IEEE Transactions on Instrumentation and Measurement*, vol. 50, no. 3, pp. 808-812.
- Bruyas, MP & Dumont, L 2013, 'Sensitivity of detection response task (DRT) to the driving demand and task difficulty', *Proceedings of the 7th international driving symposium on human factors in driver assessment, training, and vehicle design*, pp. 64–70.
- Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2018, 'Road Trauma Australia 2017 statistical summary', BITRE, Canberra, ACT.
- Brown, JD & Huffman, WJ 1972, 'Psychophysiological measures of drivers under actual driving conditions', *Journal of Safety Research*, vol. 4, pp. 172-178.
- Caird, JK, Johnston, KA, Willness, CR, Asbridge, M & Steel, P 2014, 'A meta-analysis of the effects of texting on driving', *Accident Analysis & Prevention*, vol. 71, pp. 311-318.
- Caird, JK, Simmons, SM, Wiley, K, Johnston, KA & Horrey, WJ 2018, 'Does talking on a cell phone, with a passenger, or dialing affect driving performance? An updated systematic review and meta-analysis of experimental studies', *Human Factors*, vol. 60, no. 1, pp. 101-133.
- Campbell, JL, Richard, CM, Brown, JL & McCallum, M 2007, *Crash warning system interfaces: human factors insights and lessons learned*, DOT HS 810 697, National Highway Traffic Safety Administration, Washington, DC, USA.
- Campbell, JL, Brown, JL, Graving, JS, Richard CM, Lichty, MG, et al. 2016, *Human factors design guidance for driver-vehicle interfaces*, DOT HS 812 360, National Highway Traffic Safety Administration, Washington, D.C., USA.
- Campbell, JL, Brown, JL, Graving, JS, Richard CM, Lichty, MG, et al. 2018, *Human factors design guidance for level 2 and level 3 automated driving concepts*, DOT HS 812 555, National Highway Traffic Safety Administration, Washington, D.C., USA.

- Casson, AJ, Smith, S, Duncan, JS, & Rodriguez-Villegas, E. 2008. *Wearable EEG: what is it, why is it needed and what does it entail?* Paper presented at the 2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society.
- Chiang, D, Brooks, A & Weir, D 2001, *An experimental study of destination entry with an example automobile navigation system*, SP-1593, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, USA.
- Craft, RH & Preslopsky, B 2012, 'Distraction and inattention: Top crash causes in the USA', in MA Regan, JD Lee & TW Victor (Ed.), *Driver distraction and inattention: Advances in research and countermeasures*, Ashgate, Surrey, UK.
- Cunningham, M. & Regan, M. (2018). Driver distraction and inattention. In D. Lord & S. Washington (Ed.), *Safe Mobility: Challenges, Methodology and Solutions*, Volume 11 in the series *Transport and Sustainability*. Bingley, UK: Emerald Publishing.
- Cunningham, ML, Regan, MA & Imberger, K 2017, 'Understanding driver distraction associated with specific behavioural interactions with in-vehicle and portable technologies', *Journal of the Australasian College of Road Safety*, vol. 28, no. 1, pp. 27-40.
- Darshana, S, Fernando, D, Jayawardena, S, Wickramanayake, S & DeSilva, C 2014, 'Efficient PERCLOS and gaze measurement methodologies to estimate driver attention in real time', *5<sup>th</sup> International Conference on Intelligent Systems, Modelling and Simulation, 2014, Langkawi, Malaysia*. Langkawi, Malaysia.
- Desmond, PA & Hancock, PA 2001, 'Active and passive fatigue states'. In: Hancock, PA & Desmond, PA, Eds. *Stress, workload, and fatigue*. Erlbaum; Mahwah, NJ.
- De Waard, D 1991, 'Driving behaviour on a high accident-rate motorway in the Netherlands', In C Weikert, KA Brookhuis & S Ovinius (ed.), *Man in complex systems*, Proceedings of the Europe Chapter of the Human Factors Society Annual Meeting. Work Science Bulletin 7, pp. 113-123, Lund, Sweden: Work Science Division, Department of Psychology, Lund University.
- De Waard, D, Jessurun, M, Steyvers, FJJM, Reggatt, PTF & Brookhuis, KA 1995, 'Effect of road layout and road environment on driving performance, drivers' physiology and road appreciation', *Ergonomics*, vol. 38, no. 7, pp. 1395-1407. DeWinter, J, & Happee, P 2012, 'Advantages and Disadvantages of Driving Simulators: A Discussion', In Proceedings of the Measuring Behavior, Utrecht, The Netherlands, 28–31 August; pp. 47–50.
- Dingus, TA, Guo, F, Lee, S, Antin, JF, Perez, M, Buchanan-King, M & Hankey 2016, 'Driver crash risk factors and prevalence evaluation using naturalistic driving data', *Proceedings of the National Academy of Sciences*, vol. 113, no. 10, pp. 2636-2641.
- Dingus et al. 2019, 'The prevalence of and crash risk associated with primarily cognitive secondary tasks', *Safety Science* (currently in press).
- Dingus, TA, Antin, JF, Hulse, MC & Wierwille, WW 1989, 'Attentional demand requirements of an automobile moving-map navigation system', *Transportation Research A*, vol. 23, pp. 301-315.

- Engström, J, Johansson, E & Östlund, J 2005, 'Effects of visual and cognitive load in real and simulated motorway driving', *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 8, no. 2, pp. 97-120.
- Engström, J & Victor, TW 2008. 'real-time distraction countermeasures', In MA Regan, JD Lee & KL Young (ed), *Driver distraction: Theory, effects and mitigation*, CRC Press, Boca Raton, FL.
- Engström, J, Markkula, G, Victor, T, Merat, N 2017, 'Effects of cognitive load on driving performance: The cognitive control hypothesis', *Human Factors*, vol. 59, no. 5, pp. 734-764.
- European Commission 2008, *Commission Recommendation on Safe and Efficient In-Vehicle Information and Communication Systems: Update of the European Statement of Principles on Human-Machine Interface*, European Commission, Brussels.
- Farber, E, Foley, J & Scott, S 2000, 'Visual attention design limits for ITS in-vehicle systems: the Society of Automotive Engineers standard for limiting visual distraction while driving', *Transportation Research Board annual general meeting, 79th, 2000, Washington, DC*, TRB, Washington, DC, USA.
- Fisch, B & Spehlmann, R 1999, *Fisch and Spehlmann's EEG Primer*, 3<sup>rd</sup> ed, Elsevier, Amsterdam, Netherlands.
- Fitch, G, Hanowski, R & Guo, F 2015, 'The risk of a safety critical event associated with mobile device use in specific driving contexts', *Traffic Injury Prevention*, vol. 16, pp. 124-132.
- Fitch, GM, Socolich, SA, Guo, F, McClafferty, J, Fang, Y, Olson, R, Perez, M, Hanowski, R, Hankey, J & Dingus, T 2013, *The impact of hand-held and hands-free cell phone use on driving performance and safety-critical event risk*, report no. DOT HS 811 757, National Highway Traffic Safety Administration, Washington, DC, USA.
- Gharagozlou, F, Nasl Saraji, G, Mazloumi, A, Nahvi, A, Motie Nasrabadi, A, Rahimi Froushani, A, Arab Kheradmand, A, Ashouri, M, Samavati, M 2015, 'Detecting driver mental fatigue based on EEG alpha power changes during simulated driving', *Iran Journal of Public Health*, vol. 44, no. 12, pp. 1693-700.
- Giang, WCW, Hoekstra-Atwood, L & Donmez, B 2014, 'A comparison of visual-manual interaction between smartwatches and smartphones', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 58, no. 1, pp. 2161-2165.
- Giang, WCW, Shanti, I, Chen, H-YW, Zhou, A & Donmez, B 2015, 'Smartwatches vs. smartphones: a preliminary report of driver behavior and perceived risk while responding to notifications', *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Nottingham, United Kingdom*, Association for Computing Machinery, New York, USA, pp. 154-161.
- Green, P, Levison, W, Paelke, G & Serafin, C 1993, *Suggested human factors design guidelines for driver information systems*, University of Michigan, Ann Arbor, MI, USA.
- Grzebieta, R 2015, 'Australia's naturalistic driving study', *Journal of the Australasian College of Road Safety*, vol. 26, no. 1, pp. 46-47.

- Hallett, C, Regan, MA, & Bruyas, MP 2011, Development and validation of a driver distraction impact assessment test. *The electronic proceedings of the 2nd international conference on driver distraction and inattention*, Gothenburg, Sweden, September 5–7.
- He, J, Choi, W, McCarley, JS, Chaparro, B & Wang, C 2015, 'Texting while driving using Google Glass: Promising but not distraction-free', *Accident Analysis & Prevention*, vol. 81, pp. 218-229.
- He, J, Chapparo, A, Nguyen, B, Burge, R, Crandall, J, Chaparro, B, Ni, R & Cao, S 2013, Texting while driving: Is speech-based texting less risky than hand-held texting? *Proceedings of Automotive User Interfaces and Interactive Vehicular Applications*, Eindhoven, Netherlands.
- Healey, JA & Picard, RW 2004, 'Detecting stress during real-world driving tasks using physiological sensors', *IEEE Transactions on Intelligent Transportation Systems*, vol. 6, no. 2, pp. 156-166.
- Horberry, T & Edquist, J 2008, 'Distractions outside the vehicle', in MA Regan, JD Lee & K Young (ed), *Driver distraction: Theory, effects, and mitigation*, CRC Press, Boca Raton, FL, pp. 215-228.
- International Organization for Standardization. (2016). Road vehicles — Transport information and control systems — Detection-response task (DRT) for assessing attentional effects of cognitive load in driving (ISO Standard No. 17488). Retrieved from <https://www.iso.org/standard/59887.html>
- Jahn, G, Oehme, A, Krems, JF & 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: Traffic Psychology and Behaviour*, vol. 8F, no. 3, pp. 255-75.
- Japan Automobile Manufacturers Association 2004, *Guidelines for in-vehicle display systems - Version 3.0.*, English version, Japan Automobile Manufactures Association, Tokyo, Japan.
- Klauer, SG, Dingus, TA, Neale, VL, Sudweeks, JD & Ramsey, DJ 2006, *The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data*, National Highway Traffic Safety Administration, Washington, DC.
- Klauer, SG, Guo, F, Simons-Morton, BG, Ouimet, MC, Lee, SE & Dingus, TA 2014, 'Distracted driving and risk of road crashes among novice and experienced drivers', *New England Journal of Medicine*, vol. 370, pp. 54–9.
- Lal, S & Craig, A 2002, 'Driver fatigue: Electroencephalography and psychological assessment', *Psychophysiology*, vol. 39, no. 3, pp. 313-321.
- Larue, GS, Rakotonirainy, A & Pettitt, AN 2011, 'Driving performance impairments due to hypovigilance on monotonous roads', *Accident Analysis & Prevention*, vol. 43, no. 6, pp. 2037-2046.
- Lee, J, Sawyer, BD, Mehler, B, Angell, L, Seppelt, BD, Seaman, S, Fridman, L & Reimer, B 2017, 'Linking the detection response task and the AttenD algorithm through the assessment of human-machine interface workload', *Transportation Research Record*, vol. 2663, pp. 82-9.
- Maciej, J & Vollrath, M, 2009, 'Comparison of manual vs. speech-based interaction with in-vehicle information systems', *Accident Analysis & Prevention*, vol. 41, no. 5, pp. 924-30.

- Marquart, G, Cabrall, CDD & de Winter, JCF 2015, 'Review of eye-related measures of drivers' mental workload', *The 6th international conference on applied human factors and ergonomics, 2015, Las Vegas, USA*, Las Vegas, USA.
- Mehler, B, Kidd, D, Reimer, B, Reagan, I, Dobres, J & McCartt, A 2016, 'Multi-modal assessment of on-road demand of voice and manual phone calling and voice navigation entry across two embedded vehicle systems', *Ergonomics*, vol. 59, no. 3, pp. 344-367.
- Mehler, B, Reimer, B, Coughlin, JF & Dusek, JA 2009, 'The impact of incremental increases in cognitive workload on physiological arousal and performance in young adult drivers', *Transportation Research Record*, vol. 2138, pp. 6-12.
- Merat, N & Jamson, AH 2008, 'The effect of stimulus modality on signal detection: Implications for assessing the safety of in-vehicle technology', *Human Factors*, vol. 50, no. 1, pp. 145-58.
- McEvoy, SP, Stevenson, MR, Woodward, M 2006. Phone use and crashes while driving: a representative survey of drivers in two Australian states. *Medical Journal of Australia* 185, 630–634.
- Michaels, RM 1962, 'The effect of expressway design on driver tension responses', *Public Roads*, vol. 32, pp. 107-112.
- Mulder, LJM 1988, 'Assessment of cardiovascular reactivity by means of spectral analysis', PhD Thesis, University of Groningen.
- National Highway Traffic Safety Administration 2012, *Proposed Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices*, National Highway Traffic Safety Administration, Department of Transportation, Washington, DC, USA.
- O'Donnell, RD & Eggemeier, FT 1986. Workload Assessment Methodology. In Boff, K, Kaufman, L & Thomas, J (Eds.), *Handbook of perception and human performance*, vol. II: Cognitive processes and performance (pp. 421-429). New York: Wiley.
- Olson, RL, Hanowski, RJ, Hickman, JS & Bocanegra, J 2009, *Driver distraction in commercial vehicle operations*, U.S. Department of Transportation, Washington, DC.
- Olsson, S & Burns, P 2000, 'Measuring distraction with a peripheral detection task', NHTSA Internet Distraction Forum.
- Owens, JM, McLaughlin, SB & Sudweeks, J 2011, 'Driver performance while text messaging using handheld and in-vehicle systems' *Accident Analysis & Prevention*, vol. 43, no. 3, pp. 939-47.
- Pashler, H 1994, 'Overlapping mental operations in serial performance with preview', *Quarterly Journal of Experimental Psychology*, vol. 47, pp. 161–191.
- Paxion, J, Galy, E & Berthelon, C 2014, 'Mental workload and driving', *Frontiers in Psychology*, vol. 5, pp. 1344.
- Recarte, MA & Nunes, LM 2003, 'Mental workload while driving: effects on visual search, discrimination, and decision making', *Journal of Experimental Psychology: Applied*, vol. 9, no. 2, pp. 119-37.
- Regan, MA, Young, K, Lee, K & Gordon, C 2009, 'Sources of driver distraction', In Regan, M.A., Lee, J.D. and Young, K.L. (Ed.) 2009. *Driver Distraction: Theory, Effects and Mitigation*. Florida, USA: CRC Press.



- Reed, N, & Robbins, R 2008, 'The effect of text messaging on driver behaviour', report no. PPR 387, Transport Research laboratory, England.
- Regan, MA, Lee, JD, Young, KL, 2009 'Driver Distraction: Theory, Effects and Mitigation'. CRC Press Taylor & Francis Group, Boca Raton, FL, USA.
- Regan M.A., Williamson A., Grzebieta R., Tao L., (2012). Naturalistic Driving Studies: Literature Review and Planning for the Australian NDS, Proc. Australasian College of Road Safety Conference – A Safe System: expanding the reach!", Sydney.
- Regan, MA, Hallett, C & Gordon, C 2011, 'Driver distraction and driver inattention: Definition, relationship and taxonomy', *Accident Analysis & Prevention*, vol. 43, no. 5, pp. 1771-1781.
- Ryu, K & Myung, R 2005, 'Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic', *International Journal of Industrial Ergonomics*, vol. 35, no. 11, pp. 991-1009.
- Samost A, Perlman D, Domel A, Reimer B, Mehler B, Mehler A, Dobres J, McWilliams T 2015, 'Comparing the relative impact of SmartWatch and Smartphone use while driving on workload, attention, and driving performance', *Proceedings of the Human Factors and Ergonomics Society 59th Annual Meeting, Los Angeles, California, USA*.
- Sawyer, BD, Finomore, VS, Calvo, AA & Hancock, PA 2014, 'Google Glass: Driver distraction cause or cure?', *Human Factors*, vol. 56, no. 7, pp. 1307-1321.
- Sharma, M, Kacker, S & Sharma, M 2016, 'A brief introduction and review on galvanic skin response', *International Journal of Medical Research Professionals*, vol. 2, no. 6, pp. 13-17.
- Simons-Morton, BG, Guo, F, Klauer, SG, Ehsani, JP, Pradhan, AK 2014 'Keep your eyes on the road: young driver crash risk increases according to duration of distraction', *Journal Adolescent Health*, vol. 54, pp. 61-67.
- Stevens, A, Board, A, Allen, P & Quimby, A 1999, *A safety checklist for the assessment of in-vehicle information systems*, Project Report PA3536/99, Transport Research Laboratory, Crowthorne, United Kingdom.
- Stevens, A, Quimby, A, Board, A, Kersloot, T & Burns, P 2002, *Design guidelines for safety of in-vehicle information systems*, Project report PA3721/01, Transport Research Laboratory, Crowthorne, United Kingdom.
- Strayer, DL, Cooper, JM, Turrill, J, Coleman, J, Medeiros-Ward, N & Biondi, F 2013, *Measuring cognitive distraction in the automobile*, AAA Foundation for Traffic Safety, Washington, DC, USA.
- Strayer, DL, Drews, FA & Johnston, WA 2003, 'Cell phone-induced failures of visual attention during simulated driving', *Journal of Experimental Psychology: Applied*, vol. 9, no. 1, pp. 23-32.
- Strayer, DL & Johnston, WA 2001, 'Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone', *Psychological Science*, vol. 12, no. 6, pp. 462-466.

- Strayer, DL, Turrill, J, Coleman, JR, Ortiz, EV & Cooper, JM 2014, *Measuring cognitive distraction in the automobile II: assessing in-vehicle voice-based interactive technologies*, AAA Foundation for Traffic Safety, Washington, DC, USA.
- Tijerina, L, Parmer, E & Goodman, M 1998, 'Driver workload assessment of route guidance system destination entry while driving: a test track study', *Towards the new horizon together: proceedings of the 5th world congress on intelligent transport systems*, Seoul, South Korea.
- Transport for NSW 2017, 'Fatigued and distracted driver trauma trends'. TfNSW, Sydney, Australia.
- Tsimhoni, O, Smith, D & Green, P 2004, 'Address entry while driving: speech recognition versus a touch-screen keyboard', *Human Factors*, vol. 46, no. 4, pp. 600-10.
- van Winsum, W, Martens, M & Herland, L 1999, *The effects of speech versus tactile driver support messages on workload driver behaviour and user acceptance*, TNO-Report TM-99-C043, TNO Human Factors Research Institute, Soesterberg, The Netherlands.
- Victor, TW, Engström, J & Harbluk, JL 2008, 'Distraction assessment methods based on visual behavior and event detection', in MA Regan, JD Lee & KL Young (eds), *Driver Distraction: Theory, Effects, and Mitigation*, CRC Press, Boca Raton, FL, USA.
- Wilson, GF & Eggemeier, FT 1991, 'Psychophysiological assessment of workload in multi-task environments', In DL Damos (ed.), *Multiple-task performance* (pp. 329-360). London: Taylor & Francis.
- Wilson, JA, Schalk, G, Walton, LM & Williams, JC 2009, 'Using an EEG-based brain-computer interface for virtual cursor movement with BCI2000', *Journal of Visualized Experiments*, vol. 29, pp. 1319.
- Yager, C 2013, *An evaluation of the effectiveness of voice-to-text programs at reducing incidences of distracted driving*, Texas A&M Transportation Institute, Texas A&M University System, College Station, Texas.
- Young, KL, Regan, MA, & Lee, JD 2008, 'Factors moderating the impact of distraction on driving performance and safety', In M. A. Regan, J. D., Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects, and mitigation*. Boca Raton, FL: CRC Press Taylor & Francis Group.
- Young KL, Stephens AN, Stephan KL, Stuart GW 2016, 'In the eye of the beholder: a simulator study of the impact of Google Glass on driving performance', *Accident Analysis and Prevention*, vol. 86, pp. 68–75.
- Young, KL & Lenné, MG 2014, *Cooperative Intelligent Transport Systems (CITS): Targeted literature review and Human Machine Interface guidelines development*, Final report, ISSN 1835-4815, Monash University Accident Research Centre, Clayton, Victoria, Australia.
- Young, KL, Beanland, V & Lenné, MG 2012, *Development of technological and functional guidelines for the design of technologies used in vehicles: stage 5 project synthesis & proposed Australian HMI design guidelines*, Final report, ISSN 1835-4815, Monash University Accident Research Centre, Clayton, Victoria, Australia.
- Young KL, Osborne R, Koppel S, Charlton JL, Grzebieta R, Williamson A, Haworth N, Woolley J & Senserrick T in Press, *What are Australian drivers doing behind the wheel? An overview of secondary task data from the Australian Naturalistic Driving Study*, Journal of the Australasian College of Road Safety, October 2018.
- Young, K, & Regan, M 2007, 'Driver distraction: A review of the literature', In I. J.

Faulks, M. Regan, M. Stevenson, J. Brown, A. Porter, & J. D. Irwin (Ed.), *Distracted driving*. Sydney: Australasian College of Road Safety.

Zeier, H 1979, 'Concurrent physiological activity of driver and passenger when driving with and without automatic transmission in heavy city traffic', *Ergonomics*, vol. 22, pp. 799-810.

Zhang, H, Smith, MRH & Witt, GJ 2006, 'Identification of real-time diagnostic measures of visual distraction with an automatic eye-tracking system', *Human Factors*, vol. 48, no. 4, pp. 805-821.

## CONTACT US

**Dr Anna Chevalier**

*Principal Technology Leader  
Transport Safety*

[Anna.Chevalier@ARRB.com.au](mailto:Anna.Chevalier@ARRB.com.au)

[ARRB.COM.AU](http://ARRB.COM.AU)

