Brain and behavioural reflections of distracted driving associated with emotion processing and social factors

by

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ABSTRACT

Driving is a complex task that requires a high level of attention for the safe operation of a motor vehicle. However, the human attention system is limited in capacity, and distraction arises when there is a competition for attention from non-driving related activities. When insufficient attention is prioritized to the road ahead, driving safety may be undermined. Cognitive distraction, one form of driver distraction, occurs when attention is withdrawn from the primary task of driving to a competing cognitive event. In this dissertation, I implemented four studies involving behavioural and electrophysiological methods to expand our current understanding of the impact of cognitive distraction on driver attention and performance. The first three studies focused on the emotional side of cognitive distraction, while study four focused on the social and cognitive influence of an in-car passenger. Study one aimed to examine the potential for driver distraction from emotional information presented on roadside billboards. To achieve this, participants operated a driving simulator in the presence of positive, negative, and neutral words. Study two investigated the behavioural and event-related potential (ERP) effects elicited by auditory words of different emotional valence (positive, negative, and neutral) during driving (dual-task) and non-driving (single-task) conditions. The primary goal was to determine whether distraction presented in the auditory modality would produce a similar pattern of effects as visual distraction. The secondary goal was to assess the allocation of neural resources under single and dual-task conditions. Study three aimed to examine the effects of highly arousing taboo-related distraction on driving performance. Participants operated a driving simulator in the presence of non-arousing words, moderately arousing positive and negative words, and highly arousing taboo words, presented on roadside billboards. Study four examined the attentional effects of driving with an in-car passenger, using electrophysiological methods. The objective was to

investigate the relationship between attention, cognitive load, and social demands, related to the presence of a passenger. Findings from the first three studies provided novel insights and significant contributions to the literature on driver distraction by: (a) providing evidence that emotion-related distraction can capture and modulate attention to impact driving behaviour, (b) providing evidence that the processing of emotional information while driving likely influences higher-order cognitive processes rather than lower level sensory and perceptual processes, and (c) providing evidence that driving performance is differentially influenced by the valence (positive vs. negative) and arousal (high vs. moderate) of the emotional content; these unique effects reflect separate processes in the attention system, related to how arousal and valence interacts. Study four provided novel insights and significant contributions to the driving literature by: (a) providing evidence that mere presence of a passenger is sufficient to consume driver attentional resources, (b) supporting research in social psychology that describe the social influence of others, and (c) providing evidence that a potential mechanism for the effects of passengers is that they impose additional cognitive demand on the driver's limited resources. Together, these convergent lines of research demonstrate that a main element of cognitive distraction is increased driver workload, which can modulate attention to influence driver attention and performance.

PREFACE

This thesis is an original work by Michelle Chan. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Brain activity basis of multitasking across multiple senses", No. Pro00014392, May 15, 2010.

Chapter 2 of this thesis has been published as M. Chan and A. Singhal, "The emotional side of cognitive distraction: Implications for road safety," *Accident Analysis and Prevention*, vol. 50, 147–154. I was responsible for design implementation and piloting, data collection, data analysis, writing the manuscript, and manuscript edits. A. Singhal was the supervisory author and was involved with concept formation and manuscript composition.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1:

Introduction

The objective of the present work was to investigate the influence of cognitive sources of distraction on driver attention and performance, using both behavioural and electrophysiological techniques. Specifically, the focus was on the emotional side of cognitive distraction and the social and cognitive influence of an in-car passenger. Given that driver distraction is one of the leading causes of motor vehicle accidents, it is critical to understand the mechanisms by which cognitive distraction interferes with driving behaviour.

Driving is a complex task that requires a high level of attention; despite this, drivers often engage in secondary activities while driving (e.g., talking on a cell phone). Research estimates that 20-30% of motor vehicle crashes are associated with secondary task distraction (Alberta Transportation, 2007). Driver distraction refers to “the diversion of attention away from activities critical for safe driving towards a competing activity” (Regan, Hallett, & Gordon, 2011, p. 1776). The different types of distraction can be distinguished as visual, auditory, cognitive, and physical distraction. Cognitive distraction occurs when the cognitive processes (e.g., attention, working memory, response selection) associated with the competing activity withdraws attention away the driving task. Given that attention is limited in capacity, when insufficient attention is devoted to the driving task, driving performance may be compromised.

As shown in Figure 1.1, performing a secondary task requires mental resources, which is associated with cognitive workload. When combined with a driving task, this leads to a competition for attention. Cognitive distraction arises when attention is shifted away from the processing of information that is necessary for safe driving (Strayer et al., 2013). Distraction has been shown to disrupt drivers’ detection and responses to potential hazards, situation awareness, visual scanning behaviour, the encoding and retrieval of relevant information in the driving environment, and decision-making (Young & Salmon, 2012).

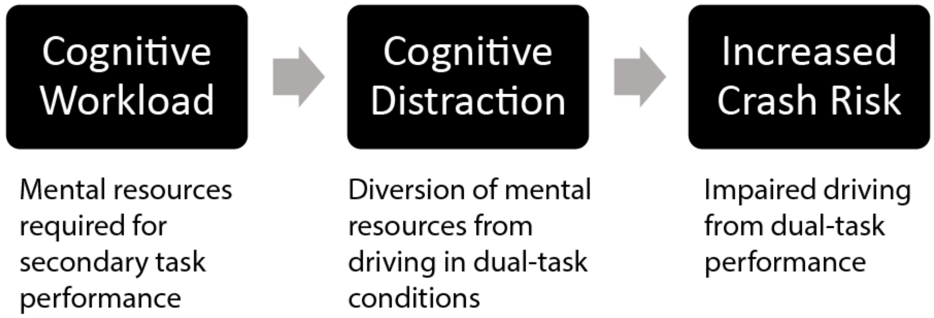

Figure 1.1. Framework for understanding cognitive distraction while driving. Adapted from Strayer et al. (2013).

While most research has focused on the effects of cell phones and other in-vehicle technologies while driving, the impact of emotion-related information that is external to the driver and vehicle has not been examined. This is an important topic given that emotional stimuli typically engages more attention than neutral stimuli (for a review, see Schupp, Flaisch, Stockburger, & Junghöfer, 2006). How emotion-related distraction may influence driving performance remains an open question.

Another topic that has not been well understood is a passenger's influence on the driver. Extant research in the field of social psychology has shown that people tend to perform differently in the mere or implied presence of spectators compared to when they are alone (Baxter et al., 1990). One theory is that the presence of others creates a context of evaluation. Behavioural research on the effects of passengers has revealed contradictory findings, with some studies showing that passengers can have a negative effect on drivers, while others have shown that passengers can have a positive (i.e., protective) effect. Thus, there is a need to have a better understanding of the internal driving environment, related to the presence of passengers, on driver behaviour, particularly with an electrophysiological approach.

Therefore, the overarching goals of the present research were to investigate potential sources of cognitive distraction, examine the extent of their influence on driver attention and performance, and understand the mechanisms that underlie the role of cognitive distraction. These goals were accomplished by investigating the impact of emotion-related information and an in-car passenger on driver behaviour, using both behavioural and electrophysiological measures.

To introduce this work, I will first begin by with a discussion on what driver distraction is and how it is distinguished from driver inattention. I will then present the sources and causes of driver distraction, followed by the different methods of measuring cognitive distraction. Next, I will review the literature on cognitive distraction, focusing on the influences of roadside billboards, emotion-related stimuli, and in-car passengers, of which my work will extend. Thereafter, I will discuss my dissertation work which aims to advance our understanding of how cognitive distraction impacts driver behaviour. To conclude, I will discuss some countermeasures to prevent and mitigate the effects of driver distraction.

1.1 What is driver distraction?

Driving is an essential part of everyday life and has remain the primary means of transportation in the United States. However, motor vehicle crashes are the leading cause of death for every age 11 through 27. In 2012, 33,561 people were killed in the estimated 5,615,000 police-reported motor vehicle traffic crashes. In the same year, an average of 92 people died each day in motor vehicle crashes – one every 16 minutes (National Highway Traffic Safety Administration [NHTSA], 2014). Factors commonly associated with these accidents have been attributable to the driver (e.g., distraction), vehicle (e.g., tire problems), or road environment (e.g., slippery roads).

According to the driver information-processing model, the processes required to operate a vehicle can be divided into 3 sequential stages: perception (detection and identification), decision, and reaction (Dewar, Olson, & Alexander, 2007). For example, when a driver approaches an intersection with traffic lights, the driver first sees the colour of the lights. If it is yellow, he must make a decision to stop or go through the intersection. Once the decision is made, he must react accordingly by making a steering, braking, or acceleration response. These processes rely on visual and motor functions, as well as multiple cognitive processes, including visual-spatial and visual-motor integration, divided attention between different modalities, and fast decision-making. Impairments in these functions may compromise driving performance.

In Rumar (1985), it was determined that the driver was the sole or contributory factor in 94% of crashes. 57% of crashes were due solely to factors related to the driver, 27% to the interaction between the road environment and driver, 6% to the interaction between the vehicle and driver, 3% solely to the environment, 3% to the interaction between the environment, driver, and vehicle, 2% solely to the vehicle, and 1% to the interaction between the environment and vehicle. These findings were reinforced in another study where it was reported that the driver's behaviour contributed to 99.2% of crashes, while environmental and vehicle factors contributed to 5.4% and 0.5% of crashes, respectively (Hendricks, Fell, & Freedman, 1999).

Of the factors attributed to the driver, driver inattention is estimated to contribute to 20-50% of motor vehicle crashes (e.g., Eby & Kostyniuk, 2003). Driver distraction, one form of driver inattention, is reported to be involved in over half of these crashes (Stutts, Reinfurt, Staplin, & Rodgman, 2001). More recent findings place this estimate higher. One study reported that 30% of drivers that were involved in a motor vehicle crash cited some source of distraction at the time of the accident (McEvoy, Stevenson, & Woodward, 2007). Findings from the 100-Car Naturalistic Driving Study suggested that distraction was a contributing factor in over 22% of crashes and near-crashes (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). In 2013, driver distraction was estimated to account for 10% of all fatal crashes and 18% of injury crashes, with drivers in their 20s making up 27% of these crashes (NHTSA, 2015).

Driver distraction and driver inattention are often used interchangeably in the literature. This has led to inconsistencies in their terminology, making it difficult to interpret and compare their research findings. For example, different uses of the terms may result in studies measuring different outcomes (Regan et al., 2011).

To distinguish between driver distraction and driver inattention, Regan et al. (2011) developed a framework to provide a common understanding of the two concepts and their relationship. As shown in Figure 1.2, driver inattention is at the top of the framework, which is defined as “insufficient, or no attention, to activities critical for safe driving” (Regan et al., 2011, pp. 1775).

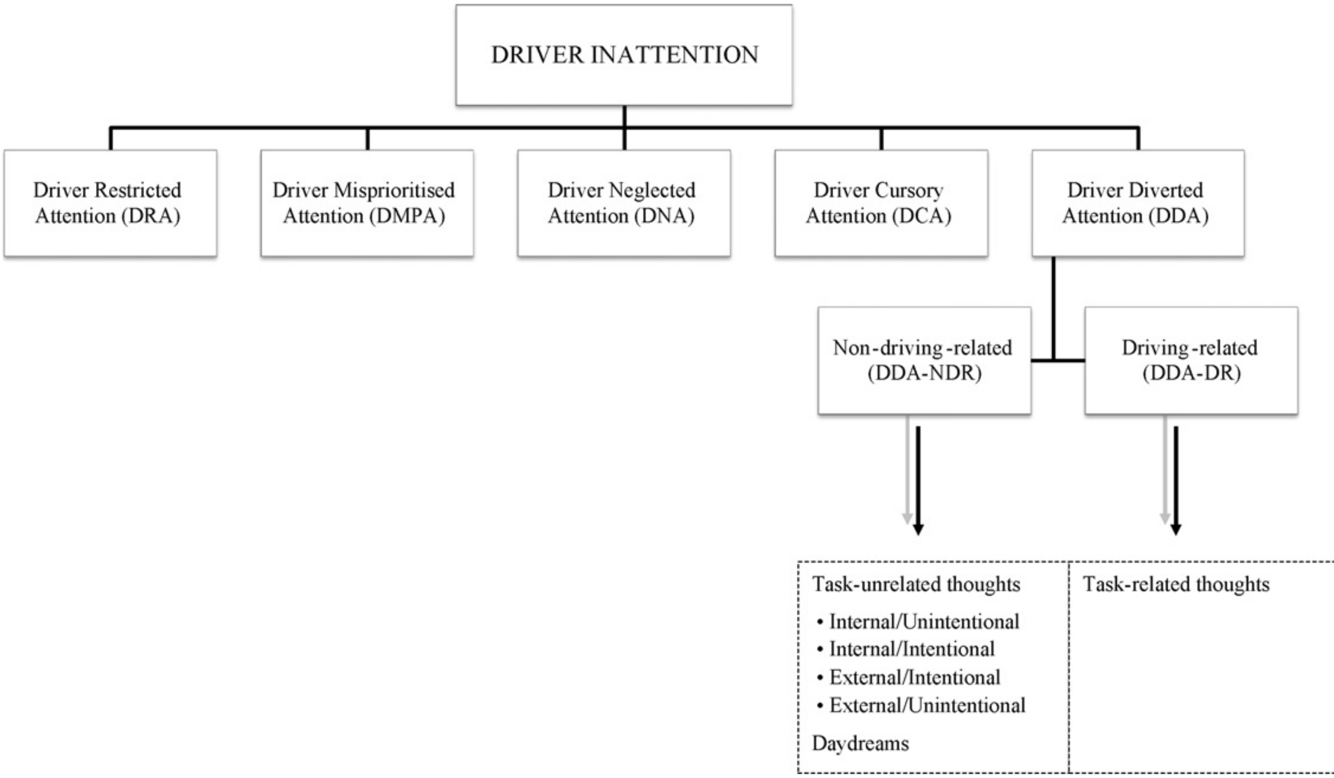

Figure 1.2. Framework for driver inattention. Reprinted from "Driver Distraction and Driver Inattention: Definition, Relationship and Taxonomy," by M. A. Regan, C. Hallett., and C. P. Gordon, 2011, *Accident Analysis and Prevention, 43*, p. 1774. Copyright 2011 by Elsevier. Reprinted with permission.

Below are the different sub-categories of driver inattention, each with their own putative mechanisms of inattention:

- Driver Restricted Attention (DRA) is inattention that is "brought about by biological characteristics of the driver that prevent him from attending to information critical for safe driving" (Regan et al., 2011, pp. 1775). Examples include moments of fatigue, saccades, or eye blinks in which a driver misses critical information or changes in the driving environment.

- Driver Misprioritised Attention (DMPA) is inattention that “arises from a failure to effectively distribute attention between multiple driving activities which are ongoing, both of which may be equally (or almost equally) critical for safe driving” (Regan et al., 2011, pp. 1775). This type of inattention occurs when, for example, a driver is shoulder checking and misses a vehicle braking ahead.
- Driver Neglected Attention (DNA) occurs when there is “insufficient or no attention to activities critical for safe driving brought about by the driver neglecting to attend to activities critical for safe driving” (Regan et al., 2011, pp. 1775). In this category, inattention is brought on by top-down processes, such as driver expectations, and occurs when, for example, a driver fails to notice a new traffic sign on a familiar route because he or she is not expecting it.
- Driver Cursory Attention (DCA) occurs when there is “insufficient or no attention to activities critical for safe driving brought about by the driver giving cursory or hurried attention to activities critical for safe driving” (Regan et al., 2011, pp. 1776). An example is when a driver is in a rush and fails to shoulder check when making a lane change, and ends up colliding with another vehicle.
- Driver Diverted Attention (DDA) is “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 et al., 2011, pp. 1776). This form of inattention is driver distraction and is distinguished from other forms of driver inattention by the presence of a triggering event or activity. DDA can further be divided into two sub-categories:

- DDA non-driving-related is “the diversion of attention away from activities critical for safe driving toward a competing non-driving-related activity” (Regan et al., 2011, pp. 1776). The source of distraction can occur from inside the vehicle (e.g., using a cell phone) or outside the vehicle (e.g., looking at a roadside billboard). It can also be triggered by internalised mental thoughts unrelated to the driving task (e.g., mind-wandering).
- DDA driving-related is “the diversion of attention away from activities critical for safe driving toward a competing driving-related activity” (Regan et al., 2011, pp. 1776). This includes activities such as attending to a warning light on the dashboard or internalised thoughts related to the driving task, such as finding the nearest gas station because of low fuel.

In summary, driver distraction (or Driver Diverted Attention) is one form of inattention, and unlike the other categories of inattention, involves a competing “trigger” (an event, activity, object, or person) that diverts attention away from driving. The driver may be distracted voluntarily (e.g., when a driver chooses to answer a cell phone) or involuntarily (e.g., when a salient billboard captures attention). Involuntary distractions have the ability to compel or induce the driver’s attention because they are unexpected (e.g., when a cell phone suddenly rings), difficult to ignore (e.g., when a baby is screaming in the backseat), highly salient (e.g., looking at an arousing roadside billboard), or interfere with concentration (e.g., being observed by a passenger) (Regan et al., 2011). For purposes of this dissertation, I will focus primarily on the sub-category of DDA non-driving-related (the diversion of attention away from driving to a non-driving-related activity).

1.2 Sources of driver distraction

Distraction associated with a non-driving related secondary task is suggested to be a contributing factor in over 23% of all traffic accidents (Klauer et al., 2006). A recent observational study reported that, of the drivers observed, 17% were engaged in a secondary task (Sullman, Prat, & Tasci, 2015). The most common activities were talking to a passenger (8.8%), smoking (1.9%), and using a hands-free phone (1.7%). Another study found that 33% of the drivers observed were involved in a distracting activity (Huisingh, Griffin, & McGwin, 2015). The most frequent distractions were interacting with another passenger (53.2%, when a passenger was present), conversing on a phone (31.4%), external-vehicle distractions (20.4%), and texting/dialing a phone (16.6%).

Driver distraction can result from sources that are internal or external to the vehicle. Internal distractions derive from inside the vehicle (e.g., a cell phone) while external distractions derive from outside the vehicle (e.g., an advertising sign). With the emergence of in-vehicle technologies (e.g., wireless communications, entertainment systems, driver assistance systems), in-vehicle distraction is a growing concern. It is estimated that distractions that occur from inside the vehicle account for 60-70% of distraction-related crashes (Stutts et al., 2001). The potential for external distraction is also on a rise as the driving environment becomes more complex, with increasing numbers of cars, pedestrians, signs, roadside billboards, and other visual information. Table 1.1 shows the various in-vehicle and external sources of distraction among drivers.

In Chapters 2 and 4, I examined the external distracting effects of emotional and highly arousing taboo information presented on roadside billboards on simulated driving performance. In Chapters 3 and 5, I investigated the impact of distraction sources that derive from inside the vehicle, namely emotion-related auditory stimuli and an in-car passenger, on driver attention and performance.

In-vehicle	**External**
Passengers	Advertising signs/billboards
Communication devices (e.g., cell phones)	Other road users (vehicles, pedestrians, cyclists)
Entertainment devices (e.g., MP3 players)	Looking for destination/location
Navigation systems (e.g., GPS)	Buildings or scenery
Vehicle controls	Checking for traffic
Food/drink	Police/crash scenes
Smoking	Sun light

Table 1.1. Sources of distraction from inside and outside the vehicle. Adapted from Gordon (2005).

Driver distraction has typically been categorized into four distinct types (Young & Regan, 2007):

- Visual distraction occurs when the driver looks away from the road (e.g., texting on a cell phone)
- Auditory distraction occurs when the driver is focused on sounds not related to the driving task (e.g., children fighting in the backseat)
- Physical distraction occurs when the driver removes one or both hands off the wheel (e.g., manipulating a device)

- Cognitive distraction occurs when attention is withdrawn from the driving task (with no visual diversion from the road)

These types of distraction can occur individually or in combination. For example, listening to the radio is a combined auditory and cognitive distraction, while looking at a salient roadside billboard is a combination of visual and cognitive distraction. In the work presented here, the focus is primarily on cognitive distraction. In one comprehensive study, the potential for distraction was measured in a variety of cognitive tasks that were performed while operating a driving simulator (Carney, McGehee, Harland, Weiss, & Raby, 2015). A combination of performances measures were collected, including reaction time and accuracy in response to a peripheral light detection task, workload measures from the NASA Task Load Index, and electroencephalographic (EEG) activity. The pattern of results showed that compared to the control driving condition (no secondary task), listening to the radio led to a small increase in cognitive distraction. Talking to a passenger and talking on the phone (hand-held or hands-free) resulted in similar levels of distraction and were associated with a moderate increase in cognitive distraction. Complex tasks, such as interacting with a speech-to-text interface, led to a significant increase in cognitive distraction. These results demonstrate the inverse relationship between the cognitive load of the secondary task and the amount of mental resources available for the driving task. Less demanding secondary tasks leave more resources available for driving, while more demanding tasks consume more resources away from driving, leading to higher levels of cognitive distraction.

In Chapters 2 and 4, I examined the potential for driver distraction from emotion-related and taboo information presented on roadside billboards (a combined visual and cognitive distraction). In Chapter 3, I investigated the influence of emotion-related auditory stimuli (an auditory and cognitive distraction) on driving performance. In Chapter 4, I examined the impact of a non-interacting in-car passenger (a cognitive distraction) on driver attention.

1.3 Causes of driver distraction

Driving is a complex task that involves a continuous switching of attention across visual, manual, and cognitive components. For safe driving, it is necessary for the driver to perceive incoming stimuli on the road (visual), comprehend the current situation by integrating information in the driving environment (cognitive), and maneuver the vehicle in a safe manner (manual). However, when distraction occurs, some of this attention is diverted away.

Attention refers to the cognitive process of being able to selectively focus on some information in the environment to the exclusion of other information present. When a stimulus is attended to, attentional resources are allocated to the stimulus to increase its information processing efficiency, while resources are drawn away from competing and irrelevant stimuli. However, research has shown that due to limits in our capacity to attend to multiple events, not all task-relevant information is processed and not all distracting information is inhibited (Scalf, Torralbo, Tapia, & Beck, 2013).

One conceptualization of attention is that it is a resource (Kahneman, 1973). This resource can be thought of as the amount of mental effort or energy required to perform a task. Resources are assumed to be limited in capacity and can be shared between tasks (Kahneman, 1973; Navon & Gopher, 1979; Wickens, 1980). During task performance, a limited supply of resources is consumed. When two tasks are performed at the same time, there is a competition for resources. The amount of resources demanded by a task is based on the difficulty of the task and the level of performance required (Wickens, 2002). The remaining resources are then allocated to the other task. As long as the available resource capacity is not exceeded, performance is successful on both tasks. However, when the limits of capacity is exceeded, the ability to attend and respond to multiple events at the same time is undermined, causing dual-task interference (Friedman, Polson, Dafoe, & Gaskill, 1982; Navon & Gopher, 1979; Wickens, 1980).

Based on this concept of limited resources, driver distraction is thought to occur when there is a competition for attentional resources between the driving task and the non-driving related task. This leads to insufficient resources for the driving task which degrades driving performance. As shown in Figure 1.3, when the combined demands of the driving task and the competing activity exceeds the driver's capacity to respond to critical events on the road, distraction arises (Lee, Young, & Regan, 2008). The degree to which a secondary task interferes with driving depends on the extent to which the secondary task competes for resources.

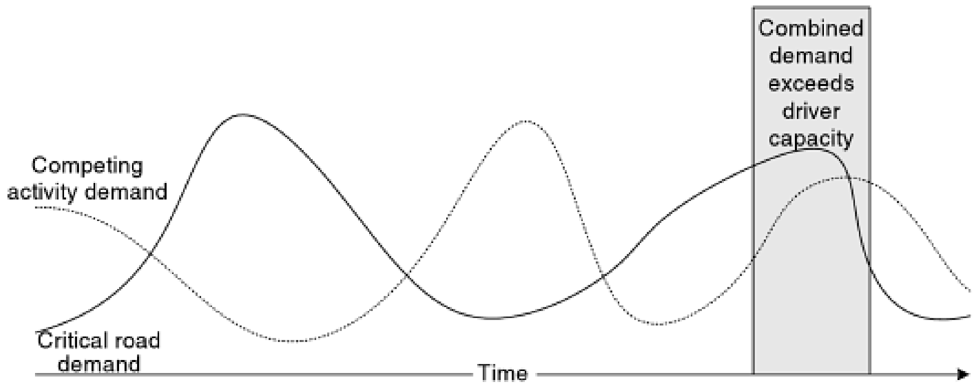

Figure 1.3. Illustration of how distraction arises. When the combined demands of the roadway and the competing activity exceeds the driver's attentional capacity it can lead to distraction. Reprinted from *Driver Distraction: Theory, Effects and Mitigation* (p. 36), by M. A. Regan, J. D. Lee, and K. L. Young (Eds.), 2008, Boca Raton, FL: CRC Press. Copyright 2008 by Taylor & Francis Group. Reprinted with permission.

In Kahneman's (1973) capacity model, attention is drawn from a single resource pool with flexible capacity. The amount of resources available is influenced by the individual's level of arousal. Attention is then allocated according to an allocation policy that determines how much attention should be given to different tasks. It is affected by factors such as enduring dispositions, which are automatic influences of attention (e.g., when a cell phone rings our attention is automatically drawn to it) and momentary intentions which are conscious decisions to pay attention to certain tasks based on current goals (e.g., when driving in heavy traffic we might decide to pay more attention to the driving task and less attention to what is on the radio). The amount of attention needed for a certain task is also adjusted by evaluating the demands made by various tasks (e.g., we might adjust the pace of a conversation with a passenger when road demands increase). Thus, according to the model, attentional resources are flexibly allocated from one task to another depending on the driver's level of arousal, automatic and voluntary shifts of attention, and the evaluation of task demands (Kahneman, 1973). If attentional demands from the driving task and the secondary task (e.g., talking on a cell phone) exceed the driver's limited capacity, performance on one or both tasks is degraded.

Contrary to a single-pool model of attention, the multiple resource theory proposes that there are several pools of resources from which attention could be drawn from (Wickens, 1980; 1984). The human operator is thought to have multiple independent information processing structures, each with its own limited resources. Separate attentional capacities are available for different input modalities (visual vs. auditory), different processing stages (perception vs. cognitive activities vs. responding), different response types (vocal vs. manual), and different visual processing channels (focal vs. ambient) (Wickens, 2002). Tasks that compete for the same structure (e.g., two visual tasks) will interfere more with each other than if they rely on different structures and draw from different resource pools (e.g., a visual task and an auditory task). Furthermore, the distinction between focal and ambient vision as separate resources may be associated with different aspects of driving performance. Focal vision is used for tasks that require high acuity, such as object recognition and visual scanning. In driving, focal vision is important for detecting signs and hazards on the road. On the other hand, ambient vision is associated with peripheral vision and is important for spatial orientation, postural control, and locomotion (Trick, Brandigampola, & Enns, 2012; Wickens 2002). In driving, ambient vision is used to maintain lateral control.

According to the multiple resource theory, secondary tasks that compete for the same pool of resources required by the driving task are more likely to impair driving performance (Wickens, 1980, 1984). It is known that driving depends on visual and cognitive/central processing in order to perceive incoming stimuli from the environment (visual) and comprehend the current driving situation (cognitive). Thus, secondary tasks that draw on these two resources are likely to distract drivers. For example, looking at a highly salient roadside billboard consumes both visual and cognitive processing resources and is likely to compromise driving performance.

In summary, both single and multiple resource pool(s) models can explain driver distraction by applying the concept of limited resources in the human attentional system. As illustrated in Figure 1.3, when a driver is multi-tasking and the demands of the road situation is low, it may not lead to distraction, as enough resources may be distributed to the non-driving related task. However, when the driver is engaged in a highly demanding secondary task and road demands suddenly increase, such as when a pedestrian suddenly runs across the street, distraction can arise, as there are now insufficient resources for both the road situation and the secondary task (Lee et al., 2008).

1.4 Measuring cognitive distraction

Cognitive distraction occurs when a competing activity withdraws attention away from the driving task. To measure cognitive distraction, experimental studies have employed a dual-task approach to assess the attentional demands of one task on another task. In a dual-task paradigm, participants are required to perform two tasks simultaneously, designated as a primary task and a secondary task. This approach is predicated on the assumption that as the primary task increases in difficulty or priority, fewer resources will be available for the secondary task (Pashler, 1994). The extent of interference between two tasks depends on the extent to which they compete for the same supply of resources (Wickens et al., 1983).

Using this logic, several experimental studies have used the dual-task approach to examine the impact that the cognitive demands of a secondary task has on driver attention and performance. In these studies, participants performed a driving task alone (single-task condition) and while simultaneously performing a secondary task (dual-task condition). In Strayer and Johnston (2001), results showed that participants involved in cell phone conversations during a tracking task were more likely to miss traffic signals and took longer to react to detected signals compared to when they were not involved in cell phone conversations. In a follow-up experiment, Strayer and Johnston (2001) found that lane-keeping performance was poorer when participants performed an attention-demanding word generation task over a cell phone (intended to simulate a cell phone conversation) compared to a simple shadowing task, in which participants repeated the words the experimenter read to them over a cell phone. With the use of an eye-tracker, Strayer and Drews (2007) found that participants using a cell phone were less likely to remember objects in the driving scene, even when they were looking directly at them, compared to the single-task driving conditions, suggesting that cell phone use while driving may lead to inattentional blindness. Other studies have cited evidence that interactions with a speech-based interface while driving a simulator increased brake reaction times (Lee et al., 2001) and reduced or delayed the detection of visual stimuli (Harbluk & Lalande, 2005). Finally, in Recartes and Nunes (2003), the effects of a variety of cognitive tasks on visual behaviour was examined while participants drove an instrumented vehicle on-road. The authors found that the visual field of drivers was reduced in the dual-task conditions and that cognitively demanding tasks reduced the detection of visual events. Taken together, these results demonstrate that increased cognitive workload resulting from secondary tasks have distraction-related effects by impairing driving performance and affecting the capacity to process visual stimuli.

Using a similar approach to these studies, all of the work presented in my dissertation employed the dual-task paradigm, in which a simulated driving task (the primary task) was performed in conjunction with a competing secondary task, in order to probe primary task performance and assess the mutual interference between tasks. In Chapters 2 and 4, participants drove a simulator while they attended to emotional and taboo information on roadside billboards and responded to target billboards. In the single-task (control) condition, participants performed the driving task with no billboards. In Chapter 3, participants drove a simulator while they attended to auditorily presented stimuli of different emotional valence and responded to targets heard. In the single-task conditions, the driving task and the listening task were performed in isolation. In Chapter 5, participants performed a driving task and a secondary oddball task alone (single-task conditions) and simultaneously. All of the conditions were performed in the presence and absence of a passenger.

1.4.1 Event-related potentials

To assess the temporal characteristics of brain activity underlying the cognitive processes involved in multi-tasking during driving, electrophysiological measures, such as event-related potentials (ERPs), have also been used. ERPs are a non-invasive measure of electrical activity in the brain recorded off the scalp using EEG. EEG is a measure of electrical potential changes generated by populations of neurons firing synchronously. The voltage measured at scalp electrodes reflects the summed excitatory postsynaptic potentials from large numbers of pyramidal neurons that are similarly oriented in the cortex. The EEG signal (voltage) represents the difference in voltage, or electrical potential, between two electrodes (Luck, 2005).

ERPs are the averaged EEG signal that have been time-locked to a specific event. A typical ERP waveform consists of a series of peaks (positive voltage deflections) and troughs (negative deflections), referred to as components. Exogenous components occur early in the waveform (within 100 ms after stimulus onset). They are linked to the physical properties of the stimulus (e.g.., its brightness) and are thought to reflect sensory processing. In contrast, endogenous components occur later and are thought to reflect various ongoing cognitive processes, including those related to perception and attention. ERP components are named according to their peak time after stimulus onset and polarity ("P" for positive deflections, "N" for negative deflections). For example, the P300 component is a positive-going waveform with a peak latency of approximately 300 ms after stimulus onset. The morphology, amplitude, latency, and topography of ERP components have been used to make inferences about the neural mechanisms underlying specific cognitive processes (Luck, 2005).

One advantage of ERPs is that they provide a relatively direct measure of neural activity. This is because the changes in electrical potential recorded on the scalp reflects the flow of current generated by neural synaptic potentials in the cortex. Another advantage of ERPs is that they provide an excellent temporal resolution in the millisecond range, which permits the precise quantification of the temporal dynamics of neural activity. However, ERPs have poor spatial resolution and are insensitive to electrical fields that are not perpendicularly oriented to the scalp or distant from it (Stern, 2013). Thus, neurons inside the sulci or within deep brain structures (such as the hippocampus) do not contribute to the EEG signal. Lastly, known as the inverse problem, it is mathematically impossible to reconstruct the source currents by localizing the generators underlying the signal measured on the scalp. This is because some currents produce surface potentials that cancel each other out. Thus, the pattern of activity measured on the scalp can produce many different combinations of source configurations (Michel et al., 2004).

One ERP component that has been widely studied in dual-task paradigms is the P300. The P300 is a positive-going waveform with a peak latency around 250-600 ms after stimulus onset. It is commonly observed in the classic oddball paradigm, in which a participant detects the occasional target stimulus interspersed among more frequent standard stimuli. The P300 is generated in response to the less frequent, target stimulus. Initially thought to be a unitary phenomenon, research has shown that the P300 consists of two subcomponents: the novelty P3a and the classic P3b (see Figure 1.4) (Squires, Squires, & Hillyard, 1975).

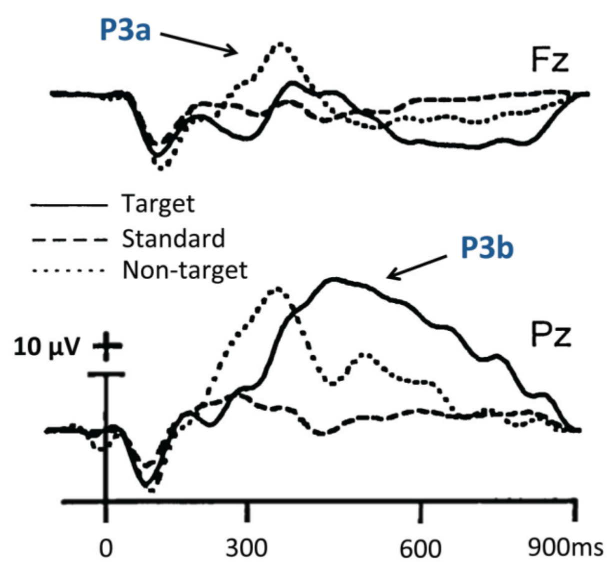

Figure 1.4. Illustration of the P3a and P3b evoked by target, standard, and non-target tones in the three-stimulus oddball task. Reprinted from “Arousal modulates auditory attention and awareness: Insights from sleep, sedation, and disorders of consciousness,” by S. Chennu and T. A. Bekinschtein, 2012, *Frontiers in Psychology, 3*, p. 2. Copyright 2012 by Chennu and Bekinschtein. Reprinted with permission.

The P3a is maximal over the frontal and central regions of the scalp with an earlier peak latency of 250-280 ms. In a three-stimulus oddball task, the P3a is generated in response to non-target distracter stimuli (e.g., the sound of a dog barking) that are inserted into the target and standard sequence. The P3a is thought to reflect the involuntary shifting of attention towards these deviant stimuli (Hillyard, Hink, Schwent, & Picton, 1975). The P3b, also referred to as the classic P300, is maximal over the centroparietal region with a peak latency of 250-500 ms. The P3b is elicited by infrequent target stimuli in the two-stimulus oddball task and is thought to reflect the amount of attention paid to a stimulus. The size of the P3b has been shown to vary inversely with target stimulus probability (Duncan-Johnson & Donchin, 1977). Source localization has identified the P3b to be generated in parietal and inferior temporal regions, while the P3a is produced in frontal areas and the insula (Bledowski et al., 2004).

Changes in P300 latency is thought to reflect the relative timing of the stimulus evaluation process. When the task of discriminating the target stimulus from the standard stimulus increases in difficulty, P300 latency is increased (Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981). P300 latency is thought to be associated with perceptual processes independent of response selection. This was demonstrated in Kutas et al. (1977), in which participants were instructed to respond as accurately or as quickly as possible. Under the accuracy instructions, peak latency of the P300 and reaction time (RT) were correlated. However, under the speed instructions, the correlation was reduced as RT occurred well before the peak latency of the P300. Thus, when speed was emphasized, the response was generated before the stimulus had been fully evaluated, suggesting that the stimulus evaluation process is independent of response-related processes (Kutas et al., 1977).

One theoretical interpretation of the P300 amplitude is that it is related to context updating in working memory, i.e., changing the mental representation of the stimulus environment in response to a change in stimulus attribute (Donchin & Coles, 1988; Polich, 2007). If an incoming stimulus matches the mental representation of the previous stimulus in working memory, no updating is required and no P300 is generated. If the stimulus is different (e.g., when a target is detected in a stream of standards), attention is engaged and the mental representation of the stimulus environment is updated, generating the P300. Thus, P300 amplitude is thought to reflect working memory processes such as context updating, or the amount of attentional resources allocated to a stimulus or task (Polich, 2007; Wickens, Kramer, Vanasse, & Donchin, 1983).

The late positive potential (LPP) occurs around the same time range as the classic P300 (onset around 400 ms) and is thought to reflect similar attention processes as the P300 (Hajcak & Olvet, 2008). Like the P300, the LPP is elicited over centroparietal regions and is larger for attended compared to unattended stimuli. The LPP is most pronounced when attention is directed toward arousing stimuli, and is thought to reflect facilitated and more elaborative processing of emotional over neutral stimuli (Schact & Sommer, 2009). In dual-task studies, there is a reciprocal relation between the amplitude of the LPP elicited by a primary task and a competing secondary task (Donchin, Kramer, & Wickens, 1986).

The negative slow wave (NSW) is another ERP associated with attentional processes. This slow, long-duration negativity can be observed following the P300 and is larger in response to novel or unexpected stimuli (Connor & Lang, 1969; Rohrbaugh, Syndulko, & Lindsley, 1979). The NSW is also thought to reflect working memory operations (Ruchkin, Johnson, Mahaffey, & Sutton, 1988). When participants maintained verbal working memory information in the auditory and visual modality, modality-specific differences were found (Ruchkin et al., 1997). NSW activity was maximal over centroparietal regions and its onset was earlier for auditory stimuli, while it was maximal over posterior regions for visual stimuli. It has been suggested that both modalities activate the phonological loop required to maintain verbal information in short-term storage, and that the onset of the phonological loop may be earlier for auditory material (Baddeley, 1986; Ruchin et al. 1997).

In dual-task paradigms, there are capacity trade-offs in attentional resources between tasks (e.g., Sirevaag, Kramer, Coles, & Donchin, 1989). The amplitude of the ERP (e.g., P300) elicited by each task is thought to reflect the difficulty of the task and the amount of resources required for task performance. In dual-task conditions, as demands of the primary task increases, fewer resources are available for the secondary task. This is reflected by a decrease in the amplitude of the ERP elicited by the secondary task (Isreal et al., 1980; Wickens et al., 1983; Singhal & Fowler, 2004, 2005). Singhal et al. (2002) demonstrated this effect in a dual-task experiment in which participants performed a primary simulated flying task in concurrent with a secondary dichotic listening task. The flying task varied in degrees of difficulty and ERPs were recorded from the dichotic task. The results showed that, compared to dichotic listening alone, the amplitude of the P300 was decreased by the introduction of the primary task, and was further reduced by an increase in flying difficulty.

Using this approach, the dual-task paradigm has been employed to assess the allocation of driver attentional resources under the cognitive demands of a secondary task. It has been suggested that tasks that are similar in kind and draw from the same resource pool presumably engage similar processes (Gopher & Donchin, 1986; Wickens, 1980). Thus, secondary tasks that tap the same cognitive resources as the driving task may lead to dual-task interference and driver distraction.

In Strayer and Drews (2007), participants drove a simulator that required them to follow a pace car that would brake randomly. The amplitude of the P300 was time-locked to the brake lights of the pace car. The results showed that the amplitude of the P300 was reduced by 50% when participants performed the task while talking on a cell phone (dual-task condition) compared to when they were not talking on a cell phone (single-task condition). These findings suggest a withdrawal of attentional resources from the driving task due to the cell phone conversation. In another study, participants performed a secondary oddball task in conjunction with a primary driving task (Wester, Bocker, Volkerts, Verster, & Kenemans, 2008). Compared to oddball alone, the P300 elicited by the oddball task was decreased in amplitude by the introduction of the driving task, supporting the notion that attentional resources normally devoted to the secondary task is consumed by the primary task in dual-task conditions.
Taken together, these findings suggest that engaging in a secondary task while driving increases the cognitive workload of drivers and leads to a division of neural resources between the two tasks.

Using a similar approach as these studies, in Chapters 3 and 5, I employed the dual-task paradigm with ERP measures to assess the impact of emotion-related auditory distraction and in-car passengers on driver attention. In Chapter 3, I examined the behavioural and ERP effects elicited by auditorily presented words of different emotional valence presented alone (single-task) and simultaneously with a simulated driving task (dual-task). ERPs were used to assess the attentional demands of the auditory distractions on the driving task. In Chapter 5, I used behavioural and ERP measures to test whether the presence of an in car-passenger affects driver attention and performance. ERPs were recorded from a secondary oddball task performed alone (single-task) and in conjunction with a driving task (dual-task). All conditions were performed with and without a passenger present. Specifically, the P300 was examined to assess the allocation of driver attentional resources in the presence and absence of a passenger.

1.5 Billboard distraction

A key element of driver distraction is a diversion of attention toward a competing activity (an event, task, object, or person) inside or outside the vehicle. This attentional engagement may be voluntary or involuntary. Voluntary distraction occurs when the driver willingly engages in a competing activity. For example, when a driver chooses to look for his or her phone or decides to reach for the cup of coffee in the vehicle. On the other hand, involuntary distraction occurs when the driver is compelled or induced to divert attention to the competing activity despite efforts to suppress the distracting information. For example, when a cell phone suddenly rings the driver's attention is automatically diverted to it even though he or she does not necessarily want to answer the phone. According to Regan et al., (2011), involuntary sources of distractions are "unusual, unpredictable, irritating, unexpected, or sudden; they have physical or psychological properties that make them highly salient; they violate our expectations" (pp. 1178).

While several studies have examined the impact of in-vehicle distractions, such as cell phone use (e.g., Strayer & Johnston, 2001), relatively little is known about the impact of distraction from external objects outside the vehicle. One external distraction that has the potential to attract attention, both voluntarily and involuntarily, is roadside billboards. Billboards are defined as any off-premise signs that are external to the vehicle and conveys visual information (Decker et al., 2015).

Hughes and Green (1986) provide evidence that a large proportion of driver attention is often diverted to advertising on signs and billboards. Other studies have shown that external distractions, including roadside billboards, are a significant risk factor in motor vehicle accidents (Stutts et al., 2001). According to Van Elslande and Fouquet (as cited in Regan et al., 2011), billboards may be categorized as an activity that contributes to human failures of “momentary interruption in information acquisition” (p. 1773), wherein the driver momentarily diverts his eyes and attention away from the driving scene to the billboard. In a study by Klauer et al., (2006), it was revealed that any distraction that takes the driver’s eyes off the road for more than two seconds doubles the risk of a crash. Thus, billboards may be potentially dangerous for drivers.

While roadside billboards are often considered a visual distraction that diverts visual attention away from the road, they also pose a cognitive distraction. For example, when a driver is looking at a billboard, cognitive processes are diverted away from the driving task to the billboard (such as when the driver determines whether the sign is relevant to the driving task). Wickens (1980) suggests that tasks that share the same information-processing structure (defined by input modality, processing stage, and response type) and draw upon the same resources are likely to interfere with each other. As visual and cognitive/central processing are essential to the driving task and involved in the attraction of roadside billboards, it is expected that billboards will interfere with driving performance (Edquist, Horberry, Hosking, & Johnston, 2011).

Roadside billboards often feature large, colorful, and conspicuous images and/or slogans to attract attention. Additionally they are often placed in strategic locations, such as in major traffic areas, to draw the attention of passing drivers. In recent years, electronic billboards with dynamic messages/images and bright lights have been installed to capture more attention than static billboards. In an early naturalistic study by Ady (1967), accident rates were compared on road sections before and after three advertising billboards were erected. One conspicuous billboard, located at a sharp bend, showed an increase in accident rates after the billboard had been placed. Ady (1976) concluded that, depending on the content of the billboard and its location, some billboards may be distracting, particularly those with conspicuous content that are located in road sections that require high attentional focus. In a more recent observational study, instrumented vehicles were used to record drivers' gaze behaviour as they passed four electronic billboards on a major road (Dukic, Ahlstrom, Patten, Kettwich, & Kircher, 2013). The results showed that drivers diverted more and longer glances toward electronic billboards than other traffic signs.

Experimental studies also provide evidence of the detrimental effects of roadside billboards. In Crundall, Van Loon, and Underwood (2006), participants watched video clips of a drive that contained street-advertisements (SLA; e.g. on a bus shelter) and raised-level advertisements (RLA; e.g., on a street light). They were instructed to look for hazards in the clip or watch for advertisements that passed. The results showed that SLAs received the most fixations when participants were asked to monitor for hazards, and the least fixations when asked to look for advertisements. The authors concluded that compared to RLAs, SLAs can attract attention at inappropriate times and reduce attention to potential driving hazards. In Young et al., (2009), mental workload and driving performance was assessed as participants drove a simulator on routes with and without billboards. The authors found that the presence of billboards increased subjective ratings of workload, impaired driving performance (in terms of lateral control), and decreased memory recall of relevant traffic signs. Bendak and Al-Saleh (2010) found that driving performance on a simulator was significantly worse on a path with billboards compared to an identical path with no billboards, as revealed by more lane wanderings and more reckless crossings of intersections. In a simulator and eye-tracking study, Edquist et al., (2011) found that the presence of billboards reduced eye fixations to the road ahead, delayed responses to road signs, and increased the number of driving errors (changes into the wrong lane or failure to change lanes). Together, all of these findings suggest that roadside billboards have visual and cognitive effects on drivers. They pose a distraction for drivers by increasing mental workload, altering drivers' visual attention, increasing the time to react to traffic signs, and impairing driving performance.

Theories of external distraction follow from theories of arousal (e.g., Hebb, 1955; Kahneman, 1973; Yerkes & Dodson, 1908). Yerkes and Dodson (1908) first proposed that the relationship between arousal and performance is an inverted U-function (see Figure 1.5). Performance is assumed to be best at moderate levels of arousal, while performance is poor at low and high levels of arousal.

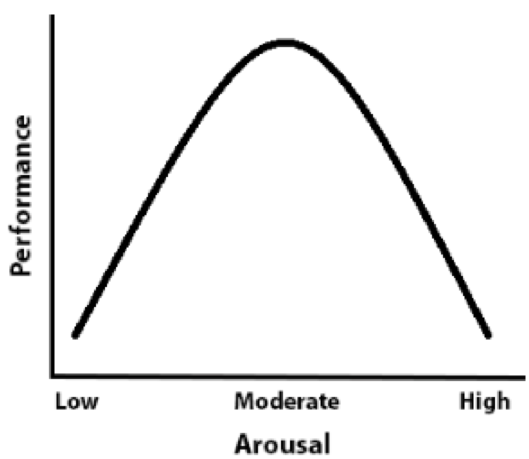

Figure 1.5. The Yerkes-Dodson curve. Adapted from Yerkes & Dodson (1908).

Kahneman (1973) proposed that arousal determines the availability of attention. Like Yerkes and Dodson (1908), he suggested that moderate levels of arousal increase the total attentional capacity, which benefits performance, while low and high levels of arousal limit the attentional capacity, which impairs performance.

Hebb (1955) adapted the Yerkes-Dodson Law to explain the function of sensory events in the environment. According to Hebb, there are two functions from sensory stimulation: the cue function serves to guide behaviour, while the arousal function strengthens or energizes behaviour (Hebb, 1955, 1972). Low arousal may lead to boredom, while high arousal may lead to stress and anxiety. Thus, humans seek a balance between being under-aroused and over-aroused in order to reach an optimal level of effective behaviour. Berlyne (1960) extended this by noting that information could modify arousal. He suggested that when humans are under-aroused, they will seek out information to raise their arousal levels; on the contrary, when humans are over-aroused, they will attempt to avoid information to lower their arousal levels (Wallace, 2003a).

The arousal and information theories were linked to Pavlov's (1927) discovery that humans in the under-aroused state were more likely to produce the orientation response (an involuntary response to new stimuli) and be distracted. In a series of experiments, Berlyne (1960) found that information that was novel, complex, and unexpected were most likely to induce the orientation response. Thus, it is suggested that when drivers are under-aroused (e.g., driving on a monotonous road), they are more likely to notice extraneous stimuli, particularly those that contain arousing and stimulating information, such as roadside billboards, and be distracted (Wallace, 2003a). On the other hand, when drivers are over-aroused (e.g., searching for hazards at an intersection), roadside billboards distract by slowing the search rate. This may lead to delayed responses to potential hazards or a failure to notice relevant road signs. For example, Theeuwes (1991) found that when participants were searching for an unknown object, response times were slowed when a distracter, such as a bright shape, appeared. This finding suggests that the orientation response (distraction) to new stimuli can occur despite efforts to ignore it (Wallace, 2003b).

In summary, distraction to features in the external environment, such as a roadside billboard, can arise when drivers are in a low arousal situation (e.g., driving on a familiar route) or a high arousal situation (e.g., driving in an unfamiliar city). In both instances, attention is diverted away from the driving task to the roadside billboard, which may be potentially dangerous.

To date, all of the studies on roadside billboards and driving performance did not control for the emotional valence of the billboard content. This is important as emotionally arousing stimuli have been shown to capture more attention than neutral stimuli. Furthermore, negative and positive emotional stimuli appear to have differential effects on attention and performance. In the next section, I will discuss the relationship between emotion and attention. I will then review the literature on the effects of emotionally arousing stimuli on task performance. Thereafter, I will discuss a different class of highly arousing stimuli, regarded as taboo stimuli. I will also relate this discussion to my dissertation work on emotion-related distraction on driving performance.

1.6 Emotion-related distraction

When we view an advertisement that depicts violence and sex our attention is captured by it. Likewise, when we witness a gruesome car accident we have a hard time focusing on anything else after. These examples illustrate the relationship between emotion and attention.

Selective attention is what allows us to prioritize processing of information so that certain information is processed more efficiently (e.g., James, 1890). Emotional relevance is an important factor in guiding selective attention as it has been shown that stimuli appraised as emotional are often adaptive and prepare the organism to act appropriately in response to environmental cues (Ellsworth & Scherer, 2003). Rolls (1990, 2000) defined emotions as "states elicited by reinforcers (rewards and punishers)." Rewards are associated with approach-related behaviours, while punishers are associated with avoidance-related behaviours. For example, a positive stimulus (e.g., money, praise) may elicit an emotion that is happiness, of which the organism will work to obtain. On the other hand, a threatening stimulus (e.g., an angry face) may produce fear, of which the organism will work to avoid. Frustration and sadness may be experienced when an expected reward is removed, and relief may be experienced when a punishing stimuli is removed. Because of limited attention, only certain stimuli in the environment can be attended to at the same time. Accordingly, it is adaptive that stimuli with emotional/motivational significance be prioritized for processing as they contribute to the survival and well-being of individuals (Compton, 2003).

Emotion is thought to involve two components: valence and arousal (Kensinger, 2009). Valance refers to how positive or negative the stimulus is, while arousal refers to how calming or exciting the stimulus is. For example, happiness is characterized as a high arousal, positive emotion, while anger is characterized as a high arousal, negative emotion. A low arousal, positive emotion is serenity, and a low arousal, negative emotion is sadness.

A large body of research suggests that attention is biased towards the emotional relevance of a stimulus. Studies have found that various emotional stimuli, such as angry facial expressions, aversive pictures (e.g., snakes), emotionally arousing words, and even emotional autobiographical memories are preferentially processed over neutral stimuli and memories (e.g, Ohman, Flykt, & Esteves; Schaefer & Philippot, 2005; for a review, see Vuillermier, 2003). Emotional capture tends to be stronger with negative stimuli, although positive emotional stimuli can sometimes produce similar effects (e.g., Brosch, Sander, Pourtois, & Scherer, 2008).

Research has also shown that arousal and valence have interactive effects (e.g., Jefferies, Smilek, Eich, & Enns, 2008). This was demonstrated in a study by Fernandes, Koji, Dixon, & Aquino (2011), where a 2 (arousal: high, low) x 2 (valence: positive, negative) design was used to assess the influence of arousal and valence on visual attention. The emotional images were displayed as participants performed a digit parity task. The results showed that response times were slower and accuracy was lower when the image was positive (high arousal) compared to negative (high arousal). For low arousal images, performance was worse when the image was positive compared to negative. These findings suggest that performance is influenced by changes in both arousal (high vs. low) and valence (positive vs. negative). Further, it has been shown that distinct neural systems are activated in response to different combinations of arousal and valence. In Nielen et al. (2009), negative pictures were found to be processed in visual and lateral prefrontal regions, while positive pictures was processed in middle temporal and orbitofrontal areas. Negative pictures that increased in arousal was accompanied by activation in the left anterior insula, while positive stimuli that increased in arousal activated the occipital cortex, parahippocampal gyrus, and posterior cingulate. These results show that the neural response to highly arousing, negative stimuli is different than the neural response to highly arousing, positive stimuli.

Electrophysiological studies have also shown enhanced ERP responses to emotional items over neutral items at different stages of stimulus processing (for a review, see Schupp et al., 2006). The early posterior negativity (EPN), which develops around 150 ms after stimulus onset, and is maximal around 250-300 ms, has been shown to be more pronounced for emotional pictures than neutral pictures (Junghöfer et al., 2006). The early time course of the EPN suggests that it is implicated in perceptual encoding and selection of stimuli for enhanced processing (Schupp et al., 2007). The late positive potential (LPP), which occurs around 400-600 ms after stimuli onset, has been implicated in sustained attention and stimulus evaluation. Larger amplitudes of the LPP have been found in response to emotional images compared to neutral images (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Another ERP that has been shown to be modulated by emotion is the sustained slow wave. The slow wave follows the LPP and appears in studies using long presentation times (Cuthbert et al., 2000). The slow wave is thought to reflect working memory processes (Ruchkin, Johnson, Mahaffey, & Sutton, 1988), and has been shown to be larger for emotional than neutral pictures (Cuthbert et al., 2000).

The rapid and reflexive manner by which attention is deployed to emotional stimuli can be beneficial but also impairing, as demonstrated by the following studies. In a variant of the dot probe task (MacLeod, Mathews, & Tata, 1986), participants responded to a target that was preceded by two stimuli (one emotional and one neutral) that appeared briefly on either side of a computer screen. Participants detected the target faster when it appeared at the same location as the emotional stimulus (valid trials). However, when the target appeared at a different location as the previous emotional stimulus (invalid trials), participants took longer to detect the target (e.g., Fox, Russo, & Dutton, 2002). These results suggest that emotion can hold attention and delay disengagement from the emotional stimulus. In Vuilleumier, Armony, Driver, and Dolan (2001), participants viewed two houses and were asked to make a same/different judgment in the presence of distracter faces. Performance was worse with fearful faces compared to neutral faces even when participants were not attending to the face stimuli. In the emotional Stroop task, participants typically take longer to name the printed color of an emotional word compared to a neutral word, suggesting that interference is occurring from the emotional word despite efforts to suppress the word meaning (Williams, Mathews, & MacLeod, 1996). Together, these findings suggest that emotional stimuli can capture attention rapidly, but also prolong the time that attention is held on the emotional stimulus before it moves on to other stimuli. Thus, attention toward emotional stimuli may come at the expense of task performance.

Surprisingly, little research has investigated the impact of emotional information on driving performance. This is particularly important as evidence suggests that the interplay of emotion and attention can affect task performance. This has important implications for road safety as the processing of emotion-related information may divert more attention away from the driving task than neutral (non-emotional) information and further increase the risk of crashes. Moreover, evidence suggests that emotional information have carry-over effects onto cognitive behaviour, including judgment and decision-making. This was demonstrated in an experiment by Lerner, Small and Loewenstein (2004). In their study, participants first watched film clips that induced feelings of disgust, sadness, or no emotion. Its subsequent effects on economic decision-making were later examined in what the participants thought was an unrelated experiment. Feelings of disgust caused participants to reduce the buying and selling prices of objects, while sadness caused participants increase the buying price but reduce the selling price. These results suggest that emotional information can have immediate and lingering effects on unrelated decisions. This may be potentially dangerous for drivers, as driving is a task that requires considerable judgment and decision-making. For example, negative stimuli that induce road rage may cause drivers to make riskier decisions.

Research on emotional driving has focused mainly on anger and aggression. Negative moods experienced while driving (e.g., frustration, anger, jealousy) have been associated with impatience, inattentiveness, recklessness, and road rage (Dula & Geller, 2003; James & Nahl, 2000). In a study that compared low and high anger drivers in daily driving, high anger drivers reported greater anger and more aggressive driving behaviours, such as speeding and having shorter times and distances to collisions, compared to low anger drivers (Deffenbacher, Deffenbacher, Lynch, & Richards, 2003). However, the effects of emotion-related distractions that are external to the driver and vehicle (e.g., roadside billboards) have yet to be examined with a driving simulator. As discussed in the previous section, roadside billboards have been shown to have a negative impact on driving performance. However, these studies did not control for the emotional content on the billboards. This is of great interest as the enhanced processing of emotional information on billboards may come at a greater expense of driving performance than neutral information. Moreover, the emotional content viewed on billboards may have carry-over effects into decision-making abilities during driving. Therefore, in Chapter 2, I examined the potential for driver distraction from emotional information presented on roadside billboards. While driving, participants viewed three types of emotional information: positive words, negative words, and neutral words. Participants also responded to target words while driving and completed a recall test of all the words at the end of the session. Performance was analysed at road sections near the billboards and away from the billboards to test for immediate and lingering effects of the emotional content.

Another research topic that is relatively unknown is the effects of emotional distraction in other modalities, such as audition. This is important as in-car listening (e.g., music) has been shown to be a risk factor among drivers (Brodsky, 2001; Brodsky & Slor, 2013). In Pêcher, Lemercier, and Cellier (2009) participants listened to experts of happy, sad, and neutral music while driving a simulator. The results showed that happy music reduced driving speeds and impaired lateral control more than sad and neutral music, suggesting that the emotional valence of music can differentially influence driving performance. However, the impact of emotion-related auditory distraction during driving has yet to be investigated with an electrophysiological approach. In Chapter 3, I explored the behavioural and ERP effects elicited by auditorily presented words of different emotional valence (positive, negative, and neutral). The words were presented alone (single-task) and while participants operated a driving simulator (dual-task). Like Chapter 2, participants also responded to target words while driving and completed a recall test of all the words at the end of the session. The primary goal was to determine whether emotion-related auditory distraction would produce similar driving behaviours as with emotional-related visual distraction (Chapter 2's work). ERPs also were used to evaluate the attentional demands of the auditory distraction on the primary driving task in dual-task conditions.

Another aspect of emotion that has not been investigated is the impact of taboo-related distraction on driving performance. Taboo stimuli has been defined as "a class of emotionally arousing references with respect to body products, body parts, sexual acts, ethnic or racial insults, profanity, vulgarity, slang, and scatology" (Jay, Caldwell-Harris, & King, 2008, pp. 84). What defines taboo stimuli from other emotional stimuli is their high arousal; thus taboo information are considered more evocative and more memorable than other types of emotional information (Janschewitz, 2008). It is suggested that taboo stimuli possess an inherent taboo-specific property, referred to as "tabooness," which is defined as how inappropriate or offensive the stimuli is to the general population (Madan, Shafer, Chan, & Singhal, submitted).

Studies have shown that taboo information is processed differently than other types of emotionally arousing information. Enhanced memory (Jay et al., 2008), increased attentional capture (Arnell, Killman, & Fijavz, 2007), and heightened autonomic responses (Harris, Aycicegi, & Gleason, 2003) have been found for taboo words compared to emotional words.

The effects of taboo-related distraction on driving is an important issue as many roadway are lined with billboard advertisements and messages that have highly arousing (e.g., sexual) content. To follow up from the study in Chapter 2, in which emotional information on roadside billboards were examined, in Chapter 4, we examined the effects that highly arousing taboo information presented on billboards have on driving performance.

Emotional experiences can be conceptualized on two levels: state and traits (Cattell & Scheier, 1961; Rosenberg, 1998). In the present work, emotional states were examined as opposed to emotional traits. It is critical to distinguish the two as research posits that state and trait emotions can have differential effects on attentional biases towards affective stimuli.

Traits are characterized by an individual's enduring disposition (i.e., personality), which is stable and consistent over time. Individual differences are due to each individual's tendency to experience a certain emotion in response to situations (Rosenberg, 1998). For example, individuals who score high in the anger trait tend to experience and express anger across a wide range of situations. On the other hand, emotional states are transient, fluctuate over time, and can vary in intensity depending on context (Rosenberg, 1998). For example, one might feel intense anxiety the day before a big exam; however after the exam, these emotions subside.

Studies have shown that emotions at the trait and state level can have different influences on attention. In Mercado, Carretié, Tapia, and Gómez-Jarabo (2006), trait anxiety (the general tendency to experience anxiety) and state anxiety (a temporary condition of negative arousal) were compared to examine their susceptibility to influences from an emotional context. In the study, low and high trait anxious participants attended to target stimuli under three types of emotional context (viewing positive, negative, and relaxing images). State anxiety was also assessed with a questionnaire. The results showed that the negative context produced an increase in attention to target stimuli only in participants with high levels of state anxiety. There were no differences associated with trait anxiety. These findings suggest that the type of anxiety experienced (trait or state) can influence how individuals allocate their attention when under negative emotional arousal.

In the work presented in this dissertation, emotional states were exclusively focused on. Participants were exposed to blocks of neutral, negative, and positive words (presented visually on billboards or auditorily) while operating a driving simulator. Thus, the effects of the words were determined by the specific context of the driving condition. The emotions experienced by each individual were transient and lasted only for the duration of the emotional condition.

1.7 In-car passengers

In the field of social psychology, extant research has shown that people’s thoughts and behaviour can be changed through the social influence of others (for a review, see Geen & Bushman, 1989). Social influence may be exerted actively or passively (Centifanti, Modecki, MacLellan, & Gowling, 2014). Active social influence involves an explicit attempt to change someone’s thoughts or behaviour through overt actions such as direct communication (e.g., goading, persuasion). Passive social influence is less explicit and occurs when, for example, behaviour is changed due to the mere presence of others or because of perceived norms, such as acting a certain way to comply with social norms.

In 1951, Asch conducted an influential study that examined the extent to which perceived social pressure by a group majority could influence an individual's opinions (Asch, 1951). In the experiment, a group of eight students participated in a visual judgment task. Seven of the eight students were confederates and their behaviour were scripted in order to examine the real participant's response to the confederates' behaviour. All of the students were given two cards, and were instructed to respond aloud which of three comparison lines matched the length of the line on the left (see Figure 1.6). Several trials occurred with different cards and the real participant always responded last in the group. On 12 of the 18 trials, the confederates unanimously gave incorrect answers. In the control condition, real participants performed the task alone with no confederates.

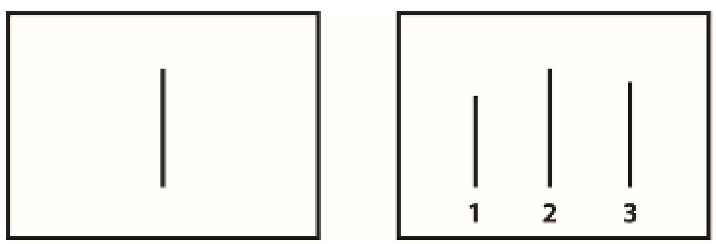

Figure 1.6. Stimuli used in Asch's conformity study. Adapted from Asch (1955).

The results showed that in the control condition, error rates were less than 1% (Asch, 1951). In the experimental condition, one-third of all responses conformed to the confederates' incorrect answer, and nearly 75% of participants conformed to the incorrect answer at least once. In interviews after the experiment, most participants stated that they knew the answer was wrong but did not want to be ridiculed by the group. Based on additional experiments, Asch determined that conformity significantly increased with majority groups of two or three people, but did not increase beyond three members (Asch, 1951, 1952, 1955).

In 1963, Milgram extended Asch's findings on conformity and conducted a controversial experiment on obedience (Milgram, 1963). Specifically, Milgram was interested in whether individuals would obey an authority figure's order to commit acts that conflicted with their moral principles. In the study, an experimenter (an actor) played the authority figure, the participant played the "teacher," and a confederate played the "learner." The teacher and learner were located in separate rooms. After learning a list of word pairs, the teacher would read the first word of a pair and the learner was to respond with the correct word that went along with it. For each incorrect response, the teacher was to administer an electric shock to the learner. As the confederate learner continued to give incorrect responses, the level of shocks increased (from 15 to 450 volts). The teacher was ordered by the experimenter to deliver shocks even when the teacher refused or expressed concern for the learner. In reality, no electric shocks were delivered to the learner. The results showed that all participants administered shocks up to 300 volts. 65% of participants continued up to the maximum level of 450 volts, even when the learner could be heard protesting in the other room. Despite feelings of tension and distress, participants continued to obey the experimenter's orders. These results provide evidence that obedience to authority is a form of social influence and that individuals will conform to the authority's orders even if they conflict with one's moral sense.

Together, these findings demonstrate the power of social influence and the ability of others to influence an individual's thoughts and behaviour. In the social situations described in Asch (1951) and Milgram (1963), participants interacted with the majority group and authority figure. However, it has been shown that the mere presence of an observer is sufficient to change how one performs on a task, even if they do not interact with the participant. Known as "social facilitation," these observer effects were demonstrated in an early study by Tripplet (1897) who found that cyclists in a race increased their speeds when an audience was watching compared to when they raced alone. Another study showed that compared to working alone, participants made less errors on a simple maze and more errors on a complex maze in the presence of a passive observer (Hunt & Hillery, 1973). Similarly, Schmitt, Gilovitch, Goore, and Joseph (1986) found that participants performed faster on a simple task (typing one's own name) and slower on a complex task (typing one's own name backwards with ascending digits interspersed between each letter) in the presence of a passive observer compared to when they were alone. These findings suggest that, in the mere presence of others, performance is enhanced on simple and familiar tasks, while performance is impaired on complex tasks.

To explain these social facilitation effects, Sanders and Baron (1975) hypothesized that observers may serve as a distraction. Distraction refers to any stimuli that is irrelevant to the individual's primary task. In this instance, the observer is a social stimulus. This distraction leads to a competition for attention between the ongoing task and the observer, which is arousing. Based on the Yerkes-Dodson Law, this increased arousal is assumed to facilitate performance. However, as the individual moves further away from the optimal level of arousal, this heightened arousal may be so disruptive that it impairs performance (Baron & Moore, 1978).

Based on these prior findings, an important question that needs to be studied more extensively is how the presence of passengers may influence driving behaviour. Recent studies have reported that in-car passengers are one of the most common sources of distraction for drivers (Huisingh et al., 2015; Sullman et al., 2015). Among teenage drivers, passengers are the leading cause of distraction-related crashes, contributing to 15% of collisions (Carney et al., 2015).

Compared to the extensive body of research on internal distractions, such as cell phone use and use of in-vehicle information systems, the internal driving environment (e.g., passengers) is less well understood, particularly at an electrophysiological standpoint. This is an important topic as the presence of a passenger changes the social context for the driver. Acting as a social stimulus, a passenger may exert social influence on the driver through active (e.g., communicating to the driver to take risks) or passive (e.g., just by being near the driver) means to change driving behaviour (Centifanti, et al., 2014). Even in the absence of any driver-passenger interactions, drivers may act in a certain way due to perceived social norms or expectations of the passenger. In addition, the presence of a passenger may influence the emotional state of the driver. For example, the driver may experience stress and anxiety when the passenger is a parent or instructor, whereas the driver may feel excitement and thrill when the passenger is a peer. Thus, the passenger's presence may be associated with emotional factors that vary depending on characteristics of the driver and passenger, such as their relationship to one another and age. These emotional aspects of the passenger may alter the driver's level of arousal to facilitate or impair driver behaviour (Sanders & Baron, 1975).

Research has shown that drivers accompanied by passengers tend to drive differently compared to those who drive alone. While some studies suggest that passengers can have a negative effect on drivers, others suggest that passengers can have a positive (i.e., protective) effect. Doherty et al. (1998) and Lin and Fearn (2003) cited evidence that drivers accompanied by passengers were more likely to be involved in crashes compared to when they drove alone. In Pradhan et al. (2014), the visual scanning range of adolescent drivers was compared when driving with a non-interacting passenger compared to driving alone. The results showed that scanning behaviour was reduced in the presence of a passenger, suggesting a narrowing of attentional focus on the driving task, even when the driver and passenger were not interacting. Contrary to these findings, Vollrath et al. (2002) reported that driving with passengers reduced the rate of crashes compared to driving alone. Lee and Abdel-Aty (2008) also found that drivers accompanied by passengers displayed safer driving behaviours (e.g., wearing seatbelts, reduced alcohol use) and reduced the likelihood of crashes. Taken together, these findings suggest that the social context, relating to the presence of passengers, can change driver behaviour. Importantly, it has been shown that the mere presence of a passenger is sufficient to change behaviour, even if they do not interact in any way with the driver.

The majority of research on passenger effects have used crash risk analyses (i.e., comparing crash rates with and without passengers), surveys, and observational methods. In addition, the few experimental studies on passenger influences have used adolescent drivers (under 17 years old), who are less experienced drivers than adults. To date, no study has used an electrophysiological approach to examine the underlying cognitive processes of an in-car passenger on drivers.

In Chapter 5, a dual-task paradigm was employed to examine the attentional effects of operating a driving simulator in the presence of a passenger. The primary driving task had two levels of difficulty and ERPs were collected from a secondary auditory oddball task. Adult participants (over 18 years of age) completed the conditions with and without a passenger present. The P300 from the oddball task was used to assess attention allocation in the presence and absence of a passenger at different levels of driving difficulty. This study is unique in that it is the first study to use an electrophysiological approach to assess the impact of an in-car passenger on driver attention.

1.8 Summary

Given that distraction can interfere with information acquisition and attentional processes while driving, the work presented in my dissertation investigated the influence of cognitive sources of distraction (both external and internal to the vehicle) on driver attention and performance, using behavioural and electrophysiological techniques. The purpose of this dissertation was to provide a comprehensive picture of the impact of emotional information and passengers on driver behaviour and shed light on the mechanisms underlying the role of cognitive distraction. The work in Chapters 2-4 is focused on the relationship between emotion and cognitive distraction, while Chapter 5 focused on the social and cognitive influence of an in-car passenger.

In Chapter 2 (*The emotional side of cognitive distraction: Implications for road safety*), participants viewed emotional information presented on roadside billboards while driving. The three types of emotional information were positive, negative, and neutral words. Participants also responded to target (animal) words while driving and completed a surprise recall task of all the words at the end of the experiment. The primary goal of the study was to examine the effects that emotional information presented on roadside billboards has on driver behaviour (driving performance, target response times, and memory recall). The secondary goal was to determine whether emotional information has carry-over effects into driver behaviour. To that end, performance was compared at road sections near the billboards and past the billboards to test for the immediate and lingering effects of emotion.

Chapter 3 (*Emotion matters: Implications for distracted driving*) examined the behavioural and electrophysiological effects of emotion-related auditory distraction during driving. Words of different emotional valence (positive, negative, and neutral) were presented in isolation (single-task) and in conjunction with a driving task (dual-task). ERPs were recorded from the auditory words. Similar to Chapter 2, participants responded to target words while driving and completed a recall test of all the words at the end of the experiment. The primary goal of the study was to determine whether distraction presented in the auditory modality would produce a similar pattern of effects as distraction presented visually, in the form of roadside billboards (the work of Chapter 2). The secondary goal was to measure ERPs elicited by the auditory distraction to assess the allocation of neural resources under single (non-driving) and dual-task (driving) conditions.

Chapter 4 (*The effects of taboo-related distraction on driving performance*) was a follow-up to the work in Chapter 2. Participants drove a simulator in the presence of roadside billboards that consisted of non-arousing (neutral) words, moderately arousing positive and negative words, and highly arousing taboo words. The primary purpose was to examine taboo-related distraction to test the influence of increased arousal on driving performance. Similar to Chapter 2, driving performance, response times to target words, and memory recall were assessed.

Chapter 5 (*Effects of a front-seat passenger on driver attention: An electrophysiological approach*) examined the nature of attentional limits while operating a driving simulator in the presence of a passenger. Using a dual-task paradigm, participant performed a primary driving task (with two levels of difficulty) and a secondary oddball task simultaneously. The conditions were performed with and without a passenger beside the participant. The primary goal of the study was to investigate the interactions between attentional demands and social demands, related to the presence of an in-car passenger, by measuring the P300 elicited by the oddball task.

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Chapter 2:

The emotional side of cognitive distraction: Implications for road safety

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ABSTRACT

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. However, little is known about the role of emotional distraction on driving, despite evidence that attention is highly biased toward emotion. In the present study, we used a dual-task paradigm to examine the potential for driver distraction from emotional information presented on roadside billboards. This purpose was achieved using a driving simulator and three different types of emotional information: neutral words, negative emotional words, and positive emotional words. Participants also responded to target words while driving and completed a surprise free recall task of all the words at the end of the study. The findings suggest that driving performance is differentially affected by the valence (negative versus positive) of the emotional content. Drivers had lower mean speeds when there were emotional words compared to neutral words, and this slowing effect lasted longer when there were positive words. This may be due to distraction effects on driving behavior, which are greater for positive arousing stimuli. Moreover, when required to process non-emotional target stimuli, drivers had faster mean speeds in conditions where the targets were interspersed with emotional words compared to neutral words, and again, these effects lasted longer when there were positive words. On the other hand, negative information led to better memory recall. These unique effects may be due to separate processes in the human attention system, particularly related to arousal mechanisms and their interaction with emotion. We conclude that distraction that is emotion-based can modulate attention and decision-making abilities and have adverse impacts on driving behavior for several reasons.

2.1 Introduction

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. In 2009, it accounted for 16% of all fatal crashes and 20% of injury crashes (National Highway Traffic Safety Administration, 2010). According to the 100-Car Naturalistic Driving Study, 22% of crashes and near crashes during the study period was associated with a driver being distracted by an object, event, or person inside or outside the vehicle (Dingus et al., 2006; Klauer et al., 2006). To date, the majority of studies have examined driver distraction from cell phone conversations (e.g., Strayer and Johnston, 2001); secondary tasks, such as eating and adjusting in-vehicle controls (e.g., Stutts et al., 2005); and roadside advertisements (e.g., Young et al., 2009); however, little is known about the role of emotional distraction on driving. This is important as prior studies have shown that emotional distracters can disrupt task performance (Holahan et al., 1978; Johnston and Cole, 1976).

Driver distraction is often defined as any activity that diverts a driver's attention away from the task of driving toward a task-irrelevant object or event, often resulting in impairment in the ability to drive safely and effectively. It has been suggested that the impairments are related to a decrease in the driver's ability to recognize and be aware of information required for critical decisions and reactions to be carried out (Ranney et al., 2000; Stutts et al., 2001). Some of the main sources of the distraction are outside objects or persons, in-car eating and drinking, cell-phone use, and adjusting dashboard controls.

Roadside billboards often provide advertising in major traffic areas where there is an increased risk for motor accidents. These billboards are largely visible and feature conspicuous images and/or slogans to attract drivers. Several studies have examined whether roadways with billboards are associated with more traffic accidents, however results have been inconsistent.

Some naturalistic studies have found no correlation between number of billboards and accident rates (Blanche, 1956) and no correlation between the number of billboards and driving performance (Lee et al., 2003). However, one ‘before and after’ naturalistic study found that ostentatious advertisements located at sharp bends increased accident rates (Ady, 1967). This suggests that conspicuous distractions located at roadways that require considerable awareness or judgment can influence driving performance.

More controlled experimental studies have revealed that reaction time is slowed when participants are to press a button in response to a target while being distracted by advertisements (Holahan et al., 1978; Johnston and Cole, 1976). Furthermore, performance decreases with number of distracters and proximity (i.e., the closer the distracting advertisements are to the target, the slower the response). Recent simulated driving studies have also demonstrated that roadside billboards have a negative impact on driving as measured by more lane deviations, more eye glances toward the billboards, and impaired memory recall of traffic signs compared to billboards (Bendak and Al-Saleh, 2010; Crundall et al, 2006; Young et al., 2009).

Overall, these observations establish that roadside billboards can visually and cognitively affect drivers (for a review, see Wallace, 2003). Two theories have been proposed to account for the negative impact of billboards on driving performance. According to the low arousal theory, when drivers are under-aroused (e.g., driving along a quiet roadway), roadside billboards “pop-out” to distract from the driving environment. In other words, when an unexpected stimulus appears, attention is immediately diverted to it at the cost of performance of the primary task. The second theory proposes that when drivers are over-aroused (e.g., watching vigilantly for a pedestrian), roadside billboards distract by providing “visual clutter.” The greater the clutter, the more likely it will interfere with the driver’s visual search of the driving scene (Wallace, 2003).

This has been supported by visual search tasks where reaction time of a target is slowed with number of distracters (Holahan et al., 1978; Johnston and Cole, 1976).

The few findings on emotional driving have shown that negative affect provokes risky and aggressive behavior, as measured by speeding and more lane wanderings (Dula and Geller, 2003); however, no study has examined the impact of emotional distractions that are *external* to the driver. This is important as the arousal level of emotional stimuli is closely linked to attention, so that a greater share of attentional resources are allocated to emotional than neutral items during processing (Schimmack, 2005; Talmi et al., 2008; for a review, see Vuilleumier, 2005). For example, findings from the emotional Stroop task have demonstrated that response times are slower when naming the ink color (e.g., red) of an emotional word (e.g., *war*) compared to a neutral word (e.g., *table*), suggesting that interference is occurring from the emotional word, despite efforts to suppress its meaning. Several studies have also established that emotional stimuli enhances memory due to prioritized attention to these items during encoding (Kensinger and Corkin, 2003; Sharot and Phelps, 2004; Talmi et al., 2008). Following a delay, more emotional items are recalled and recognized than neutral items, linking the emotional enhancement of memory effect to increased arousal and attention to these items.

While some studies have failed to find performance differences between the attentional effects of negative and positive stimuli, Pratto and John (1991) proposed that the two types of stimuli are evaluated differently. According to the categorical negativity theory, because negative stimuli are more critical for survival, we have evolved to detect these stimuli more strongly. As a result, negative stimuli attract more attention than positive and neutral stimuli. In the emotional Stroop task, it was found that negative words produced longer response times and better memory recall than positive words, suggesting that negative and positive stimuli may have different influences on attention (Pratto and John, 1991). One assumption is that negative stimuli may trigger more attentive, but time-consuming, evaluation, resulting in slower response times and better accessibility for memory (negativity bias) (Taylor, 1991; for a review, see Baumeister et al., 2001).

Together, these findings demonstrate that a) emotional stimuli produce an overall arousal effect that is closely linked to attention and, b) detection of negative and positive stimuli can differentially affect attention. This has real-world impact on driver distraction as emotional billboards can enhance the attention-arousal mechanism of emotion to increase the risk of motor accidents. For example, seeing a negative emotional billboard can result in greater diversion of attention away from the driving environment than seeing a neutral billboard. Moreover, it has been suggested that emotional information can have carry-over effects into cognitive behavior that directly influence judgments and decision-making processes (Lerner and Tiedens, 2006). Thus, another important issue to address is whether the effects of emotional information have immediate and/or lingering effects on human performance.

Accordingly, the objective of our study was to address the impact of emotional distractions by using a dual-task paradigm to examine the distracting effects of emotional information on simulated driving performance. We ran participants through four conditions: one control condition, where they drove without billboard distraction, and three experimental conditions where: 1) they drove with non-emotional (neutral) words on billboards, 2) they drove with negative emotional words on billboards, and 3) they drove with positive emotional words on billboards. In the dual-task scenarios, participants were also required to respond to target (non-emotional) words that were animal names. After all conditions were completed, we ran a surprise free recall task where participants typed out as many words as they could from memory.

Our chief measures of interest were driving performance, billboard response performance, and recall performance.

The first hypothesis is that we expect the following driving performance measures (see section 2.2.3 for details): overall course velocity, lane position in the form of root mean square error (RMSE), and steering wheel rate and angle, both in the form root mean square error (RMSE), will be most impaired in the presence of emotional words, followed by moderate impairment in the presence of neutral words, and lower impairment in the presence of no words. Because emotional words are highly arousing, we predict these items will attract attention away from the driving scene at an increased cost of driving performance compared to neutral words. The second hypothesis is that we expect that driving performance will differ in the presence of negative words compared to positive words due to their differential influences on attention. We predict that negative words will draw more attention away from driving, resulting in slower driving speed and response times than positive words. The third hypothesis is that we expect that there will be differential carry-over effects from the emotional information that impacts simulated driving performance dependent upon the valence of the information and the distance traveled after encountering the emotional billboard. The fourth hypothesis is that we expect that memory recall for emotional words will be better than memory recall for neutral words due to the memory enhancement effect of emotional items. Furthermore, because attention is drawn more strongly towards negative than positive words, we predict that more negative words will be recalled than positive words.

2.2 Methods

2.2.1 Participants

30 students (M = 21.4, SD = 2.5) from the University of Alberta participated in return for an honorarium. Participants were recruited via posters placed on campus. All were in the age range of 18 to 30 years old and had normal to corrected-to-normal vision. Data was excluded from eight participants because they did not drive to criterion (see section 2.2.4 for details).

2.2.2 Stimuli and apparatus

60 English nouns served as stimuli, with 48 words varying in valence. 16 were neutral (e.g., clock, fabric, pencil), 16 were negative emotional (e.g., abuse, reject, stress), and 16 were positive emotional (e.g., glory, humor, joy). Negative words were selected to be low in valence and high in arousal, while positive words were selected in be high in valence and high in arousal. The three categories were matched across valence for word frequency, and all negative and positive words were matched for arousal, which differed from neutral words. Outside of the three categories, there were 12 animal names (e.g., cat, lion, snake) that acted as target words that participants were instructed to respond to. All 60 words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999). See Table 2.1 for details on the word parameters and the appendix for a list of the words used. The proprietary driving simulator from STISIM Drive™ (Systems Technology, Inc.) was used to create high-resolution driving scenarios. The simulator comprised of a 22" widescreen computer monitor, steering wheel, and gas and brake pedals.

	Valence	Arousal	Word frequency	Word length
Negative	2.02 (0.31)	6.53 (0.66)	58.8 (113)	5.19 (0.83
Neutral	5.18 (0.10)	3.67 (0.45)	59.3 (52.4)	4.19 (0.91)
Positive	8.15 (0.39)	6.57 (0.73)	59.3 (60.1)	5.13 (0.89)

Table 2.1. Parameters of the words used in the experiment.

2.2.3 Design

All participants completed two practice runs and four separate conditions (one control and three experimental) in one hour. The simulated road created for the practice run was a 6.4 km-long rural scenario, consisting of straight roads and winding turns, with one lane in each traffic direction. To measure situational awareness, four pedestrians crossing the road, three stop signs, and two traffic lights were added. Pedestrians were programmed to cross the road when the participant's vehicle was within 200 m of the pedestrian. Traffic lights were programmed to turn red when the participant's vehicle was within 200 m of the traffic light. The simulations also included other visual stimuli such as buildings, trees, and other vehicles (cars, trucks, and motorcycles) that occasionally came in the opposite direction.

For the non-practice runs, the 6.4 km-long scenario was shortened to a 4.4 km-long scenario, containing three pedestrians crossing the road, two stop signs, and two traffic lights. There were four conditions in total, with the order counterbalanced across participants using a Latin-square design:

1.) In the control condition, participants drove without billboard distraction.

2.) In the neutral condition, participants drove with 16 non-emotional words and four animal words on billboards.

3.) In the negative condition, participants drove with 16 negative emotional words and four animal words on billboards.

4.) In the positive condition, participants drove with 16 positive emotional words and four animal words on billboards.

The billboards were placed on the right hand side of the road every 200 m and their content was readable to the driver when the vehicle was approximately 60 m in front of each sign. One billboard was placed before a bend, three were placed after a bend, and the rest were placed on straight paths. All target, neutral, and emotional words were randomly inserted into each driving condition.

Four driving performance measures were monitored. *Mean speed* was defined as the average longitudinal velocity, in km/h. *RMSE lane position* was defined as the root mean square deviation of the driver's lateral position with respect to the center dividing line, measured in meters. *RMSE steering wheel rate* was defined as the root mean square deviation of how fast the driver was turning the steering wheel when maneuvering, in degrees/sec. *RMSE steering wheel angle* was defined as the root mean square deviation of far the driver is turning the steering wheel with respect to 0 degrees, measured in degrees. Response times and error rates of the animal targets were logged for each condition. Response times were calculated from the time the target billboard could be read to the time the participant pressed the response button. The proportion of words recalled was also calculated for each condition.

2.2.4 Procedure

Participants were first familiarized with the driving simulator by completing the practice run twice. A two minute break was given between runs. Participants were instructed to pay attention to pedestrians, stop signs, and traffic lights, and to drive between 40 to 80 km/h to ensure that no participants were driving too slow or too fast. The experimenter sat in the same room during the practice runs to ensure the participant was driving to criterion, which was to keep a mean speed between 40 to 80 km/h and a RMSE lane position between 0.3 m to 0.4 m at the end of the second run.

Following the practice runs, participants completed four conditions (control, neutral, negative, and positive). Participants were instructed to press a button on the steering wheel using their left hand as quickly as possible when an animal target word came into view. A mandatory two minute break was given after each condition. Immediately after the simulation, a surprise recall test for the words was administered. Participants were instructed to recall by typing out as many words as possible from all conditions within three minutes.

2.3 Analyses

All effects were considered statistically significant based on the alpha level of 0.05.

2.3.1 Performance averaged over the entire simulation

All of the performance measures data was analysed with a one-way repeated measures analysis of variance (ANOVA) with four levels (driving condition: control, neutral, negative, and positive). All of the target response data was analysed with a one-way repeated measures ANOVA with three levels (driving condition: neutral, negative, and positive). All of the recall data was analysed with a one-way repeated measures ANOVA with four levels (word type: targets, neutral, negative, positive).

2.3.2 Performance averaged over particular road sections with or without billboards (targets excluded)

To further explore driving performance in this experiment we divided the roadway into four different sections for analyses: a) A 60 m pre-billboard section, where a billboard appeared in sight but the word on it could not be read, b) A 60 m billboard section, where the word on the billboard could be read, c) A 60 m post-billboard section that followed after the billboard was out of sight, and d) An extended 80 m post-billboard section that continued up to the next pre-billboard section. Thus, the two post-billboard sections were 140 m in total length.

For each participant, the mean driving performance was calculated for each section and each billboard, before being averaged across sections and billboards. Overall means were then averaged across participants. There were 16 billboards in total, excluding target words.

All of the performance measures data were analysed with a 4x3 repeated measures ANOVA containing the factors road section (pre-billboard, billboard, immediate post-billboard, extended post-billboard) and billboard word type (neutral, negative, positive).

2.3.3 Performance during road sections with target billboards only

The same analyses as in the previous section (2.3.2) were performed on the data from road sections that contained target (animal) words only.

2.4 Results

2.4.1 Driving performance data

A one-way repeated measures ANOVA revealed a significant main effect of condition on mean driving speed (MDS) [$F(3,87) = 3.98$, $p<0.01$]. Planned contrasts revealed that this effect was due to a higher MDS in the driving alone condition compared to the neutral words ($p<0.005$) and negative words ($p<0.05$) conditions. There was also an increase in MDS in the positive words condition compared to the neutral words condition ($p<0.05$). See Figure 2.1 for participants' MDS within each driving condition.

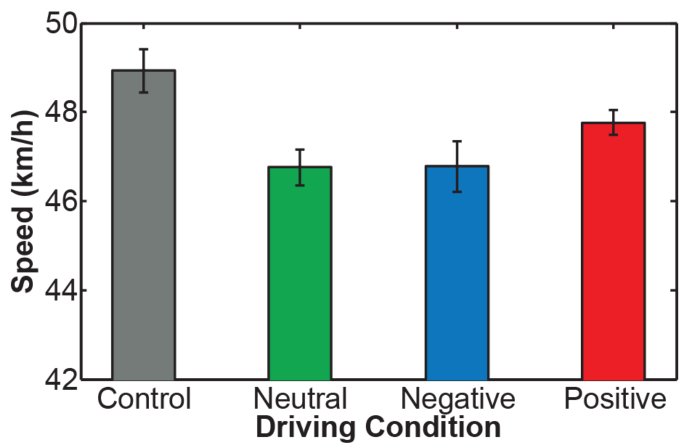

Figure 2.1. Mean driving speed within each driving condition. Error bars denote within-subject standard error of the mean.

A one-way repeated measures ANOVA revealed a significant main effect of condition on RMSE steering wheel rate [$F(3,87) = 2.89$, $p<0.05$]. Planned contrasts revealed that this effect was due to a higher RMSE steering wheel rate in the emotional words condition compared to the neutral words condition ($p<0.05$). See Figure 2.2 for participants' mean RMSE steering wheel rate within each driving condition.

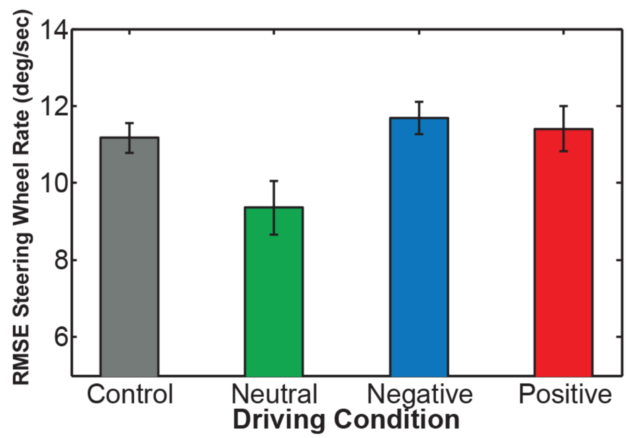

Figure 2.2. Mean steering wheel rate, in the form of root mean square error (RMSE), within each driving condition. Error bars denote within-subject standard error of the mean.

A one-way repeated measures ANOVA revealed no main effect of condition on RMSE steering wheel angle [$F(3,87) = 1.63$, $p=0.189$]. However, planned contrasts revealed that there was an effect due to a higher RMSE steering wheel angle in the negative words condition compared to the neutral words condition ($p=0.05$). See Figure 2.3 for participants' mean RMSE steering wheel angle within each driving condition.

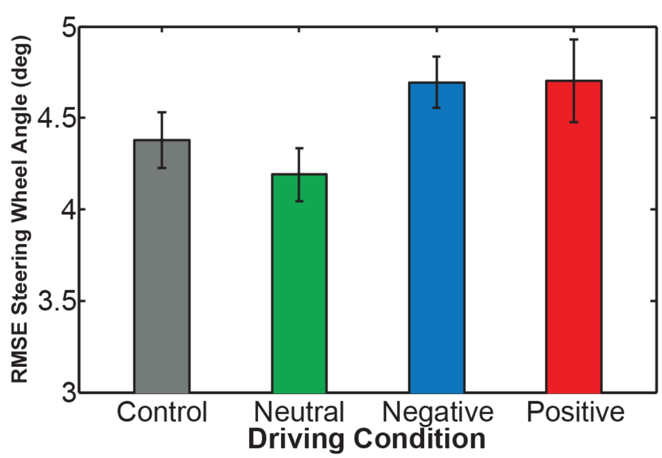

Figure 2.3. Mean steering wheel angle, in the form of root mean square error (RMSE), within each driving condition. Error bars denote within-subject standard error of the mean.

A one-way repeated measures ANOVA revealed no main effect of condition on RMSE lane position [$F(3,87) = 0.79$, $p=0.51$]. However, planned contrasts revealed that there was an effect due to a higher RMSE lane position in the driving alone condition compared to the neutral words condition ($p<0.05$). There was also an increase in RMSE lane position in the negative words condition compared to the neutral words condition ($p<0.05$). See Figure 2.4 for participants' mean RMSE lane position within each driving condition.

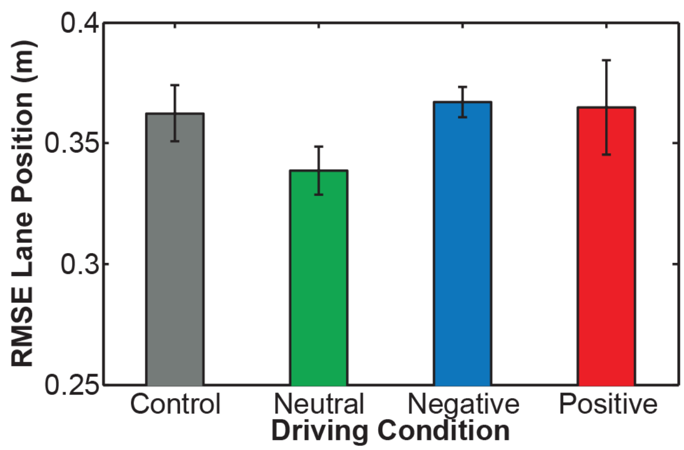

Figure 2.4. Mean lane position, in the form of root mean square error (RMSE), within each driving condition. Error bars denote within-subject standard error of the mean.

2.4.2 Target response data

No differences were found in mean error rates (1.7% for the neutral condition, 2.5% for the negative condition, and 4.2% for the positive condition). A one-way repeated measures ANOVA revealed a significant main effect of condition on target response times [$F(2,58) = 10.19$, $p<0.001$]. Planned contrasts revealed that this effect was due to faster response times to targets when the targets were embedded in the positive words condition compared to the neutral words condition ($p<0.01$) and the negative words condition ($p<0.001$). Additionally, response times to targets were faster when the targets were embedded in the neutral words condition compared to the negative words condition ($p<0.05$). See Figure 2.5 for participants' mean response times within each driving condition.

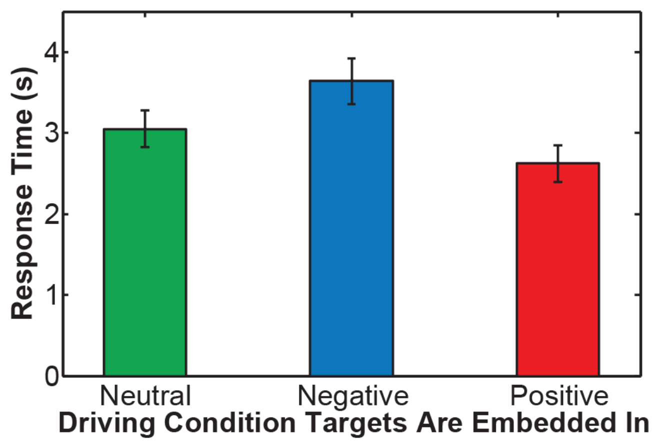

Figure 2.5. Mean response times to targets within each driving condition. Error bars denote within-subject standard error of the mean.

2.4.3 Memory recall data

A one-way repeated measures ANOVA revealed a significant main effect of condition on memory recall [$F(3,87) = 64.1$, $p<0.001$]. Planned contrasts revealed that this effect was due to more target words being recalled than neutral and emotional words combined ($p<0.001$). Further analyses revealed that more emotional words were recalled than neutral words ($p<0.001$), with negative words showing higher recall than positive words ($p<0.005$). See Figure 2.6 for participants' mean proportion of total words recalled.

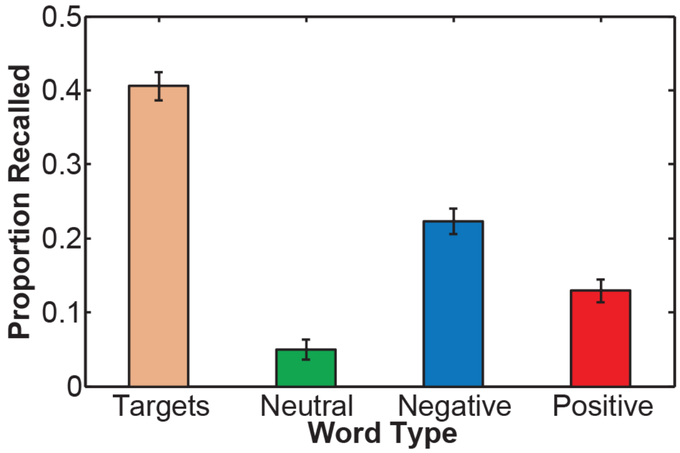

Figure 2.6. Mean proportion of each word type recalled in the free recall task. Error bars denote within-subject standard error of the mean.

2.4.4 Road sections with or without billboards (targets excluded)

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on mean driving speed (MDS) [$F(6,174) = 23.1$, $p<0.000$]. Planned contrasts revealed that this effect was due to a slower MDS in the negative ($p<0.05$) and positive words ($p<0.005$) conditions compared to the neutral words condition in the billboard sections. In the immediate post-billboard sections, MDS was slower in the positive words condition compared to the neutral words ($p<0.000$) condition. In the extended post-billboard sections, there was an effect of slower MDS in the positive words condition compared to the neutral words ($p<0.001$) and negative words ($p<0.005$) conditions. Overall, we observed that MDS was slower in response to emotional billboards compared to neutral in the billboard and immediate post-billboard sections, while MDS was slower in response to positive billboards compared to both the negative and neutral billboards in the extended post-billboard sections (see Figure 2.7).

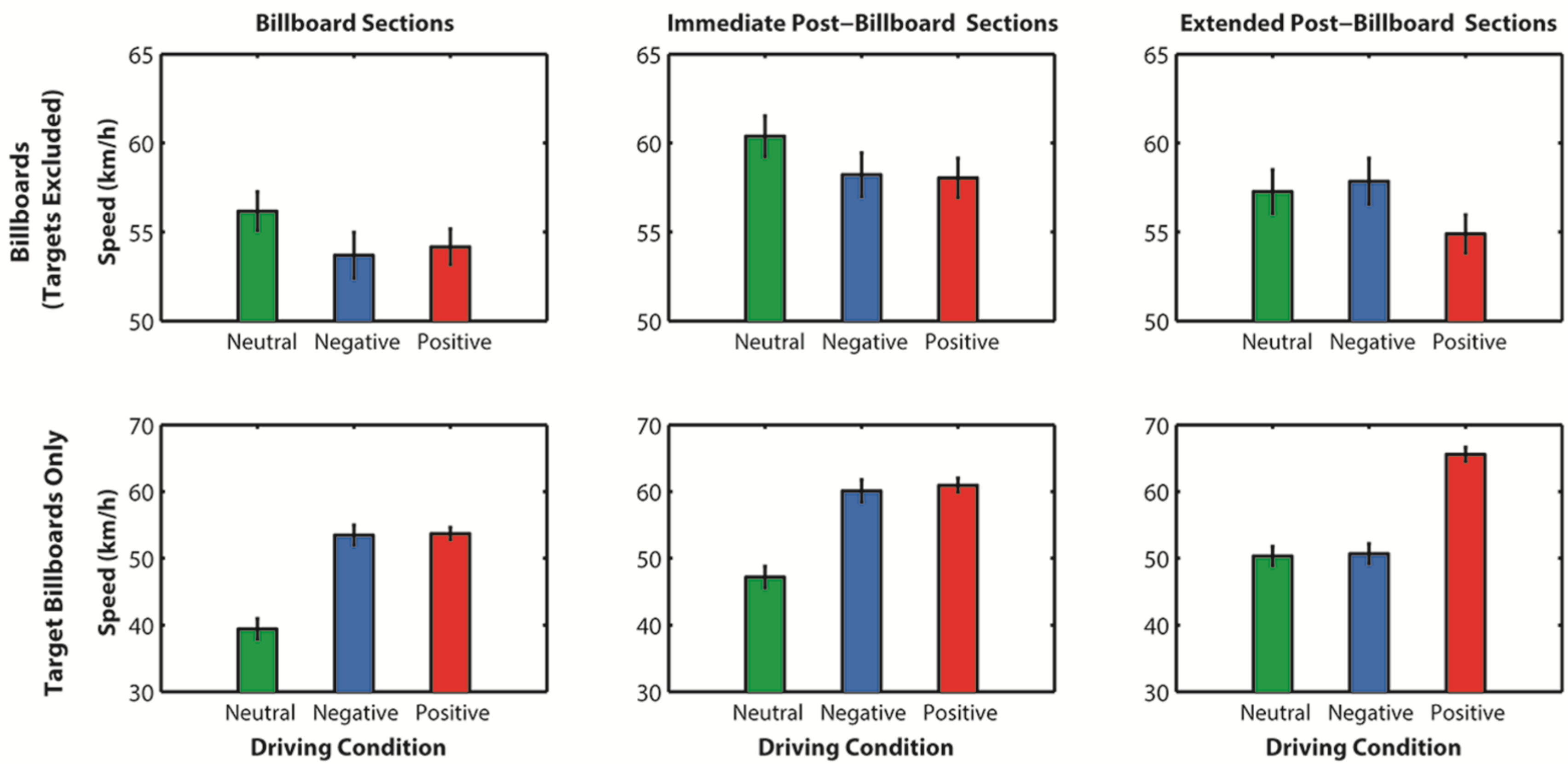

Figure 2.7. Participant's mean speed within each driving condition, separated by performance averaged over road sections during and after billboard locations (target billboards excluded) (top panel) and road sections during and after target billboards only (bottom panel). Error bars denote within-subject standard error of the mean.

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on RMSE steering wheel angle [$F(6,174) = 3.14$, $p<0.01$]. Planned contrasts revealed that this effect was due to a higher RMSE steering wheel angle in the negative words ($p<0.05$; $p<0.005$) and positive words ($p<0.000$; $p<0.05$) conditions compared to the neutral words condition in the pre-billboard and billboard sections, respectively. The means for the billboard sections were: 3.76 (SD: 3.42) in the positive words condition; 3.14 (SD: 1.17) in the negative words condition; and 2.36 (SD: 0.44) in the neutral words condition. Overall, we observed that RMSE steering wheel angle was higher in response to emotional billboards compared to neutral before and during billboard presentation.

A 4x3 repeated measures ANOVA revealed a significant main effect of road section on RMSE lane position [$F(6,174) = 0.34$, $p<0.05$]. Planned contrasts revealed that this effect was due to a higher RMSE lane position in the pre-billboard sections compared to the immediate post ($p<0.005$) and extended post-billboard ($p<0.05$) sections. RMSE lane position was also higher in the billboard sections compared to the immediate-post billboard sections ($p<0.05$), and higher in the extended post-billboard sections compared to the immediate post-billboard sections ($p<0.005$). Overall, we see that RMSE lane position is higher before and during billboard presentation compared to the immediate-post billboard sections. RMSE lane position is also higher in the extended-post billboard sections compared to the immediate-post billboard sections.

2.4.5 Road sections with target billboards only

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on mean driving speed (MDS) [$F(6,174) = 43.9$, $p<0.000$]. Planned contrasts revealed that this effect was due to a higher MDS in the negative words ($p<0.000$; $p<0.001$; $p<0.000$) and positive words ($p<0.000$; $p<0.000$; $p<0.000$) conditions compared to the neutral words condition in the pre-billboard, billboard, and immediate post-billboard sections, respectively. In the extended post-billboard sections, there was an effect of a higher MDS in the positive words condition compared to the neutral words ($p<0.000$) and negative words ($p<0.000$) conditions. Overall, we observed that MDS was greater for target billboards in the emotional words conditions compared to the neutral words condition in all road sections, except the extended post-billboard sections. In the extended post-billboard sections, MDS was greater for target billboards in the positive words condition compared to the neutral and negative words conditions (see Figure 2.7).

A 4x3 repeated measures ANOVA revealed a significant road section x word type interaction on RMSE steering wheel angle [$F(6,174) = 28.9$, $p<0.000$]. Planned contrasts revealed that this effect was due to a lower RMSE steering wheel angle in the negative ($p<0.001$) and positive words ($p<0.000$) conditions compared to the neutral words condition in the pre-billboard sections. RMSE steering wheel angle was also lower in the positive words condition compared to the negative words condition in the pre-billboard sections ($p<0.001$). In the billboard sections, there was an effect of lower RMSE steering wheel angle in the positive words condition compared to the neutral words condition ($p<0.000$). The means for the billboard sections were: 0.40 (SD: 0.40) in the positive words condition; 1.80 (SD: 5.57) in the negative words condition; and 3.22 (SD: 0.39) in the neutral words condition. Overall, we observed that RMSE steering wheel angle was lower in response to target billboards in the emotional words (particularly positive) conditions, compared to the neutral words condition, before and during billboard presentation.

A 4x3 repeated measures ANOVA revealed no significant interaction or main effects of road section or word type on RMSE lane position.

2.5 Discussion

The purpose of this study was to examine the potential for driver distraction from emotional information presented on roadside billboards using a dual-task paradigm. This purpose was achieved using a driving simulator and three different types of emotional information. The main findings suggest that driving performance is differentially affected by the valence (negative versus positive) of the emotional content. Moreover, these unique effects are likely due to separate processes in the human attention system, particularly related to arousal mechanisms and their interaction with emotion. It has been well-established that emotional stimuli can modulate the allocation of attention (Easterbrook, 1959), and more recently, it has been suggested that emotion can impact other cognitive control mechanisms, such as working memory and decision-making (Johnson et al., 2005). Based on our findings, it appears that there are at least two mechanisms of emotion-related distraction that have the potential for impact on real-world driving performance. Furthermore, driving performance varied across different sections of the driving scenario relative to the physical position of the billboards, and also depended upon whether the driver responded (targets) to the billboard information or did not respond (non-targets).

The recall task showed that memory performance was highest for target words compared to all other conditions of words. This was expected since drivers needed to attend as well as respond to these specific words. The results also showed that words describing positive and negative emotions were more likely to be recalled than neutral words. This is consistent with previous research showing enhanced attentional processing of emotional information (Kensinger and Corkin, 2003; Sharot and Phelps, 2004; Talmi et al., 2008). One possible interpretation of this finding is that drivers were taking their eyes off the road for an extended period of time in order to process the emotional billboards at the expense of processing information that was more critical for safe driving. In a real driving scenario, this could cause drivers to lose control of their vehicle and/or fail to detect other relevant roadway information. Interestingly, more negative valence words were recalled than positive valence words supporting the idea that negative stimuli received more attention than positive stimuli (Ohira et al., 1998; Robinson-Riegler and Winton, 1996). However, faster target responses were observed during blocks of positive emotional words compared to negative and neutral words. Thus, while positive words do not capture attention to the same degree as negative words, they result in quicker responses. This is consistent with other studies showing that positive words (Feyereisen et al., 1986; Pratto and John, 1991; Stenberg et al., 1998) and positive pictures (Lehr et al., 1966; Leppänen et al. 2003) are associated with faster manual responses than negative and neutral items. Other studies have also shown that negative stimuli hold attention for a longer period of time, which can also manifest in slower response times (for a review, see Baumeister et al., 2001; Fiske, 1980; Pratto and John; 1991; Taylor, 1991). Overall, drivers had lower mean speeds for the entire driving scenario when there were negative and neutral words on the billboards. However, the positive words were associated with an increase in mean speed. Other related research has shown that positive emotions are associated with better and faster physical performance, including jumping higher or running faster, compared to negative and neutral emotions (McCarthy, 2011; Ruiz, 2008). It is possible that this same type of faster behavior may also be present in driving, and may be due to similar mechanisms connecting positive emotion to human performance.

We conducted some additional analyses that divided the roadway into different sections in order to examine driving performance before, during, and after the billboards were readable. These analyses showed that billboards with negative and positive words were associated with a decrease in immediate driving speed compared to neutral words. That is, the speed of the vehicle slowed during the section of the road adjacent to where the billboard was posted and could be read, suggesting that the drivers' attention was captured by the emotional billboards. Moreover, this slowing effect carried over to sections of the road following the location of the billboard in the positive emotional conditions only. Interestingly, the pattern of effects was reversed for target signs (animal words), such that driving speed increased during the section of the road where the target billboard could be read in the emotional conditions compared to the neutral conditions, and again, these effects lasted longer in the positive emotional conditions. Thus, we observed reciprocity, where positive billboards were associated with decreased speed for a full 200 m following the sign position, but when the sign was a target word requiring a response, the effect was an increase in speed for the full 200 m following the sign position. These findings suggest that positive billboards have both immediate and lingering effects on driving behavior and may actually be more detrimental than the effects of negative billboards.

Drivers were able to maintain appropriate lane position (based on corrective steering wheel activity) when encountering negative and positive words compared to neutral words. However, these steering wheel effects were restricted to roadway positions where the billboards were visible and disappeared after the billboard had been passed. Thus, the steering wheel activity did not linger as long as the mean speed effects. Moreover, the steering effects were reversed during target billboard presentation, where there was more steering wheel activity in the neutral conditions compared to the emotional conditions. Thus, as in the mean driving speed data, we observed a switch in performance between the emotional billboards and the non-emotional target billboards that presumably required additional cognitive control processing associated with decision and response preparations. This pattern of effects may also be associated with the fact that we did not observe an increase in lane deviations.

Using a driving simulator limits the generalization of our results to the real world. However, our simulator approximates the real world experience in that participants must a) do a visual search of the environment for pedestrians, stop signs, and traffic lights, b) brake and respond accordingly, and c) maintain lane position. According to De Waard (1996), our primary measures of driving performance – RMSE lane position and RMSE steering wheel rate – are valid measures that resemble measures used in on-road driving studies. While not a substitute for real driving, various studies have shown that driving simulators have predictive validity (Bédard et al., 2010; Lew et al., 2005; Reed and Green, 1999). Furthermore, our simulation did not include an immersive environment where the visual array surrounds the operator's head, which limits the impact of our findings.

2.6 Conclusions

The relationship between emotion and cognition is complex, but it is widely accepted that human performance is altered when a person is in an emotional state. It is critically important to fully understand the impact of emotion on driving performance because North American roadways are lined with billboard advertisements and messages that contain many varieties of emotional information. Moreover, the distracting effects of emotion may come in other forms such as cell phone or passenger conversations, radio information, and texting information.

Driving is a task that requires a high level of attentional resources in order for the driver to regulate proper speed, maintain effective steering control and lane position, and safely respond to pedestrians, roadway signs, traffic lights, and other relevant sources of information. However, attentional resources are limited in nature and when distraction occurs the operator will often experience deficits in their driving performance. The findings in the present study show that distraction that is emotion-based can seriously modulate attention and decision-making abilities and have adverse impacts on driving behavior for several reasons. Our results demonstrate that emotional distraction can impact driving performance by reorienting attention away from the primary driving task to the emotional content and negatively influence the decision-making process. One implication of our findings is that roadway safety could be improved with a careful consideration for where on the road certain billboard types are placed. For example, it may not be ideal for emotionally arousing billboards to be placed on parts of roadways that require a high degree of visual attention, such as sharp bends, or sites where accident rates are high. The results reported here offer a small window into potential mechanisms for emotional distraction and may inform procedures for driver training, traffic safety issues, and roadway design. Future studies will be necessary to further examine the nature of emotional distraction in other conditions such as under day and night driving conditions, bad weather conditions, as well as to examine the brain-based effects, perhaps revealed by event-related brain potentials and eye tracking.

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2.8 Appendix

List of words* used in the experiment

Neutral	Negative	Positive	Animals
BARREL	ABUSE	BEACH	BIRD
CLOCK	CANCER	CASH	CAT
ENGINE	DEVIL	CHEER	COW
FABRIC	FEAR	COMEDY	DOG
FOOT	KILLER	FAME	FISH
ITEM	PRISON	FUN	FROG
LAWN	REJECT	GLORY	LAMB
MONTH	SLAVE	GOLD	LION
PATENT	STRESS	HEART	OWL
PENCIL	THIEF	HUMOR	RABBIT
PHASE	TOXIC	JOKE	SHARK
RAIN	ULCER	JOY	SNAKE
STATUE	VICTIM	KISS	
TABLE	VOMIT	LOVE	
TAXI	WAR	SEX	
THEORY	WHORE	WIN	

*Words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999).

The work in Chapter 2 examined the impact of emotion-related distraction presented visually, in the form of roadside billboards. Chapter 3 extended these findings by addressing how distraction presented in the auditory modality would compare to distraction presented visually. Event-related potentials (ERP) elicited by the auditory distraction were also collected to assess the allocation of neural resources during driving (dual-task) and non-driving (single-task) conditions.

Chapter 3:

Emotion matters: Implications for distracted driving

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ABSTRACT

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. Roadside billboards containing negative and positive emotional content have been shown to influence driving behaviour by modulating attention; however, the impact of emotion-related auditory distraction on driving is relatively unknown. In the present study, we explored the behavioural and event-related potential (ERP) effects elicited by auditorily presented words of different emotional valence during driving (dual-task) and non-driving (single-task) conditions. The results demonstrate that emotion-related auditory distraction can differentially affect driving performance depending on the valence of the emotional content. Negative distractions reduced lateral control and slowed driving speeds compared to positive and neutral distractions. On the other hand, the results revealed an arousal effect on memory and decision-making during driving as performance improved with both negative and positive distractions. Finally, ERPs elicited by the auditory distractions were reduced in amplitude during driving compared to non-driving, revealing a division of cognitive resources under dual-task demands. These findings have important implications for road safety and bring to light the detrimental effects of negative emotional auditory content on driving performance. Furthermore, these findings show that emotional valence and arousal can differentially influence behaviour.

3.1 Introduction

Driver distraction is estimated to be one of the leading causes of motor vehicle accidents. In 2011, it accounted for 10% of all fatal crashes and 17% of injury crashes (NHTSA, 2013). In a recent review by Young and Salmon (2012), secondary task distraction is suggested to be a contributing factor in at least 23% of all accidents.

To distinguish between inattention and distraction, driver distraction has been defined as "a specific type of inattention that occurs when drivers divert their attention from the driving task to focus on some other activity instead" (NHTSA, 2013). Thus, distraction involves a triggering event or activity as opposed to inattention due to a cognitive state (e.g., fatigue). Common sources of distraction include cell-phone use, use of in-vehicle information systems, and interactions with passengers. Distraction can also occur when highly salient objects (e.g., a roadside billboard with emotional content) inadvertently draw the attention of drivers (Chan and Singhal, 2013; Megias et al., 2011).

One theoretical account for the cause of distraction is that insufficient attention is devoted to the driving and non-driving related task at the same time. This can occur when the combined demands of driving and the competing activity exceeds the driver's capacity to respond to critical events on the road (Lee et al., 2008). Thus, when drivers are highly engaged with another task, their attention may not be optimal for safe driving due to reallocation of attention to the secondary task.

3.1.1 Emotional distraction

Emotional stimuli have been widely reported to capture attention more readily than neutral stimuli (Compton, 2003; Vuilleumier, 2005). However, compared to the extensive body of research on secondary task distraction such as cell-phone use, emotion-related distraction is a relatively recent topic in the driver distraction literature. This has important implications as enhanced processing of emotional stimuli may come at the expense of driving performance compared to neutral stimuli.

In Chan and Singhal (2013), roadside billboards containing words of different emotional valence were shown to have differential effects on driving behaviours. The presence of negative words decreased driving speeds and slowed response times compared to positive words. A similar study found that the number of eye fixations and total fixation time elicited by emotional images on billboards were larger than for neutral billboards. In addition, gaze disengagement was later for negative billboards compared to positive and neutral ones (Megias et al., 2011). In an interesting study by Trick et al. (2012), negative images were associated with poorer steering control than positive images. Together, these findings demonstrate that visual stimuli with emotional, particularly negative, content can modulate attention to influence driving performance. It has been suggested that negative stimuli may trigger more attentive, but time-consuming, evaluation than positive stimuli (Pratto and John, 1991); therefore, negative content may lead to worse driving performance.

However, the impact of emotional distraction in other modalities, such as audition, is relatively unknown. This is important as research has shown that in-car listening while driving can be an auditory distracter (Brodsky, 2002, 2013). Only a few studies have examined the effects of emotional auditory content while driving. In Pêcher et al. (2009), happy music reduced driving speeds and impaired lateral control more than sad and neutral music. In Di Stasis et al., (2010), emotional sounds (e.g., a scream or laugh) decreased alertness in drivers compared to a neutral beep. All these results demonstrate that emotional music and sounds can influence driving performance. However, the impact of emotion-related auditory distraction while driving has yet to be investigated with an electrophysiological approach.

3.1.2 Event-related potentials

It is widely considered that the human attention system has a limited capacity, and studies show that when two tasks are performed at the same time, there is competition for attentional resources (Bunge et al., 2000; Szameitat et al., 2002). Event-related potentials (ERPs) are well-suited for studying attention-related phenomenon because of their excellent temporal resolution. Extracted from electroencephalography (EEG), ERPs are averaged brain responses that are time-locked to the onset of a stimulus. It is generally considered that the morphology, timing, and topography of ERP components reflect various ongoing cognitive processes, including those related to attention and working memory (Luck, 2005).

In Strayer and Drews (2007), the amplitude of the P300, an ERP known to reflect attention allocation, was reduced in response to the onset of participants' brake response to a pace car's brake lights when conversing on a cell-phone (dual-task) compared to driving alone (single-task). Memory performance on objects in the driving scene was also worse in dual-task conditions, suggesting a diversion of attention from driving to the cell-phone conversation. In a similar study using functional magnetic resonance imaging (fMRI), concurrent performance of a sentence listening task on driving was shown to decrease brain activation associated with the driving task, namely in parietal areas, which has been implicated in the allocation of visual spatial attention (Just et al., 2008). At the same time, driving performance was impaired compared to driving alone. These findings provide evidence of driver distraction caused by dual-task interference, in which a secondary task hinders driving behaviour by competing for attentional resources. In Wester et al. (2008), ERPs related to an auditory oddball task were reduced in amplitude during driving compared to non-driving conditions, indicating that attention was allocated to maintain focus on the driving task at the cost of processing the secondary stimuli. Taken together, these results demonstrate that multi-tasking during driving can increase cognitive workload and lead to competition for limited neural resources.

3.1.3 Research objectives

In the present study, we sought to examine the nature of distraction due to emotion by measuring the behavioural and electrophysiological effects elicited by auditorily presented words of different emotional valence (neutral, negative, and positive). The words were presented alone (single-task) and while participants operated a driving simulator (dual-task).

There were seven conditions in total: one control condition, where participants drove with no auditory distraction; three single-task conditions, where they listened to: (1) neutral, (2) negative, and (3) positive words; and three dual-task conditions, where they drove and simultaneously listened to: (1) neutral, (2) negative, and (3) positive words. At the same time, decision-making was assessed by having participants respond to target words (animal names) presented in the context of the three types of words. At the end of the study, participants were given a surprise free recall test in which they were asked to recall as many as words as possible from all conditions.

Word stimuli were used in order to more directly compare the findings in this study with those in Chan and Singhal (2013). Our main objective was to determine whether emotion-related auditory distraction would produce similar driving behaviours as has been shown with visual distraction, where driving performance and response times were shown to be differentially affected by the emotional valence of words on roadside billboards (Chan and Singhal, 2013). Our secondary objective was to use ERPs elicited by the auditory distraction to assess the allocation of neural resources under single (non-driving) and dual-task (driving) conditions. To that end, we collected behavioural and ERP data while participants drove a simulator and concurrently listened to words of different emotional valence. We hypothesize that emotion-related auditory distraction will have differential effects on driving behaviours and memory depending on the emotional valence of the words; specifically we predict that (1) negative words will have a higher influence on driving performance than positive and neutral words due to greater recruitment of attentional resources, and (2) more negative words will be recalled than positive and neutral words. We also hypothesize that ERPs elicited by the auditory words will be reduced in amplitude under dual-task compared to single-task conditions, presumably due to a division of neural resources between the driving task and processing of the distracting stimuli.

3.2 Methods

3.2.1 Participants

25 participants (13 males; *M* = 21.1, *SD* = 3.35, range 18-30 yrs) from the University of Alberta were recruited via advertisements placed on campus. All were in the age range of 18 to 30 years old and had normal to corrected-to-normal vision. Each received $20 as an honorarium.

3.2.2 Stimuli and apparatus

120 words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999). As detailed by Bradley and Lang (1999), each word has an assigned valence value on a scale from 1 (“very negative”) to 9 (“very positive”), and an arousal value from 1 (“not arousing”) to 9 (“highly arousing”). Of these words, 40 were neutral, 40 were negative, and 40 were positive. All words were matched for word frequency. Emotional words were matched for high arousal, with negative words being low in valence and positive words being high in

valence. In addition, 30 animal words were selected from the University of Toronto categorized word pool (Murdock, 1976), which acted as target words that participants had to respond to. See Table 3.1 for details on the word parameters and the appendix for a list of the words used.

	Valence	Arousal	Word frequency
Negative[a]	2.24 (0.74)	6.30 (0.69)	49.0 (81.9)
Neutral[a]	5.27 (0.41)	3.53 (0.34)	49.6 (54.9)
Positive[a]	7.91 (0.42)	6.30 (0.72)	48.0 (56.8)
Target (animals)[b]	4.95 (1.43)	4.49 (1.11)	9.27 (11.14)

Table 3.1. Mean and standard deviation ratings for the words used in the experiment.

[a]Ratings were taken from the Affective Norms for English Words database (Bradley and Lang, 1999).

[b]Ratings were taken from Warriner, Kuperman, and Brysbaert (2013).

All words were spoken by a male voice and presented through two speakers located on either side of the monitor. They were presented in a randomized manner with an interstimulus interval ranging 2,500-7,500 ms (volume: 70-85 dB SPL).

Participants drove a STISIM Drive™ (Systems Technology, Inc.) fixed-based driving simulator modeled as a small automatic transmission passenger vehicle. The simulator consisted of a steering wheel, gas/brake pedals, and a 22” widescreen computer monitor providing a projected field-of-view of approximately 60° horizontal and 40° vertical. The display included a rear-view mirror and speedometer.

3.2.3 Design and procedure

The driving scenario was 3.6-km long and simulated a two-lane, bidirectional highway in a rural setting. The road consisted of straight roads and slight bends. Daytime and good weather conditions were adopted to provide good visibility. In addition, buildings, trees, and oncoming traffic were included to enhance realism.

Participants were first familiarized with the simulator by completing a practice run of the driving scenario. They were instructed to drive their vehicle in the center of their lane and maintain a speed of 40-80 km/h. The experimenter monitored the practice run to ensure participants were driving to criterion.

Following the practice, a repeated-measures design was employed in which seven conditions (one control and six experimental) were performed in 1 hr. The order of all seven conditions was counterbalanced across participants.

The single-task conditions were: (1) listening-neutral, (2) listening-negative, and (3) listening-positive. The dual-task conditions were: (1) driving-neutral, (2) driving-negative, and (3) driving-positive. In the control condition participants drove with no auditory distraction.

In each experimental condition, participants were auditorily presented with 25 words, of which 20 were neutral, negative, or positive, and five were animal names. Participants were instructed to press a button on a response pad located near their dominant hand as quickly as possible when they heard an animal target word. In the single-task conditions, participants fixated on a dot located in the center of the monitor. In the dual-task conditions, participants operated the driving simulator at the same time.

Upon completion of all conditions, participants were given a surprise free recall test on the words, in which they were instructed to type as many words as they could from memory within 5 min.

3.2.4 Behavioural measures

Three driving performance measures were collected: speed, lane maintenance (assessed as the root mean square error [RMSE] of the driver's lane position down the center of the road), and steering wheel rate (assessed as the RMSE of how fast the driver is turning the steering wheel while doing steering manuveurs) (Rosenthal, 1999). Response times (RTs) and error rates for the animal target words were also collected. Error rates included false positives (i.e., responses to a non-target word) and misses (i.e., failure to respond to the target at all). Proportion of words recalled was defined as the mean number of correct words recalled of each word type, divided by the total number of words presented of each type.

3.2.5 EEG recording and pre-processing

Recording took place in a sound-attenuated and electrically shielded room. The EEG was recorded with 256 electrodes referred to the vertex electrode (Cz) using a Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, OR). Impedances were kept below 50 kΩ. After re-referencing to a common average reference, the data was filtered with a 50 Hz low-pass and a 1 Hz high-pass filter before being segmented into 1,200 ms epochs, time-locked to the auditory stimuli (200 ms pre-stimulus and 1,000 ms post-stimulus). Eye blinks and eye movements were corrected for using an ocular artifact algorithm (Gratton et al., 1983). Grand averages of the ERPs were calculated for all participants from artifact-free EEG segments from each condition.

3.3 Results

All effects were considered statistically significant based on the alpha level of 0.05. Greenhouse-Geisser corrections were applied to account for violations of sphericity.

3.3.1 Driving task

All of the driving performance data were analysed with separate one-way repeated measures analysis of variance (ANOVA) with four levels (driving condition: control, neutral, negative, positive).

Results revealed a significant main effect of driving condition on mean driving speed, $F(3, 72) = 3.36$, $p < 0.05$, $\eta_p^2 = 0.123$, as shown in Figure 3.1a. Planned contrasts indicated that mean speed was slower in the negative words condition compared to the control ($p < 0.05$), neutral words ($p < 0.05$), and positive words ($p < 0.05$) conditions.

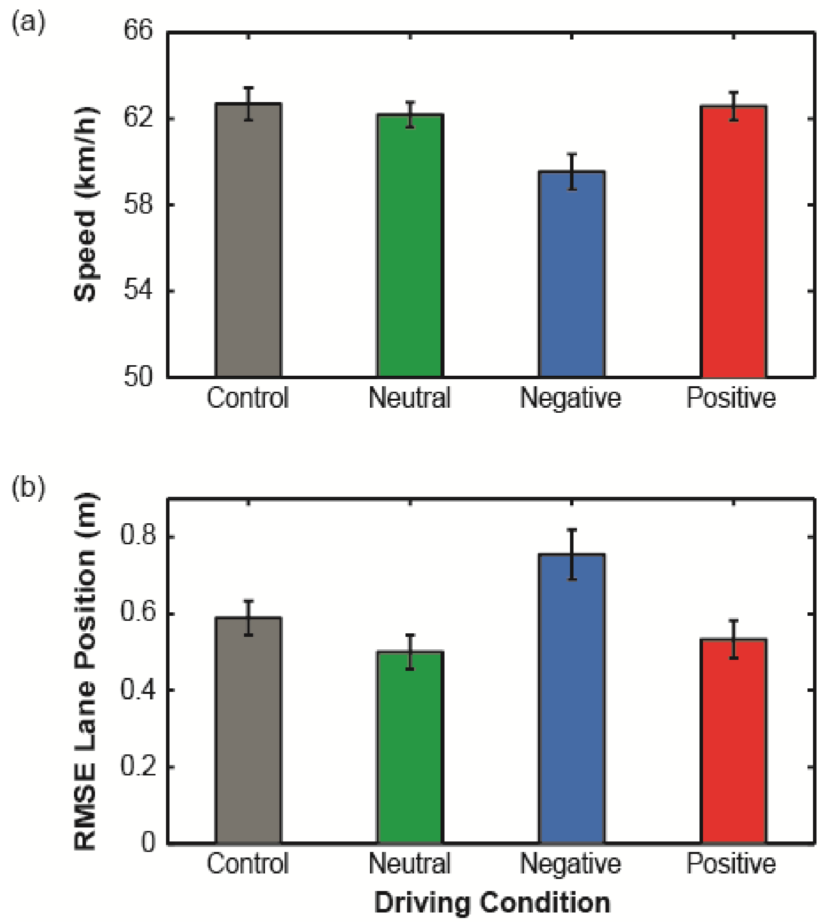

Figure 3.1. Participants' mean driving performance, measuring (a) speed and (b) root mean square error (RMSE) lane position. Error bars denote within-subject standard error of the mean.

The analysis also revealed a significant main effect of driving condition on RMSE lane position, $F(3, 72) = 3.62$, $p < 0.05$, $\eta_p^2 = 0.131$, as shown in Figure 3.1b. Planned contrasts indicated that RMSE was higher in the negative words condition compared to the control ($p < 0.05$), neutral words ($p < 0.05$), and positive words ($p < 0.05$) conditions.

RMSE steering wheel rates did not differ significantly between driving conditions, $F(3, 72) = 1.42$, $p = 0.252$, $\eta_p^2 = 0.056$.

3.3.2 Target RT

The RT and error rate data were analysed with separate 2 (task condition: single-task, dual-task) x 3 (driving condition: neutral, negative, positive) repeated measures ANOVA. Mean RTs and mean error rates for the animal target words are shown in Table 3.2.

Task condition	Driving condition that targets are in	Mean RT (ms)	Mean Error (%)
Single-task	Neutral	1573 (82.0)	8.00 (2.58)
	Negative	1513 (63.5)	9.60 (3.67)
	Positive	1460 (63.7)	7.20 (1.96)
Dual-task	Neutral	1503 (80.5)	11.2 (3.66)
	Negative	1414 (48.0)	15.2 (5.33)
	Positive	1361 (49.5)	9.60 (2.61)

Table 3.2. Mean response times (RTs) and mean error rates for the animal target words, with standard errors.

Error rates did not differ significantly between task condition, $F(1, 24) = 1.65$, $p = 0.211$, $\eta_p^2 = 0.064$, and driving condition, $F(2, 48) = 0.775$, $p = 0.447$, $\eta_p^2 = 0.031$. However, there was a significant main effect of driving condition on mean RTs, $F(2, 48) = 4.46$, $p < 0.05$, $\eta_p^2 = 0.157$, as shown in Figure 3.2a. Planned contrasts revealed that mean RTs to targets were faster for targets embedded in the positive words condition compared to the neutral words condition ($p < 0.05$).

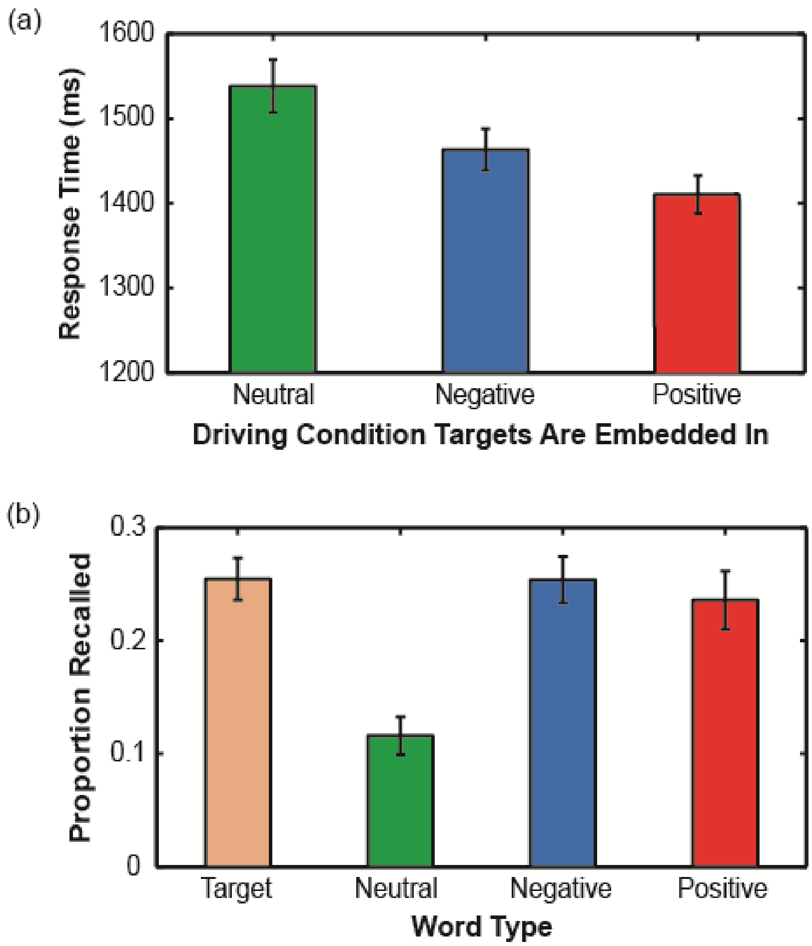

Figure 3.2. Participants' (a) mean target response times and (b) mean proportion of each word type recalled across conditions. Error bars denote within-subject standard error of the mean.

3.3.3 Memory recall

The recall data were analysed with a 2 (task condition: single-task, dual-task) x 4 (word type: target, neutral, negative, positive) repeated measures ANOVA.

The proportion of words recalled did not differ significantly between task condition, $F(1, 24) = 1.28$, $p = 0.270$, $\eta_p^2 = 0.050$. However, there was a significant main effect of word type, $F(3, 72) = 15.82$, $p < 0.001$, $\eta_p^2 = 0.397$. Planned contrasts revealed that recall was higher for negative words compared to neutral words ($p < 0.001$), and higher for positive words compared to neutral words ($p < 0.01$). Recall of target and emotional words did not differ significantly from each other ($p = 0.710$). As there was no effect of task condition on recall, we collapsed the mean proportion of words recalled across single- and dual-task conditions in Figure 3.2b.

Recall for target words as a function of driving condition was also analysed with a 2 (task condition: single-task, dual-task) x 3 (driving condition: neutral, negative, positive) repeated measures ANOVA. There were no significant effects.

3.3.4 Event-related potentials

The negative slow wave (NSW) was quantified as the most negative-going ERP in the range 430-995 ms at electrodes Fz and Cz. The ERP component was scored by determining the mean peak voltage within the analysed time window. 2 (task condition: single-task, dual-task) x 3 (word type: neutral, negative, positive) repeated measures ANOVA was performed on the amplitude at each electrode site separately. Mean amplitudes of the NSW to the auditory words in single and dual-task conditions are shown in Table 3.3.

Results revealed a significant main effect of task condition on NSW amplitudes at Fz, $F(1, 24) = 9.24$, $p < 0.001$, $\eta_p^2 = 0.278$, as shown in Figure 3.3. Planned contrasts indicated that amplitudes were smaller in dual-task compared to single-task conditions ($p < 0.05$).

		Word type			
Electrode	Condition	Neutral	Negative	Positive	Total mean
Fz	Single-task	-4.22 (0.61)	-2.84 (0.77)	-1.81 (0.80)	-2.96
	Dual-task	-1.27 (0.70)	-0.56 (0.62)	-2.12 (0.74)	-1.32
Cz	Single-task	-3.33 (0.63)	-1.60 (0.68)	-1.35 (0.63)	-2.09
	Dual-task	-2.39 (0.47)	0.06 (0.56)	-0.73 (0.49)	-1.02
	Total mean	-2.80	-1.24	-1.50	

Table 3.3. Mean amplitudes (in μv, with standard errors) of the negative slow wave to the auditory words in single and dual-task conditions.

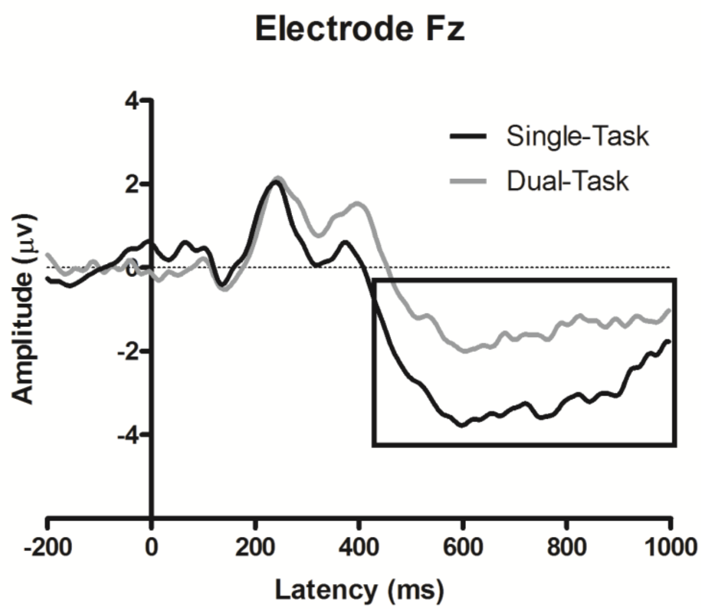

Figure 3.3. Grand average ERP waveforms at Fz to the auditory words heard in concurrent with a driving task (dual-task) and alone (single-task). Negative slow wave amplitudes were reduced in dual-task compared to single-task conditions.

A significant main effect of task condition on NSW amplitudes was also revealed at Cz, $F(1, 24) = 4.64$, $p = < 0.05$, $\eta_p^2 = 0.162$, as shown in Figure 3.4. Planned contrasts indicated that amplitudes were smaller in dual-task compared to single-task conditions ($p < 0.05$). In addition, there was a significant main effect of word type on NSW amplitudes at Cz, $F(2, 48) = 12.2$, $p < 0.001$, $\eta_p^2 = 0.338$. Planned contrasts revealed that amplitudes were smaller for negative than neutral words (p < 0.001) and smaller for positive than neutral words (p < 0.001).

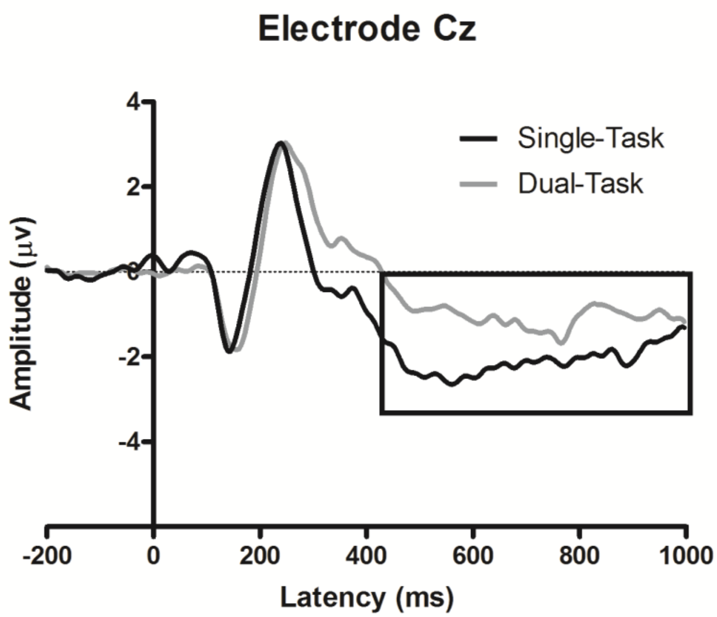

Figure 3.4. Grand average ERP waveforms at Cz to the auditory words heard in concurrent with a driving task (dual-task) and alone (single-task). Negative slow wave amplitudes were reduced in dual-task compared to single-task conditions.

3.4 Discussion

The present study sought to expand upon the few studies that have examined the impact of emotion-related distraction on driving performance. Specifically, behavioural and electrophysiological effects elicited by auditory words of different emotional valence were examined under non-driving (single-task) and driving (dual-task) conditions. Results showed that driving speeds were slower and lateral control was reduced in the presence of negative words compared to positive and neutral words. RTs to targets were faster within the context of positive than neutral words, and participants recalled more emotional than neutral words. Finally, ERP amplitudes in response to the auditory stimuli were reduced under dual-task compared to single-task conditions. These findings suggest that auditory distraction during driving can increase cognitive workload and that negative emotional auditory content may impact one's ability to drive safely. Furthermore, we demonstrate that emotional valence and arousal can differentially affect behaviour.

3.4.1 Effects of emotional distraction on driving behaviours

Our main objective was to determine whether auditory distraction of different emotional valence would produce similar driving behaviours as has been previously shown with visual word distraction (Chan and Singhal, 2013). The results support our earlier work, and extend them to emotion-related distraction within the auditory modality.

First, driving performance was found to be differentially affected by the emotional valence of the auditory content. Negative words reduced driving speeds and impaired lateral control compared to positive words, suggesting that the two types of valence modulated performance in different ways. Similar results were found in Trick et al. (2012), where negative images were associated with poorer lane control than positive images. It has been proposed that because negative stimuli facilitate adaptive behaviour and promote survival, there is a stronger attention bias towards these stimuli (Pratto and John, 1991). In light of this, negative distractions may have recruited more attentional resources than positive and neutral distractions, resulting in poorer driving performance. On the other hand, our findings indicate that positive words were associated with safer driving behaviours and faster responses to targets. It has been suggested that positive states may have an effect of broadening attention (known as the "broaden-and-build" effect) (Fredrickson and Branigan, 2005). This may have led to better driving behaviours, as opposed to driving with a narrower field of vision.

Second, memory performance was found to be higher for emotional words compared to neutral words. This finding suggests that attention was selectively prioritized to emotional information, despite the fact that participants were not given explicit instruction to attend to those words. The relationship between attention and memory has been widely established (Chun and Turk-Browne, 2007; Singhal and Fowler, 2004). It is possible that attention triggers neural-networks in the prefrontal cortex to fire more frequently to keep information in working memory. Persistent firing intensifies the information and increases the likelihood that it will be encoded in short-term memory (Wang et al., 2011). Because memory has a limited capacity, attentional resources are allocated between competing stimuli to determine which information is encoded. It has also been suggested that emotional stimuli often have priority in attention allocation because they are motivationally relevant and adaptive, i.e., they activate the appetitive and defensive system to facilitate approach and avoidant behaviours, respectively. For instance, when facing an aversive stimulus, a fast response may be necessary for escape, and an appetitive stimulus may facilitate ingestive, exploratory, or sexual behaviours (Briggs and Martin, 2008). As neutral words are much lower in arousal than positive or negative words, our recall finding reflects an effect of arousal, rather than valence. One possible explanation for the lack of difference in recall between single- and dual-task conditions is that two forms of attention may be utilized during the driving and recall task. The literature strongly suggests that there are two forms of attention: bottom-up automatic attention and top-down controlled attention (e.g., Armstrong and Singhal, 2011). It is possible that automatic processes that require little executive attention may be associated with the driving task, while controlled processes that rely on executive control (e.g., working memory) may be associated with the encoding and storage of items in memory. This distinction may explain why there was little to no interference between the driving task and memory performance.

Finally, the results showed that RTs to animal target words were faster within the context of positive words compared to neutral words. This converges with Chan and Singhal (2013) and is consistent with several lines of research associating positive states with faster physical performance and decision-making (in the form of RTs) compared to negative and neutral emotions (Feyereisen et al., 1986; Leppänen et al., 2003; McCarthy, 2011; Stenberg et al., 1998). The results also showed that RTs to targets did not significantly differ within the context of positive and negative words, suggesting an effect of arousal, rather than valence (i.e., drivers respond faster to targets when arousal is high). Similar results were found in Trick et al., (2012), where braking RT to hazards were shown to be faster following high arousal images.

Collectively, we were able to show that auditory distraction of different emotional valence can produce similar driving behaviours as has been shown with visual word distraction (Chan and Singhal, 2013). In both modalities, emotional word distraction has priority in attention, with unique effects on driving performance, memory, and decision-making. Our findings also suggest that emotional valence and arousal can differentially influence behaviour: the effect of driving performance appears to be driven by valence, while memory and decision-making appears to be driven by the arousal aspect of emotion.

3.4.2 ERP effects during driving

The secondary objective of our study was to use ERPs elicited by the auditory distraction to assess the allocation of neural resources under single and dual-task conditions. In cognition, it is likely that sensory information must be committed to short-term working memory before it can be acted on. Our auditory task required participants to manually respond to target words embedded in blocks of neutral, negative, and positive words. To accomplish the task, auditory information must be attended to and then retained in conscious awareness. This engages selective attention processes, along with the transfer of information into working memory, before it can be acted on (Singhal and Fowler, 2004). ERPs related to working memory operations can be used to make inferences about cognitive workload under single- and dual-task demands. Thus, we examined early NSW activity at electrodes located in the frontal and central scalp regions to assess working memory operations likely associated with information encoding, maintenance, and retrieval (Ruchkin et al, 1995).

From a cognitive resource point of view, NSW amplitude can be thought to reflect the amount of available working memory resources allocated to the auditory stimuli. From this perspective, smaller amplitude reflects less processing of the auditory words, presumably due to interference of the primary driving task (Gopher and Donchin, 1986). Our results showed that NSW amplitudes were reduced in dual-task compared to single-task conditions, suggesting that working memory processes toward the auditory stimuli are load-dependent. Reduced processing of the secondary stimuli under dual-task demands is consistent with prior research (Singhal et al., 2002; Singhal and Fowler, 2004; Wester et al., 2008), and suggests that the primary driving task may have shifted cognitive resources away from processing the distracting stimuli. Thus, there is a division of neural resources under dual-task demands.

At Cz, NSW amplitudes were smaller in response to emotional than neutral words, suggesting that cortical processing of emotional words differs from that of neutral words. It has been shown that the arousal response to emotional stimuli can activate a broad network of brain regions to influence perception, memory, and attention (Compton, 2003). The amygdala is part of an extensive network that has been implicated in enhancing the effects of emotion on attention and memory; thus, it is conceivable that this "emotion network" may be involved in processing the emotional words. This distinct NSW modulation to emotional stimuli likely reflects unique emotional processing in the brain.

3.4.3 Simulation validity

Driving simulators provide a safe environment to assess driving behaviour in risky situations. Factors that affect driving behaviour, such as weather and traffic density, can also be optimally controlled by the researcher. However, the simulator is limited in generalizability to actual driving for the following reasons: 1) The simulator has a limited field-of-view that does not surround the driver, 2) a fixed-based simulator offers no vestibular and proprioceptive information for self-motion perception, and 3) the simulated image has limited resolution. Additionally, there is controversy regarding the extent to which behavioural measures of the simulator resembles actual driving. Despite these limitations, there is ample evidence indicating the relative and predictive validity of driving simulators when considering measures of velocity, lateral control, and RT (Bédard et al., 2010; Kaptein et al., 1996; Lew et al., 2005; Mullen et al., 2011; Wang et al., 2010). Moreover, Reimer and Mehler (2011) has shown that physiological measures (heart rate and skin conductance) recorded in a driving simulator during varied levels of task difficulty can provide valid measures of what to expect in the real world when assessing the impact of cognitive workload.

3.4.4 Conclusions

In 2011, 10% of all fatal motor vehicle crashes and 17% of all injury crashes involved driver distraction (NHTSA, 2013). Our findings confirm that auditory distraction during driving can increase cognitive workload. This was supported by a division of neural resources, as demonstrated by reduced ERP amplitudes to the distractions under dual-task (driving) compared to single-task (non-driving) demands. We also show that emotion-related auditory distraction can modulate attention to differentially influence driving performance. Specifically, negative distractions reduced lateral control and slowed driving speeds compared to positive and neutral distractions.

These results have important implications for road safety, particularly when considered in conjunction with analogous findings that emotional words on billboards can disrupt driving performance (Chan and Singhal, 2013). First, our findings reinforce the importance of taking into account emotional valence and arousal in driver distraction research as they can differentially influence behaviour. We confirm a valence effect on driving performance as negative and positive emotional words were shown to differentially affect driving speeds and lateral control. On the other hand, we found an arousal effect on memory and decision-making during driving. Second, these results bring to light the detrimental effects of auditory content containing negative emotional words. We suggest the need for risk prevention programs, drivers' training protocols, and road safety interventionists to increase public awareness on these sources of distraction in order to limit their occurrence. Finally, these findings may provide important information for the improvement of speech messages/words from in-car driving support systems.

To better understand the influence of emotional content while driving, future work should be conducted with more realistic emotional stimuli, such as having drivers listen to radio broadcasts with different emotional messages. It would also be useful to vary the complexity of the driving situations (e.g., driving in a busy city compared to a monotonous highway) to examine the influence of emotion under different cognitive loads.

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3.6 Appendix

List of words used in the experiment.

Neutral words[a]

Banner	Column	Kettle	Plant
Barrel	Cottage	Lamp	Square
Basket	Curtains	Locker	Statue
Bench	Elbow	Mantel	Table
Board	Engine	Metal	Taxi
Bus	Fabric	Museum	Tree
Cabinet	Foot	Paper	Umbrella
Chin	Fork	Patent	Utensil
Circle	Headlight	Pencil	Violin
Cloud	Item	Phase	Writer

Negative words[a]

Abuse	Fight	Misery	Suicide
Abortion	Gun	Murderer	Torture
Aggression	Hostage	Nightmare	Toxic
Agony	Illness	Pain	Trouble
Assassin	Injury	Poverty	Ulcer
Bomb	Insult	Prison	Victim
Cancer	Jealousy	Rape	Violent
Devil	Killer	Slaughter	Vomit
Disaster	Loser	Slave	War
Fear	Massacre	Stress	Whore

Positive words[a]

Acceptance	Ecstasy	Justice	Profit
Achievement	Enjoyment	Kiss	Progress
Adventure	Fireworks	Laughter	Promotion
Affection	Freedom	Love	Romantic
Ambition	Fun	Lust	Success
Beach	Gift	Miracle	Sunlight
Beauty	Glory	Money	Treasure
Champion	Gold	Passion	Triumph
Desire	Holiday	Perfection	Valentine
Diamond	Joy	Prestige	Victory

Animal words[b]

Ant	Giraffe	Peacock
Antelope	Goat	Penguin
Bear	Horse	Racoon
Bee	Leopard	Rat
Camel	Lion	Sheep
Cat	Llama	Spider
Chicken	Monkey	Tiger
Cockroach	Moose	Wasp
Donkey	Ostrich	Wolf
Fox	Panther	Zebra

[a]Words were selected from the Affective Norms for English Words database (Bradley and Lang, 1999).

[b]Words were selected from the University of Toronto categorized word pool (Murdock, 1976).

The findings from Chapters 2 and 3 showed that emotion-related visual distraction can produce similar driving behaviours as with auditory distraction. Importantly, in both studies, attention was modulated by the emotional valence (positive vs. negative) of the distracting content to differentially influence driving performance. Chapter 4 extended these findings by examining the impact of highly arousing taboo distraction, in the form of roadside billboards, on driving performance.

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Chapter 4:

The effects of taboo-related distraction on driving performance

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ABSTRACT

Roadside billboards containing negative and positive emotional content have been shown to influence driving performance, however, the impact of highly arousing taboo information is unknown. Taboo information more reliably evokes emotional arousal and can lead to greater attentional capture due to its inherent ‘shock value.' The objective of the present study was to examine driver distraction associated with four types of information presented on roadside billboards: highly arousing taboo words, moderately arousing positive and negative words, and non-arousing neutral words. Participants viewed blocks of taboo, positive, negative and neutral words presented on roadside billboards while operating a driving simulator. They also responded to target (household-related) words by pressing a button on the steering wheel. At the end of the session, a surprise recall task was completed for all the words they saw while driving. Results showed that taboo words captured the most attention as revealed by better memory recall compared to all the other word types. Interestingly, taboo words were associated with better lane control compared to the other word types. We suggest that taboo-related arousal can enhance attentional focus during a complex task like simulated driving. That is, in a highly arousing situation, attention is selectively narrowed to the road ahead, resulting in better lane control.

4.1 Introduction

According to the National Highway Traffic Safety Administration (NHTSA), driver inattention contributes to over 25% of motor vehicle crashes. Driver distraction, one form of driver inattention, is estimated to be involved in over half of these crashes (Stutts, Reinfurt, Staplin, & Rodgman, 2001). More recent findings place this estimate higher. In 2012, driver distraction accounted for 10% of all fatal crashes and 18% of injury crashes, making it the leading cause of motor vehicle accidents (NHTSA, 2014).

While distraction and inattention are often used interchangeably, NHTSA defines driver distraction as “a specific type of inattention that occurs when drivers divert their attention from the driving task to focus on some other activity instead” (NHTSA, 2014). Secondary task distraction, including cell-phone use, use of in-vehicle information systems (e.g., GPS), and interactions with passengers, has been estimated to contribute to over 23% of all traffic accidents (Young & Salmon, 2012).

A key element of driver distraction is the voluntary or involuntary diversion of attention toward a competing activity (event, task, object, or person) inside or outside the vehicle. When a cell phone suddenly rings or a baby is screaming in the backseat, the driver is involuntarily compelled to look for the phone or turn to the screaming baby. On the other hand, when a driver reaches for the cup of coffee in his vehicle, he voluntarily chooses to devote his attention to the activity. In general, competing activities that capture attention involuntarily are unpredictable, sudden, and highly salient (Regan, Hallett, & Gordon, 2011); in other words, they are difficult to ignore.

One competing activity that has the potential to compel attention is roadside billboards. The amount of attention that drivers give to billboards and other irrelevant objects is estimated to vary from 30% to 50% (Hughes & Green, 1986). Studies have found that distraction by foreign objects (including signs) is a significant cause of crashes (Stutts et al., 2001) and that drivers do look and process billboards (Hughes & Green, 1986). However, little is known about the influences of emotional content on billboards, even though emotional stimuli have been widely reported to capture attention (for review, see Compton, 2003). In a recent study, roadside billboards containing negative and positive emotional content were shown to have differential effects on driving performance (Chan & Singhal, 2013). Drivers drove slower in the presence of negative information, while positive information was associated with faster driving speeds. Moreover, drivers recalled the content of negative billboards better than positive billboards. Another study found that viewing positive images led to better steering performance than negative images (Trick, Brandigampola, & Enns, 2012). Finally, in Jones, Chapman, and Bailey (2014), emotional images were shown to reduce the ability to detect driving-related hazards compared to neutral images. Together, these findings demonstrate that emotionally valenced information can be a significant factor in driving performance, and suggests that emotional distraction can modulate attention. Moreover, these effects appear to generalize to other sensory modalities, such as audition. In Chan and Singhal (2015), it was found that negative auditory distractions led to slower driving speeds compared to positive and neutral distractions, suggesting that the processing of emotional stimuli during driving likely reflects the impact on higher-order cognitive process rather than lower level sensory and perceptual processes.

While these results shed some light on the influence of emotional distraction on driving, the impact of taboo information on driving has not been investigated. Taboo (e.g., sexual-related) information have been shown to more reliably evoke emotional arousal than other types of emotional information (Jay, Caldwell-Harris, & King, 2008; Kensinger & Corkin, 2003; LaBar

& Phelps, 1998; MacKay, Shafto, Taylor, Marian, Abrams, & Dyer, 2004; Madan, Caplan, Lau, & Fujiwara, 2012). Previous studies have found that taboo stimuli can lead to greater attentional capture, presumably due to its inherent 'shock value' (Arnell, Killman, & Fijavz, 2007; Bertels, Kolinsky, & Morais, 2010; Mathewson, Arnell, & Mansfield, 2008). Arnell et al. (2007) showed that in a rapid serial visual presentation (RSVP) task, accuracy was worse when the target was preceded by a sexual word compared to a threat, anxiety, positive, negative, or neutral word, suggesting involuntary attentional capture of arousing sexual words. In another study, Aquino and Arnell (2007) showed that sexually explicit words presented between two digits increased reaction times on a digit-parity task, compared to emotionally neutral and negative words. Additionally, it was revealed that more sexual words were later encoded into memory for recall compared to the other word types.

The effect of taboo distraction on driving has ecological relevance as many North American roadways are lined with billboard advertisements that contain highly arousing and/or sexual content (e.g., an anti-smoking billboard depicting mouth cancer or an advertisement with a woman in a bikini). In the present study, we examined driver distraction associated with four different types of information presented on roadside billboards. The five conditions were driving with: (1) highly arousing taboo words, (2) moderately arousing positive words, (3) moderately arousing negative words, (4) non-arousing neutral words, and (5) no billboard distraction. At the same time, participants responded to target words (household-related items) presented in the context of the four types of words. At the end of the study, participants were given a surprise free recall test in which they were asked to recall as many as words as possible from all conditions.

We hypothesized that driving performance would be most impaired by taboo words compared to all the other word types, as attention would be most involuntarily captured by the taboo distraction. As a result, less attention would be devoted to the driving task, which would impair driving performance. Alternatively, there is evidence that arousal can enhance focus. The narrowing of attention under highly arousing situations has been demonstrated in several studies (Easterbrook, 1959, Agnew & Agnew, 1963; Bacon, 1974; Eysenck & Willett, 1962; Hancock & Dirkin, 1982). It is suggested that as the level of arousal increases, observers tend to become more selective in their patterns of attending, a process known as "cognitive tunneling" (Dirkin & Hancock, 1985). As observers focus their attention on one specific aspect of the environment, information outside this highly attend area is excluded (Dirkin, 1983; Thomas & Wickens, 2001). Thus, it is possible that in the presence of highly arousing taboo words, driving performance would show no decrements as attentional focus would be enhanced towards the road ahead.

4.2 Methods

4.2.1 Participants

39 introductory psychology students from the University of Alberta participated for partial course credit. Data were excluded from nine participants because they did not drive to criterion (see Procedure) or due to technical issues, resulting in a final sample of 30 participants (13 males; $M = 19.5$, $SD = 3.3$). All participants had a valid driver's license, normal to corrected-to-normal vision, and were in the age range of 18 to 35 years old. The study was approved by the University of Alberta Ethical Review Board.

4.2.2 Materials

4.2.2.1. Word lists. Five 16-word lists were used in the study: one list of highly arousing taboo words; one list of moderately arousing, positive words; one list of moderately arousing, negative words; one list of non-arousing, neutral words; and one list of household-related ("target") words that participants were asked to respond to.

All of the words were selected from the Janschewitz (2008) normative word database. In the database, several subjective ratings were used for each word, including: arousal, valence, tabooness (the extent to which the rater found the word offensive to people in general), offensiveness (the extent to which the rater found the word personally offensive), familiarity (how often the rater encountered the word in any setting), personal use (how often the rater used the word on him or herself), and imageability (conduciveness to mental imagery), as well as number of letters and syllables.

Words were additionally selected based to match within-list similarity between the word lists using the latent semantic analysis method (LSA; Landauer & Dumais, 1997), and were matched for word frequency (occurrences in the English language, per million words), number of orthographic neighbors (number of words of the same length that differ in only one letter), and average word frequency of orthographic neighbors (per million words) were calculated with MCWord (Medler & Binder, 2005) based on the CELEX Lexical Database (Baayen, Piepenbrock, & Gulikers, 1995). See Table 4.1 for the word property statistics and the appendix for the specific words used.

	Taboo	Positive	Negative	Neutral	Target
Emotional word properties					
Arousal	5.01 (0.66) [a]	2.84 (0.56) [b]	2.85 (0.56) [b]	1.49 (0.14) [c]	1.46 (0.10) [c]
Valence	3.76 (1.31) [a]	6.50 (0.61) [b]	3.48 (0.39) [a]	5.03 (0.07) [c]	5.05 (0.07) [c]
Tabooness	5.40 (1.05) [a]	1.10 (0.14) [b]	1.38 (0.17) [c]	1.03 (0.03) [b]	1.02 (0.04) [b]
Offensiveness	2.82 (1.10) [a]	1.04 (0.05) [b]	1.23 (0.13) [c]	1.02 (0.01) [b]	1.01 (0.01) [b]
Non-emotional word properties					
Imageability	5.50 (1.83) [a]	5.03 (2.25) [a]	4.82 (1.92) [b]	6.34 (2.22) [a]	7.67 (0.53) [a]
Familiarity	5.35 (1.10) [a]	5.18 (0.81) [b]	4.96 (0.89) [b]	4.61 (0.85) [b]	5.20 (0.90) [b]
Personal use	3.98 (1.09) [a]	4.48 (0.88) [a]	4.15 (0.92) [a]	3.94 (0.88) [a]	4.85 (1.11) [b]
Letters	5.50 (1.10) [a]	6.00 (0.89) [a]	5.69 (1.01) [a]	5.69 (1.14) [a]	5.75 (1.18) [a]
Syllables	1.94 (0.57) [a]	2.00 (0.73) [a]	1.56 (0.51) [a]	1.69 (0.48) [a]	1.81 (0.66) [a]
Semantic similarity	0.09 (0.16) [a]	0.19 (0.14) [a]	0.19 (0.16) [a]	0.12 (0.16) [a]	0.15 (0.16) [a]
Word frequency	7.19 (9.24) [a]	16.07 (17.39) [b]	12.45 (8.57) [a]	22.81 (17.94) [b]	39.47 (55.85) [b]
ON number	3.25 (3.70) [a]	2.12 (2.25) [a]	2.50 (2.00) [a]	2.56 (3.33) [a]	2.62 (2.55) [a]
ON mean Frequency	6.27 (14.63) [a]	5.40 (13.77) [a]	6.53 (10.04) [a]	9.02 (13.43) [a]	16.56 (20.18) [a]

Table 4.1. Word property statistics for each list used in the experiment.

Note. Mean ratings are shown with standard deviation in parentheses. Means in a row with the same superscript are not significantly different at $p < .05$. See text for further details about each measure. *ON = Orthographic Neighbors.*

4.2.2.2. Driving simulator. Participants drove a STISIM Drive™ fixed-based driving simulator (Systems Technology Inc., Hawthorne, CA, USA), modeled as a small automatic transmission passenger vehicle. The simulator included a steering wheel, gas and brake pedals, and a projected display of approximately 60° horizontal and 40° vertical on a 22" widescreen computer monitor. The simulated display included a dashboard, speedometer, and rear-view mirror.

4.2.3 Design

The driving scenario was 4.4 km in length and consisted of a two-lane (one in each direction) rural road that was mostly straight, with some winding turns. Road events included pedestrians crossing the road, stop signs, and traffic lights. Pedestrians were programmed to cross the road when the participant's vehicle was within 200 m of the pedestrian. Traffic lights were programmed to turn red when the participant's vehicle was within 200 m of the traffic light. Other features included buildings, trees, and other vehicles approaching in the opposite lane.

Participants completed five different driving conditions that each took approximately 5 min: (1) In *Control,* participants drove without billboard distraction. (2) In *Taboo*, participants drove with 16 taboo words and four target words on billboards. (3) In *Positive*, participants drove with 16 positive words and four target words on billboards. (4) In *Negative*, participants drove with 16 negative words and four target words on billboards. (5) In *Neutral*, participants drove with 16 neutral words and four target words on billboards. The order of conditions was counterbalanced across participants using a Latin-square procedure. Figure 4.1 shows a screenshot from the taboo condition.

Figure 4.1. Screenshot of a scenario from the taboo condition.

Similar to Chan and Singhal (2013), billboards were placed on the right-hand side of the road every 200 m. The words on the billboards were legible to the driver when the vehicle was approximately 70 m in front of the sign. The order of the words for each condition was randomized for each participant.

2.4. Procedure

Participants were first familiarized with the driving simulator by completing a practice drive that was 6.4 km in length and similar to the control scenario. The practice drive took approximately 8 min. Using the same criterion in Chan and Singhal (2013; 2015), participants were instructed to drive their vehicle in the center of their lane, maintain a speed of 40-80 km/h, and attend to pedestrians, stop signs, and traffic lights.

In the experimental session, each participant completed all five driving conditions (control, taboo, positive, negative, neutral) with a 1-min break between conditions. They were instructed to press a button on the steering wheel with their left hand as quickly as possible when a target (household-related) word came into view. Participants were told that house-related words were “words commonly associated with the house/home” and were given a list of examples. These example words were not used in the actual experiment. Target words were used to ensure that participants were attending to the words.

Upon completion of all driving conditions, participants were given a surprise free recall test, in which they were given 5 min to recall and type all of the words they could remember from the study, in any order. The entire study was completed in 1 hr.

4.3 Results

All effects were considered statistically significant based on the alpha level of 0.05. Greenhouse-Geisser corrections were applied to account for violations of sphericity.

All of the driving performance data were analysed with separate one-way repeated measures analysis of variance (ANOVA) with five levels (driving condition: control, taboo, positive, negative, neutral). The target response time data were analysed with a one-way repeated measures ANOVA with four levels (driving condition: taboo, positive, negative, neutral). The target error rate data were analysed with a 2 (error type: miss, false alarm) x 4 (driving condition: taboo, positive, negative, neutral) repeated measures ANOVA. The recall data were analysed with a one-way repeated measures ANOVA with five levels (word type: target, taboo, positive, negative, neutral).

4.3.1 Driving performance data

To assess driving performance, three measures were collected from the simulator: mean driving speed, lane maintenance (assessed as the root-mean-square error [RMSE] of the driver’s lateral lane position with respect to the roadway dividing line), and steering wheel rate (assessed as the RMSE of how fast the driver is turning the steering wheel while doing steering maneuvers) (Rosenthal, 1999). Each measure was aggregated over the entire driving scenario.

We observed a significant effect of driving condition on mean driving speed, $F(4, 116) = 2.80$, $p = .037$, $\eta_p^2 = .088$. As shown in Figure 4.2A, planned contrasts indicated that driving speed was faster in the positive condition compared to the taboo ($p = .019$), negative ($p = .020$), and neutral ($p = .001$) conditions, similar to the results of Chan and Singhal (2013). No other comparisons were significant (all *p*'s > .05).

Driving condition also had a significant effect on RMSE lane position, $F(4, 116) = 3.57$, $p = .013$, $\eta_p^2 = .110$. As shown in Figure 4.2B, planned contrasts indicated that RMSE lane position was lower in the taboo condition compared to the control ($p = 0.002$), positive ($p = .002$), and neutral ($p = .022$) conditions. A trend effect was observed suggesting lower RMSE lane position in the taboo condition compared to the negative condition ($p = .084$). The other word types did not differ significantly (all *p*'s > .05).

RMSE steering wheel rates did not significantly differ between conditions, $F(4, 116) = 1.87$, $p = .151$, $\eta_p^2 = .060$.

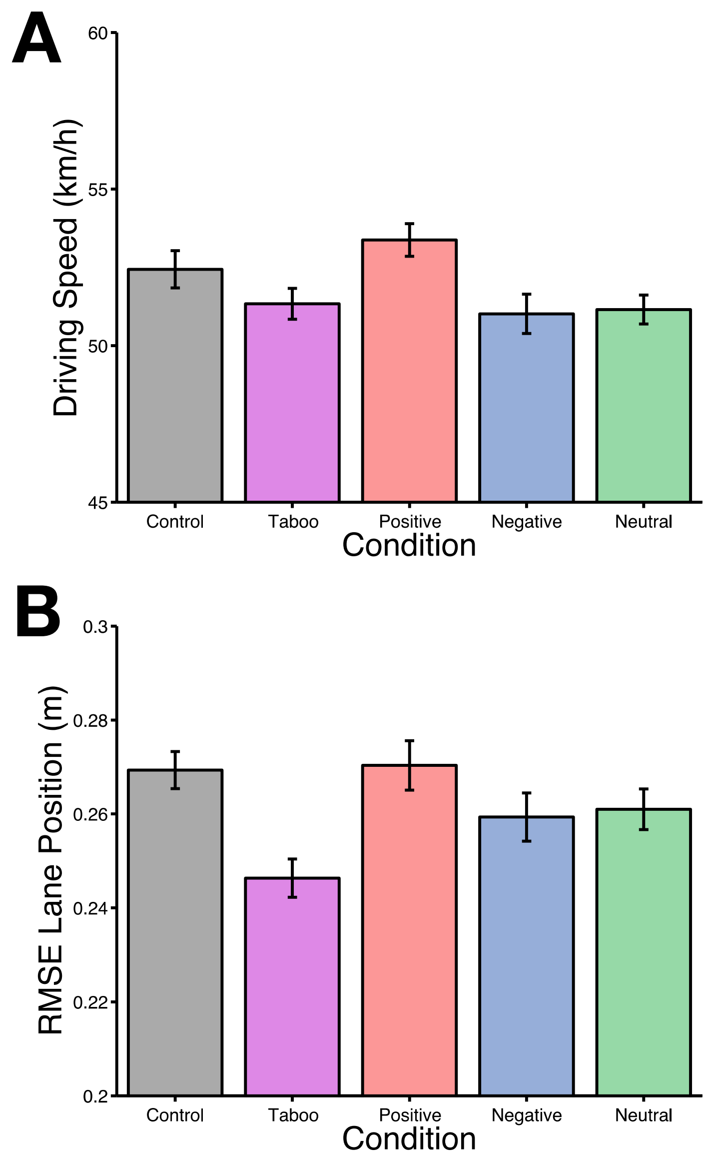

Figure 4.2. Driving performance measures for each driving condition. (a) Driving speed. (b) Root mean square error (RMSE) lane position. Error bars denote within-subject standard error of the mean.

4.3.2 Target response data

Driving condition may influence participants' speed at responding to the targets. Response time (RT) for each target word was calculated as the time from when the target billboard could be read to when the participant pressed the button. Only correct responses were included for analysis. RTs more than three standard deviations from the mean were excluded. The main effect of condition on RT was not significant, $F(3, 87) = .432$, $p = .705$, $\eta_p^2 = .015$.

As driving condition may also influence participants' ability to accurately detect the household-related target words, we conducted an error analysis on target responses. Miss (i.e., no response to a target) rate was defined as the number of misses, divided by the total number of targets in each condition (i.e., 4 targets per condition). False alarm (i.e., responses to a non-target word) rate was defined as the number of false alarms, divided by the total number of non-targets in each condition (i.e., 16 non-targets per condition). The mean miss rate and false alarm rate for each driving condition are shown in Figure 4.3.

Results revealed a significant main effect of error type, $F(1, 29) = 8.85$, $p = .006$, $\eta_p^2 = .234$. The false alarm rate was higher than miss rate across all driving conditions. There was also a significant main effect of driving condition, $F(3, 87) = 3.41$, $p = .029$, $\eta_p^2 = .105$. Planned contrasts indicated that the error rate (misses and false alarms) was lower in the taboo condition compared to the positive ($p = .038$) and neutral ($p = .034$) conditions. The ANOVA also revealed a significant interaction between error type and driving condition, $F(3, 87) = 3.81$, $p = .019$, $\eta_p^2 = .116$. As shown in Figure 4.3B, planned contrasts indicated that the false alarm rate was lower in the taboo condition compared to the positive ($p = .001$), negative ($p = .001$), and neutral ($p = .001$) conditions.

Further inspection of the data indicated that the false alarms were to random non-target words, and not to any specific word(s) in each condition that had a tendency to cause participants to mistakenly confuse it for a target.

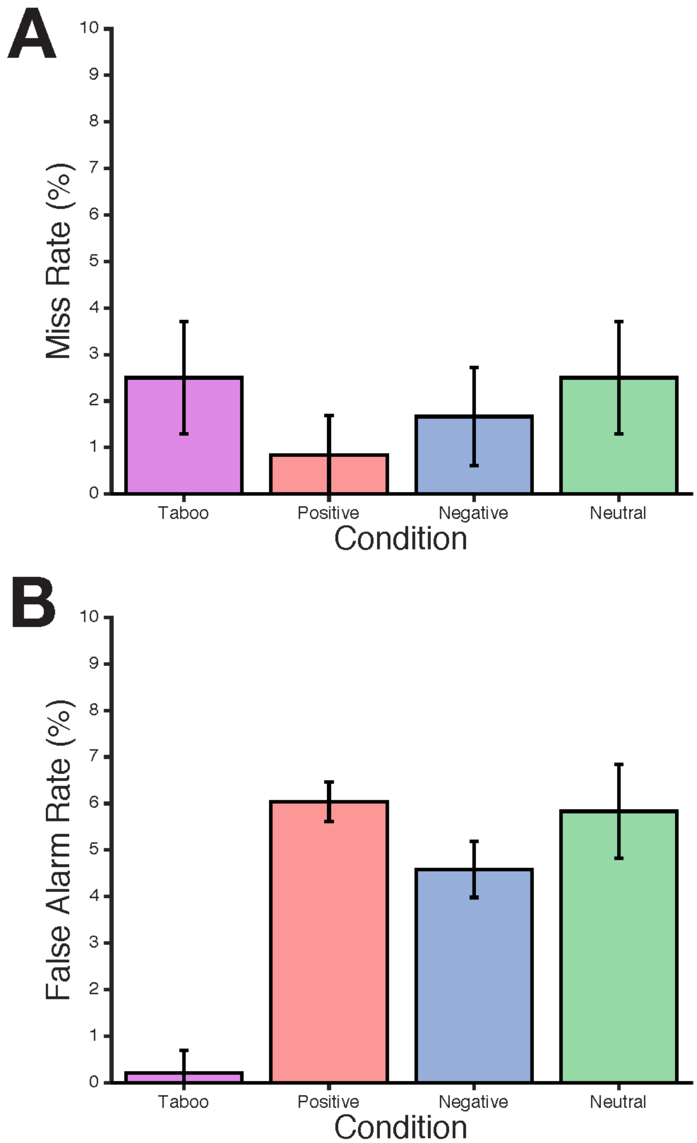

Figure 4.3. Error rates of target words for each driving condition. (a) Misses. (b) False alarms. Error bars denote within-subject standard error of the mean.

4.3.3 Relationship between driving performance and target false alarm rates

Pearson correlations were conducted to assess the relationship between RMSE lane position and false alarm rates for each driving condition. There were no significant correlations (all *p*'s > .05). Pearson correlations were also conducted between driving speed and false alarm rates for each driving condition. No significant correlations emerged (all p's > .05). These analyses suggests that performance of the driving task and target response task are unrelated and do not influence each other directly.

4.3.4 Memory recall data

As the billboard words competed for attention with the driving task and were the main manipulation of interest, we additionally analysed the recall data for differences in memory for the different word types. Proportion of words recalled was defined as the mean number of correct words recalled of each word type, divided by the total number of words presented of each type.

Results revealed a significant main effect of word type, $F(4, 116) = 40.19$, $p = .001$, $\eta_p^2 = .581$. As shown in Figure 4.4, planned contrasts revealed that taboo words were recalled more so than any other word type (all p's < .001). Target words were recalled more than positive, negative, and neutral words (all p's < .001). The proportion of words recalled for positive, negative, and neutral words did not differ significantly (all p's > .05).

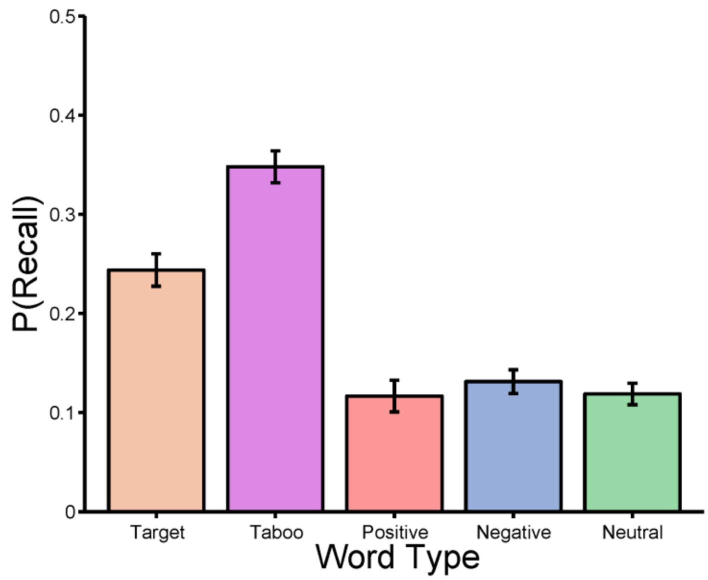

Figure 4.4. Proportion of each word type recalled in the free recall task. Error bars denote within-subject standard error of the mean.

4.4 Discussion

In the present study we examined the effects of driving performance associated with four types of information presented on roadside billboards: highly arousing taboo words, moderately arousing positive words, moderately arousing negative words, and non-arousing neutral words. The results showed that positive words were associated with faster driving speeds compared to all the other word types. On the other hand, taboo words were associated with better lane control, better memory recall, and better target response accuracy compared to the other word types. These findings suggest that driving performance and attention are differentially affected by the arousal level of the billboard content.

Emotional arousal is an important factor in guiding selective attention as it has been shown that stimuli appraised as emotional are often motivationally relevant and adaptive (Compton, 2003). For example, a threatening stimulus prepares the individual for avoidance-related behaviors (e.g., escape). On the other hand, a positive stimulus that signals reward activates approach-related behaviors (e.g., ingestion of food). As human attention has a limited capacity, only certain stimuli can be attended to at the same time; accordingly it is adaptive that stimuli with high emotional arousal be prioritized for processing (Compton, 2003). Our findings showed that memory performance was highest for taboo words compared to the other word types in the surprise recall task (see also Buchanan, Etzel, Adolphs, & Tranel, 2006; Madan et al., 2012), suggesting that attention was most captured by taboo words despite no instructions to attend to those words. Prior studies have also found preferential processing of sexual or taboo information compared to other emotional information (Arnell et al., 2007; Bertels et al., 2010; Mathewson et al., 2008). For example, Schimmack (2005) showed that highly arousing pictures (e.g., scantily clad opposite-sex models) involuntarily captured more attention than pictures of mildly arousing pictures. Together, these findings suggest that arousal level modulates the amount of attention that is given to information, with highly arousing stimuli receiving the most attention.

The driving performance results showed that positive words were associated with faster driving speeds compared to all the other word types. This is consistent with prior findings that positive states can lead to enhanced physical performance, such as the ability to run faster or jump higher, compared to negative and neutral emotions (McCarthy, 2011; Ruiz, 2008). It is possible that this same type of faster behavior seen in human performance may also be present in a driving task.

Interestingly, we found that drivers had better lane control in the presence of taboo words. It is possible that drivers may have allocated more attention to the road ahead when in a highly arousing situation. “Cognitive tunneling” is a phenomenon that occurs when observers focus their attention on one aspect of the environment to the exclusion of information outside this highly attended area (Dirkin, 1983; Thomas & Wickens, 2001). In other words, observers become more selective in their patterns of attending. The hypothesis that attention is narrowed as levels of arousal increase has been demonstrated in several studies (Easterbrook, 1959, Agnew & Agnew, 1963; Bacon, 1974; Eysenck & Willett, 1960; Hancock & Dirkin, 1982). For example, it has been found that attention towards salient cues is “narrowed” under heightened arousal, regardless if the cues are located in the central or peripheral field of vision (e.g., Reeves & Bergum, 1972). As previous findings confirm that arousal can enhance attentional focus, it is possible that drivers may have narrowed their attention to the road ahead in the presence of taboo stimuli. This would also limit the processing of other sensory information in the driving environment (e.g., trees. buildings, oncoming traffic), resulting in better lane control.

On the other hand, positive emotional states have been shown to broaden the scope of attention (Fredrickson, 1998, 2001). Several studies have found that positive emotions can lead to greater global perceptual processing in global-local focus tests, whereas negative affect leads to greater local processing (Basso, Schefft, Ris, & Dember, 1996; Fredrickson & Branigan, 2005; Gasper & Clore, 2002). The impact of positive emotion on visual attention has also been measured using eye tracking in response to emotional pictures (Wadlinger & Isaacowitz, 2006). Using a mood induction task, it was found that participants who experienced positive emotional states had a broader area of visual attention. In a driving task, positive arousal may increase attention to peripheral information, due to a broadening of attention to global aspects of the driving environment, which may reduce the drivers’ ability to maintain lane control, compared to the presence of taboo stimuli.

The target response results showed that drivers made fewer false alarms in the taboo condition compared to the other word conditions. One possible explanation is that drivers were more vigilant and attentive in the presence of taboo words, resulting in better accuracy (i.e., lower false alarm rates). Providing some support for this idea, prior studies have also found that participants showed more attentional vigilance (i.e., attentional capture) to taboo words compared to other word types (Arnell et al., 2007; Bertels et al. 2010; Mathewson et al., 2008).

Research has also shown that taboo and threatening stimuli (e.g., pictures of mutilated bodies) can elicit a motor response suppression in humans that is similar to the freezing response exhibited in animals when faced with a potential threat (Azevedo et al., 2005; Fox, Russo, Bowels, & Dutton, 2001; Wilkowski & Robinson, 2006). Evidence of this can be found in a study by Azevedo et al. (2005). Here, participants viewed images that were threatening (mutilation), pleasant (sports), and neutral (objects) while standing on a platform. Posturographic recordings showed that during pictures of mutilation, participants exhibited a more immobile posture (i.e., reduced body sway and increased muscle stiffness) compared to the other pictures. Thus, the presence of threatening stimuli reduced motor activities. In this study, it is possible that the viewing of taboo words (which are similar to threat-related words; Schmidt & Saari, 2007) induced a similar response suppression during the target response task, so that participants were less prone to making incorrect responses (i.e., false alarms).

Chan and Singhal (2013) observed faster RTs when target words were embedded in the context of positive words compared to negative and neutral words. However, in the present study, we found no effect on target RT across driving conditions. Chan and Singhal (2013) used animal words as target words, while household-related items were used here. It is likely that since we intentionally matched the word properties of the target (household-related) items to the other word pools [in contrast to Chan and Singhal (2013)], the target words here were less distinct from the non-target words and thus, not as readily detectable.

While we suggest that cognitive tunneling may have occurred in the presence of taboo words, resulting in better lane control, it is likely not the only mechanism that may have contributed to this finding. For instance, our effects may have been mediated by linguistic properties that may not generalize to non-verbal (i.e., pictorial) taboo stimuli, such as pictures of scantily clad models. Some researchers have proposed that emotional information in pictures and words are processed differently, and that emotional pictures induce higher levels of arousal than emotional words (Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo; 2009; Carretié et al., 2008; Keil, 2006; Kissler, Assadollahi, & Herbert, 2006). Evidence for this can be found in a functional magnetic resonance imaging (fMRI) study by Kensinger and Schacter (2006), where participants were presented with positive, negative, and neutral pictures and words. Both emotional pictures and words were associated with increased activity in the amygdala, regions of the prefrontal cortex, and the anterior temporal cortex; however, the effects were stronger and more bilateral for pictures. In Hinojosa et al. (2009), event-related potentials (ERP) were recorded as participants viewed pictures and words that were emotional and neutral. The authors found that emotion-related ERP modulations were more pronounced for emotional pictures than for emotional words. Future research will be necessary to determine whether driving performance will differ with emotionally arousing pictures on billboards compared to words. Based on prior findings that emotional pictures are more arousing than emotional verbal stimuli (e.g., Hinojosa et al., 2009), it is predicted that emotional images on billboards will impact driving performance and target detection in a similar pattern as words but to a greater extent (i.e., taboo pictures will be associated with better lane control, better memory recall, and lower false alarm rates compared to taboo words). Taboo words are also relatively rare and unusual, and thus, more distinctive compared to other word types (Kensinger & Corkin, 2003; Schmidt & Saari, 2007). The effects of distinctive non-taboo words (e.g., names of animals, diseases, or germs) should also be compared with taboo words in future studies.

Driving simulators provide a safe and objective method to assess driving performance in dangerous situations, however there are limitations in the generalizability of our findings to real-world driving. For instance, our simulator has a limited projected field of view of 60° horizontal and 40° vertical. As a result, there is no rotation of the head to view the billboards or other visual information in the environment when these objects become located in the periphery, unlike actual driving. Additionally, the simulator is static and provides no vestibular and proprioceptive information to simulate motion. Nonetheless, despite these limitations, a large body of evidence suggests that simulators can provide a valid tool to assess driving performance (e.g., Kaptein, Theeuwes, & van der Horst, 1996; Mullen et al., 2011).

4.5 Conclusion

Our results showed that highly arousing taboo words captured the most attention and were associated with better lane control compared to moderately arousing and non-arousing words. One possible explanation is that cognitive tunneling may have occurred under high arousal; in other words, attention was selectively narrowed to the road ahead, resulting in better lane control. Additionally, as ‘shock value’ is an intrinsic attribute specific to taboo words (distinct from arousal and valence alone; Madan et al., 2012), it is possible that this additional property may have contributed to the differential effects on driving performance.

Overall, our findings demonstrate that attention and arousal are linked, and can impact driving performance in the laboratory. Our results suggest that the effects of emotional distraction may be more complicated than previously thought: Highly arousing stimuli can influence performance in different ways than moderately arousing stimuli.

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4.7 Appendix

Experiment word pools

Taboo words	Positive words	Negative words	Neutral words	Target words
ANUS	ADMIRED	BLISTER	BANNER	ARMCHAIR
ASSHOLE	ANGEL	CHAOS	CIRCLE	BENCH
BASTARD	BEAUTY	CRASH	CONTEXT	CABINET
BITCH	BRAVE	GLOOM	ENGINE	CHAIR
BONER	BREEZE	HEADACHE	ERRAND	CLOSET
BREASTS	BUNNY	HORROR	GLACIER	DESK
DILDO	CHAMP	PANIC	PHASE	DRESSER
FUCK	ELATED	QUARREL	PRAIRIE	DRYER
HOOKER	LIBERTY	RESENT	QUART	FREEZER
ORGASM	LUSCIOUS	SCREAM	SHIP	FURNACE
PENIS	MELODY	SNAKE	SPRAY	KETTLE
PUSSY	PILLOW	STENCH	TAXI	MIRROR
SCROTUM	PROFIT	TOMB	TOWER	PATIO
SEMEN	QUEEN	TOXIC	TRUCK	ROOF
SLUT	SNUGGLE	TRASH	WAGON	STOVE
VAGINA	SUNSET	TRAUMA	WINDMILL	TABLE

The findings from Chapters 2-4 showed that incidental emotions arising from external distraction during driving can influence driver behaviour. Following from this work, a question of interest is how the presence of a passenger in the vehicle will interact with the effects of emotion-related distraction. However, before this issue can be studied, we must first have a clear understanding of the social and cognitive impact of a passenger on driver attention and performance; this was the focus of Chapter 5.

Chapter 5:

Effects of a front-seat passenger on driver attention: An electrophysiological approach

A version of this chapter has been submitted for publication: **Chan, M.,** Nyazika, S., & Singhal, A. (2015). Effects of a front-seat passenger on driver attention: An electrophysiological approach. *Transportation Research Part F: Traffic Psychology and Behaviour.*

ABSTRACT

The human attention system is limited in capacity, and when performing two concurrent tasks there is competition for cognitive resources. This is particularly important in dangerous scenarios, such as driving in heavy traffic where deficits in performance can be caused by various sources of distraction, including the presence of a passenger in the vehicle. In the present study, a dual-task paradigm was employed to examine the nature of attentional limits while operating a driving simulator in the presence of a passenger. The primary driving task had two levels of difficulty and event-related potentials (ERP) were collected from a secondary auditory task. Participants completed the conditions with and without a passenger present. Our primary hypothesis was that the presence of a passenger would consume more attentional resources, reflected in the morphology of the P300 elicited by the auditory task, particularly in the more difficult driving conditions. The results showed that operators drove faster and had better lane control in the easy driving conditions compared to the hard conditions. As expected, we observed a decrease in P300 amplitude and an increase in its latency from single to dual-task conditions. Importantly, compared to driving solo, the presence of a passenger was associated with smaller P300 amplitudes in the more difficult driving conditions. Taken together, these results show that in-car passengers may consume valuable resources in difficult driving situations that require more attentional focus in the first place.

5.1 Introduction

Driver distraction is a major contributing factor in motor vehicle crashes. In 2013, 18% of all crashes and 16% of fatal crashes were associated with distracted driving. Drivers under 40 years of age made up the largest proportion of those involved in distraction-related fatalities, with those in the age group of 20-29 contributing to 27% of these fatalities (NHTSA, 2015). Recent observational studies report that nearly 17% (Sullman et al., 2015) and 33% (Huisingh et al., 2015) of the drivers observed were involved in distracting activities.

Driver distraction has been defined as a form of inattention that occurs when attention is diverted "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 et al., 2011, pp. 1776). The competing activity may be from inside the vehicle (e.g., talking to a passenger) or outside the vehicle (e.g., looking at a roadside billboard). It has been estimated that 84% of distraction-related fatalities involve carelessness and inattentiveness due to cell-phone use, interacting with a passenger, eating, looking at something outside the vehicle, etc. (NHTSA, 2009). As human operated motor vehicles remain the primary means of transportation in the United States, it is important to identify the potential sources of driver distraction and have an understanding of its impact on driver behavior in order to improve road safety.

5.1.1 Effects of passengers on drivers

According to a recent study, the most common distractions among drivers were interacting with a passenger (53%), talking on a cell-phone (31%), looking at something outside the vehicle (20%), and texting/dialing a cell-phone (17%) (Huisingh et al., 2015). Another study also found that talking to passengers was the most frequent distraction among drivers (Sullman et al., 2015). The AAA Foundation for Traffic Safety (2015) reported that, among teenage drivers, interacting with passengers was the leading cause of distraction-related crashes (15%), followed by cell-phone use (12%). While several experiments have examined the effects of cell-phone use (e.g., Strayer & Johnston, 2001) and roadside billboards (e.g., Chan & Singhal, 2013) on driving performance, the impact of in-car passengers is less well understood. Within this body of work, the majority of research has focused on the influence of passengers on teenage drivers (e.g., Williams et al., 2007), rather than adult drivers.

The role of passengers is an important issue as the presence of more than one passenger in the vehicle can change the driver's social environment. Previous research has long suggested that individuals tend to perform differently in the presence or absence of an observer (e.g., Baxter et al., 1990). Thus, driving a car with a passenger may have a profound impact on driver behavior. Drivers may also be affected by various attributes associated with the passenger, such as the passenger's relationship to the driver, whether the passenger is silent or communicating with the driver, and the nature of the interaction occurring between the driver and passenger (William et al., 2007).

Studies evaluating crash rates have come to inconsistent conclusions about the impact of passengers on driving. Some studies suggest that passengers can distract and increase crash rates, while others suggest that passengers can have a positive (i.e., protective) effect on drivers and reduce crashes. These contradictory findings are likely due to different characteristics of the driver and passengers, such as their relationship to one another, age and gender, as well as varying driving conditions.

Doherty et al. (1998) found that teenage drivers were more likely to be involved in crashes in the presence of passengers compared to older drivers. Lee & Abdel-Aty (2008) reported that younger drivers were at a higher likelihood of being involved in a motor fatality when accompanied by younger passengers compared to older passengers. In Ouimet et al. (2013), teenage drivers showed greater inattention to driving hazards in the presence of a passenger compared to driving alone. Centifanti, Modecki, MacLellan, and Gowling (2014) found that teenage drivers displayed more risky driving behaviors in the presence of a high risk-inclined peer compared to a low risk-inclined peer. This effect was observed even when the driver and peer were not directly communicating, suggesting that peer passengers can exert social influence just by being near the driver. In Hing et al. (2003), drivers over 75 years of age were more likely to be involved in crashes when accompanied by a passenger compared to drivers between 65-74 years of age. Furthermore, it was found that this negative effect was greater when driving on curved or graded road conditions. Together, these studies suggest that passengers may act as social stimuli and provide a source of distraction from within the vehicle. Attention may be diverted away from the driving task to the passenger, resulting in insufficient or no attention to the road ahead. In driving situations that require higher driver workload and attention, such as making turns as opposed to driving straight (Hancock et al., 1990), the distracting effects of passengers may be more detrimental.

On the other hand, passengers may have a protective effect on drivers by warning them of potential hazards, helping with navigation, and encouraging safer driving behaviors. Vollrath et al. (2002) found that, for the majority of the driving population, passengers reduced the rate of accidents compared to driving solo; however this positive effect was smaller in driving situations where high attentional demand was required, such as when passing another vehicle. Lee and Abdel-Aty (2008) found that, with the exception of younger drivers with younger passengers, the presence of passengers was generally associated with safer driving behaviors, such as wearing seatbelts and not driving after alcohol use.

Together, these findings suggest that the social environment, relating to the presence of passengers in the vehicle, can change driver behavior. Depending on certain driver and passenger characteristics (e.g., age) and the driving situation, passengers can have positive or negative effects on road safety. However, to date, no study has used an electrophysiological approach to study the effects of a passenger on driver attention.

The human attention system is limited in capacity, and when performing two concurrent tasks there is competition for cognitive resources (Wickens, 1980). This is particularly important in more demanding driving scenarios, such as making turns, where performance deficits can be caused by various sources of distraction, including the presence of a passenger in the vehicle.

5.1.2 Event-related potentials

Event-related potentials (ERPs) have been widely used to study attention-related phenomena. Derived from electroencephalogram (EEG), ERPs are averaged brain responses that are time-locked to the onset of a stimulus. One advantage of ERPs is that, because of their excellent temporal resolution, they are well-suited for studying ongoing cognitive processes, such as attention. Another advantage is that they provide a more specific measure of underlying cognitive/brain processing compared to what is provided by behavioral measures (Luck, 2005).

One ERP component that is known to reflect attention allocation is the P300. The P300 is a positive-going waveform that occurs between 250 and 600 ms after stimulus onset, and is typically maximal over centroparietal regions (e.g., Donchin & Coles, 1988). It is commonly observed in the classic two-stimulus oddball paradigm, in which participants detect and respond to the occasional infrequent target stimulus interspersed among more frequent standard stimuli. The P300 is typically observed in response to the less frequent, target stimulus, and its amplitude varies inversely with target probability (Duncan-Johnson & Donchin, 1977).

The latency of the P300 is thought to reflect the time required to evaluate and categorize a stimulus. It has been shown that the peak latency of the P300 is longer when the task of discriminating the target stimulus from the standard stimulus increases in difficulty (Kutas et al., 1977; McCarthy & Donchin, 1981). P300 latency is also thought to be independent of response selection and motor processes. This was observed in the Stroop task, in which response times were increased when the display color of a word was incongruent with the color name, but P300 latency did not increase (Duncan-Johnson, 1981). However, motor responses that have memory requirements have been shown to increase P300 latency (Armstrong & Singhal, 2011).

The amplitude of the P300 has been interpreted to reflect the brain activity that is required when the mental representation of the stimulus context is updated in working memory (Donchin & Coles, 1988; Polich, 2007). If the incoming stimulus is the same as the previous stimulus, the current representation is unchanged and no P300 is elicited. If the stimulus is different, attention is allocated to the novel stimulus and the mental representation of the stimulus context is updated, which elicits the P300. Thus, the change in P300 amplitude reflects the ease with which the stimulus context is updated in working memory or the amount of attentional resources that is allocated to a stimulus (Polich, 2007; Wickens et al., 1983).

In dual-task studies, the amplitude of the P300 has been shown to vary with cognitive load (Isreal et al., 1980; Wickens et al., 1983; Singhal & Fowler, 2004; 2005). In a dual-task paradigm, a primary task is performed simultaneously with a secondary task. This approach is predicated on the assumption that as the difficulty of the primary task increases, less resources will be available for the secondary task (Pashler, 1994). Using this approach, Singhal et al. (2002) had participants perform a secondary dichotic listening task alone or in conjunction with a primary simulated flying task with varying levels of difficulty. The results showed that the amplitude of the P300 elicited by the dichotic task was reduced by the introduction of the primary task, and was further reduced by an increase in its difficulty. Similarly, Wester et al. (2008) had participants perform a secondary oddball task alone or simultaneously with a primary driving task. The results showed that the P300 elicited by the oddball task was decreased in amplitude by the introduction of the driving task. Together, these findings support the idea that attentional resources normally recruited to the secondary task is consumed by the primary task in dual-task conditions. These studies also show that the dual-task method offers a power approach for the assessment of attention allocation between tasks.

5.1.3 Research objectives

Previous studies have examined the effects of passengers using behavioral methods, crash risk analyses (e.g., comparing the number of crashes with and without passengers), surveys, and observational data. However, these techniques are limited in their ability to assess underlying cognitive processing, such as how driver attentional resources are allocated when driving with and without a passenger. In addition, the majority of studies have used adolescents (16-17 year olds), who are less experienced drivers than fully licensed adults.

In the present study, we sought to combine ERP measures with a driving simulation to test whether the presence of a passenger impacts the attention and performance of the driver. Using a dual-task paradigm, we had adult participants perform a primary driving task and a secondary auditory oddball task simultaneously. The driving task had two levels of difficulty, and participants performed the conditions with and without a passenger present. Behavioral measures from both tasks were analysed and ERP data from the oddball task was collected to assess attention allocation in the presence and absence of a passenger at different levels of driving difficulty.

We hypothesized that (1) compared to driving solo, the presence of a passenger would consume more attentional resources, as reflected by smaller P300 amplitudes elicited by the oddball task, particularly in the more difficult driving conditions, and (2) driving performance would be more impaired with a passenger present than without, particularly in the more difficult driving conditions.

5.2 Methods

5.2.1 Participants

27 students from the University of Alberta participated for partial credit in an introductory psychology course. All were in the age range of 18 to 40 years old (*M* = 20.0, *SD* = 4.53), had normal to corrected-to-normal vision, and had a class 5 Alberta driver's license for at least one year. This licence class requires a road rest to obtain and allows one to drive independently without an accompanying licensed adult. Data was excluded from six participants due to technical issues with the EEG recording equipment or excessive noise in the EEG data, resulting in 21 participants in the final analyses (11 males; *M* = 20.4, *SD* = 5.10). No participants experienced simulator sickness. The study was approved by the University of Alberta Ethical Review Board.

5.2.2 Driving task

Participants drove a STISIM Drive™ driving simulator that consisted of a steering wheel, gas and brake pedals, and a 22" widescreen computer monitor providing a projected field-of-view of approximately 60° horizontal and 40° vertical.

The display included a rear-view mirror and speedometer. The driving scenarios were 10 km long and consisted of a four-lane highway, with two lanes in each direction, separated by double yellow lines (see Figure 5.1). Daytime conditions with clear skies were adopted in the scenery.

Figure 5.1. Screenshot of the driving task.

Traffic in both directions appeared occasionally. Participants started in the left lane and were instructed to remain in that lane for the duration of the run.[1] Other vehicles travelling behind the participant's vehicle would occasionally pass it from the right (see Figure 5.2a, b). When the passing vehicle was 10 m in front of the participant's vehicle, it would pull back into the participant's lane after a duration of 500 ms or 3 s (see Figure 5.2c, d).

[1] Participants drove in the left lane because lateral lane position was measured in relation to the center dividing line (between opposite directions of traffic) in the simulator program.

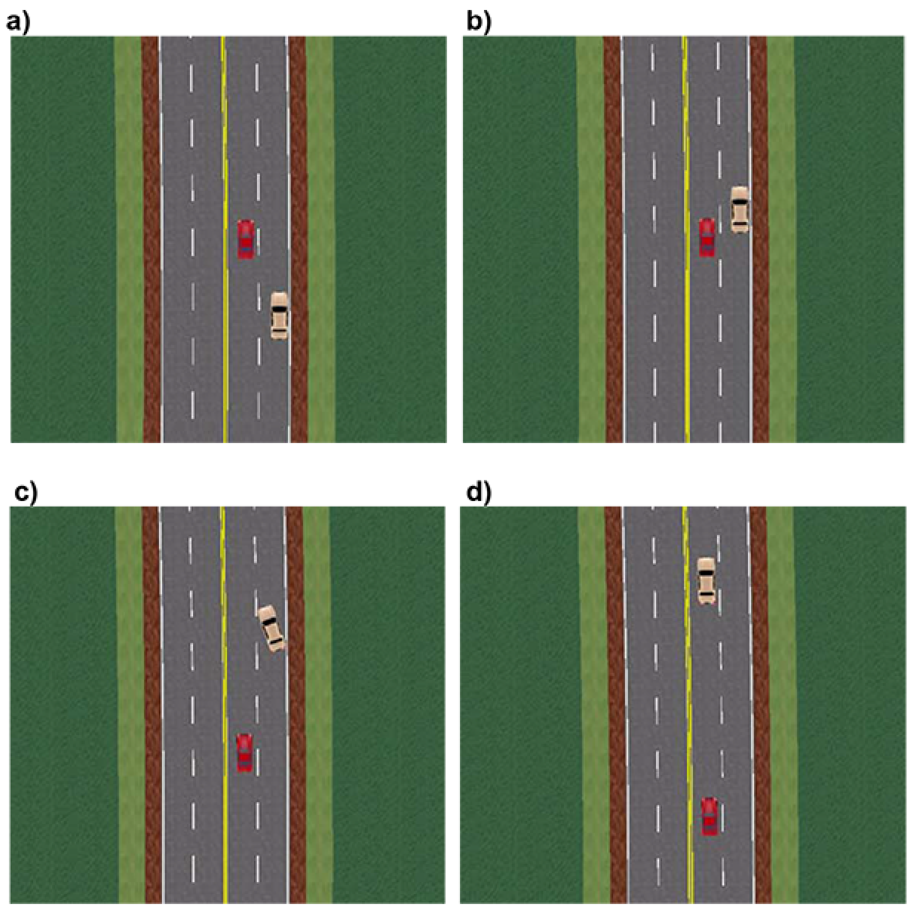

Figure 5.2. (a, b) Aerial views of a vehicle coming from behind to pass the participant's vehicle, which is depicted in red. (c, d) When the other vehicle was 10 m in front of the participant, it would enter back into the participant's lane after a duration of 500 ms or 3 s.

Driving difficulty was manipulated at two levels. The easy scenario consisted of straight roads and slight bends, with a posted speed limit of 90 km/h. Seven passing vehicles pulled in front of the participant after a duration of 3 s and four passing vehicles pulled in after 500 ms. The hard scenario consisted of straight roads and sharp curves; the posted speed limit was 90 km/h for the straight roads and 50 km/h for the sharp curves. Seven passing vehicles pulled in front of the participant after a duration of 500 ms and four passing vehicles pulled in after 3 s. The hard scenario was aimed to impose a higher cognitive load on drivers as they had to negotiate speed limit changes and sharp curves; additionally, more passing vehicles pulled in after a duration of 500 ms, increasing the risks of a collision.

The primary performance measures were (1) mean driving speed, measured in km/h, and (2) lane maintenance, which was assessed as the root mean square error (RMSE) of the driver's lateral position with respect to the center dividing line, measured in meters (Rosenthal, 1999). The measures were monitored for the entire driving scenario.

5.2.3 Oddball task

The oddball paradigm consisted of 80 target tones (1500 Hz, 40% probability) randomly interspersed among 120 standard tones (1000 Hz). The tones were presented through computer speakers, and the ISI varied between 800 and 1200 ms, with a duration of 100 ms (volume: 60 dB SPL). Mean reaction time (RT) in response to the target tones and error rates (misses and false alarms) were calculated for each condition.

5.2.4 Design and procedure

A repeated-measures design was employed in which ten conditions were performed in 2 hr. The order of conditions was counterbalanced across participants using a Latin-square design.

In the single-task conditions, participants performed: (1) the oddball task, (2) the easy driving scenario, and (3) the hard driving scenario. All three tasks were performed with a passenger and with no passenger.

In the dual-task conditions, participants simultaneously performed the oddball task with the easy driving scenario (dual-easy) and the oddball task with the hard driving scenario (dual-hard). Both dual-tasks were performed with a passenger and with no passenger.

The passenger was portrayed by a 21 year old male confederate. The same confederate was used throughout the entire study and sat on the right side of the participant.

Participants were first familiarized with the driving task by completing a 4.0 km practice drive without the passenger (there were no passing vehicles in the drive unlike the experimental scenarios). They were also trained in performing the oddball task. Following these procedures, each participant completed all ten conditions. Participants were instructed to perform both tasks as well as possible. For the oddball task, they were instructed to respond to the target tones as accurately and quickly as possible by pressing one of the buttons on the steering wheel. For the driving task, participants were instructed to keep to the left lane, drive as they normally would, and follow the posted speed limits. They were also told that vehicles would occasionally pass them from the right lane and they were to adjust their speed accordingly to avoid a collision. Finally, participants were told that a passenger would be sitting beside them for some of the conditions. They were instructed to refrain from talking to the passenger. The confederate passenger said hi to the participant at the beginning of the experiment and then refrained from looking at or engaging in any verbal and physical interactions with the participant.

5.2.5 EEG acquisition and pre-processing

The EEG was recorded during the auditory oddball task with 256 electrodes referred to the vertex electrode (Cz) using a Geodesic Sensor Net (Electrical Geodesics Inc., Eugene, OR). The sample rate was 250 Hz and all electrode impedances were kept below 50 kΩ. After re-referencing to a common average reference, the data was filtered with a 50 Hz low-pass filter and a 1 Hz high-pass filter before being segmented into 1,200 ms epochs, beginning 200 ms before stimulus onset. Artifacts were rejected, and eye blinks and eye movements were corrected with the Gratton et al. (1983) method. A -200 to 0 ms pre-stimulus baseline was used for the data.

Our ERP of interest was the P300, which is typically elicited by infrequent, target stimuli and is maximal at centroparietal midline sites (e.g., Donchin & Coles, 1988). Grand averages of the P300 were calculated from the oddball task for each stimulus (standard and target) and each condition from artifact-free EEG segments. The P300 was quantified as the maximum amplitude in the 250 to 600 ms post-stimulus time window at clusters of electrodes surrounding the Pz and Cz scalp locations. There were nine electrodes in the Pz cluster and six electrodes in the Cz cluster.

5.3 Results

All effects were considered statistically significant based on the alpha level of 0.05. Greenhouse-Geisser corrections were applied to account for violations of sphericity.

5.3.1 Driving task

The driving performance data were analysed with separate 2x2x2 repeated measures analysis of variance (ANOVA) with the following factors: driving difficulty (easy, hard), task type (single-task, dual-task), and passenger presence (no passenger, passenger-present). The driving measures were aggregated over the whole driving scenario for each condition.

Driving difficulty had a significant effect on both mean speed [$F(1, 20) = 183.78$, $p < 0.001$, $\eta_p^2 = 0.902$] and RMSE lane position [$F(1, 20) = 5.68$, $p < 0.05$, $\eta_p^2 = 0.221$]. Mean speeds were slower and lateral deviation was higher in the hard scenarios compared to the easy scenarios (*M* ± *S.E.,* hard = 64.0 ± 0.96 km/h, 0.46 ± 0.03 m; easy = 87.2 ± 0.81 km/h, 0.38 ± 0.03 m).

Results also revealed a significant two-way interaction between task type and passenger presence on RMSE lane position [$F(1, 20) = 4.49$, $p < 0.05$, $\eta_p^2 = 0.183$]. In the dual-task (driving + oddball task) conditions, lateral deviation was higher in the presence of a passenger compared to no passenger ($p < 0.05$), as illustrated in Figure 5.3. This shows that driving performance was worse with a passenger in the dual-task conditions compared to no passenger.

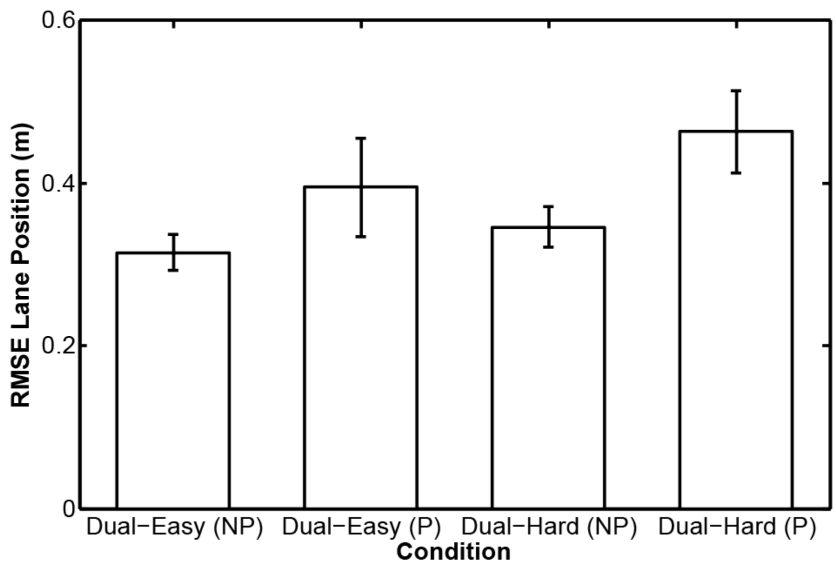

Figure 5.3. Participant's root mean square error (RMSE) lane position in the dual-task (oddball + driving task) conditions. Error bars denote within-subject standard error of the mean.

5.3.2 Oddball task

The Mean RT and error rate data were analysed with separate 3x2 repeated measures ANOVAs with the following factors: condition (oddball only, dual-easy, and dual-hard) and passenger presence (no passenger, passenger-present). Only correct RTs were included in the analysis. Table 5.1 shows the mean RT and error rates for each condition.

Condition	Passenger presence No	Yes	Total Mean
RT			
Oddball task only	509 (25.5)	519 (17.4)	514 (21.4)
Oddball + easy driving task (dual-easy)	541 (14.0)	566 (20.2)	553 (17.1)
Oddball + hard driving task (dual-hard)	569 (19.7)	584 (20.8)	576 (20.2)
Error rates			
Oddball task only	1.67 (0.53)	0.67 (0.34)	1.17 (0.43)
Oddball + easy driving task (dual-easy)	0.48 (0.22)	0.76 (0.32)	0.62 (0.27)
Oddball + hard driving task (dual-hard)	0.90 (0.51)	1.14 (0.41)	1.02 (0.46)

Table 5.1. Mean reaction time (RT, ms) and error rates (%) under single and dual-task conditions, in the presence and absence of a passenger. Standard errors in parentheses.

The RT analysis revealed that latency was longer in both the dual-easy and dual-hard conditions compared to the oddball only condition [$F(2, 40) = 16.67$, $p < 0.001$, $\eta_p^2 = 0.455$; contrasts, $p < 0.01$ and $p < 0.001$, respectively). Latency was also longer in the dual-hard condition compared to the dual-easy condition ($p < 0.01$). The error analysis showed no significance. This shows that participants took longest to respond to targets when the oddball task was performed in conjunction with the hard driving task.

5.3.3 P300

5.3.3.1. Single vs. dual-task. To compare between single and dual-task conditions, P300 amplitude and latency were analysed with separate 3x2 repeated measures ANOVAs with the following factors: condition (oddball only, dual-easy, dual-hard) and tones (standard, target). The analysis was performed for each electrode cluster (Pz and Cz) separately.

As shown in Table 5.2, targets elicited larger P300 amplitudes than standards at the Pz cluster [$F(1, 41) = 185.29$, $p < 0.001$, $\eta_p^2 = 0.819$] and Cz cluster [$F(1, 41) = 62.31$, $p < 0.001$, $\eta_p^2 = 0.603$]. Results also revealed a significant reduction in target P300 amplitude in both the dual-easy and dual-hard conditions compared to the oddball only condition at the Pz cluster [$F(2, 82) = 15.08$, $p < 0.001$, $\eta_p^2 = 0.269$; contrasts, both p's < 0.001] and Cz cluster [$F(2, 82) = 12.38$, $p < 0.001$, $\eta_p^2 = 0.232$; contrasts, both p's < 0.001].

		Passenger presence		
Condition	Stimuli	No	Yes	Total Mean
Cz cluster				
Oddball task only	Target	4.61 (0.70)	5.06 (1.14)	4.84 (0.92)
	Standard	2.36 (0.42)	1.92 (0.42)	2.14 (0.42)
Oddball + easy driving task (dual-easy)	Target	2.93 (0.54)	2.99 (0.46)	2.96 (0.50)
	Standard	1.15 (0.17)	0.55 (0.17)	0.85 (0.17)
Oddball + hard driving task (dual-hard)	Target	3.89 (0.44)	2.78 (0.35)	3.33 (0.39)
	Standard	0.79 (0.16)	0.92 (0.13)	0.85 (0.14)
Pz cluster				
Oddball task only	Target	6.41 (0.87)	6.71 (0.82)	6.56 (0.84)
	Standard	2.58 (0.40)	1.90 (0.26)	2.24 (0.33)
Oddball + easy driving task (dual-easy)	Target	4.33 (0.51)	3.92 (0.38)	4.12 (0.45)
	Standard	1.13 (0.15)	1.00 (0.15)	1.06 (0.15)
Oddball + hard driving task (dual-hard)	Target	5.42 (0.49)	4.09 (0.39)	4.76 (0.44)
	Standard	1.21 (0.17)	1.17 (0.17)	1.19 (0.17)

Table 5.2. Mean amplitudes (μv) of the P300 in response to standard and target tones at the Cz and Pz clusters under single and dual-task conditions, in the presence and absence of a passenger. Standard errors in parentheses.

As shown in Table 5.3, targets elicited longer latencies than standards at the Pz cluster [$F(1, 41) = 15.26$, $p < 0.01$, $\eta_p^2 = 0.271$] and Cz cluster [$F(1, 41) = 5.13$, $p < 0.05$, $\eta_p^2 = 0.111$]. In the case of the Pz cluster, an increase in target P300 latency was found in the dual-hard conditions compared to both the oddball only and dual-easy conditions [$F(2, 82) = 26.79$, $p < 0.001$, $\eta_p^2 = 0.395$; contrasts, both p's < 0.01).

		Passenger presence		
Condition	Stimuli	No	Yes	Total Mean
Cz cluster				
Oddball task only	Target	419 (20.4)	425 (17.4)	422 (18.9)
	Standard	403 (23.3)	382 (25.6)	393 (24.5)
Oddball + easy driving task (dual-easy)	Target	409 (12.6)	412 (16.6)	410 (14.6)
	Standard	404 (25.5)	402 (28.7)	403 (27.1)
Oddball + hard driving task (dual-hard)	Target	434 (15.6)	406 (19.5)	420 (17.6)
	Standard	367 (24.8)	381 (21.0)	374 (22.9)
Pz cluster				
Oddball task only	Target	368 (12.8)	409 (16.1)	389 (14.4)
	Standard	361 (19.7)	383 (23.9)	372 (21.8)
Oddball + easy driving task (dual-easy)	Target	418 (13.7)	429 (13.9)	424 (13.8)
	Standard	344 (19.3)	373 (20.3)	358 (19.8)
Oddball + hard driving task (dual-hard)	Target	450 (16.9)	439 (15.5)	444 (16.2)
	Standard	408 (20.2)	405 (19.9)	406 (20.0)

Table 5.3. Mean latencies (msec) of the P300 in response to standard and target tones at the Cz and Pz clusters under single and dual-task conditions, in the presence and absence of a passenger. Standard errors in parentheses.

5.3.3.2. Presence of the passenger. To analyse effects of the presence of the passenger, separate ANOVAs were conducted for the oddball only, dual-easy, and dual-hard conditions. For each condition, two 2x2 repeated measures ANOVA with the factors tones (standard, target) and passenger presence (no passenger, passenger-present) were performed on P300 amplitude and latency separately. The analysis was performed for each electrode cluster (Pz and Cz) separately.

The analyses conducted for the oddball only condition showed that amplitude and latency at the Pz and Cz clusters were unaffected by the presence of the passenger. The ANOVAs conducted for the dual-easy condition also revealed no significant effects of the presence of the passenger on amplitude and latency at the Pz and Cz clusters.

For the dual-hard condition, the analyses revealed a significant two-way interaction between tones and passenger presence on amplitude at the Pz cluster [$F(1, 20) = 7.88$, $p < 0.05$, $\eta_p^2 = 0.283$] and Cz cluster [$F(1, 20) = 9.00$, $p < 0.01$, $\eta_p^2 = 0.310$]. As illustrated in Figure 5.4, P300 amplitudes to targets were smaller in the presence of a passenger compared to no passenger [contrast, Pz cluster ($p < 0.05$) and Cz cluster ($p < 0.05$)].

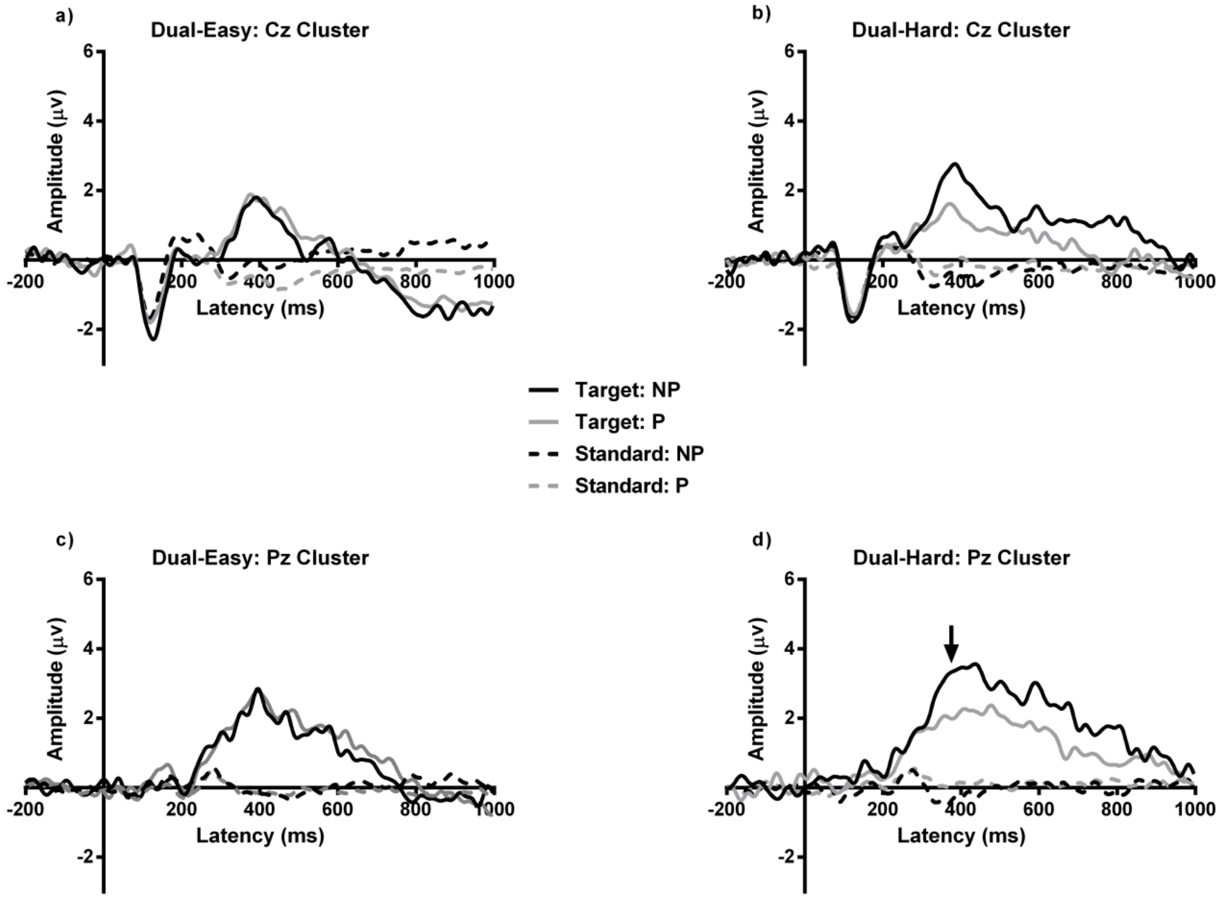

Figure 5.4. Grand average P300 waveforms to the oddball task at the Cz (a, b) and Pz (c, d) clusters.

5.4 Discussion

The present study sought to combine ERP measures with a driving simulation to examine whether the presence of a passenger impacts driver attention and performance. Using a dual-task paradigm, we had participants perform a driving task and an auditory oddball task simultaneously. The primary driving task had two levels of difficulty, and we had conditions with and without a passenger present. Our results showed that in the dual-task conditions, driving performance was poorer with a passenger present compared to driving with no passenger.

Importantly, the presence of a passenger was associated with smaller P300 amplitudes in the more difficult driving conditions, confirming our first hypothesis.

5.4.1 Driving performance

As expected, driving performance was poorer in the difficult driving scenario compared to the easy scenario; however performance was not affected by the secondary oddball task. Similarly, Wester et al. (2008) found that driving performance did not differ with the addition of an auditory oddball task. As Wester et al. (2008) speculated, it is possible that the driving task and oddball task used different resource pools, and therefore did not interfere with each other. According to the multiple resources theory, the human operator has several independent information processing structures, each with its own resource pool (Wickens, 1980). Tasks that utilize separate structures will interfere less with each other than if they rely on the same structure and require the same pool of resources. It is also possible that the oddball task may have been too simple.

In the dual-task (driving + oddball task) conditions, drivers showed poorer lateral control, as indicated by an increase in RMSE lane position, when accompanied by a passenger compared to having no passenger. This may suggest that a change in the social environment, relating to the presence of a passenger, can influence driving performance. It is important to note that the driver and passenger did not converse or interact, suggesting that the mere presence of the passenger was sufficient to change driver behavior. Along the same lines, Pradhan et al. (2014) found that the visual scanning range of drivers was reduced in the presence of a silent passenger compared to driving alone, indicating a narrowing of attentional focus on the driving task. This reduced scanning behavior has also been found in drivers engaged in cell-phone conversations (Maples et al., 2008) and cognitively demanding tasks (Engström et al., 2005; Harbluk et al., 2007). Thus, it is suggested that the presence of a passenger may impose some cognitive demand on the driver to reduce attentional focus from the driving task and lead to poorer performance.

On the face of it, our results showed that the presence of a passenger had no effect on driver performance when the driving condition was easy. However, when a more substantial cognitive load was imposed by the difficult condition we saw that the passenger affected driving performance, such as when he or she is involved in a secondary task. To further investigate this interesting effect of an in-car passenger on driver attention we also examined the P300.

5.4.2 P300 effect

The P300 was used to assess attention allocation in the presence and absence of a passenger. The P300 has been used in dual-task studies to assess how attention is allocated to different tasks. This approach is predicated on the assumption that human attentional resources are limited and can be shared between tasks (Wickens, 1980). As demands of one task increases (e.g., driving), fewer resources are available for the other task (e.g., an oddball task), as reflected by a decrease in P300 amplitude elicited by oddball targets.

The competition for cognitive resources may be particularly important in high-load situations, such as driving along sharp curves where deficits in performance can be caused by various sources of distraction, including the presence of a passenger in the vehicle. Using a dual-task approach, we assessed how attention is allocated to a driving task and a secondary oddball task in the presence and absence of a passenger. We also manipulated the difficulty of the driving scenarios (easy and hard) to test whether the effects would differ with cognitive load.

As expected, we observed a decrease in P300 amplitude from single (oddball task only) to dual-task (driving + oddball task) conditions. This finding is consistent with several studies and demonstrates a sharing of resources between the driving task and the oddball task under dual-task conditions (e.g., Chan & Singhal, 2015; Isreal et al., 1980; Singhal & Fowler, 2004; Wickens et al., 1983). Processing of the target tones was reduced at the cost of performing either the easy or hard driving task perhaps due to the limits of attentional capacity. Additionally, P300 latency was longer in the dual-hard conditions compared to both the oddball only and dual-easy conditions. Thus, while an equivalent amount of attention was diverted to the oddball task during both the easy and hard driving tasks, other processes were affected differently. Changes in the latency of the P300 are thought to reflect perceptual processes associated with stimulus evaluation time. We observed a cost of concurrence in P300 latency only when the hard driving task was introduced, likely due to greater interference from the more difficult driving task and the oddball task. This follows the pattern of the RT data, where RTs were longer in the dual-hard condition compared to the dual-easy and oddball alone conditions.

When we compared conditions with and without a passenger, interestingly, we found that the presence of a passenger was associated with smaller P300 amplitudes in the more difficult driving conditions. This decrease in amplitude likely reflects reduced processing of the target tones and suggests that the presence of the passenger may have contributed to more consumption of attentional resources by the driving task. Thus, it appears that the presence of a passenger may have imposed some demand on the operator's limited capacity of attention.

There were no differences in P300 amplitude with and without a passenger in the easy driving conditions, suggesting that in-car passengers may consume driver resources only in situations that require more attentional focus in the first place. In the easy driving scenario, the driver's cognitive load should be relatively low because of the mostly straight roads and lack of obstacles. In contrast, the hard scenario required drivers to negotiate sharp curves and adjust their speed in response to several vehicles suddenly pulling in ahead, which presumably involves greater attention. It is possible that because there was less demand on the driver's limited capacity of attention in the easier conditions, there was enough resources available to process both the secondary task and the driving task simultaneously even in the presence of a passenger. This is in line with Kahneman's (1973) theory that when the total amount of attentional resources demanded by two concurrent tasks does not exceed one's capacity, performance on both tasks are successful. Easier tasks that require lower workload will share resources more effectively (Kahneman, 1973).

Overall, our results are in line with previous research showing that individuals tend to perform differently in the presence or absence of an observer. For example, in a study by Markus (1977), participants were to dress in clothing that was familiar (e.g., their own shoes) or unfamiliar (a lab coat provided by the experimenter) either alone or with an observer present. Compared to the alone condition, the time it took to dress in the observer condition was improved when dressing in familiar clothing and hindered when dressing in unfamiliar clothing. In Hunt and Hillery (1973), participants made more errors on a complex maze with an observer present than when alone. Similarly, in Schmitt et al. (1986), a task that involved typing one's own name backwards with ascending digits interspersed between each letter was found to be slower with an observer present than when alone. Of note is that the participant in all of these studies did not engage in any verbal or physical interactions with the observer, demonstrating that the mere presence of the observer was sufficient to change behavior. According to Sanders and Baron (1975), the reason for these effects is that observers represent social stimuli and therefore, are distracting. This creates conflict between attending to the ongoing task and attending to the observer, leading to more competition for attentional resources between the two activities. The few experimental studies on the effect of passenger presence on driving has shown that drivers tend to behave differently when they are accompanied by passenger compared to driving alone. For example, there is evidence that the visual scanning behavior of drivers is reduced in the presence of a passenger, implying a narrowing of attentional focus on the driving task (Pradhan et al. 2014). Similarly, Ouimet et al., (2013) reported fewer eye glances to potential driving hazards when drivers were accompanied by a passenger compared to driving alone.

We extended these prior findings by demonstrating that the presence of a passenger is associated with smaller P300 amplitudes in difficult driving situations. This decrease in amplitude suggests that the passenger may have mediated the consumption of more attentional resources from the dual-task situation, and is consistent with Sanders and Baron's (1975) explanation that an observer is a distracting social stimulus. Thus, it appears that the presence of a passenger may have imposed some cognitive demand on the driver so that they are less focused on the secondary task. Because we observed no passenger effects in driving conditions that were easy, it is speculated that passengers may be distracting only in certain driving situations, such as when the level of attention required to successfully operate the driving task is high.

5.4.3 Limitations

The generalizability of these results is limited for the following reasons. First, our sample was small, and the participants were between the ages of 18 and 40. Future research would benefit from using a larger sample size and including participants in a larger range of age groups to increase the generalizability of results. Another limitation is that the driver and passenger did not interact, which is somewhat unrealistic in the real world. In the future, it would be useful to explore the attentional limits of driving when conversing or interacting with a passenger. The use of a confederate as a passenger also reduces the reality of the situation. It is possible that because the confederate was an unknown person, the driver might have behaved differently or felt pressured compared to driving with a friend. Finally, because the experiment was conducted in a laboratory setting with a driving simulator and a secondary oddball task, the artificial environment decreases the generalizability of the results. In the future, it is warranted to use more realistic tasks to examine these phenomena.

5.4.4 Conclusions

This study offers new insight into the effects of interactions between attentional demands and social demands on simulated driving performance. Our study is unique in that it provides the first ERP evidence that the mere presence of a passenger is sufficient to influence the driver's attentional focus. In the present study, we combined ERP measures with a driving simulation at two levels of difficulty to test whether the presence of a passenger impacts the attention and performance of the driver. The results showed that in dual-task conditions, driving performance was poorer with a passenger present compared to having no passenger. Importantly, we found that the presence of a passenger was associated with a decrease in P300 amplitude in the more difficult driving conditions. Taken together, these findings demonstrate that a change in the social environment, related to the presence of a passenger, can impact the driver. Specifically, an in-car passenger may contribute to the consumption of valuable driver resources in high-load driving situations.

These findings have important implications for traffic safety as they highlight that the human attention system is limited in capacity, and when distraction occurs, there is competition for attentional resources. Our study suggests that there may be a risk associated with driving with another person in the car, particularly when the driver is involved in a secondary task and driving in situations that require high attentional focus (e.g., driving along sharp curves). It is suggested that roadway safety could be improved by increasing awareness of the detrimental effects of a front-seat passenger on driver attention. This could be raised in driver training programs or road safety campaigns to promote safer driving practices.

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Chapter 6:

General Discussion

The studies reported in this dissertation examined the influence of cognitive sources of distraction (both internal and external to the vehicle) on driver attention and performance. Specifically, the work addressed open questions in the literature concerning the emotional side of cognitive distraction and the social and cognitive impact of an in-car passenger. This is an important topic as over 90% of motor vehicle crashes are caused by human error (National Highway Traffic Safety Administration [NHTSA], 2008). Of the factors associated with these crashes, driver distraction is estimated to be one of the leading causes (NHTSA, 2015). To improve road safety, it is critical to identify the factors that contribute to cognitive distraction, assess the extent of their influence on driver behaviour, and understand the mechanisms underlying the role of cognitive distraction.

Much research in the field of driver distraction has focused on the effects of cell phones and other in-vehicle technologies (e.g., GPS). Prior to the present work, what remained unclear was the impact of emotion-related information on driver behaviour. The literature on passenger effects was also relatively limited and not well understood, particularly at an electrophysiological standpoint. For these reasons, I set out to address the following questions:

1) Given that emotional stimuli typically guide selective attention and receive priority in processing compared to non-emotional stimuli, what are the effects of emotion-related distraction on driver behaviour?
2) Given that driving is highly dependent on visual information in the environment, how does visual distraction, of which attention shifts are intramodal, compare to auditory distraction, of which attention shifts are crossmodal?

3) Given that taboo stimuli are considered more arousing, more shocking, and more memorable than other emotional stimuli, what are the effects of highly arousing taboo distraction on driver behaviour?
4) Given that individuals tend to perform differently in the presence or absence of an observer, what the social and cognitive effects an in-car passenger on driver attention?

The work presented in this dissertation used behavioural and electrophysiological techniques to provide novel insights into these questions. In the next section, I will summarise these novel findings and discuss their contributions to the research on driving and distraction. Thereafter, I will discuss the limitations of my research and outline some future directions. Finally, I will conclude with a discussion on the implication of these findings for road safety.

6.1 Review of the main findings

6.1.1 Chapter 2 (The emotional side of cognitive distraction: Implications for road safety)

At the time of the work, only a handful of articles addressed the role of emotion during driving (e.g., Deffenbacher, Deffenbacher, Lynch, & Richards, 2003). Within this body of work, the majority of findings were focused on the driver's mood. For example, angry moods were associated with road rage and aggressive driving behaviours, such as speeding and tailgating. However, no studies had ever examined the influence of emotions arising from incidental events that were external to the driver and vehicle. This was one of the first studies to investigate the potential for driver distraction from emotional information presented on roadside billboards. Using a dual-task paradigm, participants viewed blocks of positive emotional words, negative emotional words, and neutral words presented on roadside billboards while they operated a driving simulator. Participants also responded to target (animal) words presented in the context of the three types of words and completed a surprise recall task of all the words at the end of the experiment.

This research accomplished several major things. First, this was one of the first studies to address the role of emotion-related distraction while driving. This is an important topic as emotional stimuli tend to capture more attention than non-emotional (neutral) stimuli (for a review, see Schupp, Flaisch, Stockburger, & Junghöfer, 2006). An open question was whether these effects would generalize to a more complex and real-world task, such as simulated driving. While prior research had demonstrated the detrimental effects of roadside billboards on driving performance, these studies did not control for the emotional valence of the billboard content. The work in Chapter 2 achieved this by placing words of different valence on billboards (positive, negative, and neutral). Positive and negative words were matched on arousal, with both being more arousing than neutral words.

Second, the findings provide evidence that distraction that is emotion-based can modulate attention to influence driving-related behaviours. Importantly, the results showed that driving performance was differentially affected by the valence (positive vs. negative) of the emotional content. When driving performance was analysed over particular road sections relative to the position of the billboards, driving speeds were slower in the immediate presence of emotional words compared to neutral words, and this effect lasted longer with positive words only. Thus, compared to negative information, positive information had both immediate and lingering effects on driving performance, which could be potentially harmful to drivers. The pattern of results from target response times and the recall task were consistent with prior studies: response times to targets were faster within the context of positive words compared to the other word types (e.g., Stenberg, Wiking, & Dahl, 1998) and memory recall was higher for emotional words than neutral words (e.g., Kensinger & Corkin, 2003), demonstrating that the effects of emotion can generalize to tasks performed within a driving context. Together, these findings make a significant contribution to the field by revealing that emotional distraction can capture attention to influence driving-related behaviours. These results are also significant in that they are the first to demonstrate the differential effects of valence on driving performance. These unique effects may be due to separate processes by which emotion interacts with arousal in the attention system.

6.1.2 Chapter 3 (Emotion matters: Implications for distracted driving)

The work in Chapter 2 examined the impact of emotion-related distraction presented visually, in the form of roadside billboards. The first open question this study addressed was how distraction presented in the auditory modality would compare to distraction presented visually. This is an important question as both simulated and real-world driving is highly dependent on visual information in the driving environment. When attention is directed to another sensory modality (e.g., listening to a radio broadcast), it may reduce the strength of early cortical representations in the visual system and reduce perception of the visual scene (Shomstein & Yantis, 2004). This may impair the driver's ability to attend to the driving task. The second objective of the study was to use ERPs elicited by the auditory distraction to assess the allocation of neural resources during driving (dual-task) and non-driving (single-task) conditions.

To investigate these issues, this study examined the behavioural and electrophysiological effects elicited by auditorily presented words of different emotional valence (positive, negative, and neutral). The words were presented alone (single-task) and in conjunction with a simulated driving task (dual-task). Similar to Chapter 2, participants responded to target words and completed a surprise recall task of all the words at the end of the experiment.

This research accomplished several major things. First, this was the first study to explore the impact of emotion-related auditory distraction while driving with an electrophysiological approach. Second, the behavioural findings support some of the work from Chapter 2, and extend them to emotional distraction in the auditory modality. Findings from both studies suggest that visual and auditory emotion-based distraction can modulate attention, with unique effects on driving performance, memory, and target response times. Similar to Chapter 2, the results showed that memory performance was higher for emotional words compared to neutral words, and response times to target words were faster within the context of positive words compared to neutral words. Driving performance was also differentially influenced by the emotional valence (positive vs. negative) of the auditory content. Performance averaged over the entire simulation run showed that driving speeds were slower and lateral control was poorer in the presence of negative words compared to positive and neutral words. While the effect of driving performance did not correspond exactly to the effect in Chapter 2, both studies demonstrated that positive and negative information had differential effects on driving performance.

Differences in the pattern of driving results from the two studies may be due to the modality of the distraction. In this study, participants had to shift their attention between the visual scene of the driving task and the auditory distraction (crossmodal), while attentional shifts were intramodal (visual-visual) in Chapter 2. A comparison of the findings from the two studies showed that overall mean speeds were faster and lateral control was poorer in the presence of auditory distraction compared to visual (billboard) distraction. Research has shown that when attention is momentarily focused to a different modality it can suppress neural activity produced by visual stimuli at early stages of visual processing (V1) (Shomstein & Yantis, 2004). This can impair a highly visual task, such as driving. Findings from the two studies suggest that auditory distraction may presumably produce greater interference on the driving task compared to visual distraction, due to crossmodal shifts of attention.

The finding that auditory target stimuli yielded faster response times than visual target stimuli corroborate prior research (Brebner & Welford, 1980; Welford, 1980). It has been suggested that an auditory stimulus only takes 8-10 ms to reach the brain (Kemp, 1973), while a visual stimulus takes 20-40 ms (Marshall, Talbot, & Ades, 1943). The faster the stimulus signal is processed, the faster the necessary responses are sent for the necessary motor response execution.

In Chapter 2, more negative billboards were recalled than positive billboards, while in this study, negative and positive auditory words yielded similar levels of recall. In Chapter 2, response times to targets were slower in the presence of negative billboards compared to positive billboards. On the other hand, response times to targets were similar in the presence of negative and positive auditory words. These discrepant findings are likely due to differences in how auditory and visual emotional stimuli are processed. The presentation duration of each auditory word was 750 ms; thus, the auditory information had to be processed immediately. On the other hand, the visual billboards were legible for 3 to 5 seconds (for driving speeds between 40 to 80 km/h); consequently, each billboard was available in perception for a longer period of time, permitting deeper processing of the emotional word content. This could presumably increase the negative affective value of visual information and enhance the negativity bias, leading to better memory and longer response times for negative visual stimuli compared to negative auditory stimuli.

Behavioural findings in this study also suggest that valence and arousal aspects of the emotional auditory distraction have differential effects on behaviour: driving performance is driven by valence, while memory and response times are driven by the arousal aspect of emotion (recall and response times are improved when arousal is high). This finding highlights the importance of taking into account emotional valence and arousal in driver distraction research as they can differentially influence driving behaviours.

Third, the findings provide the first electrophysiological evidence that auditory distraction recruits memory and attentional processes that are reflected in the negative slow wave (NSW). The NSW was reduced in amplitude by the introduction of the driving task, suggesting a competition for limited neural resources under dual-task demands, which is consistent with prior research (e.g., Isreal, Chesney, Wickens, & Donchin, 1980; Singhal & Fowler, 2004; Wickens, Kramer, Vanasse, & Donchin, 1983). In addition, the amplitude of the NSW was smaller to emotional words than neutral words. This distinct ERP modulation to emotional words suggests that emotional items are processed differently in the brain than neutral items.

Taken together, these findings demonstrate that driving in the presence of auditory distraction can increase cognitive workload in the driver. These findings also show that emotion-related auditory distraction are processed differently than neutral distraction (based on the recall and ERP results). Finally, this study confirms a valence effect on driving performance; specifically, auditory content containing negative emotional words may have more adverse effects on driving performance than positive emotional words.

A general conclusion of Chapters 2 and 3 is that the effect of emotional words on driving performance is due to attentional distraction. In other words, attention is diverted away from the primary driving task to process the emotional information. This was inferred from evidence that emotional words were better recalled than neutral words, suggesting that emotional words captured and received more attention, which might have competed with the driving task to impair driving performance.

Additional ERP results from Chapter 3 provide support for this. Supplementary data revealed that in both single- and dual-task conditions, the negative slow wave at a central electrode site showed clear and significant amplitude differences elicited by emotional and neutral words (see the appendix for a figure). These differences in emotional processing were not influenced by the introduction of the driving task. This suggests that the emotional load was independent of the dual-task attentional load, and that participants were processing the emotional words even at the expense of driving performance.

Another method to ensure that the effect of emotional words on driving performance is due to attentional distraction is to examine driving task difficulty as a possible factor modulating the impact of emotional and neutral distraction on driving performance. A more difficult driving scenario is considered to require greater attention than an easier scenario. If emotional words modulate driving performance via attentional distraction, it is expected that in the more difficult driving task, the detrimental effect of driving performance should be more robust in the presence of emotional words compared to neutral words.

6.1.3 Chapter 4 (The effects of taboo-related distraction on driving performance)

Findings from Chapters 2 and 3 expand our understanding of the impact of emotional distraction on driving performance; specifically, the two studies provide novel insights into the differential influences of valence and arousal on driving-related behaviours (driving performance, recall of the distracting stimuli, and target response times). Importantly, the emotional valence (positive vs. negative) of the distracting content is an important factor in how attention is modulated to differentially affect driving performance.

At the time of the work, one aspect of emotion that had not been investigated in the literature was the impact of taboo information on driving performance. In terms of valence, taboo items are rated most similar to negative emotional items. In terms of arousal, taboo items are rated higher than either positive or negative emotional words (Janschewitz, 2008). Thus, taboo stimuli are distinguished from other emotional stimuli by high arousal. Research also suggests that taboo stimuli are processed differently than emotional stimuli because they have inherent taboo-specific properties, such as offensiveness or shock value (Janschewitz, 2008; Jay & Janschewitz, 2008).

An open question this study addressed was how highly arousing taboo distraction would affect driving performance. Given that taboo information typically captures and engages more attention than other emotional information, it was expected that taboo distraction would modulate attention to influence driving performance in different ways than positive or negative emotional distraction. Prior studies have shown that taboo distractors can impair task performance (Arnell, Killman, & Fijavz, 2007; Aquino & Arnell, 2007), thus, it was hypothesized that driving performance would be poorer in the presence of taboo distraction compared to emotional distraction. Alternatively, there is evidence that high arousal can enhance focus by narrowing attention to certain aspects of the environment (cognitive tunneling) (Dirken & Hancock, 1985). Thus, the alternate hypothesis was that, in the presence of taboo distraction, driving performance would show no decrements as attention would be highly focused to the road ahead.

To test these hypotheses, this study investigated the effects of taboo-related distraction on driving performance. Participants drove a simulator in the presence of four types of emotional information presented on roadside billboards: non-arousing (neutral) words, moderately arousing positive words, moderately arousing negative words, and highly arousing taboo words. Participants also responded to target (household-related) words presented within the context of the other words and completed a surprise recall task for all the words at the end of the study.

Once again, the findings confirmed a valence effect on driving performance. Drivers had faster mean speeds in the presence of positive words compared to negative words, consistent with the finding in Chapter 2, where positive words were associated with faster speeds when driving performance was averaged over the entire simulation run.

Replicating previous studies, memory performance was highest for taboo words compared to the other word types, suggesting that taboo words received the most attention (Buchanan, Etzel, Adolphs, & Tranel, 2006; Madan, Caplan, Lau, & Fujiwara, 2012). Similar to Madan, Shafer, Chan, and Singhal (submitted), the results showed no effect of memory enhancement for positive and negative words, perhaps due to interference from the taboo words on the retrieval process of other emotional words.

This study identified two novel findings. First, taboo words were associated with better lane control than the other word types. Previous studies have shown that high arousal can narrow the focus of attention (Agnew & Agnew, 1963; Bacon, 1974; Easterbrook, 1959). Based on this, it is suggested that drivers may have increased their focus on the road ahead due to being in a high arousal situation. This relates to the concept of “cognitive tunneling” – a phenomenon in which observers tend to focus their attention on one aspect of the environment to the exclusion of information outside this highly attended area (Dirken, 1983; Thomas & Wickens, 2001). Attentional focus on the forward road would limit the processing of other sensory information in the driving environment (e.g., trees, buildings, and oncoming traffic), leading to better driving performance.

The second novel finding is that false alarm rates to the target words were lower in the taboo condition compared to the other word conditions. It is suggested that drivers may have been in a state of heightened vigilance in the presence of highly arousing taboo information, resulting in higher accuracy (i.e., fewer false alarms). This is consistent with theories that arousal is linked to sustained attention and vigilance (Parasuraman, Warm, & See, 1998). Moreover, by narrowing attention to the road ahead, drivers may have been able to better focus on the driving and the target response task.

Taken together, these finding uniquely contribute to the literature by demonstrating that taboo-related arousal can enhance attentional focus in simulated driving. These results are significant as they suggest that the effects of emotional distraction may be more complicated than previously thought. Highly arousing information may modulate attention and alter performance in different ways than moderately arousing information.

6.1.4 Chapter 5 (Effects of a front-seat passenger on driver attention: An electrophysiological approach)

The findings from Chapters 2-4 demonstrate that information with emotional content can influence driver behaviour. Stemming from this, an open question was how the presence of a passenger in the vehicle would interact with the effects of emotion-related distraction. However, in order to investigate this we must first have a clear understanding of the impact of a passenger on driver attention.

The influence of passengers on driver behaviour is a topic that has been relatively understudied, particularly in an experimental setting with adult drivers/passengers. Moreover, the electrophysiological effects of driving with a passenger had never been examined. This is important as studies have shown that an individual's behaviour can be changed by the social context of the setting, including whether spectators are present or not (for a review, see Geen & Bushman, 1989). Understanding the social and cognitive influence of passengers on driver attention is critical to improving road safety, given that at least 50% of car trips carry more than one passenger (Nevile & Haddington, 2010).

The primary objective of this study was to use an electrophysiological approach to assess the attentional limits of operating a driving simulator in the presence of a passenger. Using a dual-task paradigm, participants performed a primary driving task and a secondary auditory oddball task simultaneously. The driving task had two levels of difficulty and ERPs were collected from the oddball task. Participants performed the conditions with and without a passenger present.

The P300 is thought to reflect the amount of attentional resources allocated to a task or stimulus. In dual-task studies, P300 amplitude is closely related to task workload (Isreal et al., 1980; Wickens et al., 1983; Singhal & Fowler, 2004; 2005). Increases in primary task difficulty lead to a reduction in P300 amplitude elicited by a concurrent task. This is thought to reflect capacity trade-offs in processing resources under dual-task conditions. In this study, the P300 was used to assess the allocation of driver attentional resources under the cognitive demands of a secondary oddball task, during conditions with and without a passenger present. The amplitude of the P300 from the oddball task was analysed to measure the amount of attentional resources invested in processing the target stimulus (Polich, 2007).

The most significant finding is that compared to having no passenger, the presence of a passenger was associated with a decrease in P300 amplitude in the more difficult driving conditions. This P300 effect reflects a reduction in the processing of oddball target tones and suggests that the presence of the passenger may have contributed to more consumption of attentional resources by the driving task. Of note is that the driver and passenger did not engage in any visual, verbal, or physical interactions, suggesting that the mere presence of the passenger was sufficient to create a social situation in which the driver performed differently compared to when they were alone.

This study is unique in that it provided the first ERP evidence that the mere presence of a passenger can consume attentional resources under dual-task demands. The findings also suggest that one potential mechanism for the impact of passengers is that they impose additional demand on the driver's limited cognitive resources.

6.2 Summary and significance

During driving, high attention is essential for the safe operation of a vehicle. However, attention is limited in capacity, and when distraction occurs the driver will often reallocate their limited resources from the driving task to the distracting event. As demonstrated in the work presented, this not only affects driving performance, but also memory for the distracting events and target detection response times.

The present work offers novel insights that allow for an increased understanding of cognitive distraction while driving. Specifically, Chapters 2-4 provided contributions to the research on driver distraction by demonstrating that emotion-related distraction, in the form of roadside billboards and auditory inputs, can capture attention and influence the performance of driving-related tasks (driving performance, memory, and response times). When considering the findings from all three studies, two novel lines of evidence emerge. First, the findings suggest that the processing of emotional information while driving likely influences higher-order cognitive processes rather than lower level sensory and perceptual processes. Second, emotional valence and arousal can differentially affect driving-related behaviours. Importantly, driving performance differs depending the valence (positive vs. negative) and arousal (high vs. moderate) of the distracting content. These unique effects are likely due to separate processes in the attention system, related to how arousal and valence interacts. Based on the findings, there may be at least three mechanisms of emotion-related distraction that have the potential to impact driving performance, depending upon whether the information processed is positive emotional, negative emotional, or taboo-related.

Chapter 5 provided contributions to the driving literature by demonstrating that the mere presence of a passenger was sufficient to consume driver attentional resources under dual-task demands. This supports research in the field of social psychology where studies have shown that the social influence of others can be exerted passively (without any overt actions or communication) to change people's thoughts and behaviours. The passenger's influence on the driver may have created feelings of social pressure or apprehension due to a belief that he or she is being evaluated. This additional cognitive load imposed by the passenger may have contributed to more consumption of attentional resources in the driver. Furthermore, the passenger's presence may have influenced the emotional state of the driver. Given that the passenger was a confederate in the study, it is possible that the driver may have experienced feelings of stress and anxiety; whereas if the passenger was a friend or peer, the driver may have experienced different emotions, such as excitement. These emotional factors associated with the passenger may alter the driver's level of arousal to impact driver attention and performance.

Cognitive distraction has often been associated with driver workload. Workload is described as "the cost of accomplishing task requirements for the human element of man-machine systems" (Hart & Wickens, 1990), where "cost" refers to the depletion of internal resources (effort, attention) in the operator. As shown in Figure 6.1, workload is a product of the external demands placed on the operator and task and the amount of resources invested by the operator for task performance (Hart & Wickens, 1990; Mehler, Reimer, & Zec, 2012).

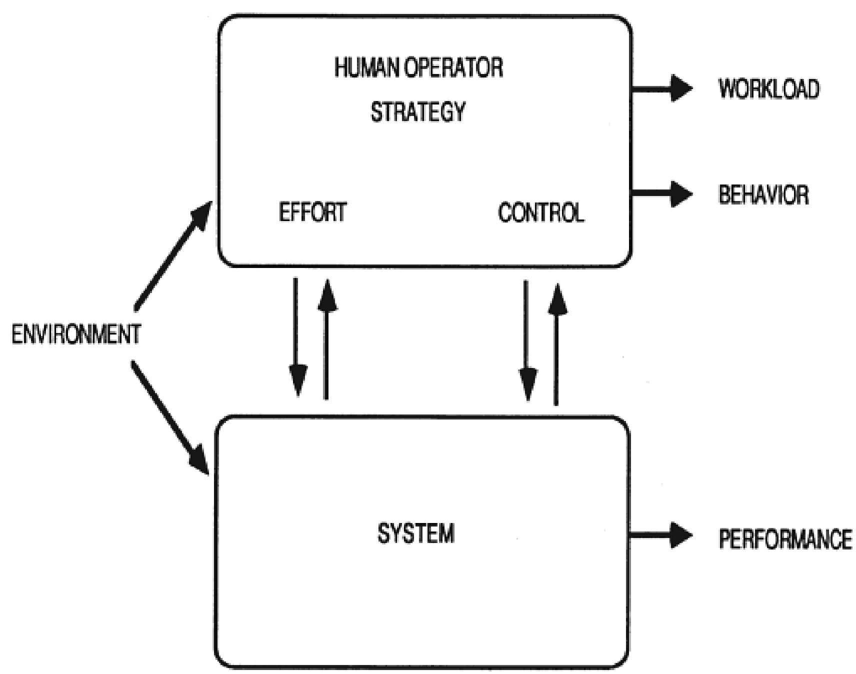

Figure 6.1. Framework for understanding workload in the human operator. Reprinted from "Workload Assessment and Prediction," by S. G. Hart and C. D. Wickens in *MANPRINT: An Approach to Systems Integration* (p. 258) by H. R. Booher (Ed.), 1990, New York, NY: Van Nostrand Reinhold. Copyright 1990 by Van Nostrand Reinhold. Reprinted with permission.

When a driver is involved in a secondary cognitive activity, resources are depleted from the driving task to process the competing activity. This increases overall workload as the driver must now exert more effort to maintain an acceptable level of driving performance. Cognitive distraction arises when there is an overload of information from concurrent tasks and insufficient resources are available for the driving task (Lee, Reyes, & McGehee, 2004). At critical moments, such as when roadway demands are high, this can be particularly dangerous.

The work in this dissertation showed that emotion-related distraction captured more attention than less salient neutral distraction, and that valence and arousal uniquely contribute to workload. The presence of a passenger was also shown to contribute to more consumption of attentional resources in difficult driving situations as compared to having no passenger. It is possible that the simple existence of a passenger may have created a social situation in which the driver felt he or she was being evaluated. Likewise, it is possible that the driver experienced a change in emotional state or some sort of social pressure due to perceived social norms or expectations of the passenger, which may have added to the driver's cognitive load.

Collectively, these convergent lines of research demonstrate that emotion-related information and an in-car passenger are significant sources of cognitive distraction: they add to the driver's overall workload and shift attention away from the driving task to process the competing event. As a consequence, attention is modulated to influence driver attention and performance. These effects were observed regardless of the modality of the distraction (visual/auditory) and regardless of whether the driver was overtly attending to the distraction (directing one's gaze to the billboards) or covertly attending to the distraction (directing cognitive attention to the passenger).

In sum, cognitive distraction may be understood in terms of driver workload. When overall workload is low, drivers can respond appropriately to critical events, such as making a brake response when the leading vehicle has braked. However, when workload is high, due to involvement with a cognitive activity, a competition for limited attention in the driver can arise, which may undermine driving safety.

6.3 Limitations and future directions

While the studies reported in my dissertation provide novel insights into the influence of cognitive sources of distraction, they also raise a number of questions that require further investigation. A more in depth discussion on the limitations related to each experimental chapter in the dissertation may be found at the end of each chapter.

A limitation of the work in Chapters 2-4 is that arousal was not controlled for in the set of emotional words used. This is important as evidence suggests that high and low arousal stimuli are processed in different regions of the brain (Nielen et al., 2009). Moreover, Chapter 4 revealed that highly arousing (taboo) words have unique effects on task performance compared to moderately arousing emotional words. Thus, it would be beneficial in future research to compare the effects of different combinations of valence (positive, negative) and arousal (high, moderate, low) on driving behaviour. It is predicted that positive and negative stimuli will have unique effects on driving performance, and that these effects will differ across arousal levels. Thus, arousal level may modulate the effects of valence on driver attention and performance.

Future research should also build on the present work and evaluate other forms of distraction, such as emotional images presented on billboards and emotion-related sounds (e.g., the sound of a crying baby). As previously mentioned, an additional study should be conducted to extend the work in Chapter 5 and investigate how the presence of a passenger will interact with the effects of emotion-related distraction.

An important limitation of the present work is that personality traits were not assessed. This may be a confounding variable as existing literature has shown that personality factors may be associated with driving behaviour. Individuals who score high on extroversion tend to endorse more risky driving behaviours, while those that score high on agreeableness and conscientiousness endorse safer driving practices (Taubman-Ben-Ari & Yehiel, 2012). It has also been reported that extraverts incur more traffic accidents and violations than introverts (Fine, 1963). Eysenck (1967) attributed these behavioural differences to variability in baseline cortical arousal. Extraverts have lower baseline levels of arousal, and so they seek out stimulation in order to increase arousal to the optimal level. In contrast, introverts have higher baseline levels of arousal, and so they avoid stimulation in an effort to decrease arousal to the optimal level. Based on these previous studies, it is possible that drivers with different personalities and temperaments may respond differently to external distraction due to how one customarily drives. Future research should include personality measures to understand how individual differences would relate to drivers' proneness to distraction.

Another cause for concern is the relatively low sample sizes used in investigating the issues in the present work. While this may temper the ability to draw more concrete conclusions from the data, it nevertheless allowed an initial exploration into the issues of emotion-related and passenger distraction. Additional research will be necessary to examine other characteristics of the passenger that may influence driver attention, including age, gender, and their relationship to the driver. This is important as prior studies have shown that driving behaviour can vary with certain driver-passenger characteristic combinations (e.g., young drivers tend to drive more recklessly when accompanied by younger passengers compared to older passengers) (Lee & Abdel-Aty, 2008).

Finally, given that all of the studies were conducted in a laboratory setting with a driving simulator, the artificial environment may have limited the generalizability of the findings. For example, the simulator has a limited forward field-of-view, therefore there are differences in the visual behaviour of operating a simulator and driving on actual roads. Also, because the image the driver views is projected on a flat screen, there is little to no information regarding motion, optic flow, and depth perception. Another difference is that because driving errors have no real safety consequences in the simulator, overall workload is likely lower compared to operating an actual vehicle; as a result, the process of allocating resources between the primary driving task and the competing activity may differ in simulated driving compared to real-world driving (Young, Regan, & Lee, 2009).

Despite these limitations, driving simulators are known to provide a controlled and safe environment to assess driving performance, particularly in potentially dangerous scenarios. A large body of evidence indicates that simulators have relative validity and are sufficient for assessing driving performance measures, such as speed, lateral position, and divided attention (e.g., Bédard, Parkkari, Weaver, Riendeau, & Dahlquist, 2010; Mullen, Charlton, Devlin, & Bédard, 2011).

6.4 Implications for road safety

The novel features of the findings in this dissertation offer insight into the potential mechanisms of emotion-related and passenger distraction. These findings may inform procedures for driver training, public awareness, enforcement, and driver support functions.

One strategy that has been used to promote road safety is through improving driver education. Given that drivers are often not aware of the dangers of competing cognitive activities, it is critical that drivers understand the basis of attentional capacity and the consequences of increased workload in dual-task situations. While it may be difficult to ignore all roadside billboards, particularly salient ones, continued or increased education on the dangers of cognitive distraction should be emphasized to promote self-awareness. Additionally, it would be beneficial to include a component on distracted driving as part of the driver's training program and in driver's license manuals, where drivers are taught to limit their cognitive workload, be vigilant, and drive defensively. As passengers can be a source of distraction, drivers should also be educated on the influence of passengers. Given that novice drivers have reduced attentional control and are more likely to over-estimate their driving abilities compared to experienced drivers, passenger restrictions should be considered during the beginning stages of licensing, such as limiting new drivers to carry only one adult passenger.

Other initiatives to increase public awareness of the dangers of cognition distraction is through road safety campaigns, presentations in classrooms and work settings, television/radio commercials, and newspapers/magazines. By educating drivers on these issues it will increase their understanding and awareness of cognitive sources of distraction.

Given the link between emotion-related distraction and driving performance, there is a need for legislation to carefully regulate the content on roadside billboards to ensure the safety of road users. Guidelines should be formulated so that images and words on billboards do not contain highly salient information that compels attention to a large degree. Regulations should also be enforced to prevent the implementation of billboards with emotional content on main roads or high-risk locations, such as intersections, sharp curves, and high traffic areas, in which high attentional focus is required.

Recently, driver support systems that operate in real-time have been designed to prevent or mitigate driver workload. One of these methods is to integrate workload management systems in vehicles. These systems are designed to prevent excessive driver workload and distraction by controlling the functionality of in-vehicle technologies, such as phone or navigation systems, according to driving demands (Engström & Victor, 2008). For example, when in a high traffic area, an incoming call is delayed or the use of a GPS system is locked, until the area has been passed. To date, two workload management systems have been designed for these purposes: the Saab Dialogue Manager and the Volvo Car Intelligent Driver Information System (Broström, Engström, Agnvall, & Markkula, 2006). These systems monitor the demands of driving conditions using vehicle sensors that measure speed, acceleration, gear position, etc.

Once distraction has already occurred, it can be mitigated through the use of distraction warning systems (Engström & Victor, 2008). These systems provide an alert when the driver is cognitively distracted so that drivers can shift their full attention back to the driving task. For example, it has been shown that cognitive distraction is associated with gaze concentration toward the center of the driving scene, thereby reducing peripheral vision (Harbluk, Noy, Trbovich, & Eizenman, 2007; Recarte & Nunes, 2003). A project by Volvo (VISREC) developed an algorithm to detect drivers' gaze using a PRC (percent road center) metric. PRC is a measure of the time that gaze is focused in the center area. When a certain PRC threshold is reached, LED lights are reflected on the windshield. The LEDs are reflected in the center, left, and right side of the windshield to increase visual scanning and direct attention back to all aspects of the driving scene (Victor, 2005).

Finally, one promising method to mitigate the impact of emotional distraction is through the design of an interface that monitor drivers' emotions through EEG or physiological data. The idea behind these systems is that an alert can be issued when a particular emotion is recognized so that drivers can self-regulate their emotional states. In Zheng, Dong, and Lu (2014), EEG and eye-tracking data were collected while participants watched film clips that were positive emotional, negative emotional, and neutral. Emotion-relevant features from EEG signals and pupillary responses were extracted to build an emotion recognition model that provided information about the three different emotional states.

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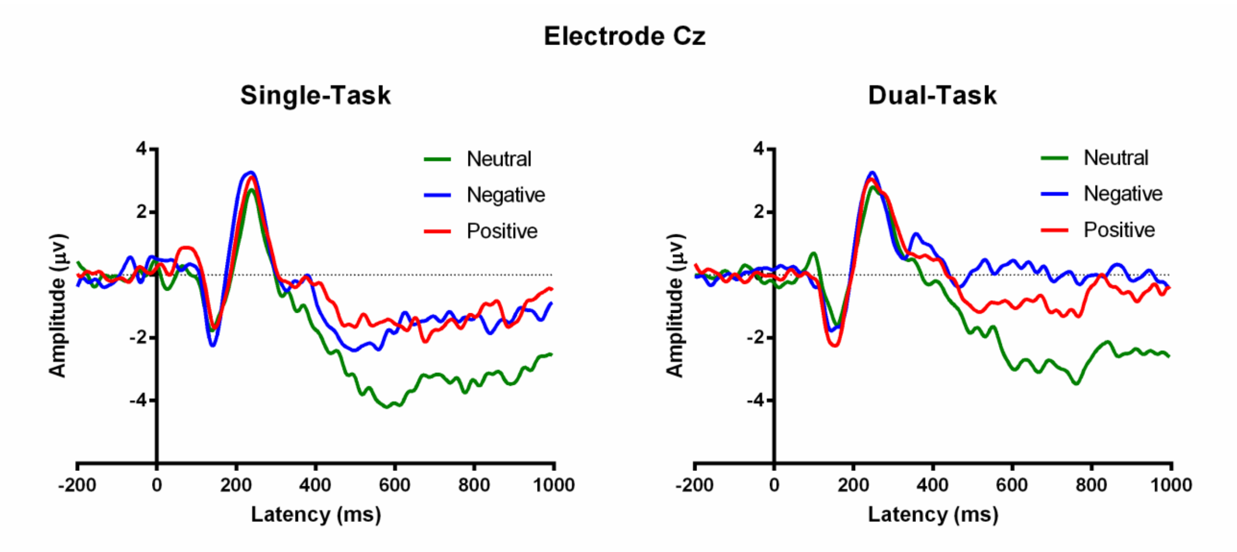
6.6 Appendix



Supplementary data for Chapter 3. Grand-averaged ERP waveforms at Cz to neutral, negative, and positive words heard in concurrent with a driving task (dual-task) and alone (single-task). In both single- and dual-task conditions, negative slow wave amplitudes to emotional words were smaller compared to neutral words. These differences in emotional processing were not influenced by the introduction of the driving task, suggesting that the emotional load was independent of the dual-task attentional load.

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