

# **The Effects of Route-Familiarity and Mind Wandering on Driving Behaviour: Examining Driving Performance Using a High Fidelity Driving Simulator**

by

**Matthew R. Yanko**

B.A., Simon Fraser University, 2007

M.A., Simon Fraser University, 2009

Dissertation Submitted in Partial Fulfillment of the  
Requirements for the Degree of  
Doctor of Philosophy

In the  
Department of Psychology  
Faculty of Arts and Social Sciences

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**SIMON FRASER UNIVERSITY**

**Fall 2013**

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**Name:** Matthew R. Yanko

**Degree:** Doctor of Philosophy

**Title of Thesis:** *The Effects of Route-Familiarity and Mind Wandering on Driving Behaviour: Examining Driving Performance Using a High Fidelity Driving Simulator*

**Examining Committee:** **Chair:** Dr. Rachel Fouladi  
Associate Professor

**Dr. Thomas Spalek**  
Senior Supervisor  
Associate Professor

---

**Dr. Vincent Di Lollo**  
Supervisor  
Adjunct Professor

---

**Dr. John McDonald**  
Supervisor  
Associate Professor

---

**Dr. Brian Fisher**  
Internal Examiner  
Associate Professor  
Interactive Arts and Technology

---

**Dr. Paul Atchley**  
External Examiner  
Professor  
Department of Psychology  
University of Kansas

---

**Date Defended/Approved:** December 16, 2013

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## Abstract

Many traffic accidents occur because the driver is in an inattentive state of mind (mind wandering). I hypothesize that as a route becomes more familiar, less effort is required for the driving task, thus increasing the occurrence of mind wandering. On this hypothesis, a driver's response to unexpected emergencies should be impaired along familiar relative to unfamiliar routes. Over the course of three chapters I present a series of experiments designed to test this hypothesis.

In Chapter 1, participants followed a vehicle along a route with which they were either familiar or unfamiliar. During the experimental session, participants had to respond when the lead-vehicle braked (central emergency) and when they noticed pedestrians heading towards the road from a sidewalk (peripheral emergency). I found that drivers familiar with the route follow the lead vehicle more closely and, with following distance held constant, are slower to respond to both central and peripheral emergencies.

In Chapter 2, I explored the notion that if the route-familiarity effect is mediated by mind-wandering, similar effects should be in evidence when mind-wandering is studied independently. I found that mind wandering impairs driving behaviour in much the same way as route familiarity, supporting the hypothesis that the route familiarity effect is mediated by mind wandering.

Finally, in Chapter 3 I investigated whether increasing the explicitness of monitoring would lead to improved performance (Hawthorne effect) and possibly reverse the negative effects of route familiarity. The idea being that, when monitored, drivers are unlikely to mind wander, thus freeing resources for focusing on the driving task. Drivers familiar with the route should have more free resources and should, therefore, show more *improved* performance compared to drivers unfamiliar with the route. The results support the mind-wandering hypothesis.

**Keywords:** Driving Simulator; Mind-Wandering; Route-Familiarity; EEG

## **Acknowledgements**

I would like to thank my committee members, Dr. Vincent Di Lollo and Dr. John McDonald, for all of the helpful discussions and constructive comments that have contributed to this thesis. I would also like to thank Greg Christie, who was an expert consultant for the electroencephalography (EEG) methods employed in this work. Finally, I would like to thank Ashley Livingstone for her expertise in the EEG data collection. Without her, the project would not have been completed as smoothly as it was.

Finally, I would like to thank my supervisor, Dr. Thomas Spalek, for all of the motivation and inspiring discussions that made this research possible. He truly made my graduate school experience an enjoyable one. I'll always be grateful for that.

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# Chapter 1.

## Introduction

Motor vehicles are by far the most popular form of transportation in North America. Even though most of us drive regularly and we feel comfortable behind the wheel, driving can be dangerous. In 2011, there were over 32,000 deaths and 2.22 million injuries resulting from traffic accidents in the United States (National Highway Traffic Safety Administration, 2012). In fact, according to McIlvenny (2006), traffic accidents are the second leading cause of death amongst young people who drive.

Many motor vehicle accidents are caused by things like excessive speed, equipment failure (brake failure, steering or suspension failure, tire blowouts, etc.), bad weather (e.g., poor visibility, icy roads), poor roadway maintenance, etc. However, it has been estimated that roughly 18 percent of all accidents involve some form of distracted driving. The term 'distracted driving' has been defined in several ways, but most definitions agree that distraction involves a diversion of attention away from the driving task in favor of some other task. A general definition adopted for the purposes of this thesis is as follows:

... distraction occurs when drivers attend to other, non-driving tasks or events to the degree that they fail to allocate sufficient attention to the driving task and their driving performance is degraded. (Young & Regan, 2007, p. 380)

When thinking about the term 'distracted driving', the first thing that usually comes to mind is dual-task distraction, as when driving and operating a cell-phone. As a source of dual-task distraction, cell phones are especially noteworthy in that they involve auditory, physical (manually manipulating the phone), and cognitive factors (see Ranney, Mazzae, Garrott, & Goodman, 2001 for an overview of the

different categories of distracted driving). Countless studies have confirmed that cell phones are a significant source of distraction (Burns, Parkes, Burton, Smith & Burch, 2002; McKnight & McKnight, 1993; Strayer, Drews & Johnston, 2003; Strayer & Johnston, 2001 to name a few). In light of these findings, laws have been passed prohibiting the use of hand-held cell phones while driving.

According to a recent report by the Erie Insurance Company of Pennsylvania, however, cell-phone related distraction is *not* necessarily the biggest concern when it comes to distracted driving. That company analyzed two years of data from the National Highway Traffic Safety Administration and found that cell phones were associated with only 12 percent of all fatal crashes that included at least one distracted driver (Erie Insurance, 2013). There were nine other types of distraction that were identified, like talking to occupants (5 percent), and eating or drinking (2 percent), but the most prominent source of distraction was found to be mind-wandering, or being lost in thought (mind wandering is discussed in detail later in this chapter) . This source of distraction was linked with a whopping 62 percent of all fatal crashes that were attributed to distracted driving. This statistic points compellingly to mind wandering as a major source of driver distraction, accounting for a large portion of accidents that involve a distracted driver.

The research reported in this thesis was motivated by the finding – noted above – that many accidents occur because the driver is in an inattentive state of mind. One of the main objectives was to investigate driving behaviour under conditions that may promote mind wandering. As noted later in this chapter, route familiarity has the potential of being one such condition. It is plausible to hypothesize that, as the route becomes more familiar, less effort is required for the driving task, thus increasing the occurrence of mind wandering. On this hypothesis, a driver's response to unexpected emergencies should be impaired along familiar relative to unfamiliar routes.

This hypothesis was corroborated by the outcomes of the experiments reported in Chapters 1 and 2. On the other hand, route familiarity can also be a source of driving *enhancement*. The experiment in Chapter 3 shows that, when driving performance is monitored explicitly, thus motivating drivers to concentrate

more on the driving task and less on mind wandering, responses to unexpected emergencies are enhanced when the route is familiar. Thus, depending on the circumstances, route familiarity can be a source of driving impairment or improvement.

The remainder of this introduction provides a theoretical overview and the foundation for the experiments to be reported. First, I discuss the general concept of *attention*, and how it is often regarded as being akin to a limited resource that can be distributed among concurrent mental tasks. Second, I discuss how route familiarity can serve to decrease attentional demands, thus freeing up resources that can be used to perform some other task. Third, I discuss the relationship between route familiarity and mind wandering. Finally, I provide an overview of the experiments reported in this thesis (Chapters 1-3).

## **1.1. Attention, Automaticity And Driving**

Our sensory systems are continuously flooded with information from the environment, but there are limits to the system's ability to process all of that input. The term *attention* is the label that we use – broadly – to describe the mechanism used to select only a portion of the vast stream of incoming information for processing. I say “broadly” because even though the concept of attention is in common usage, we have only a limited understanding of its underlying mechanisms. It has been aptly asserted by Sutherland (1998; p.350) that “after many thousands of experiments, we know only marginally more about attention than about the interior of a black hole”.

To pursue Sutherland's point, one need only review the myriad of models that have been put forth to describe how attention works. Some models have described attention as working like a filter allowing for the selection of only one class of items (e.g., red items) at a time, with unselected information being discarded. Early selection models (e.g., Broadbent, 1958) proposed that the filter sieves through incoming information preattentively and selects relevant information based on low level physical characteristics (colour, sound intensity etc.). Late selection

models (e.g., Deutsch & Deutsch, 1963) are similar to early-selection models, with the exception that the filter is positioned at a later stage of processing, just prior to conscious awareness. Treisman (1964) proposed an early selection account in which the filter attenuates, rather than discards, irrelevant sensory information. These filter theories of attention make up only a small portion of the total number of theories that have been proposed. In other theories, attention has been portrayed as a 'spotlight' (Shulman, Remington & McLean, 1979), as a 'zoom lens' (Eriksen & St. James, 1986), and as a glue that binds features to form consciously experienced objects (Treisman & Gelade, 1980).

In this tradition, attention is regarded as means of selecting information that is relevant for the task at hand. In a somewhat different tradition, known as *capacity sharing* (e.g., Kahneman, 1973; Knowles, 1963) attention is regarded as a limited resource that can be depleted by deploying it to more than one task. Much of the research described in this thesis employs the idea that attention is a limited resource that can be distributed to one or more tasks at the same time. Therefore, the *attentional resource* model deserves some description here.

Resource theory posits that there is a general limit on our ability to perform mental activities (Kahneman, 1973). That is, the finding that performance suffers when one attempts to perform multiple tasks concurrently is due to the fact that the amount of attention that can be deployed at any given time is limited. To use a common 'hydraulic' metaphor, attention can be thought of as a reservoir of energy that can be dispensed throughout the system. This energy is necessary to perform mental tasks (see Wickens, 1984 for a thorough description of the hydraulic metaphor). The important feature of this model is that it assumes that attention is not limited to performing only one task at a time. Depending on task demands and the amount of resources available, several tasks can be performed simultaneously. In essence, mental processes are fueled by this reservoir, and as long as there is enough energy to go around, all tasks can continue without impairment. However, when the supply of attention is insufficient to meet the demands, performance wanes.

A more detailed description of resource allocation has been provided by Schneider and Shiffrin (1977). They differentiate between two processing states that lie on opposite ends of a continuum: *controlled* and *automatic* (see also Posner & Snyder, 1975). Controlled processes are in evidence when a task requires conscious control and is not well learned. These processes can be easily halted in order to perform other tasks, and can be modulated efficiently in response to changes in task demands. However, controlled processes are slow and deplete the available attentional resources. In contrast, automatic processes do not require conscious control, are fast, and take up few (if any) attentional resources. The ability to execute a mental process without attentional control is the hallmark of an automatic process. However, automatic processing has a disadvantage. If there is a change in the way the task must be executed, the system will initially attempt to continue to perform automatically, but this approach will no longer be efficient and the system must switch to performing the task in a controlled way. This results in a performance decrement.

An important consideration is that when a task is novel, the system will initially perform the task in a controlled way, using attentional resources and conscious control. However, with practice, the system will shift to more automatic processing, using few attentional resources. A classic example to illustrate this effect comes from our experience with driving. When we first learn to drive, a lot of attention needs to be paid to everything we do. We need to pay attention to steering, to depressing the pedals and to looking in the mirrors. At the same time we need to look for potential hazards that need to be avoided. Performing all of these tasks at the same time requires a lot of effort and depletes our attentional resources. With practice, however, these aspects of driving become almost effortless since the system starts to perform these tasks more automatically.

A hierarchical control model of skill acquisition proposed by Rasmussen (1983) is an attempt at incorporating the ideas of automatic and controlled processing (Schneider & Shiffrin, 1977) into vehicle operator performance. Rasmussen (1987) theorized that there are three distinct levels of behaviour: knowledge-based, rule-based and skill-based. Knowledge-based and rule-based behaviors both involve conscious problem-solving and engage controlled processes

in response to changes in the environment. While the knowledge-based level deals with controlled processing in new and unexpected situations (e.g., a novice driver on his first lesson), the rule-based level evokes a procedure (or set of rules) in order to carry out an action (e.g., negotiating a right turn at an intersection) and relies more on memory of past experiences. With extensive practice, rule-based behaviors will shift to a more skill-based behavior, essentially becoming an automatic action. However, when there is a change in task demands during an automatic process (skill-based), the system must switch to controlled problem-solving (knowledge-based).

Perhaps the most advantageous outcome associated with practice is that the transition from controlled to automatic processing will be accompanied by a reduced demand on attentional resources since less attention is required to perform optimally. From the viewpoint of attentional-resource theory, it follows that those attentional resources will be available to perform some other task(s). For example, for drivers, freedup resources could be deployed to hazard-detection and avoidance.

In the following section, I discuss how one particular aspect of driving — route familiarity— has the potential to free up attentional resources that can be used for hazard detection.

## **1.2. Route Familiarity**

As noted in the forgoing, when learning to drive a car, there is a shift from controlled to automatic processing with corresponding reduction in the need for attentional resources.

The same can be said for the process of learning a route between two locations. When a route is new, the driver must pay attention to subtle aspects of the drive. For example, speed-limit signs, intersection locations and subtle curves in the road must be attended in order to reach the destination successfully and safely. Once the route has become familiar, however, attentional requirements are much reduced in that the details of the route have been committed to memory, and the appropriate responses are more automatic. Thus, there is a shift from conscious

control, to more automatic control. This shift in processing mode should free up resources that can be used to perform other mental tasks (Schneider & Shiffrin, 1977).

What effect does route familiarity have on driving performance with respect to hazard detection and avoidance? Given the above discussion involving practice and its effect of attentional resources requirements, one would expect that hazard detection will be improved along familiar routes. This is because, with extensive practice, fewer resources are required, thus liberating resources that can be utilized for hazard detection. However, there is evidence in the extant literature on mind wandering that may undermine this hypothesis.

### **1.3. Mind Wandering**

Mind wandering, or task-unrelated-thoughts, refers to a cognitive state in which the mind is engaged in thoughts unrelated to the task at hand. The incidence of mind wandering is known to vary inversely with task difficulty. Also, mind wandering can occur spontaneously, often without awareness (Smallwood, Beach, Schooler & Handy, 2008; Smallwood, Schooler, Christoff, Handy, Reichle & Sayette, 2011).

Research aimed at examining the underlying mechanisms has consistently demonstrated a link between mind-wandering and the availability of attentional resources, along the lines discussed above. In one of the first demonstrations of this relationship, Antrobus (1968) found that during a signal-detection task the incidence of mind wandering decreases as the rate of stimulus presentation is increased. This is consistent with the idea that the faster rate of presentation required more attentional resources to the detriment of resources available for mind wandering. Many later experiments have shown that mind wandering decreases as a task becomes more attentionally demanding (Giambra, 1995; Grodsky & Giambra, 1990; Smallwood, Davies, et al., 2004). Considered collectively, these findings strongly suggest that mind wandering requires attentional resources.

Given that the frequency of mind wandering is inversely related to the amount of resources allocated to a given task, it makes intuitive sense that as one becomes

more familiar with the task – thereby lowering task demands – the incidence of mind wandering should increase. Indeed, it is well documented that as a task becomes more familiar, the frequency of mind wandering increases (Antrobus, 1968; Giambra, 1995; Smallwood, Baracaia, Lowe & Obonsawin, 2003; Smallwood, Obonsawin & Reid, 2003; Teasdale et al., 1995).

In what ways might these known facts about mind wandering impact driving performance? Four considerations are important in this respect: (a) mind wandering recruits attentional resources; (b) the frequency of mind wandering increases with task familiarity; (c) when driving along a familiar route, the incidence of mind wandering is likely to increase because the task is well learned; and (d) to the extent that mind wandering preempts attentional resources, it will interfere with actions that require attentional resources, such as responding to emergencies while driving. A counterintuitive example stems from these considerations: a driver will apply the brakes more promptly in response to an unexpected event – such as a dog running onto the road – when the route is unfamiliar than when it is familiar. This is because when an emergency event occurs, a task switch must take place where the system must be reconfigured to process and respond to the event. If an unexpected event were to occur while the driver is engaged in mind wandering, there will be a delay the drivers' response time because the system must be reconfigured from processing internal thoughts to processing the external environment. This switch is likely to be more time-consuming than the switch from one external environmental task (route-monitoring) to another (hazard avoidance) because both tasks are related– they both require processing of external stimuli and relate to the global task of driving. Indeed, it has been shown that task-switching is slower when the two tasks are more dissimilar (Arrington, Altmann & Carr, 2003). Therefore, route-familiarity should lead to slower reaction times (RT) in responding to hazardous stimuli when familiar with the route compared to when the route is unfamiliar. The present work was designed to examine this conjecture.

## 1.4. A Brief Overview

From the research described above, it is clear that as a task becomes familiar, the amount of attention deployed to cope with task demands will decrease. This is likely to be the case for drivers as they become familiar with a route. That is, in a familiar environment the driver does not need to process trivial features of the route because those characteristics are already well known. Consequently, it can be theorized that more attentional resources will be available to fuel other tasks (Kahneman, 1973). One possibility is that these resources will go to hazard detection, making a driver faster at responding in the event of an emergency. On the other hand, it is possible that the decrease in task demands associated with processing the route will promote a higher frequency of mind wandering (Smallwood & Schooler, 2006).

Chapter 1 presents three experiments designed to answer a question that arises from two competing hypotheses regarding the role of route familiarity: does route familiarity impair or enhance driving performance? Using a high-fidelity driving simulator, participants followed a pace car along a route with which they were either familiar or unfamiliar. Responses to a series of unexpected events were assessed, along with other measures of driving performance. To anticipate, consistent with the hypothesis that route familiarity invites mind wandering, I found performance to be impaired when the route was familiar. In Chapter 2, I found that mind wandering impairs driving behaviour in much the same way as route familiarity, supporting the hypothesis that the route familiarity effect is mediated by mind wandering. Finally, in Chapter 3 I investigated factors that can reverse the negative effects of route familiarity. This occurred when each driver's performance was monitored explicitly. That is, drivers familiar with the route showed *improved* performance compared to drivers unfamiliar with the route. The idea was that, when monitored, drivers are unlikely to mind wander, thus freeing resources for focusing on the driving task.

## Chapter 2.

# Route Familiarity Breeds Inattention: A Driving Simulator Study<sup>1</sup>

### 2.1. Abstract

Inattention is a major cause of traffic accidents. Here, we show that, contrary to common-sense expectation, familiarity with a route is itself a source of driving impairment. This effect may be attributed to increased mind-wandering along familiar routes. In the present work, participants followed a vehicle along a route with which they were either familiar or unfamiliar. During the experimental session, the lead-vehicle braked at random locations, forcing participants to brake to avoid a collision. Participants were also required to respond with a button press when they noticed pedestrians heading towards the road from a sidewalk. In Experiment 1 we found that familiar drivers follow the lead vehicle more closely and are slower to notice approaching pedestrians. In Experiment 2, with following distance held constant, reaction times to central and peripheral events were longer for familiar drivers. Consistent with the mind-wandering hypothesis, all these effects were eliminated in Experiment 3 when drivers were made to focus on the driving task.

<sup>1</sup> This chapter has been published as Yanko, M.R., & Spalek, T.M. (2013). Route Familiarity Breeds Inattention: A Driving Simulator Study. *Accident Analysis and Prevention*, 57, 80-86.

## 2.2. Introduction

Repeatedly engaging in a task, often results in a gradual transition from initially needing to consciously control one's actions, to a state where our actions are governed by more automatic processes (Schneider & Shiffrin, 1977). This transition from controlled to automatic processing is thought to be accompanied by a reduced demand on attentional resources. Neuroanatomical evidence consistent with this position is found in a study showing reduced brain activation patterns in participants practiced in completing a word generation task versus unpracticed participants (Raichle et al., 1994).

Posner and Snyder (1975) characterized the difference between *controlled* and *automatic processes* as follows. Controlled processes are those that are under top-down control (i.e., are volitional), can be modified based on task demands, and require attentional resources in order to be carried out. Automatic processes, on the other hand, occur without conscious awareness, are ballistic, and do not interfere with separate processes that require attentional resources.

One task that most of us engage in daily that illustrates this practice effect is the task of driving a car. When we first started driving, we had to devote a lot of attention to checking our mirrors, having our hands in the 10 and 2 positions, watching the speedometer, etc. (this is even more evident if the car has a manual transmission). Over time, however, the task of driving that car becomes easier. In addition to learning the general aspects associated with driving a vehicle, similar learning also occurs with respect to learning the route between two locations. Initially we have to pay a lot of attention to road signs, etc., but as we become familiar with the route, these aspects, as well as more subtle things like the curves in the road and intersection locations, no longer have to be sought out, but rather are provided to us through our memories. That is, we shift from a more controlled, effortful, processing of the route, to a more automatic one. This shift to more automatic processing of the route should free up resources (Posner & Snyder, 1975) that could be allocated to some other task, like hazard detection. As a result, one might predict that familiar drivers should be more efficient at executing an appropriate response to

a hazardous event than unfamiliar drivers. Although it makes intuitive sense that the development of efficient route processing should aid driving performance, this possibility has not been previously explored.

On the other hand, the idea that route-familiarity might promote a *delay* in hazard response is indirectly supported by evidence in the driving literature. For example, compared to novice drivers, drivers with extensive experience are less likely to check their mirrors and to follow a lead vehicle at an adequate distance (Duncan, Williams & Brown, 1991). These findings could be an indication that experienced drivers are less likely to successfully monitor the environment for hazards, thereby limiting the ability to respond promptly when needed. In addition, it has been shown that as one becomes familiar with a route, there is a decrease in the amount of time spent looking at peripheral items, and drivers are less likely to notice changes in the environment (Charlton & Starkey, 2011; Martens & Fox, 2007). In fact, Martens and Fox (2007) demonstrated that route familiarity can promote a state of *inattentional blindness*, where drivers are less likely to notice a critical stimulus in the environment even when the driver fixates on that stimulus.

One possible explanation as to why route familiarity promotes a form of inattentional blindness comes from the literature on *mind wandering*. The reasoning goes something like this. Mind wandering is a state where the thought processes that occupy the mind are on topics that are unrelated to the task(s) at hand (Smallwood & Schooler, 2006). The incidence of mind wandering has been shown to increase as a task becomes more practiced (Cunningham, Scerbo & Freeman, 2000; Mason, Norton, Van Horn, Wegner, Grafton & Macrae, 2007; Teasdale et al., 1995). An important consideration for the present work is that mind wandering can occur spontaneously and is thought to utilize the same resources as goal directed thought (Christoff, Ream & Gabrieli, 2004; Smith, Keramatian, Smallwood, Schooler, Luus and Christoff, 2006; Teasdale et al., 1995). Thus any other task that requires these resources, like the encoding of sensory information from the external environment, would be impaired (Smallwood & Schooler, 2006). This conjecture is supported by the common phenomenological experience that, having driven along a familiar route, a driver can hardly remember any of the specifics associated with the drive. These 'time gaps' (Chapman, Ismail, & Underwood, 1999) that are often

experienced by drivers provide a clear indication that, during those periods, the vehicle operator was driving without full awareness of the environment. To the extent that executive attention is necessary to respond appropriately to a hazard, familiar drivers should perform worse than unfamiliar drivers when encountering a hazard.

The results obtained by Martens and Fox (2007) may be explained by the mind wandering hypothesis as follows. As familiarity with the route is increased, drivers may have been more likely to let their minds wander, thereby making it less likely for them to successfully process incoming sensory information – inattentional blindness – because the system is otherwise preoccupied. This possibility is supported by anecdotal evidence provided by Charlton and Starkey (2011) who noted that many participants found themselves starting to ‘daydream’ as they excessively practiced a route. Based on these findings, it is reasonable to expect that when driving along a familiar route, drivers might take longer to notice an emergency event, and hence would be expected to take longer to respond than if they were driving along an unfamiliar route.

There are two opposite theoretical predictions concerning the effect that route familiarity has on hazard avoidance. Familiarity might lead to the route being processed automatically and thus freeing up resources that could be used to process other stimuli in the environment, like potential hazards. From this it follows that reaction time (RT) to avoid a hazardous stimulus should be faster in familiar than in unfamiliar route conditions. On the other hand, given the previous evidence linking automaticity and route familiarity to a reduced likelihood of successfully monitoring the environment (Charlton & Starkey, 2011; Martens & Fox, 2007), one might predict the opposite pattern of results. For example, it could be that as the route becomes familiar, the incidence of inattentional blindness might increase, and thus the driver would be less able to deal with the hazardous stimulus. In this case, it follows that RT to the hazardous stimulus should be *slower* in familiar than in unfamiliar routes. The present experiments were designed to test these two competing theories.

## **2.3. Experiment 1**

The objective of Experiment 1 was to investigate whether familiarity with the route will affect driving performance, such as responding to emergencies, in a positive or a negative way. If familiarity with the route leads to the route being processed more automatically, the extra attentional resources made available should improve driving performance. In contrast, if route-familiarity promotes a form of inattentive blindness (Martens & Fox, 2007) then driving performance should be impaired relative to when unfamiliar with the route. This issue was explored in the present experiment using a simple car-following paradigm (see Strayer, Drews & Johnson, 2003), where participants followed a pace car through a route that they had either previously been made familiar with or not. Responses to a series of unexpected events were assessed, along with other measures of driving performance.

## **2.4. Method**

### **2.4.1. Participants**

Fifteen female and five male undergraduate students (mean age = 20.9 years,  $SD = 1.66$ ) from Simon Fraser University participated either for class credit or for payment. All had self-reported normal or corrected to normal vision. All had a valid British Columbia driver's license (class 5) and reported driving on average 5.6 times per week.

Before starting the experiment, participants filled out a modified 'Simulator Sickness Questionnaire' with questions such as "are you taking any medications" or "are suffering from any ailments that might make you prone to motion sickness." In order to minimize the incidence of simulator sickness we excluded any participants who answered yes to any such questions (see Kennedy, Lane, Berbaum, & Lilienthal, 1993, for an overview).

### **2.4.2. Materials**

A DriveSafety high-fidelity driving simulator (model DS-600c) was used. Examining driving performance with a driving simulator grants several advantages over real-world on-road tests. Driving simulators not only provide a safer environment, but also allows for complete control over the driving conditions. In addition, driving simulators allow consistent and reliable data to be collected over a broad range of variables.

Participants were seated in a modified Ford Focus cab equipped with a windshield, driver and passenger seats, dash board, instrument panels, and a central console, as well as all the devices needed to operate a car (accelerator and brake pedal, turn signal switch, a steering wheel etc.). The simulated environment was generated using HyperDrive Authoring Suite and was displayed using DriveSafety's Vection Simulation software (Version 1.9.35: <http://www.drivesafety.com>). The simulator is also equipped with an automatic gearbox.

### **2.4.3. Driving Routes**

Five freeway driving routes were developed for this experiment (Routes 1-5). Each route was approximately 12 km in length and included a series of overpasses (where the roadway passes over another), underpasses (where the roadway passes under another) and cloverleaf intersections (on and off ramps: where the roadway gradually corners to merge with a new roadway). Each route was designed to have the same number of cloverleaf intersections and each route had the same number of left and right turns. The five routes were programmed to look very similar to one another, consisting mainly of long stretches of rural freeway. However, the exact location for each cloverleaf intersection was different for each route. Consequently, the specific sequence of exits that participants were required to take to get to the end was different for each route. These routes were driven in daytime conditions with good visibility. There were three lanes of traffic going in each direction (separated by a cement median). For all routes, a pace car and the participant's vehicle were the only two cars on the road. The participants were instructed to follow

the pace car, and the pace car was programmed to maintain its position in the right lane.

#### **2.4.4. Procedure**

The experiment comprised three sessions: Acclimatization, Training, and Testing.

In the Acclimatization session, participants who passed the Simulator Sickness Questionnaire took part in a 3-minute session to get used to the equipment and to adapt themselves to the physical sensations involved in driving the simulator. The acclimatization session consisted of one short driving scenario where participants followed a pace car down a stretch of a simulated freeway. The freeway consisted of a long straight stretch and two cloverleaf intersections. At each intersection, the participants practiced exiting from and merging onto the freeway. The Training session followed directly after the Acclimatization session.

In the Training session, participants were randomly assigned to the *familiar group* or the *unfamiliar group*. Participants assigned to the Familiar group drove down 'Route 1' a total of four times to become familiar with the route. Participants assigned to the Unfamiliar group drove down routes 2-5 in chronological order. All participants (from both familiar and unfamiliar groups) were instructed to follow the pace car during each driving session. The pace car drove at a constant speed of approximately 72 km/h and led the participants from the beginning to the end of each route. Participants were instructed to follow the pace car at a reasonable distance that they felt comfortable with, while abiding by all traffic laws. However, if the participants' vehicle fell more than 60 meters behind the pace car, a tone was administered to prompt the driver to maintain a closer distance. Once the route was finished, the route was restarted (for the Familiar group) or the next successive route was started (for the Unfamiliar group). The Testing session followed directly after the Training session.

During the Testing session, all participants drove through 'Route 1'. This means that the route was known to the Familiar group, but was unknown to the Unfamiliar group. During this phase, the pace car was programmed to brake at 20

randomly selected locations (which we refer to as the Central event). The position of each braking event was determined prior to the study, and was the same for each participant. During this event, the pace car instantly reduced speed to 33 km/h, and the brake lights were illuminated. The pace car then gradually accelerated back to 72 km/h at a rate of acceleration that was approximately  $2 \text{ m/s}^2$ , and the brake lights stayed illuminated for 3 seconds. To avoid a collision during these events, the driver was required to respond by stepping on the brake pedal. RTs to activate the brakes was recorded, as well as the degree of brake depression, sampled at a rate of 60Hz. Brake depression was defined by the position of the brake pedal, and was given as a proportion from 0 to 1 (a value of zero indicates that the brake is not being pressed, and any value above indicates that the brake is being pressed).

In addition to the lead vehicle braking events, 19 women, each wearing a red dress, were programmed to stand on the side of the road (approx. 5 meters from the center of the far right lane) at randomly chosen locations in the testing phase. Five of those women were programmed to walk towards the road when the participant was 50 meters away (which we refer to as the Peripheral event). The participant was instructed to make a push button response when they noticed a woman start to walk towards the road. The button was located on the backside of the steering wheel on the right hand side. RTs to make the button response were recorded. The depression state of the button was sampled at a rate of 60Hz. Each walking woman eventually entered the roadway, and participants were told not to worry about avoiding a collision with the woman. This was done to try to get an accurate measure of when they noticed the movement rather than that measure being confounded with trying to make an evasive maneuver. The other fourteen women remained motionless as the participant approached, and participants were not required to make a response in that situation.

#### **2.4.5. Dependent Measures**

There were a total of six dependent measures associated with this experiment. *Central Response RT* was defined as the interval of time between the braking of the pace car (i.e., the instant velocity change and illumination of the brake lights) and the instant that the participant depressed the brake pedal. *Peripheral*

*Response RT* was defined as the interval of time between the onset of the woman's movement and the initial depression of the steering wheel button. *Headway distance* was defined as the distance in meters between the pace car and the participant's car at the beginning of each central event. In other words, a measure of distance was taken at the beginning of each central event epoch, and averaged over the entire test session. *Lateral Position* was defined as the root mean square (RMS) of the lane position in meters between the center of the lane, and the center of the participant's car. The lateral position was sampled continuously throughout the entire testing session. *Velocity* was defined as the average velocity (in meters per second) that the participants were travelling at the beginning of each central event. In other words, a measure of velocity was taken at the beginning of each central event epoch, and averaged over the entire test session. *Collisions* was the total number of collisions that the participant had with either the car or the woman.

## 2.5. Results and Discussion

The results for all of the driving performance measures are shown in Table 1. Independent samples t-tests were conducted on each measure of interest throughout the paper. Familiar drivers took significantly longer to respond to the peripheral event as compared to unfamiliar drivers,  $t(18) = 2.18$ ,  $p = .04$ , but were significantly faster at the central response,  $t(18) = 2.48$ ,  $p = .02$ . Headway distance was also different between the two groups, with familiar drivers following significantly closer to the pace car,  $t(18) = 3.38$ ,  $p < .01$ . The number of collisions with the woman, and the number of collisions with the pace car were not significantly different between the two groups ( $p = .25$  and  $p = .24$ , respectively). Lateral position and velocity were also not significantly different between the two groups ( $p = .62$  and  $p = .45$ , respectively). The results for the central and peripheral responses are illustrated in Figure 1. Familiar drivers took longer to notice pedestrian movement on the side of the road, as indicated by their longer RTs compared to unfamiliar drivers. This finding is consistent with the inattention blindness theory, but is inconsistent with the automaticity theory, both outlined in the Introduction. In addition, familiar drivers followed more closely behind the pace car. This difference in following distance possibly indicates that familiar drivers were paying less attention to this

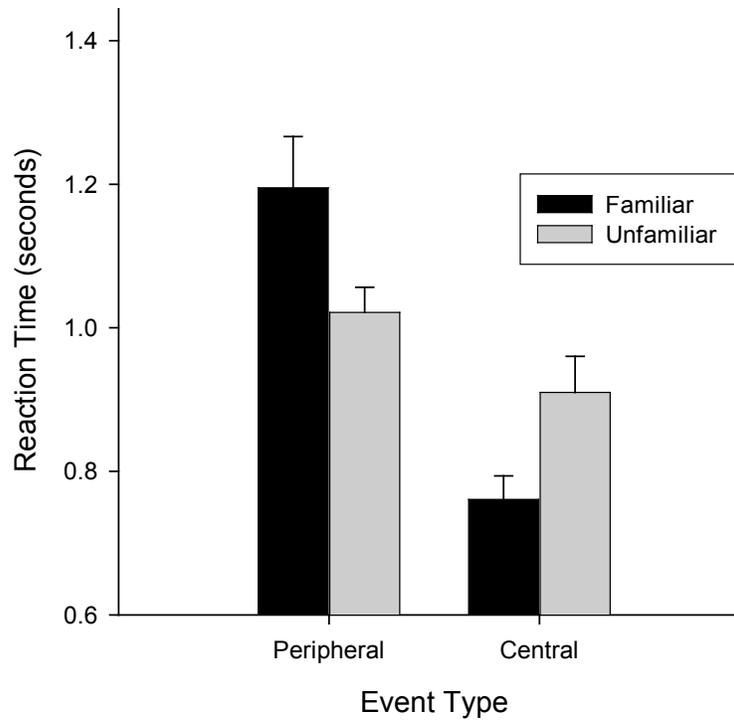
aspect of vehicle control, and is in line with previous research demonstrating that experienced drivers are more likely to follow a lead vehicle at an unsafe distance than novice drivers (Duncan et al, 1991). However, central response RTs were significantly faster for familiar drivers, indicating that they were faster to notice the lead vehicle braking. The observation that familiar drivers are faster to respond to the lead vehicle braking, is not consistent with the inattentional blindness hypothesis, but is in line with the automaticity hypothesis, outlined in the introduction of the present work.

Overall, these results are difficult to interpret. On the one hand, familiar drivers seem impaired when it comes to responding to peripheral events, but seem to be superior when it comes to responding to central events. However, the current experiment showed that familiar drivers kept a shorter distance between them and the pace car as compared to unfamiliar drivers, and therefore, had less time to react in order to avoid a collision. As a result, central response RT is inextricably confounded with headway distance. We checked this possibility in Experiment 2.

Dependent measures

	Central Response RT (seconds)	Peripheral Response RT (seconds)	Headway Distance (meters)	Velocity (m/s)	Lane Position (RMS)	Collisions (Pace car)	Collisions (Pedestrian)
<b>Experiment 1</b>							
Familiar	.760 (0.10)	1.20 (0.23)	25.2 (5.1)	20.7 (0.37)	0.60 (0.16)	1.3 (2.11)	1.7 (0.95)
Unfamiliar	.910 (0.16)	1.02 (0.11)	32.6 (4.7)	20.5 (0.43)	0.57 (0.09)	0.40 (0.97)	2.62 (0.92)
<b>Experiment 2</b>							
Familiar	.919 (0.17)	1.18 (0.23)	31.2 (0.56)	19.4 (0.92)	0.62 (0.17)	0.08 (0.28)	3.0 (0.30)
Unfamiliar	.811 (0.05)	1.01 (0.14)	31.5 (0.77)	19.7 (0.89)	0.60 (0.13)	0 (0.00)	2.7 (1.3)
<b>Experiment 3</b>							
Familiar	.930 (0.11)	1.28 (0.42)	29.6 (0.26)	19.7 (0.30)	0.54 (0.13)	0 (0.00)	2.7 (0.48)
Unfamiliar	.963 (0.14)	1.12 (0.35)	29.5 (0.24)	19.6 (0.19)	0.57 (0.09)	0 (0.00)	2.6 (0.84)

**Table 1:** Means and standard deviations for each dependent measure for Experiments 1 to 3



**Figure 1.** Reaction times in response to peripheral and centrally occurring emergency events as a function of route familiarity. Error bars indicate SEM.

## **2.6. Experiment 2**

Experiment 2 was designed to eliminate the confounding of headway distance that was present in Experiment 1, in order to equate familiar and unfamiliar drivers on measures of vehicle control. We repeated the procedure of Experiment 1 while programmatically keeping the lead vehicle's distance from the participant's vehicle constant. If the central response RTs observed for familiars in Experiment 1 were the result of decreased headway distance, one would expect either no differences in RT between groups, or slower RT for the Familiar group – as predicted by the inattentive blindness hypothesis.

## **2.7. Method**

### **2.7.1. Participants**

Nine female and seventeen male undergraduate students (mean age = 21.3 years,  $SD = 2.32$ ) drawn from the same population as Experiment 1 participated in Experiment 2. All had a valid British Columbia driver's license (class 5) and reported driving on average 5.8 times per week. None had participated in Experiment 1.

### **2.7.2. Materials**

The materials used in Experiment 2 were the same as in Experiment 1.

### **2.7.3. Procedure**

The procedure was the same as in Experiment 1, with the following exceptions. First, instead of driving at a constant speed of 72 km/h, the pace car was programmed to maintain a constant distance of 30 meters in front of the participant's vehicle at all times. In other words, if the participant sped up or slowed down at any time, the pace car adjusted speed accordingly to maintain the set distance of 30 meters. The only time that this was not the case was during the central braking events in the testing phase. At those times, the sequence of events was identical to that of Experiment 1, with the pace car instantly reducing speed to 33 km/h, and the

brake lights being illuminated for 3 seconds. After that time, the pace car accelerated back to the set distance of 30 meters. To avoid a collision during these events, the driver was required to respond by stepping on the brake pedal. Second, since the pace car no longer maintained a set speed (thereby limiting the participant's speed), the participants were instructed to maintain a speed of 72 km/h at all times, except when slowing down for corners, or for central braking events.

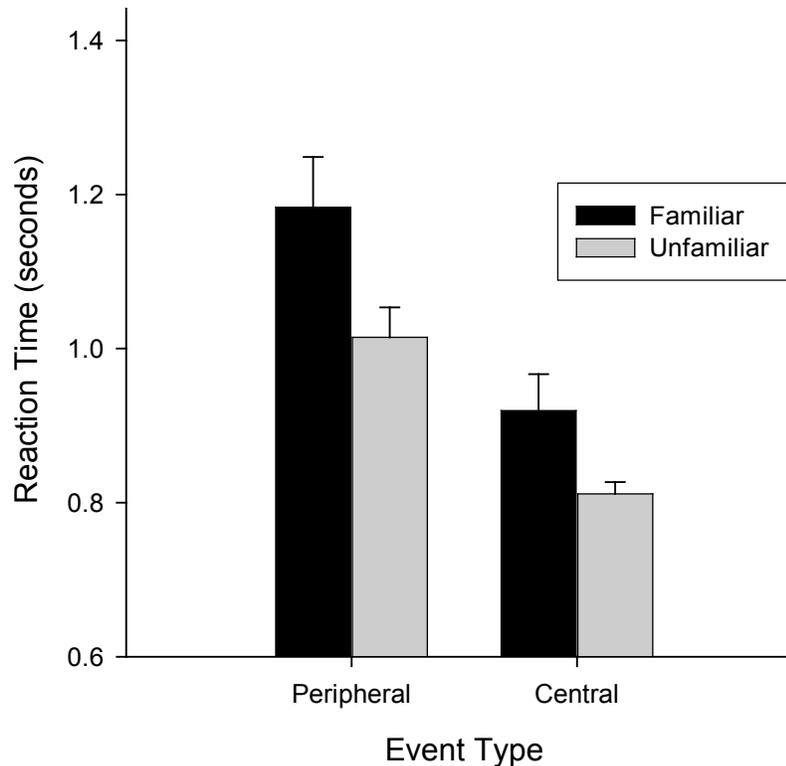
#### **2.7.4. Dependent Measures**

As in Experiment 1, *Central Response*, *Peripheral Response*, *Lateral Position*, *Velocity* and *Collisions* were included as dependent measures. *Headway distance* was also included as a dependent measure, in order to confirm that the two groups were indeed equivalent on that variable (the central goal of this study).

#### **2.7.5. Results and Discussion**

The results for all of the driving performance measures are shown in Table 1. A *t* test between the headway distance for the Familiar and Unfamiliar groups confirms that the confound from Experiment 1 was eliminated in the present experiment ( $p=0.24$ ). In addition, drivers also did not differ in their lane position or their velocity ( $p$ 's > 0.49). Therefore, we can conclude that these two groups were equated on all primary measures of vehicle control. The number of collisions with the woman, and the number of collisions with the pace car were not significantly different between the two groups ( $p = .21$  and  $p = .33$ , respectively).

These two groups did differ, however, on the two response time measures. Consistent with Experiment 1 Familiar drivers took significantly longer to make the Peripheral Response as compared to the unfamiliar drivers,  $t(24) = 2.35$ ,  $p = .04$ . Unlike Experiment 1, however, the time to make the Central Response was significantly longer for the Familiar group,  $t(24) = 2.17$ ,  $p = .04$ . Thus implicating that the reduced Central Response RT observed in Experiment 1 was due to the tendency of familiar drivers to follow more closely to the pace car. The results for the central and peripheral responses are illustrated in Figure 2.



**Figure 2.** Reaction times in response to peripheral and centrally occurring emergency events as a function of route familiarity. Error bars indicate *SEM*.

The finding of principal interest is that when measures of vehicle control are equated, route familiarity seems to result in drivers being less able to respond to hazardous events. This is consistent with the results of Martens and Fox (2007) that showed that route familiarity can lead to inattentive blindness. As noted in the introduction to the present work, one possible account as to why route familiarity promotes a form of inattentive blindness is that familiarity might increase the incidence of mind wandering. These thought processes occur spontaneously and utilize the same resources as executive attention, and therefore have the potential to interfere with tasks that require executive control, like hazard avoidance. One possible way that the incidence of mind wandering might be decreased is to get participants to pay more attention to their primary task (i.e. driving). If the route-familiarity effect is mediated by mind wandering, then reducing the incidence of mind

wandering should greatly reduce, or even eliminate the familiarity impairments observed in Experiment 2. Experiment 3 was designed to test this hypothesis.

## **2.8. Experiment 3**

In Experiment 3, participants were instructed to maintain a speed of 72 km/h. An auditory signal was presented whenever they were driving at a speed outside of a 65-75 km/h window, to prompt them to adjust their speed accordingly. Getting participants to focus on their speed should keep them more focused on the driving task, thereby reducing the incidence of mind wandering. If the results obtained in Experiment 2 were due to mind wandering, then we expect the RT differences between Familiar and Unfamiliar drivers to be nullified (or greatly reduced).

## **2.9. Method**

### **2.9.1. Participants**

Twenty undergraduate students drawn from the same population as Experiment's 1 and 2 participated in Experiment 3. Demographic information for three participants was not available. Eight females and nine males (mean age = 22.6 years  $SD$  = 4.43) made up the remaining seventeen participants. All had a valid British Columbia driver's license (class 5) and reported driving on average 5.2 times per week. None had participated in Experiment 1 or 2.

### **2.9.2. Materials**

The materials used in Experiment 3 were the same as in Experiment's 1 and 2.

### **2.9.3. Procedure**

The procedure was the same as in Experiment 2, with the following exception. Throughout the entire experiment, participants were instructed to maintain a constant speed of 72 km/h (~20 m/s). They were told that if their velocity

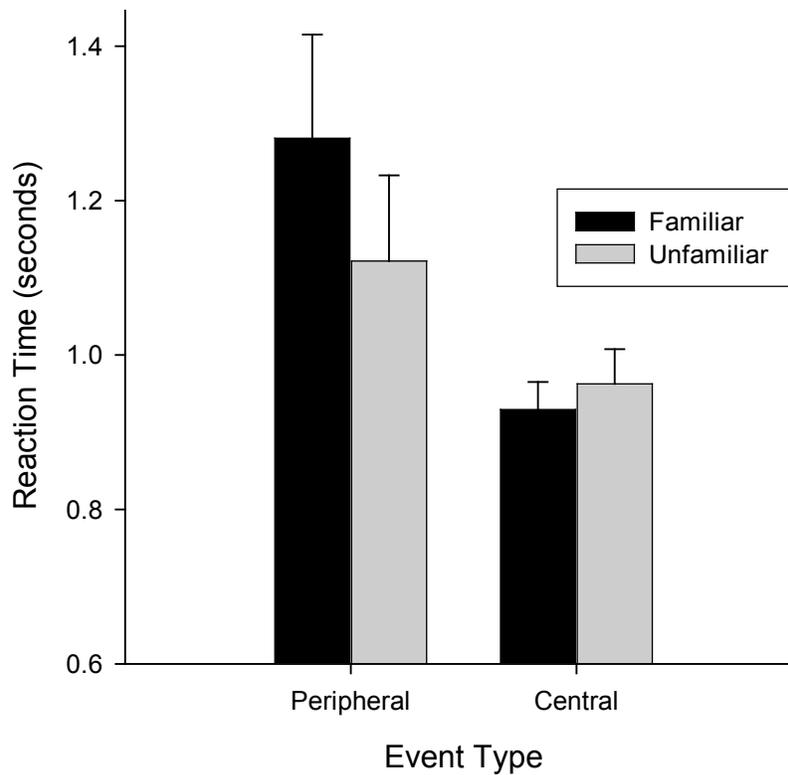
fell below 65 km/h (~18 m/s), they would hear a 'Ding' sound, which was a prompt for them to speed up. Alternatively, if their velocity rose above 75 km/h (~21 m/s), they heard a 'Buzzer' sound, which was a prompt for them to slow down. The auditory prompts did not occur during cornering, or during the central braking events.

#### **2.9.4. Dependent Measures**

The dependent measures were the same as in Experiment 2.

### **2.10. Results And Discussion**

The results for all of the driving performance measures are shown in Table 1. Contrary to Experiment 2, Familiar and Unfamiliar drivers did not differ on either the central response ( $t(18) = .579, p = .57$ ) or peripheral response measure ( $t(18) = .913, p = .37$ ). Similar to Experiment 2, velocity, headway distance, collision rates and lateral position did not differ between the two groups ( $p$ 's > .54). The results for the Central and Peripheral responses are illustrated in Figure 3.



**Figure 3.** Reaction times in response to peripheral and centrally occurring emergency events as a function of route familiarity. Error bars indicate *SEM*.

The only difference in methods employed in Experiments 2 and 3 was that participants were encouraged to pay more attention to the primary task (i.e., their speed). This increased focus on the primary task should greatly reduce the incidence of mind wandering and any effects that could be attributed to that mind wandering state. Given that the speeded response differences observed in Experiment 2 were eliminated in the present experiment, this strongly suggests that the impaired responses to both the central and peripheral hazards observed in Experiment 2 were due to increased mind wandering along familiar routes.

## 2.11. General Discussion

It is generally understood that when one practices a task, less effort, or attention, is needed in order to perform optimally. With respect to driving along a

familiar route, the potential benefit then, is that one may have additional attentional resources available to attend to potentially hazardous stimuli in the environment. Thus a driver that is familiar with the route may be better at responding to an emergency than someone that is unfamiliar with the route. An alternative possibility is that familiarity with the route might lead to a greater incidence of inattention blindness, which might result in the person being less able to respond in an emergency. The present work explored these two possibilities by directly manipulating route familiarity within three experiments.

Although in Experiment 1, participants familiar with the route responded to the central braking events faster than participants unfamiliar with the route, familiar drivers followed the pace car at a shorter headway distance, thus necessitating a faster braking response in order to avoid a collision. Responses to the peripheral events, however, were slower for familiar than unfamiliar drivers. Also, with headway distance controlled in Experiment 2, participants familiar with the route took longer to respond to both central and peripheral events. The effects observed in Experiment 2 were eliminated in Experiment 3 when drivers had to maintain a set velocity, thus making them more engaged in the driving task. Taken together, these results are inconsistent with the hypothesis outlined in the Introduction, that route familiarity might lead to the freeing up of attentional resources that could be used to process other stimuli in the environment, like potential hazards. Instead, these findings are consistent with the mind wandering hypothesis which suggests that familiarity with a route might induce a false sense of security with a corresponding wandering of attention away from the driving task, which promotes a form of inattention blindness. Indeed, these results are consistent with previous findings that show that when mind wandering, drivers tend to show a breakdown in the ability to monitor their surroundings (He et al., 2011).

At first blush, the impairment due to route familiarity observed in the present work seems similar to the impairment observed when drivers are in a dual task situation, such as driving while talking on a cell-phone. For example, it is known that RTs to respond to emergencies are longer when talking on a cell-phone than when attention is deployed exclusively to the driving task (Strayer et al, 2003). When dual tasking, drivers also tend to reduce their speed (Alm & Nilsson, 1995; Chiang,

Brooks & Weir, 2004; Haigney, Taylor & Westerman, 2000; Rakauskas, Gugerty & Ward, 2004) and increase their headway distance (Jamson, Westerman, Hockey & Carsten, 2004; Strayer & Drews, 2004; Strayer et al, 2003).

Consistent with the dual-tasking RT findings, in the present Experiment 2 both central and peripheral response RTs to sudden events were longer when the driver was familiar with the route than when unfamiliar with the route. However, the results of the present work were inconsistent with the dual-tasking effects on headway distance and velocity. In the present work when participants were free to control their headway distance (Experiment 1), drivers familiar with the route tend to follow *closer* to the car in front of them rather than further back. Also no effects on velocity were observed in any of the experiments.

These differences observed in the impairments between dual-tasking and familiarity suggest that the mechanisms giving rise to the effects are likely different. When dual tasking, the driver must consciously divide the available attentional resources between the two tasks. It has been suggested that because drivers are consciously aware of the reduction in resources allocated to the driving task, they end up compensating for this reduction by increasing their margin of safety (Strayer et al., 2003). This compensation takes the form of reducing their velocity and increasing their headway distance. If the familiarity effects are due, at least in part, to the driver entering more mind wandering states, then the deficits might arise not from resource depletion but rather from the driver being in an inattentive state of mind. The consequence of this is that the driver is likely less aware of their surroundings and so would have more difficulty detecting an emergency situation, or even realize that their headway distance had changed and may now be unsafe.

The idea that a driver's state of mind while mind wandering may differ fundamentally from that while dual tasking is supported by neurophysiological evidence (Buckner, Andrews-Hanna, & Schacter, 2008; Fox, Snyder, Vincent, Corbetta, Van Essen & Raichle, 2005). That evidence suggests that there are two distinct neural networks involved in information processing. The *task-positive network* is used for focused external attention, and when activated, the system is geared to process information arriving from the external environment. In contrast, the

*default network* is used when we are not engaged by the external world, and when activated, the system is geared to process task-unrelated thoughts (mind wandering). Of importance to the present work is that these two networks are negatively correlated with one another. That is, activation in one promotes deactivation of the other.

We suggest that when dual tasking, the task positive network is activated since the driver must consciously attend to both external tasks simultaneously. A driver may then compensate for the depleted attentional resources by increasing the margin of safety. This leads to longer headway distance and slower velocity. In contrast, when familiar with the route, thus promoting mind wandering, the default network is activated with a subsequent deactivation of the task positive network. Thus, when familiar with the route, the driver will be more likely to be disengaged from the environment, and therefore, will be less able to implement a margin of safety. It must be noted that no explicit measure of mind wandering was collected in the present work and, therefore, although plausible, the hypothesis that the route-familiarity effect is mediated by mind wandering is speculative and in need of further investigations.

### **2.11.1. An Alternative Account**

While the MW hypothesis seems readily able to explain the results obtained in the present work, an alternative explanation should be considered. A relatively new theory – the malleable attentional resources theory (MART) – has been proposed to help explain the negative effects of low mental workload on performance (Young & Stanton, 2001; see also the theory put forth by de Waard, 1996; Brookhuis & de Waard, 2002). It is possible that route familiarity produces a low level of mental workload (MWL) for the driver. MART posits that during mental underload situations, there is shrinkage of the attentional resource capacity to accommodate the reduction in task demands (Young & Stanton, 2002). According to this theory, task performance is assumed to vary as a function of MWL, much like it does with changes in arousal levels (Yerkes & Dodson, 1908). Namely, performance is optimal at an intermediate level of either MWL or arousal. If the MWL is too low, then the shrunken resource pool may have an inadequate capacity to

cope with a sudden increase in demand – like during a critical situation where a driver has to react to an emergency event. If one assumes that familiarity with a route reduces the MWL required then the present findings appear consistent with the MART theory.

However, recall that in Experiment 3, drivers were required to monitor their velocity, a situation which should increase the total workload required. According to MART, one would predict that for familiar drivers, the resource capacity will expand to accommodate the increase in task demand. Therefore, there should be an improvement in RT for Familiar drivers that are required to monitor their velocity (the Familiar group in

Experiment 3) compared to Familiar drivers that are not required to monitor their velocity (the Familiar group in Experiment 2). A comparison of these particular conditions between Experiments 2 and 3 reveals no such improvements. In fact, RTs for both the peripheral and central response measures were statistically equivalent between these two experiments (both  $t$ 's < 1). Nevertheless, since MART predicts that performance is said to follow an inverted “U” shaped function with MWL, it could be that route familiarity only slightly reduces MWL from that which would result in maximal performance (i.e., the apex of the inverted-U-shaped function). The added task of monitoring velocity may increase MWL to a degree which makes performance fall on the corresponding point on the opposite side of the U-shaped function. Thus, the fact that central and peripheral event RTs for familiar drivers do not change between Experiments 2 and 3 is not necessarily inconsistent with the MART theory. Determining if MART is a possible explanation for the route familiarity effect is beyond the scope of the present work, and future research should endeavor to test this theory further.

## **2.12. Conclusion**

Regardless of the theoretical explanations, the take home message of the present work is that far from being of help, route familiarity actually makes driving more hazardous. Notably these results were obtained with a very subtle

manipulation of route familiarity. That is, participants were only required to traverse the route a total of four times before being exposed to the experimental condition. One question, then, is how does performance change while driving down a route that is excessively learned? It could be that performance would decline even further than that observed here. Alternatively, it is possible that performance may follow a parabolic function with respect to familiarity, such that performance would actually improve when a high-degree of route-familiarity is achieved. Further research is needed to examine the impact of extensive route practice on driving performance.

## Chapter 3.

# Driving with the wandering mind: The effect that mind-wandering has on driving performance<sup>2</sup>

### 3.1. Abstract

**Objective:** The principal objective of the present work was to examine the effects of mind state (mind-wandering vs. on-task) on driving performance in a high-fidelity driving simulator. **Background:** Mind-wandering is thought to interfere with goal-directed thought. It is likely, then, that when driving, mind-wandering might lead to impairments in critical aspects of driving performance. In two experiments, we assess the extent to which mind-wandering interferes with responsiveness to sudden events, mean velocity and headway distance. **Method:** Using a car-following procedure in a high-fidelity driving simulator, participants were probed at random times to indicate whether they were on-task at that moment, or mind-wandering. The dependent measures were analyzed based on the participant's response to the probe. **Results:** Compared to when on-task, when mind-wandering participants showed longer response times to sudden events, drove at a higher velocity and maintained a shorter headway distance. **Conclusion:** Collectively, these findings indicate that mind-wandering affects a broad range of driving responses, and may therefore lead to higher crash risk. **Application:** The results suggest that situations which are likely associated with mind-wandering (e.g., route-familiarity) can impair driving performance

<sup>2</sup> This chapter has been published as Yanko, M.R., & Spalek, T.M. (in press). Driving with the wandering mind: The effect that mind-wandering has on driving performance. *Human Factors*.

## 3.2. Introduction

When driving a car, a large number of stimuli need to be attended. For example, pedestrians on the side of the road, upcoming intersections, driving speed, and the vehicle's position within the lane are all competing for attentional resources. In addition, there are often other unrelated stimuli, like passenger or cell-phone conversations, that also compete for attention. These added attentional demands create a problem when the driver needs to react to an emergency, such as a lead car braking abruptly, or a child running out on the road.

It is well known that talking on a cell-phone or text messaging can have detrimental effects on driving behavior (e.g, Strayer, Drews & Johnston, 2003). However, one's own thoughts, or mind-wandering, might also be a source of distraction. Mind-wandering is a cognitive state in which the thought processes that occupy the mind are on topics that are unrelated to the task at hand (Giambra, 1995; Smallwood & Schooler, 2006). The incidence of mind-wandering is known to increase as a task becomes more practiced, or if the task is dull or repetitive (Cunningham, Scerbo & Freeman, 2000; Mason, Norton, Van Horn, Wegner, Grafton & Macrae, 2007; Teasdale et al., 1995). An important consideration for the present work is that mind-wandering is thought to interfere with goal-directed thought (Christoff, Ream & Gabrieli, 2004; Smith, Keramatian, Smallwood, Schooler, Luus and Christoff, 2006; Teasdale et al., 1995) and is associated with decreased awareness of the external environment (Smallwood, Baracaia, Lowe & Obonsawin, 2003; Smallwood & Schooler, 2006). Avoiding obstacles and responding appropriately to emergencies are important goals when driving. It follows then, that mind-wandering would impair a driver's ability to respond to these hazards.

Galera et al. (2012) have provided evidence consistent with this supposition. Using a standardized questionnaire they determined the degree of responsibility in causing the accident. The interview also included a question regarding the drivers' thought content just prior to the crash. Participants classified their responses into one of three categories (no thoughts, or thoughts unrelated or related to the driving task) and rated the thoughts on a scale from 0 to 10 with respect to how distracting that thought was. The critical finding was that highly distracting thoughts were associated with a greater likelihood of being responsible for the crash. Although providing a link between

mind-wandering and increased crash risk in the real world, the study was correlational and so a causal association between mind-wandering and impaired driving is yet to be demonstrated.

Mind-wandering has also been shown to influence driving behaviour in a recent high-fidelity driving-simulator study by He, Becic, Lee and McCarley (2011). In that study, participants drove along a straight rural road while following a vehicle at a distance that felt safe. There was also a vehicle behind the participant's vehicle in order to encourage drivers to monitor their side mirrors. Drivers were required to indicate, via a button press, when they felt that their mind was on thoughts unrelated to the driving task (i.e., mind-wandering). The data were separated into two conditions – mind-wandering and on-task. It was found that, while mind-wandering, drivers showed decreased variability in horizontal gaze, and spent less time monitoring the side mirrors, suggesting a general impairment in monitoring the environment. The study of He et al. is informative, but did not address other important issues regarding the relationship between mind-wandering and driving performance. Notably, the experimental protocol did not include measures of response times to salient events, which may also be affected by mind-wandering. The present work was designed to fill this gap.

That mind-wandering might lead to slower reaction times (RT) to sudden events has been raised in a recent study by Yanko and Spalek (2013). They found that participants who were driving down a familiar route showed decreased separation from the lead vehicle (headway distance) and, with headway distance controlled, took longer to respond to a lead vehicle braking and to pedestrians stepping onto the road. This *Route-Familiarity effect* was attributed to increased mind-wandering along familiar routes. However, because mind-wandering was not measured in that study, the link between route familiarity and mind-wandering remains speculative. The present study further explored this link. If the route-familiarity effect is mediated by mind-wandering, similar effects should be in evidence when mind-wandering is studied independently.

Mind-wandering was assessed in the present work using a variant of the probe-caught mind-wandering procedure (Smallwood & Schooler, 2006). Participants were prompted with a tone at random times to indicate, via a button press, whether they felt their mind was on-task at that moment, or mind-wandering. This procedure was used in

preference to the self-caught procedure used by He et al. (2011) in which drivers pressed a button only when they felt that they were mind-wandering. Although both are valid ways of assessing mind-wandering, the probe-caught procedure is better able to measure mind-wandering episodes that occur without explicit awareness (Smallwood & Schooler, 2006).

Based on the extant literature we chose to examine three variables that could foreseeably be impacted by mind-wandering: RT to hazards, velocity, and headway distance. Given that mind-wandering has been associated with reduced awareness of the external world (e.g., Smallwood, et al., 2003) as well as a decrease in horizontal gaze while driving (He et al., 2011), we predict that a drivers responsiveness to both central and peripheral emergencies will be slowed when mind-wandering compared to when on-task. The predictions are less clear with respect to headway distance and velocity. If the act of mind-wandering saps attentional resources similar to that of dual-task distraction, like talking on a cell-phone, then the driver should compensate for the increased attentional demand by increasing headway distance (Jamson, Westerman, Hockey & Carsten, 2004; Strayer & Drews, 2004; Strayer, et al., 2003) and reducing velocity (Alm & Nilsson, 1995; Chiang, Brooks & Weir, 2004; Haigney, Taylor & Westerman, 2000; Rakauskas, Gugerty & Ward, 2004). Alternatively, the decreased awareness of the external environment may result in the driver being less aware of their possibly impaired reactions, making it less likely that they would compensate by increasing headway distance and slowing velocity. Indeed, Yanko and Spalek (in press) showed that when familiar with a route, which might promote mind-wandering, drivers tend to follow closer to a lead vehicle. No change in velocity was observed in that study.

### **3.3. Experiment 1**

The objective of Experiment 1 was to determine the extent to which mind-wandering, assessed via the probe-tone procedure described in the Introduction, interferes with critical aspects of driving. Responsiveness to sudden events was indexed by RT to apply the brakes in order to avoid a collision with a braking lead vehicle. We also measured the velocity of the participant's vehicle in relation to the driver's mind

state. To obtain unbiased estimates of the effects of mind state on RT and velocity, headway distance was fixed under computer control.

## **3.4. Method**

### **3.4.1. Participants**

Seventeen undergraduate students at Simon Fraser University participated either for class credit or for payment. All had self-reported normal or corrected-to-normal vision. All had a valid British Columbia driver's license (class 5).

### **3.4.2. Materials**

A DriveSafety high-fidelity driving simulator (model DS-600c) was used. Participants were seated in a modified Ford Focus cab equipped with a windshield, driver and passenger seats, dash board, instrument panels, and a central console, as well as all the devices needed to operate a car (accelerator and brake pedal, turn signal switch, a steering wheel etc.). The simulated environment was generated using HyperDrive Authoring Suite and was displayed using DriveSafety's Vection Simulation software (Version 1.9.35).

Before starting the experiment, participants filled out a modified 'Simulator Sickness Questionnaire' to screen out those likely to become nauseous while driving in the simulator (see Kennedy, Lane, Berbaum, & Lilienthal, 1993, for an overview).

The route developed for this experiment was a stretch of rural highway that was formed into a continuous 12-km oval track. There were two lanes going in each direction, separated by a cement median. A pace car and the participant's vehicle were the only two cars on the road. The participants were instructed to follow the pace car, which was programmed to maintain a constant separation of 30 meters from the participant's vehicle at all times. If the participant sped up or slowed down, the pace car adjusted speed accordingly. The only time that this was not the case was during the braking events (see below). Participants were instructed to try and maintain a speed of 20 meters per second (m/s) at all times, except during braking events.

### **3.4.3. Procedure**

The experiment was comprised of a practice session and an experimental session. Both sessions were identical with the exception that the practice session lasted three minutes, and the experimental session lasted thirty minutes. The practice session also served as an acclimatization session, allowing participants to adapt to the physical sensations involved in driving the simulator. The experimental session followed directly after the practice session.

Participants were instructed to follow the pace car, while abiding by all traffic laws. The pace car was programmed to brake at randomly-selected times throughout the route. On average, the time interval between each braking event was 30 seconds, and was never less than 10 seconds. Therefore there were approximately sixty braking events within the thirty minute experimental session. During a braking event, the pace car immediately reduced speed to 9.2 m/s for three seconds, and the brake lights were illuminated until the participant depressed the brake. The pace car then accelerated so as to regain a separation of 30 m from the participant's vehicle. RTs to activate the brakes were recorded, as well as the degree of brake depression, sampled at a rate of 60Hz.

At randomly-selected times throughout the session, a tone was played through the speakers of the simulator. At that point, participants were required to press one button to indicate whether their minds were "on-task" (i.e., focused on the driving task) over the previous ten seconds or so, and a different button if they were mind-wandering (engaged in task-unrelated thoughts) during that time. Both buttons were located at the back of the steering wheel. The auditory prompt is analogous to the "thought probe" commonly used in mind-wandering experiments (see Smallwood, Beach, Schooler & Handy, 2008). Participants were given a definition of mind-wandering along with several examples prior to starting the experiment (e.g., thinking of a term paper or thinking of an upcoming movie release). They were also told that if they felt that their mind was blank, they should indicate that their mind was wandering. On average, the time interval between each tone was 60 seconds, and was never less than 20 seconds. Therefore there are approximately thirty probes within the thirty minute experimental session.

### **3.4.4. Dependent Measures**

There were three dependent measures. *Braking RT* was the RT to the pace car braking events and was defined as the interval of time between the onset of the brake light of the pace car and the depression of the brakes in the participant's vehicle. *Velocity* was defined as the average speed in m/s over a 10-second period prior to the probe-tone. Time epochs that included a pace car braking event were not included in the velocity calculation. Although the pace car was programmed to maintain a fixed separation from the participant's vehicle, we also recorded *Headway Distance* to confirm that the programmed separation worked equally, regardless of the participant's mind state. Headway distance was defined as the average separation in meters between the pace car and the participant's car over a 10-second period prior to the probe-tone. Time epochs that included a pace car braking event were not included in the headway distance calculation.

## **3.5. Results And Discussion**

In all present experiments, two-tailed paired-sample t-tests were conducted for all dependent measures. The results were separated into two categories – mind-wandering or on-task – based on the participant's response to the probe-tone. In each case, the data for analysis came from the 10-second period directly preceding the probe-tone.

### **3.5.1. Mind-Wandering**

On average, the probe-tone was presented 30.2 times ( $SD = 4.6$ ). Of those, participants reported being on-task 18.4 times ( $SD = 6.2$ ) and mind-wandering 11.8 times ( $SD = 5.8$ ), suggesting that they were mind-wandering for about 39 percent of the experimental session.

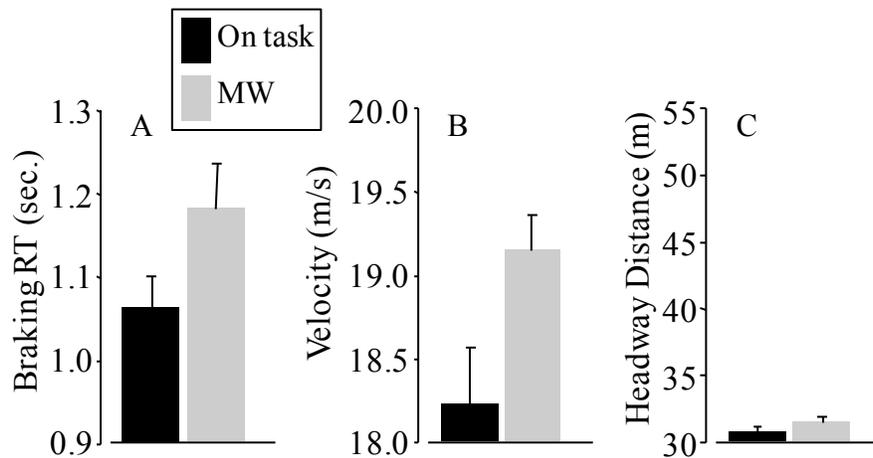
### **3.5.2. Braking RT**

The braking RT, headway distance, and velocity measures, averaged over all participants, are illustrated in Figure 1. The median braking RT for both on-task and mind-wandering epochs were computed separately for each participant, and were then

averaged across participants. Braking RTs were found to be significantly longer during mind-wandering than on-task episodes ( $M=1182$  ms and  $M=1062$  ms, respectively),  $t(16) = 2.39$ ,  $p = .03$ . This result supplements the findings of He et al. (2011) who showed that mind-wandering affects driving performance in such non-time-critical measures as variability in horizontal gaze and dwell time when monitoring the side mirrors. The present results add to He et al.'s findings by showing that mind-wandering impairs also such time-critical aspects of driving performance as the ability to respond promptly to external events demanding quick action. The similarity between these results and those of Yanko and Spalek (in press) is also consistent with the proposed link between mind-wandering and familiarity outlined in the Introduction.

### **3.5.3. Velocity Measures**

An additional way in which the present study supplements that of He et al. (2011) is in respect to the effect of mind-wandering on driving velocity. As He et al. noted, an unbiased assessment of that effect was not possible in their study because the velocity of the participant's vehicle was determined by the velocity of the lead vehicle, which was fixed. The present design permitted and assessment of the effect of mind-wandering on driving velocity.



**Figure 1.** Mean RTs to the pace car braking events (A), mean velocity (B) and mean headway distance (C) for both on-task and mind-wandering (MW) episodes. Error bars indicate standard error of the mean for each condition.

When analyzing velocity in the present context, an important consideration is that velocity is necessarily lower during a braking event. For that reason, all epochs that included a braking event were excluded from the analysis. This procedure resulted in one participant being removed from the analysis because all mind-wandering epochs contained a braking event for that participant. The analysis showed that velocity was significantly faster during mind-wandering episodes than when the driver was on-task ( $M=18.2$  m/s and  $M = 19.2$  m/s, respectively),  $t(15) = 3.83$ ,  $p < 0.01$ .

### 3.5.4. Headway Distance

Headway distance was controlled by the simulation, therefore, it is not surprising that headway distance was the same for on-task and mind-wandering conditions (Figure 1C;  $t(15) = 1.72$ ,  $p = 0.11$ ). As such, it is unlikely that headway distance biased the other two dependent measures: braking RT and velocity.

## **3.6. Experiment 2**

In Experiment 1, we found that that braking RTs were longer – and velocity higher – when the driver was mind-wandering than when s(he) was on-task. Experiment 2 examined whether the driver’s mind-state has corresponding effects on headway distance. As noted above, this could not be done in Experiment 1 because headway distance was controlled programmatically. As noted in the Introduction two possibilities were foreseen based on the literature. If mind-wandering is akin to dual-tasking then headway distance should be greater when mind-wandering, as compared to when on-task, because drivers compensate for the increased attentional demand. If, however, the route-familiarity effect described by Yanko and Spalek (in press) is due, at least in part, to mind-wandering then shorter headway distance should be observed when drivers are mind-wandering relative to when on-task.

The design of Experiment 2 included an extra task that was not part of Experiment 1. A peripheral RT task (responding to a pedestrian stepping onto the road) was included in addition to the foveal RT task (responding to the lead car braking) from Experiment 1. Peripheral events were included to investigate further the hypothesized relationship between route familiarity and mind-wandering. Namely, Yanko and Spalek (in press) found that route familiarity led to longer RTs to both foveal and peripheral sudden events. On the hypothesis that the effects of route familiarity are mediated by mind-wandering, it should be also the case that mind-wandering leads to longer RTs in response to both foveal and peripheral events.

## **3.7. Method**

### **3.7.1. Participants**

Thirty-two undergraduate students drawn from the same population as Experiment 1 participated in Experiment 2. None had participated in Experiment 1.

### **3.7.2. Materials**

The materials used in Experiment 2 were the same as in Experiment 1.

### **3.7.3. Procedure**

The procedure was the same as in Experiment 1, with the following exceptions. First, instead of being controlled programmatically, headway distance was allowed to vary. Second, the lead vehicle was programmed to maintain a speed of 20 m/s, except during braking events where the pace car immediately reduced speed to 9.2 m/s for three seconds, after which it accelerated back to 20 m/s. Third, women were added along the side of the road such that they stood approximately 5 meters from the center of the far right lane, and were spaced 200 meters apart. Twenty percent of these women were randomly selected to walk towards the road when the participant was 50 meters away, otherwise the women remained motionless.

Finally, the response buttons on the steering wheel were used differently from Experiment 1. Participants were instructed that, upon hearing the probe-tone, they had to press the left-hand button if they were mind-wandering, and to withhold the response if they were on-task. To measure RT to the approaching woman, participants were instructed to press the right-hand button when they noticed a woman starting to walk towards the road. The buttons were sampled at a rate of 60Hz.

### **3.7.4. Dependent Measures**

In addition to the dependent measures collected in Experiment 1, *Peripheral RT* was included and was defined as the interval of time between the initial movement of the pedestrian, and the depression of the peripheral response button.

## **3.8. Results And Discussion**

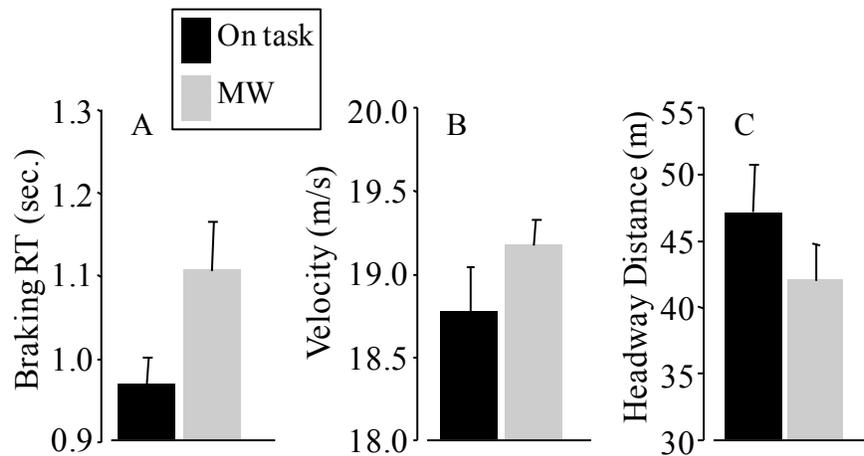
As in Experiment 1, the data were separated into two categories based on the response to the probe-tone: on-task and mind-wandering. The braking RT, velocity, and headway distance measures are illustrated in Figures 2A, 2B, and 2C, respectively.

### **3.8.1. Mind-Wandering**

On average, the probe-tone was presented 30.2 times ( $SD = 5.2$ ). Of those, participants reported being on-task 17.2 times ( $SD = 7.4$ ) and mind-wandering 13.0 times ( $SD = 6.2$ ), suggesting that they were mind-wandering for about 42 percent of the experimental session.

### **3.8.2. Braking RT**

The median braking RT for both on-task and mind-wandering epochs were computed separately for each participant, and were then averaged across participants (Figure 2A). Braking RTs were significantly longer during mind-wandering episodes than during on-task episodes ( $M=1107$  ms and  $M=967$  ms, respectively),  $t(31) = 2.98, p < .01$ . This result closely replicates the braking RT result in Experiment 1 (Figure 1A), and confirms that mind-wandering leads to slower responding to sudden events. Considered jointly, these two results also support Yanko and Spalek's (in press) hypothesis that the longer braking RTs associated with route familiarity are mediated by mind-wandering.



**Figure 2.** Mean RTs to the pace car braking events (A), mean velocity (B) and mean headway distance (C) for both on-task and mind-wandering (MW) episodes. Error bars indicate standard error of the mean for each condition.

### 3.8.3. Velocity

As was done in Experiment 1, data for epochs that included a braking event were excluded from the analysis. One participant was removed because all mind-wandering epochs contained a braking event for that participant. The analysis revealed no difference in velocity between on-task and mind-wandering episodes ( $M=18.8$  m/s and  $M = 19.2$  m/s, respectively),  $t(30) = 1.32$ ,  $p = 0.2$ . Given that the speed of the lead car was fixed, however, it is not surprising that velocity was not affected by the driver's mind state.

### 3.8.4. Headway Distance

As was done for the velocity measure, data for epochs that included a braking event were excluded from the analysis, with one participant being removed. The analysis showed that drivers followed the lead car more closely when mind-wandering than when on-task ( $M = 42.1$  m and,  $M= 47.13$  m respectively),  $t(30) = 2.27$ ,  $p = 0.03$ . This finding could not be observed in Experiment 1 because, in that experiment, headway distance was fixed programmatically. He et al. (2011) also found that headway distance was unaffected by mind-wandering. Those authors pointedly noted, however, that the presence of a trailing vehicle in their experiment might have prevented an effect of mind-wandering on headway distance. The finding, however, is consistent with that observed

by Yanko and Spalek (in press) providing further support for the hypothesis that the route-familiarity effect is mediated by mind-wandering.

### **3.8.5. Peripheral RT**

To be categorized as a mind-wandering or on-task response, the RT to the peripheral event had to occur during the critical 10-s period that preceded the probe-tone. Given that only 20% of the women ever stepped onto the road, the likelihood of this happening during one of the critical 10-s periods was low. As a consequence, 11 participants were excluded from the analysis because no peripheral RTs were collected in at least one of the two mind-state conditions. The median peripheral RTs for both conditions were computed separately for each of the remaining participants, and were then averaged across participants. The analysis revealed that drivers took significantly longer to respond to the peripheral event when mind-wandering than when they were on-task ( $M=1269$  ms and  $M = 1113$  ms, respectively),  $t(20) = 2.30$ ,  $p = 0.03$ . This finding is again consistent with that of Yanko and Spalek (in press) who found that route familiarity led to longer RTs to both foveal and peripheral sudden events. Thereby this lends further support to the hypothesis that the driving impairments associated with route familiarity are mediated by mind-wandering.

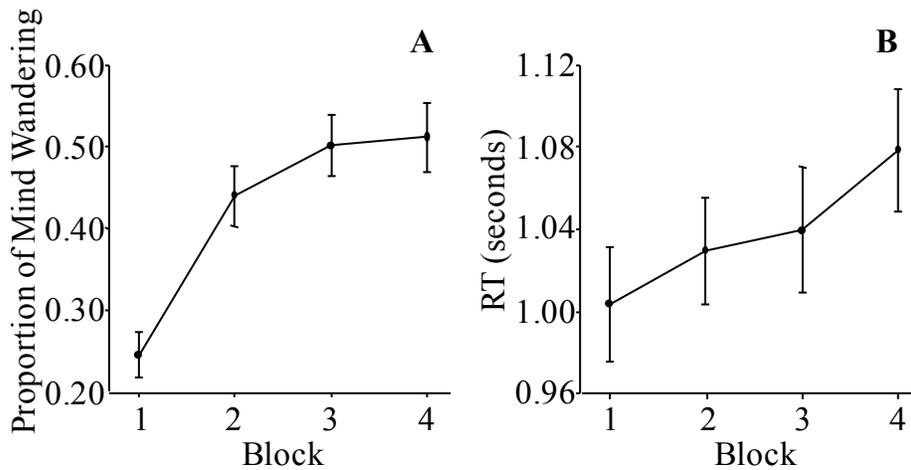
### **3.8.6. Probability of Mind-wandering and RT Changes Over Time**

As noted above, one of the objectives of the present work was to pursue Yanko and Spalek's (in press) supposition that the driving impairments associated with route familiarity (e.g., longer RTs to sudden events) can be attributed, at least in part, to mind-wandering. On this hypothesis, it must be the case that as a driver becomes familiar with the route/environment, the relative proportion of time spent mind-wandering will increase. This increased propensity to mind wander must be coupled with longer RTs to sudden emergencies.

To test this hypothesis, data from Experiments 1 and 2 were separated into four 7.5 min time-blocks. The proportion of time that each driver reported mind-wandering was then calculated for each of the four blocks. Data were then collapsed across Experiment because an initial 2 (Experiment) x 4 (Block) mixed-factor analysis of

variance (ANOVA) revealed no main effect or interaction involving Experiment. The subsequent ANOVA examining only the effect of Block was significant,  $F(3,141) = 23.49$ ,  $p < 0.01$ . Post-hoc planned pairwise comparisons showed that all blocks differed from one another (all  $p$ 's  $\leq 0.05$ ), with the exception of two comparisons: block 3 versus 4 ( $p = 0.68$ ), and block 2 versus 4, which was marginally significant ( $p = 0.06$ ). The proportion of mind-wandering as a function of Block, averaged across all participants, is illustrated in Figure 3A. The same analyses were conducted on the braking RTs from Experiments 1 and 2. Once again the data were collapsed across Experiment because no main effect or interaction was observed. The subsequent ANOVA examining the effect of Block was significant,  $F(3,141) = 4.62$ ,  $p < 0.01$ . A linear trend analysis revealed that RT increases steadily from blocks 1 to 4 ( $p < 0.01$ ). The mean braking RT as a function of Block, averaged across all participants, is illustrated in Figure 3B.

Thus, as the experimental session progressed, notionally making the drivers more familiar with the environment, there was a progressive increase in the proportion of time spent mind-wandering, and a steady increase in RT to an emergency braking event. The present finding that both mind-wandering and RT increased steadily across the experimental session is once again consistent with Yanko and Spalek's (2013) hypothesis.



**Figure 3.** The proportion of time that the drivers reported mind-wandering (A) along with the mean RTs to the pace car braking events (B) broken up into four 7.5 min time-blocks. Data for both measures were averaged across participant’s from Experiments 1 and 2. Error bars indicate standard error of the mean for each condition.

### 3.9. General Discussion

The principal objective of the present work was to examine the effects of mind state (mind-wandering vs. on-task) on driving performance in a high-fidelity driving simulator. Participants followed a pace car along a stretch of rural highway and indicated (via a button press) whether they were currently on-task or mind-wandering when prompted with a tone at random times. The pace car was programmed to brake at randomly selected locations throughout the route. In two experiments, we examined three aspects of driving performance: RT to apply the brakes in response to the pace car braking, velocity, and headway distance. To assess the effect of mind state on these measures, the data were separated into two categories (mind-wandering or on-task) based on the responses to the probe-tone.

In Experiment 1, we found that braking RTs were longer and velocity was higher when the drivers were mind-wandering than when they were on-task. The effect of mind state on headway distance could not be assessed in Experiment 1 because headway distance was fixed programmatically. In Experiment 2, headway distance was free to vary, and was found to be shorter when the drivers were mind-wandering than

when they were on-task. Experiment 2 also showed that mind-wandering increased RTs, regardless of whether the sudden event was foveal or peripheral.

The present work provides the first demonstration that mind-wandering affects time-dependent aspects of driving. Our results are consistent with – and supplement – the findings of He et al. (2011) that, when mind-wandering, drivers show decreased variability in horizontal gaze, and spend less time monitoring the side mirrors. Although narrowing of visual attention, as proposed by He et al. may at least partially explain the slowdown in peripheral RTs, there would be no reason to expect central braking RTs to change. The finding that RTs to both central and peripheral hazards are longer when mind-wandering is more consistent with a form of *inattentional blindness*, where drivers are less likely to notice a critical stimulus in the environment even when the driver fixates on that stimulus (Strayer et al., 2003). Collectively, these findings indicate that mind-wandering affects a broad range of driving responses; they also harmonize with previous correlational studies that have linked mind-wandering, or daydreaming, to higher crash risk (Galera et al., 2012; Larson, Alderton, Neideffer, & Underhill, 1997; Stutts, Reinfurt, Staplin, & Rodgman, 2001). Even though the present results were obtained under very specific driving conditions (i.e., fixed headway distance and fixed lead vehicle speed in Experiments 1 and 2, respectively), the consistency between the present findings and those noted above suggests that our results would transfer to more naturalistic driving conditions. This conjecture, however, is speculative and merits further investigation.

### **3.9.1. Route Familiarity And Mind-Wandering**

Along with investigating the effect of mind-wandering on driving performance, the present work indirectly addressed the hypothesized relationship between route familiarity and mind-wandering (Yanko & Spalek, in press). As noted in the foregoing, Yanko and Spalek reported a *route familiarity effect* in which RTs to emergencies are slower and headway distance is shorter when driving along a familiar route. Yanko and Spalek hypothesized that the route familiarity effect is mediated by mind-wandering. However, without directly measuring mind-wandering in that study, the link between route familiarity and mind-wandering was speculative.

The results of the present study, in which mind-wandering was assessed directly, parallel closely those obtained by Yanko and Spalek (2013) with route familiarity, supporting the hypothesis that the route-familiarity effect is mediated, at least in part, by mind-wandering.

### **3.9.2. Mind-Wandering Versus Dual-Tasking**

On the face of it, mind-wandering seems to compromise the driver's responsiveness to sudden events in much the same way as dual-tasking. That is, it is known that RTs to emergencies are longer when talking on a cell-phone than when attention is deployed exclusively to the driving task (Strayer et al, 2003). A similar impairment was observed in the present work, inviting the idea that mind-wandering is simply another instance of dual-tasking. However, dual-tasking has been shown to affect other aspects of driving performance as well. For example, dual-tasking promotes longer headway distance (Jamson, et al., 2004; Strayer & Drews, 2004; Strayer, et al., 2003) and slower velocity (Alm & Nilsson, 1995; Chiang, et al., 2004; Haigney, et al., 2000; Rakauskas, et al., 2004). In contrast, the present results indicate that mind-wandering leads to *decreased* headway distance and *increased* velocity, thereby vitiating the link between mind-wandering and dual-tasking.

That a driver's state of mind while dual-tasking differs fundamentally from that while mind-wandering is supported by neurophysiological evidence (Buckner, Andrews-Hanna, & Schacter, 2008; Fox, Snyder, Vincent, Corbetta, Van Essen & Raichle, 2005). That evidence revealed the existence of two distinct neural networks: the *task-positive network* used for focused external attention, and the *default network* used when we are not engaged by the external world. Mind-wandering has been explicitly identified with activity in the default network. The important point for the present purposes is that these two networks show a strong negative correlation with one another, suggesting that the brain shifts discretely between the two modes of processing.

Therefore, an account of the dissimilar results can be given in terms of differential awareness of environmental demands when dual-tasking and when mind-

wandering. When the task-positive network is activated, the system is geared to process information arriving from the external environment. This, we suggest, is the case in dual-tasking, in which the driver must attend to both tasks and compensates for the depletion of attentional resources by increasing the margin of safety. This leads to longer headway distance and slower velocity. In contrast, when the default network is active, the system is geared to process task-unrelated thoughts. This is characteristic of mind-wandering in which the driver is less aware of the driving environment and, therefore, less likely to be concerned with implementing a margin of safety. This can result in shorter headway distance and higher velocity. We hasten to note that, although plausible, the hypothesis that dual-tasking and mind-wandering mediate different driving behaviours because they are subserved by different systems is in need of further empirical verification.

## Chapter 4.

# Reining in the wandering mind reverses the route-familiarity effect<sup>3</sup>

### 4.1. Abstract

We have shown that as drivers become more familiar with a route, they respond less promptly to emergencies (e.g., a vehicle braking). This *Route-Familiarity effect* was attributed to increased mind wandering along familiar routes (Yanko & Spalek, 2013). We speculate that the stress of someone monitoring/evaluating you would likely reduce the incidence of mind-wandering. Therefore, in the present work we measured driving performance while either doing the driving task normally or while we concurrently recorded EEG activity using an electrode cap. Consistent with our past findings, when drivers were not monitored with EEG, the typical Route-Familiarity effect was observed, whereby familiar drivers were slower to respond to emergencies than were unfamiliar drivers. On the other hand, when drivers were additionally monitored with EEG, the route-familiarity effect was reversed. These results are consistent with the hypothesis that the route-familiarity effect is due to increases in the incidence of mind-wandering.

<sup>3</sup> This chapter has been submitted for publication as Yanko, M.R., & Spalek, T.M. Reining in the wandering mind reverses the route-familiarity effect.

## 4.2. Introduction

For new drivers, the first time behind the wheel of a car can be a distressing and overwhelming experience. This is because a flood of stimuli are competing for attention, all at the same time. The driver must remember to check the mirrors, monitor the speed, maintain lane position, etc. With time, however, the aspects of driving that once seemed attentionally demanding start to feel almost effortless. In other words, with practice, there is a shift from conscious control of one's actions to a state in which actions are performed more automatically. This shift from *controlled* to more *automatic* processing (see Posner & Snyder, 1975) is commonly thought to be associated with a reduced demand on attentional resources.

A similar process occurs as one becomes familiar with a route from one location to another. The first time along the route, the driver must pay attention to road signs, street names, intersections and subtle curves in the road. However, as the route becomes more familiar, the driver no longer needs to pay attention to these aspects of the route because they are available to us through memory. This transition from controlled to automatic processing of the route, should free up attentional resources which could then be allocated to some other task.

Based on the notion that efficient route processing should free up attentional resources, it makes intuitive sense that as one becomes familiar with a route, driving performance should improve, especially when a driver needs to react to an emergency (e.g., a lead car braking abruptly or a child running out on the road). The idea is that, since the route is being processed more efficiently, the attentional resources that would normally be used to process the route, can now be allocated to hazard detection, and avoidance. Yanko and Spalek (2013) have recently shown that, contrary to this expectation, route-familiarity is actually associated with *impaired* hazard response. In that study, participants followed a lead car along a route that was either familiar or unfamiliar. Critically, drivers needed to respond to a series of randomly-positioned emergencies (the lead vehicle braking and pedestrians running onto the road). Compared to drivers that were unfamiliar with the route, drivers that were familiar with

the route followed the lead vehicle at a shorter distance and, when the following distance was controlled, took longer to respond to both central emergencies (lead vehicle braking) and peripheral emergencies (a pedestrian running onto the road).

Yanko and Spalek (2013) proposed that this *Route-Familiarity effect* arises from increased mind-wandering along familiar routes. Mind wandering is a cognitive state in which thoughts that occupy the mind are unrelated to any task being performed in the external environment. These thoughts occur more often with simple tasks, can occur spontaneously, and often occur without awareness (Smallwood, Beach, Schooler & Handy, 2008; Smallwood, Schooler, Christoff, Handy, Reichle & Sayette, 2011). In addition, when mind wandering, information processing is decoupled from the external environment, causing the processing of incoming sensory information to be weakened (Buckner, Andrews-Hanna, & Schacter, 2008; Smallwood & Schooler, 2006). Therefore, Yanko and Spalek hypothesized that, because route-familiarity leads to more fluent processing of the route – thereby making the task simpler – the incidence of mind wandering should be increased. One potential account of this effect is that task-switching is slower when the two tasks are more dissimilar (Arrington, Altmann & Carr, 2003). In the present context, when mind wandering, a task-switch must take place between processing internal thoughts to processing the external environment. This switch is likely to be more time-consuming than the switch from one external environmental task (route-monitoring) to another (hazard avoidance). In turn, this would lead to slower reaction times (RT) in responding to hazardous stimuli when familiar with the route compared to when unfamiliar.

Under the assumption noted above that route familiarity leads to more resources being available for some other task, route familiarity will provide a possible source of driving *enhancement*. This is because the resources that are liberated by route familiarity can potentially be allocated to other driving related tasks, most notably hazard detection and avoidance. However, under normal circumstances route-familiarity will also promote mind wandering which will recruit the resources made available from being familiar with the route. Thus, any driving enhancements afforded by route familiarity will be counteracted by mind wandering.

If it is the case that the Route-Familiarity effect is mediated by mind wandering, what would happen under conditions in which mind wandering is discouraged by getting drivers to focus more on the driving task? Presuming that route familiarity leads to more resources being available for some other task, reducing mind wandering should free up resources that can be deployed to other aspects of driving, notably, to monitoring the external environment. As noted above, under such conditions, it should be expected that route familiarity will lead to an *improvement* in driving performance. The present work was designed to test this hypothesis.

### **4.3. The Present Experiment**

The main objective of the present work was to devise a situation in which the incidence of mind wandering would be reduced. This was done by making drivers more aware that their performance was being monitored. The idea being that the knowledge of being monitored/evaluated would cause the driver to focus more on the task at hand.

The idea that monitoring someone's behaviour may lead to improved performance is not novel. The *Hawthorne effect* (see Wickström & Bendix, 2000 for an overview) was first reported in the late 1920's, when the Hawthorne plant of the Western Electrical Company in Chicago decided to conduct a series of studies aimed at identifying environmental conditions that might increase productivity. For example, one manipulation involved systematically adjusting the lighting conditions in the workplace in order to find the level that led to greatest worker efficiency. The most interesting finding was that every manipulation resulted in higher worker productivity. This led to the conclusion that the improved efficiency stemmed not from the experimental manipulations but from the workers' knowledge that their performance was being monitored (the Hawthorne effect).

Research examining how monitoring behaviour in a driving context affects performance has yielded mixed results. A number of studies involving professional drivers have reported large reductions in speeding, increases in seatbelt use, and crash reductions when monitoring technologies were used (Levick & Swanson, 2005; Olson & Austin, 2001; Toledo & Lotan, 2006; Wouters & Bos, 2000). In addition, McGehee, Raby,

Carney, Lee, and Reyes (2007) showed that performance of teen drivers improved when an event-triggered video clip was recorded whenever a shock (e.g., collision), longitudinal (e.g., sudden braking) or lateral threshold (e.g., hard swerve) was exceeded. However, not only was performance monitored but there were also bi-weekly review sessions of the recordings to discuss the situation, so it is unclear if the effects were due to monitoring or extra instruction. In addition, no control group was used so maturational effects cannot be excluded. In contrast, Farmer, Kirley and McCartt (2010) found that monitoring a driver's performance led to improved seat belt use but had no significant effect with respect to speeding or sudden braking/acceleration.

In the present work, relatively novice drivers drove in the completely novel context of a high-fidelity driving simulator. Their task was to follow a car along a route that through the experimental session was made either familiar or unfamiliar. A series of randomly-timed emergencies (i.e., the lead vehicle braking) were programmed to take place, requiring a braking response from the driver. Critically, we manipulated whether or not the participants were overtly monitored while driving. This was done by recording electroencephalography (EEG) activity with an electrode cap fitted to the drivers' scalp, thus increasing the explicitness of monitoring. This procedure has the added benefit of allowing the measurement of EEG time-locked to the emergency braking events (i.e., event related potentials, ERPs). Specifically, we were interested in the P300 component of the ERP, which is a positive voltage with a latency of around 300-400 milliseconds (ms) post-event. Although, as noted by Pontifex, Hillman, and Polich (2009), the latency of the P300 can be delayed up to 800, depending on task demands. The P300 can be thought of as a measure of resource allocation, with greater amplitude representing a greater amount of resources being assigned to the task at hand (see Polich, 2007 for an overview of the P300).

This is not the first time that the P300 has been used to examine attentional allocation while driving. Using a car-following procedure similar to that used in the present study, Strayer and Drews (2007) showed that the P300 was reduced while drivers were simultaneously conversing on a cell-phone relative to when they were just driving. This was taken as an indication that, while conversing on a cell phone, drivers pay less attention to the driving task.

There were four conditions in the present work: (a) familiar route, EEG monitored; (b) unfamiliar route, EEG monitored; (c) familiar route, EEG not monitored; (d) unfamiliar route, EEG not monitored. Obviously, only Conditions (a) and (b) are relevant to the P300 analysis. Based on the reasoning outlined in the foregoing, we expected the magnitude of the P300 to be greater and RT to be faster in Condition (a) than in Condition (b). This is because, being familiar with the route, and free from mind-wandering, drivers in Condition (a) can deploy more attentional resources to the driving task than drivers in Condition (b). In contrast, we expected RT to be slower for those in Condition (c) than in Condition (d), replicating the results of Yanko and Spalek (2013).

## **4.4. Method**

### **4.4.1. Participants**

18 female and 22 male undergraduate students (mean age = 21.8 years,  $SD = 4.8$ ) from Simon Fraser University participated either for class credit or for payment. All had self-reported normal or corrected to normal vision. All had a valid British Columbia driver's license (class 5). Before starting the experiment, participants filled out a modified 'Simulator Sickness Questionnaire' with questions such as "are you taking any medications" or "are suffering from any ailments that might make you prone to motion sickness." In order to minimize the incidence of simulator sickness we excluded any participants who answered yes to any such questions (see Kennedy, Lane, Berbaum, & Lilienthal, 1993, for an overview).

### **4.4.2. Materials**

A DriveSafety high-fidelity driving simulator (model DS-600c) was used. Participants were seated in a modified Ford Focus cab equipped with a windshield, driver and passenger seats, dash board, instrument panels, and a central console, as well as all the devices needed to operate a car (accelerator and brake pedal, turn signal switch, a steering wheel etc.). The simulated environment was generated using HyperDrive Authoring Suite and was displayed using DriveSafety's Vection Simulation

software (Version 1.9.35: <http://www.drivesafety.com>). The simulator is also equipped with an automatic gearbox.

#### **4.4.3. Electrophysiological Recording**

For half of the participants, EEG was recorded from 23 surface electrodes aligned with the 10-10 montage system using a standard stretch-Lycra cap (Electro-Cap International; Eaton, OH). Data were recorded through the ASA system with a direct coupled (DC) amplifier (ANT; Advanced Neuro Technology, Enschede, Netherlands). Electrode impedances were kept below 5 K $\Omega$ . EEG signals were sampled at 1024 Hz. The EEG was recorded by use of the EEProbe Software (ANT B.V., Enschede, Netherlands). All electrodes were referenced during recording to the right mastoid and later digitally re-referenced to the algebraic average of the signals recorded at the left and right mastoids.

#### **4.4.4. Driving Routes**

Five freeway driving routes were used in this experiment (Routes 1-5). The routes were identical to that used by Yanko and Spalek (2013), and were designed as follows. Each route was approximately 12 km in length and included a series of overpasses (where the roadway passes over another), underpasses (where the roadway passes under another) and cloverleaf intersections (on and off ramps: where the roadway gradually corners to merge with a new roadway). Each route was designed to have the same number of cloverleaf intersections at which participants either exited to the left, to the right or kept going straight. The number of left and right exits was also equal across the different routes. The five routes were programmed to look very similar to one another, consisting mainly of long stretches of rural freeway. However, the exact location for each cloverleaf intersection was different for each route. Consequently, the specific sequence of exits that participants were required to take to get to the end was different for each route. These routes were driven in daytime conditions with good visibility. There were three lanes of traffic going in each direction.

For all routes, a pace car and the participant's vehicle were the only two cars on the road. The participants were instructed to follow the pace car, which was programmed

to maintain a constant separation of 30 meters from the participant's vehicle at all times. If the participant sped up or slowed down, the pace car adjusted speed accordingly. The only time that this was not the case was during the braking events (see below). Participants were instructed to try and maintain a speed of 72km/h, or 20 meters per second (m/s), at all times except during braking events.

#### **4.4.5. Procedure**

Prior to beginning the experiment, participants were randomly assigned to the *Familiar group* or the *Unfamiliar group* and were then assigned to be in the *Monitored* condition or the *Not-Monitored* condition. If assigned to the Monitored condition, an electrode-cap (described above) was placed on the participant's head prior to running through the experiment, thus increasing the explicitness of monitoring. If assigned to the Not-Monitored condition, participants simply began the experiment. Regardless of whether participants were in the Monitored or Not-Monitored condition, the experimental sequence of events was the same, and was as follows.

The experiment comprised three sessions: Acclimatization, Training, and Testing. In the Acclimatization session, participants who passed the Simulator Sickness Questionnaire took part in a 3-minute session to get used to the equipment and to adapt themselves to the physical sensations involved in driving the simulator. The acclimatization session consisted of one short driving scenario where participants followed a pace car down a stretch of a simulated freeway. The freeway consisted of a long straight stretch and two cloverleaf intersections. At each intersection, the participants practiced exiting from and merging onto the freeway. The Training session followed directly after the Acclimatization session.

In the Training session, participants assigned to the Familiar group drove down 'Route 1' a total of four times to become familiar with the route. Participants assigned to the Unfamiliar group drove down routes 2-5 in sequential order. All participants (from both familiar and unfamiliar groups) were instructed to follow the pace car during each driving session. The pace car led the participants from the beginning to the end of each route. Once the route was finished, the route was restarted (for the Familiar group) or

the next successive route was started (for the Unfamiliar group). The Testing session followed directly after the Training session.

During the Testing session, all participants drove through 'Route 1'. This means that the route was known to the Familiar group, but was unknown to the Unfamiliar group. During this phase, the pace car was programmed to brake at randomly selected times (which we refer to as the Braking event). On average, the time interval between each braking event was 30 seconds, and was never less than 10 seconds. The Braking events could occur at any location throughout the route, with the exception that they never occur while the driver was exiting, or entering the freeway. During a braking event, the pace car immediately reduced speed to 33 km/h, and the brake lights were illuminated for a period that lasted until the participant depressed the brake. The pace car then accelerated so as to regain a separation of 30 m from the participant's vehicle. To avoid a collision during these events, the driver was required to respond by stepping on the brake pedal. Reaction times (RTs) to activate the brakes were recorded, as well as the degree of brake depression, sampled at a rate of 60Hz.

In addition to the lead vehicle braking events, 15 grazing deer were programmed to stand in randomly selected locations in the rural grass fields bordering to the freeway. All deer were within 30 meters from the roadway and were easy to be seen. The participant was instructed to make a push button response every time they saw a deer (which we refer to as the Peripheral task). Participants were told to only make one button response per deer. The button was located on the backside of the steering wheel on the right hand side. The depression state of the button was sampled at a rate of 60Hz. The sum of the number of times a button press was executed was calculated for each participant so as to determine each participant's Peripheral task accuracy.

#### **4.4.6. Dependent measures**

There were three behavioural dependent measures associated with this experiment. *Braking RT* was defined as the interval of time between the braking of the pace car (i.e., the instant velocity change and illumination of the brake lights) and the instant that the participant depressed the brake pedal. *Peripheral task performance* was

defined as the number of button press responses to the deer in the periphery. *Velocity* was defined as the average velocity that the participant was travelling in m/s.

## **4.5. Results And Discussion**

The results for all of the behavioural driving performance measures are shown in Table 1.

### **4.5.1. Braking RT**

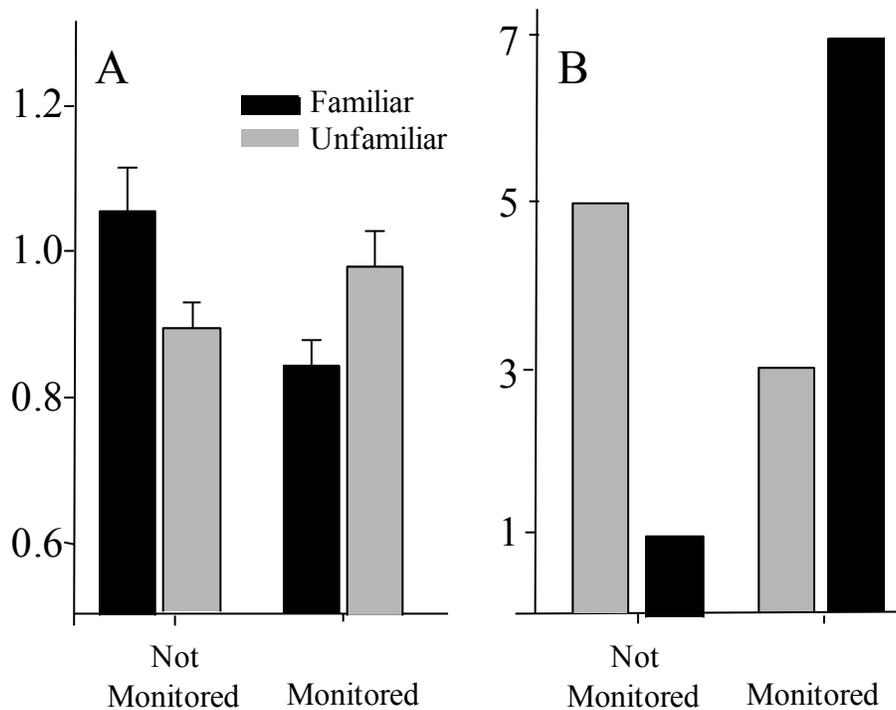
The mean braking RT as a function of experimental condition, averaged across all participants, is illustrated in Figure 1A. The mean braking RT represents the median RT, computed separately for each participant, averaged across participants. An analysis of variance (ANOVA) was performed on the Braking RTs and comprised two between-subject factors: Route-familiarity (Familiar vs. Unfamiliar) and Monitoring (Monitored vs. Not-Monitored). The analysis revealed no significant main effect of either Route-familiarity,  $F(1, 36) = .08, p = .78$ , or Monitoring,  $F(1, 36) = 1.77, p = .19$ . The interaction between Route-familiarity and Monitoring, however, was significant  $F(1, 36) = 10.30, p < .01$ .

The pattern of results illustrated in Figure 1A suggests that the Route-familiarity effect is markedly different between the two monitoring conditions. When participants were not monitored with an electrode cap, the typical route-familiarity effect was observed, replicating the findings of Yanko and Spalek (2013). That is, the Familiar group responded less promptly to the braking events than the Unfamiliar group.

Behavioral dependent measures

	Braking Response RT (seconds)	Peripheral Response ACC (out of 15)	# of participants to score perfectly on peripheral task	Velocity (m/s)
<b>Not Monitored</b>				
Familiar	1.05 (0.19)	13.7 (1.34)	1	18.4(0.94)
Unfamiliar	0.89 (0.11)	14.3(0.82)	5	19.2 (0.78)
<b>Monitored</b>				
Familiar	.841 (0.12)	14.5 (0.85)	7	19.9 (2.60)
Unfamiliar	.978(0.16)	14.1 (0.88)	3	19.2 (2.40)

**Table 1:** Means and standard deviations for each behavioural dependent measure



**Figure 1.** Mean reaction times (RTs) to the pace car braking events (A), as well as the number of participants to score perfectly on peripheral task (B) for the Not-Monitored and Monitored conditions. Error bars indicate standard error of the mean for each condition.

The pattern of results illustrated in Figure 1A suggests that the Route-familiarity effect is markedly different between the two monitoring conditions. When participants were not monitored with an electrode cap, the typical route-familiarity effect was observed, replicating the findings of Yanko and Spalek (2013). That is, the Familiar group responded less promptly to the braking events than the Unfamiliar group. Conversely, when participants were monitored with an electrode cap, the opposite effect was observed, with familiar drivers showing faster response times to the braking events compared to the unfamiliar drivers. One-tailed, independent-samples t-tests revealed these effects to be significant ( $t(18) = -2.34, p = .02$  and  $t(18) = 2.19, p = .02$ , respectively).

The present findings are in line with the hypothesis outlined in the Introduction. Namely, being familiar with a route frees up attentional resources that can be allocated to some other task. When the driver is not monitored, the incidence of mind-wandering should be relatively high for those familiar with the route resulting in impaired hazard detection. In contrast, when the driver is monitored, mind-wandering is reduced and resources become available for monitoring the environment for hazards.

#### **4.5.2. Peripheral Task Performance**

As noted above, the total number of observations (button presses) were added together to obtain a Peripheral task performance score for each participant. A score of fifteen was considered perfect performance. Initial inspection of the results revealed that accuracy was quite high under all four conditions, ranging from 91-97%. As a result, instead of using raw accuracy scores, participants were binned into one of two categories: They were determined to be either 100% accurate or not. Thus, each participant was coded as being either a 1 or 0, and a Pearson chi-square test was conducted. The number of participants that scored 100% on the peripheral task, as a function on route-familiarity and monitoring conditions, is illustrated in Figure 1B.

The analysis revealed that within the Not-Monitored condition, the number of participants in the Familiar group (1 out of 10) that scored 100% was significantly lower than that of the Unfamiliar group (5 out of 10),  $\chi^2(1) = 6.4$ ,  $p < .01$ . Within the Monitored condition, the somewhat opposite pattern was observed. That is, the number of participants in the Familiar group (7 out of 10) that scored 100% was higher than that of the Unfamiliar group (3 out of 10). This effect, however, was marginally significant,  $\chi^2(1) = 3.20$ ,  $p = .07$ .

The pattern of results observed for Peripheral task accuracy mirror that observed for Braking RT. Specifically, performance for the Familiar group is superior compared to the Unfamiliar group, but only when the drivers are explicitly monitored. When not being monitored, this pattern reverses, with the Familiar group being impaired compared to the Unfamiliar group (although in the peripheral task this effect was only marginally significant). The present results suggest that increased route-familiarity is associated with a decreased propensity to monitor the environment for hazards, and may therefore lead to higher crash risk. Similar results have been shown in studies that have investigated mindwandering independent of route-familiarity (He, Becic, Lee, and McCarley, 2011; Yanko & Spalek, In press), suggesting that the route-familiarity effect is mediated, at least in part, by mind-wandering. The present work supplements previous findings by suggesting that this effect can not only be eliminated, but reversed under conditions that encourage focused attention on the driving task (explicit monitoring the driver, in this case).

### **4.5.3. Velocity Measures**

An important concern when analyzing velocity in the present context is that velocity is necessarily lower during a braking event. Although this should be similar across all conditions, in order to obtain unbiased measures of velocity, the velocity measures were averaged over the entire test session with the restriction that a braking event had not occurred within the last ten seconds. In other words, time epochs of ten seconds after each braking event were removed from the Velocity analysis. An ANOVA was performed on the Velocity measure and comprised two between-subject factors: Route-familiarity (Familiar vs. Unfamiliar) and Monitoring

(Monitored vs. NotMonitored). The analysis revealed no significant main effects of either Route-familiarity,  $F(1, 36) = .002, p = .96$  or Monitoring,  $F(1, 36) = 1.60, p = .22$ . Finally, the interaction between Route-familiarity and Monitoring, was not significant,  $F(1, 36) = 1.59, p = .22$ .

The finding that Velocity is unaffected by route-familiarity is consistent with Yanko and Spalek (2013) who showed no relationship between route familiarity and driving velocity.

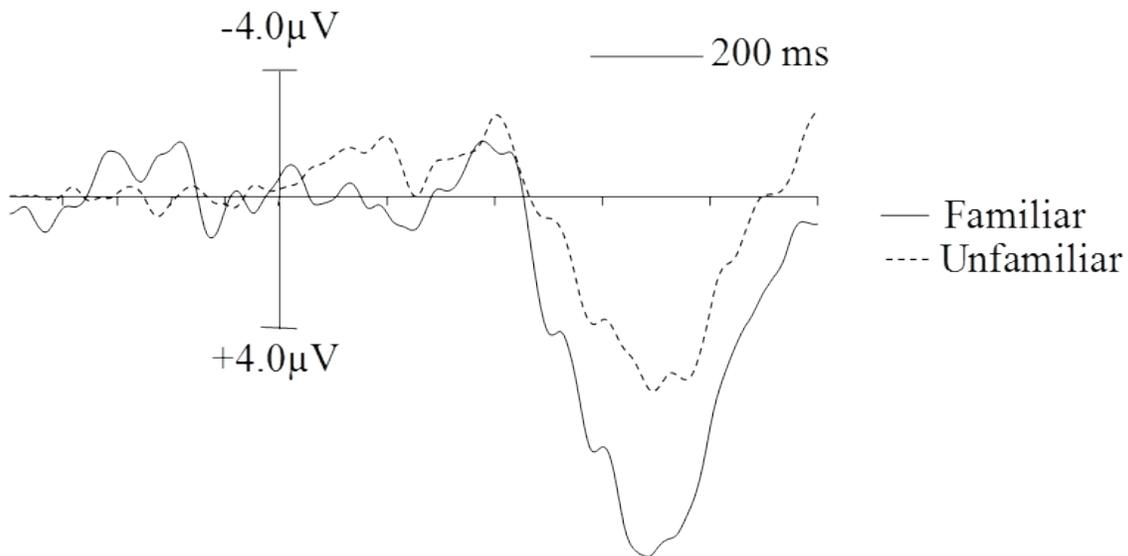
#### **4.5.4. The P300**

The ERP, time-locked to the braking event, was calculated by averaging the EEG over a 1000ms window post-event, relative to a 500ms pre-stimulus baseline. Artifacts with an amplitude of 120  $\mu\text{V}$  were rejected during automatic artifact detection. Ocular artifacts were corrected using an adaptive artifact correction algorithm (Ille et al., 2002). HEOG and VEOG threshold voltages were 150  $\mu\text{V}$  and 250  $\mu\text{V}$  respectively. As a result of this artifact correction technique, along with the requirement to obtain impedances below 5 K $\Omega$ , three subjects were removed from the analysis. The data were then grandaveraged and filtered with a low-pass (30Hz, 24dB/octave) zero-phase Butterworth filter.

The average ERPs recorded from a central parietal electrode site (Pz electrode) are illustrated in Figure 2 for both the Familiar and Unfamiliar groups in the Monitored condition. A clear positive deflection starting around 400ms, and lasting well beyond 800ms, is in evidence for both experimental conditions (the P300). There is an obvious difference in amplitude, however, with the Familiar group showing a larger deflection than the Unfamiliar group. To determine if the amplitude difference is reliable, the P300 amplitude was calculated separately for each participant by computing the peak mean amplitude between 400ms and 800ms post stimulus onset. A one-tailed, independent sample t-test revealed that the P300 was indeed larger for the Familiar group,  $t(15) = 1.71, p = .05$ .

As noted above, the P300 component of the ERP is thought to be associated with the amount of attentional effort that one distributes to a task. In other words, P300

amplitude can be thought of as a measure of resource allocation, with greater amplitude representing greater amount of resources being assigned to the task at hand (see Polich, 2007 for an overview of the P300). Consequently, the observation that Familiar drivers produce a larger P300 is completely in line with the hypothesis that route-familiarity frees up attentional resources that can be distributed to some other task (e.g., hazard detection). We hypothesize that under normal conditions (the Not-Monitored condition in the present work) these resources are diverted away from the driving



**Figure 2.** Event-related potentials elicited by the Braking events for the Familiar and Unfamiliar groups in the Monitored condition (electrode Pz)

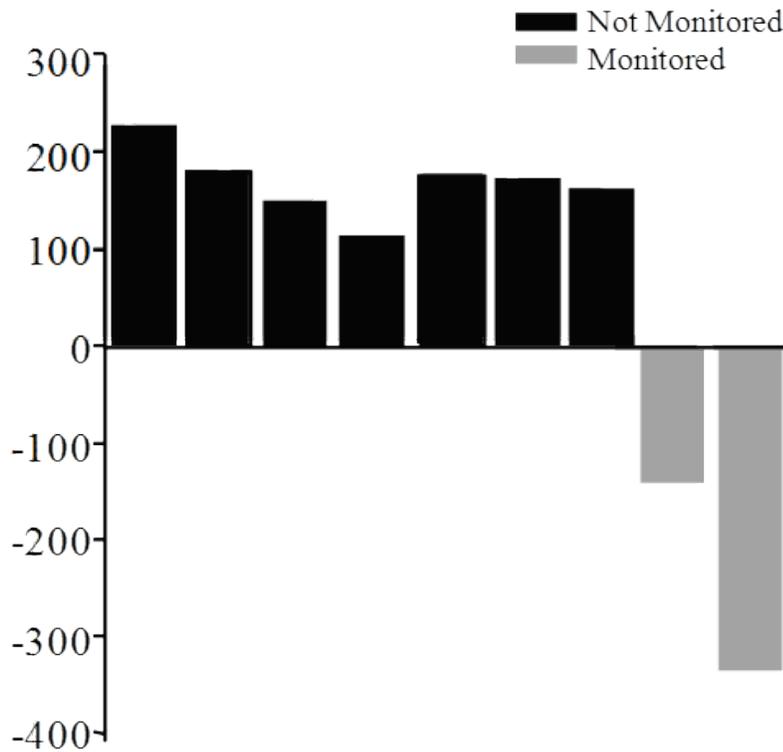
environment to task-unrelated thoughts. Consequently, as noted in the Introduction, in order for the driver to respond to a stimulus in the environment, a task switch must take place from processing internal thoughts to processing incoming sensory information. This would result in a switch cost, slowing down response time. Thus, when mind-wandering, the system is ill prepared to respond in the event of an emergency. However, under conditions where the driver has a desire to perform well – as is likely the case when the drivers’ performance is explicitly monitored – these resources are no longer deployed to mind wandering and thus become available to improve hazard detection/avoidance. Thus, depending on the situation, it seems that route-familiarity can be a source of driving impairment or improvement.

#### 4.5.5. Converging Evidence

To provide converging evidence in support of this hypothesis, we analyzed several route-familiarity experiments conducted in our laboratory over the past several years. All of the experiments analyzed were designed to investigate the effects of route familiarity on reaction time under a myriad of different conditions (e.g., normal driving conditions, when there is low visibility due to fog, while talking on a cell-phone, etc.). Of importance to the present work is that two of these

experiments were conducted while the driver was being explicitly monitored. One of those two experiments is the EEG condition presented in the present work. The other was from a condition where the driver was required to wear an eye tracking monitor. The data were from both published (Yanko & Spalek, 2013) and unpublished studies. For each experiment or condition, a Route-Familiarity effect was quantified by taking the difference in RT scores between the

Familiar and Unfamiliar group (Familiar RT *minus* Unfamiliar RT). Thus, positive scores represent the typical route-familiarity effect, and negative scores would represent the reversal of the effect. Illustrated in Figure 3 is the breakdown of each route-familiarity score as a function of experimental study (or condition). Inspection of the figure reveals a clear difference in the pattern of results when the driver is monitored compared to when the driver is not monitored. That is, when monitored, there is a clear flip in the routefamiliarity effect providing strong evidence that the attentional resources that are freed up from extensively practicing a route, can be exploited to assist in hazard detection.



**Figure 3.** A breakdown of all of several experiments done in our lab, each designed to investigate the effect of route-familiarity on driving performance. Each bar represents a Route-Familiarity score which is obtained by calculating the difference in RT between the Familiar and Unfamiliar group (Familiar RT *minus* Unfamiliar RT). Positive scores represent the typical route-familiarity effect in which drivers familiar with the route take longer to respond to emergencies than drivers unfamiliar with the route.

#### 4.6. General Discussion

As one becomes familiar with a task, it is generally understood that there is a corresponding reduction in the amount of attentional resources required to perform optimally. Theoretically, these liberated attentional resources can be allocated to some other task. In regards to driving along a familiar route, the possible advantage

is that the attentional resources that would usually be used to process the route can be allocated to hazard detection.

It has been shown, however, that when familiar with the route, a drivers' response time to an emergency event is impaired, rather than enhanced (Yanko & Spalek, 2013). This Route-Familiarity effect was ascribed to increased mind wandering along familiar routes. Following this assumption, the principal objective of the present work was to devise a situation in which the frequency of mind wandering would be reduced, thus freeing up resources which can potentially be used for hazard detection. To this end, we used a paradigm in which drivers were made more aware that their performance was being monitored by placing an electrode cap on the scalp to record EEG activity while driving. The idea being that the knowledge of being monitored/evaluated would cause the driver to focus more on the task at hand (the Hawthorne effect).

In the testing session, participants followed a lead car along a route that was either made familiar (Familiar group) in the training session, or not (Unfamiliar group). There were a total of four conditions: (a) familiar route, EEG monitored; (b) unfamiliar route, EEG monitored; (c) familiar route, EEG not monitored; (d) unfamiliar route, EEG not monitored. To assess the effect of Route-Familiarity and EEG Monitoring on hazard detection and response, the lead car was programmed to brake at randomly selected times throughout the testing session and requiring a braking response from the participant in order to avoid a collision. In addition, drivers were to respond every time they saw a target (deer) in the periphery. Based on the reasoning outlined in the Introduction, we expected that familiar drivers in condition (a) would perform better at detecting hazards than the unfamiliar drivers in condition (b), as indexed by lead vehicle braking RT and peripheral task performance. On the other hand, we expected conditions (c) and (d) to show the opposite pattern, replicating Yanko and Spalek (2013): familiar drivers in condition (c) should perform worse at detecting hazards than the unfamiliar drivers in condition (d). In addition, we expected to find similar patterns in the EEG data. Namely, because EEG data was only available for the Monitored-conditions we expected to find that drivers in the Familiar group would elicit a larger P300 than the Unfamiliar

group, consistent with the idea that when familiar with the route, attentional resources are freed up that can be deployed to other aspects of driving.

The pattern of results matched the predicted pattern quite nicely, and supported the hypothesis that being familiar with a route frees up attentional resources that can be allocated to another task. When a driver is not monitored, those resources are likely deployed to mind-wandering. Although a task-switch would be necessary to respond to an emergency event for both the Familiar (from mind-wandering to hazard detection) and the Unfamiliar group, the former switch is assumed to take more time because the two tasks are more dissimilar. In contrast, when the driver is monitored, the frequency of mind wandering is reduced, and those resources are available for monitoring the environment for hazards.

It should be noted that a similar experiment was conducted by Yanko and Spalek (2013; Experiment 3) where drivers were instructed to maintain a speed of 72 km/h. An auditory signal was presented whenever they were driving at a speed outside of a set window (65-75 km/h), to prompt them to adjust their speed accordingly. Getting participants to focus on their speed, and making them somewhat aware that they were being monitored by way of the tone, should have kept them more focused on the driving task, and thereby reduced the incidence of mind wandering. Consistent with the present rationale, no impairment was found for the Familiar group relative to the Unfamiliar group. However, the results did not completely flip around to show an actual benefit for the Familiar group. This can easily be accounted for on the assumption that the EEG manipulation in the present work was likely a more tangible monitoring situation (as was eye-tracking in the study mentioned in 1.4.5 Converging evidence) and, thereby, reduced mind wandering more than the velocity monitoring manipulation used by Yanko and Spalek.

The present work provides the first demonstration that route familiarity can enhance driving performance given the right circumstances. That is, the attentional resources that are no longer needed to process the route can facilitate faster RTs to emergencies. Here we show that this is the case when drivers are explicitly

monitored. However, this outcome is likely to be in evidence whenever drivers are motivated to pay attention to the driving environment.

#### **4.6.1. Implications For Future Research**

The present results reinforce the need for caution in simply applying results from the lab to the everyday world. Of particular relevance in this regard is the point that in the everyday world, most of the time drivers drive down highly familiar routes as they travel home or to work/school. However, the work conducted in the lab typically has people driving down routes that are completely foreign to the individual. The results of the present study, however, show that, the effect of explicitly monitoring participants had very different outcomes for participants who were familiar with the route that they were driving. That is, for the Unfamiliar groups (conditions b and d, described above), monitoring the driver with EEG had no effect on braking RT or peripheral accuracy. Post-hoc t-tests revealed that these conditions did not differ statistically on either of those measures ( $p$ 's = 0.17 and 0.36, respectively). Conversely, EEG monitoring had clear effects on the Familiar groups (conditions a and c, described above), with monitored drivers showing faster reaction times and higher peripheral task accuracy scores (both  $p$ 's < 0.01). Given these results, it seems prudent to take route-familiarity into consideration when planning out and interpreting experiments that are designed to investigate driver distractibility or hazard response.

## **Chapter 5.**

### **General Discussion**

#### **5.1. Summary**

The preceding three chapters addressed an unanswered question concerning the effect of route familiarity on driving performance. Does route familiarity impair or enhance driving performance, particularly for time-dependent measures (reaction time to sudden events)?

In the Introduction section of this thesis, I presented two opposite theoretical predictions regarding effect of route familiarity on driving performance. Both predictions stem from the idea that as the route becomes familiar, the amount of attention deployed to cope with task demands will decrease. Subsequently, more attentional resources can be deployed to other mental tasks. One possibility is that these resources will be deployed to hazard detection, thus making a driver faster to detect and respond to hazards. In contrast, another possibility is that the decrease in task demands associated with processing the route will promote a greater incidence of mind wandering. Since mind wandering recruits attentional resources (Giambra, 1995; Grodsky & Giambra, 1990; Smallwood, Davies, et al., 2004), performance on tasks that require those resources (e.g., responding to an emergency) will be impaired. This is because when an emergency event occurs, a task switch must take place where the system must be reconfigured to process and respond to the event. The switch from mind wandering to hazard processing is likely more timeconsuming than the switch from one external environmental task (route-monitoring) to another (hazard avoidance) because both tasks are related— they both require processing of external stimuli and relate to the global task of driving.

Chapter 1 presented three experiments designed to test these two competing theories by manipulating route familiarity. All three experiments used a car-following paradigm, and the general procedures were as follows. Participants followed a car down four routes during a training phase. The routes were either all identical (Route 1: Familiar group), or different from one another (Routes 2, 3, 4 and 5: Unfamiliar group). During the testing phase, all participants drove down the same route, which was identical to that trained by the Familiar group (Route 1). Thus, the route used in the testing phase was well known to the Familiar group, but unknown to the Unfamiliar group. Responses to a series of unexpected events were assessed during the testing phase, along with other measures of driving performance. I found that drivers familiar with the route followed the lead vehicle more closely, and with following distance controlled for, took longer to respond to both central and peripheral emergencies. Collectively, the results of the experiments presented in Chapter 1 support the hypothesis that route familiarity is coupled with a wandering of attention away from the driving environment, making the driver less prepared to respond in the event of an emergency. These findings are also consistent with previous research that showed that route familiarity can promote a form of *inattentional blindness* where drivers are less likely to notice changes in the environment (Charlton & Starkey, 2011; Martens & Fox, 2007).

The second series of experiments (Chapter 2) was designed to further explore the link between route familiarity and mind wandering. In two experiments, the effects of mind wandering on driving performance were studied independent of route familiarity. The idea being that if the poorer driving performance associated with route familiarity is mediated by mind-wandering, similar effects should be in evidence when mindwandering is studied independently. While following a car down a rural road, mind wandering was assessed using a probe-caught mind wandering procedure (Smallwood & Schooler, 2006) in which drivers were randomly prompted with a probe-tone to indicate whether or not they were mind wandering over the preceding few seconds. Much like the experiments presented in Chapter 1, the lead vehicle was programmed to brake suddenly at random times during both experiments, and in Experiment 2 peripheral emergencies were randomly scattered throughout the experiment as well. RT to these emergency events was recorded,

along with following distance and velocity. The dependent measures were analyzed based on each driver's responses to the probe-tone. The results were highly consistent with the results presented in Chapter 1. That is, when mind wandering, drivers followed the lead vehicle more closely, and took longer to respond to both central and peripheral emergencies. In addition, participants tended to drive at a higher velocity when mind wandering compared to when on-task. Taken together with the results presented in Chapter 1, these findings support the hypothesis that the route-familiarity effect is mediated, at least in part, by mind wandering.

Since Chapters 1 and 2 established a link between route familiarity and mind wandering, the primary objective of the experiment in Chapter 3 was to create a situation in which the frequency of mind wandering would be reduced, thereby freeing up resources that can be used for hazard detection. This was done by explicitly monitoring the driver with EEG, thus making the driver more aware that their performance was being monitored. The thought was that if the driver was made more aware that they were being monitored, the driver would focus more on the driving task. The task was similar to

Experiment 2 in Chapter 1. Participants followed a car along a route that was either Familiar or Unfamiliar (based on the training phase of the experiment). There were a total of four conditions: (a) familiar route, EEG monitored; (b) unfamiliar route, EEG monitored; (c) familiar route, EEG not monitored; (d) unfamiliar route, EEG not monitored. A series of randomly-timed braking events were programmed to take place, with reaction time as a dependent measure. In addition, drivers responded to randomly placed targets in the periphery (grazing deer). When drivers were not monitored with EEG, the typical route familiarity effect was observed with drivers familiar with the route taking longer to respond to the lead vehicle braking, and noticing fewer targets in the periphery compared to drivers unfamiliar with the route. In contrast, when drivers were monitored with EEG, the Route-Familiarity effect reversed: Drivers familiar with the route were *faster* at responding to the braking events and noticed *more* targets in the periphery compared to drivers unfamiliar with the route. Additionally, the P300 was found to be larger for drivers familiar with the route compared to those unfamiliar with the route, consistent with

the notion that the Familiar group was able to allocate more attentional resources when responding to the braking car.

Taken together, the results of presented in this thesis support the hypothesis that becoming familiar with a route will free up attentional resources that can be allocated to some other mental task. Under ordinary circumstances, these available resources will be deployed to mind wandering, thus impairing any task that requires those resources, such as responding to a sudden emergency. When the driver is focused on the driving task, however, the frequency of mind wandering will decrease. Therefore, attentional resources will no longer be depleted. In that case, resources become available to aid in hazard detection.

## **5.2. Resource Depletion Or A Reduction In The Ability To Process Incoming Sensory Information?**

As noted in the foregoing, this thesis provides strong evidence that the Route-Familiarity effect is caused by mind wandering along familiar routes. The mechanism with which mind wandering impairs driving performance is thought to be a depletion of available attentional resources available to cope with changes in task demands. It is likely, however, that there is an additional way with which mind wandering interferes with a driver's ability to detect and respond to hazards.

In addition to the impairments associated with resource depletion, mind wandering may impair performance because it brings about a dampening in the system's ability to process incoming stimuli. As noted in Chapters 1 and 2, research investigating the neurophysiological aspects of mind wandering suggests that there are two separate neural networks: the *task-positive* network and the *default* network. The task-positive network is activated when the system is set for goal-oriented activities and is thus prepared to process incoming sensory information. In contrast, the default network is active during introspection and task-unrelated thoughts (Buckner, Andrews-Hanna, & Schacter, 2008; Fox Snyder, Vincent, Corbetta, Van Essen & Raichle, 2005). The important consideration is that these two networks work in opposition to one another. As activity in the default network increases, there

is a corresponding *deactivation* of the task-positive network. From this it follows that as the frequency of mind wandering increases, there will be a concomitant reduction in the system's ability to process incoming sensory information.

Indeed, several studies have demonstrated that increased activity in the default network is associated with attenuated physiological responses to external stimuli, and poorer task performance (Greicius & Menon, 2004; Li, Yan, Bergquist, & Sinha, 2007; Weissman, Roberts, Visscher, & Woldorff, 2006). Although only correlational, these studies provide compelling evidence that default network activation, coupled with taskpositive network deactivation, causes a decreased ability for one to process external stimuli.

Mind wandering is thus associated with two possible sources of driving impairment: resource depletion and a reduction in the ability to process incoming sensory information. It is well known that when attentional resources are being used by one task, the necessity to give processing resources to another task will likely reduce performance (Schneider & Shiffrin, 1977). From this it follows that the resource-depletion hypothesis noted above seems a reasonable one. However, since mind wandering is also associated with a deactivation of the task-positive network, the effects observed throughout this thesis may have been partly caused by a dampening in the processing of external stimuli. In what way did these two sources of impairment contribute to the effects found in the present work? Unfortunately, the experiments presented in this thesis do not allow me to answer that question. Whether or not the driving performance impairments associated with mind wandering are partly associated with a deactivation of the task-positive network is beyond the scope of the present work. Future research should endeavor to test this theory further.

### **5.3. Velocity Discrepancy**

Many of the negative driving performance effects associated with route familiarity are also associated with mind wandering. That is, I found that drivers familiar with the route followed the lead vehicle more closely, and with following

distance controlled for, took longer to respond to both central and peripheral emergencies. The effects were much the same with regards to mind wandering, in which drivers maintained a shorter headway distance, and took longer to respond to both central and peripheral emergencies when mind wandering compared to when on-task. These consistent findings suggest that the route-familiarity effect is mediated, at least in part, by mind wandering. However, it was also found that drivers maintained a slightly higher velocity (1 m/s) when mind wandering compared to when on-task. No such effect was associated with route familiarity. If the route-familiarity effect is mediated by mind wandering, one would expect that drivers familiar with the route would drive faster than those unfamiliar with the route.

One probable explanation for this inconsistent finding is that the optical flow rate, or the speed with which objects in the environment flow around the driver, may have differed between the route-familiarity and mind-wandering experiments. When we move through the environment, the objects and surrounding surfaces will seem to flow around us. Furthermore, objects closer to the observer will seem to move faster than objects farther away (a phenomenon known as *parallax*). Drivers tend to use the optical flow rate of objects around them to help regulate their speed. For example, when entering a tunnel, drivers are likely to slow down, and this change in speed is thought to be caused by an inflation of perceived velocity resulting from an increase in the optical flow rate (Denton, 1980; Manser & Hancock, 2007; Törnros, 1998). That is, the world seems to be moving past the driver a lot faster in a tunnel compared to in an open area. Thus, the driver slows down to compensate for the higher perceived velocity.

The experiments investigating the effects of mind wandering on driving performance (Chapter 2) used a narrow two-lane road, with a large cement median in relatively close proximity (one lane away on the left side). The experiments investigating the effects of route familiarity, however, used much wider, three-lane roads. A cement median was present, but only a portion of the time. Much of the environment was wide open. Figure 1 illustrates the typical view for a participant in one of the route-familiarity experiments from Chapters 1 and 3 (Column A) and the typical view for a participant in one of the mind-wandering experiments in Chapter 2

(Column B). The narrow roadway and the presence of the large median likely made the optic flow rate higher during the mind-wandering studies compared to the route-familiarity experiments. Consequently, it could be that during the mind-wandering studies, the high optic flow rate encouraged drivers to slow down when 'on-task' (not mind wandering). When drivers were mind wandering, however, the optical flow rate would have been much less apparent, and drivers would be less likely to adjust their velocity. This would result in a reliable velocity difference between the two conditions. During the route-familiarity studies, the optical flow rate remained low throughout the entire experiment. Therefore, drivers unfamiliar with the route would have been less likely to adjust their velocity, resulting in a null effect between the two groups. One would expect then, that if the route-familiarity effect was investigated using roads with a high optic flow rate, velocity differences should be in evidence. Future research should attempt to test this hypothesis further.

Although differences in the optical flow rate may account for the divergent velocity results between the route familiarity and mind wandering experiments, there are two other possibilities that cannot be dismissed. First, when dealing with null effects, one must always consider the possibility of a type 2 error. That is, it could be that drivers familiar with the route do tend to drive faster than those unfamiliar with the route, but the effect was simply not reliable in my data set. Given that the experiments investigating mind wandering were within-subject designs, and those investigating route familiarity were between-subject designs, the fact that I did not obtain a reliable velocity effect associated with route familiarity may have been due to insufficient power. However, an analysis revealed that the velocity effect linked to mind wandering had a relatively large effect size (Cohen's  $d > .8$ ). Given this fact, along with the fact that there was no observed mean difference in velocity between the Familiar and Unfamiliar groups, the possibility of a type 2 error seems remote (but still a possibility).



**Figure 1.** An example of the typical view from the driver's seat for an observer participating in one of the route-familiarity experiments (A) and one participating in one of the mind-wandering experiments (B). The large cement median present during the latter, may have increased the optic flow rate, thus inflating the drivers' perceived velocity.

A second possibility is that in manipulating route familiarity, general arousal levels may have been different between the two groups. In other words, those familiar with the route may have been slightly more relaxed than those unfamiliar with the route given that they were comfortable with the environment. Lower arousal is likely inextricably linked to mind wandering, but arousal level may have effects on velocity separate from the effects associated with mind wandering. For example, as one becomes familiar with a route, arousal levels go down and mind wandering increases. Mind wandering might cause the driver to speed up, but lower arousal may simultaneously promote lower speeds, thus cancelling out any velocity differences between the Familiar and Unfamiliar groups. To my knowledge, however, no previous work has made a definitive link between arousal levels and driving velocity. Thus, although it makes intuitive sense, the hypothesis that lower arousal leads to lower velocity is in need of further investigation.

## 5.4. Future Research

The results presented in this thesis provide a number of directions for future research. First, the results presented in Chapters 1 and 3 were obtained with very subtle manipulations of route familiarity. That is, participants practiced a route only four times before being taking part in the experimental session. In addition, as can

be seen in Figure 1A (above), the environment was relatively bare, with very few landmarks that may strengthen any effects associated with route familiarity (buildings, billboards, etc.). This raises an important question: In what ways do excessive route practice and environmental landmarks have on the route familiarity effect? This question can be answered by repeating the procedures of Chapter 1, with two changes: extending the training session to include more route practice and using a more visually complex environment, such as a city landscape.

I hypothesize that any variables that will increase the ease with which the route is processed will be positively correlated with the incidence of mind wandering, thus amplifying the negative route familiarity effect. Therefore, driving down a route that is practiced more than four times should amplify the route familiarity effect that was found in Chapter 1. In addition, landmarks that provide more detailed information regarding the drivers location along the route should aid in the automatic processing of the route, thus increasing the incidence of mind wandering (and increasing RT to emergencies).

A second avenue for future research stems from the fact that in the real world, the driving route will include both static and *dynamic* visual stimuli. For example, when driving to work tomorrow, the buildings, road signs, intersection locations etc., will be the same as they were today (static stimuli). However, there will likely be different cars parked on the side of the road, pedestrians walking on the sidewalk, and a different traffic density than there was today (dynamic stimuli). It is possible that these subtle changes in the environment might provide enough stimulation to keep the drivers attention engaged in the driving environment, thus decreasing the incidence of mind wandering somewhat. It could be then, that the proportion of time spent mind wandering along a familiar route in the real world may differ from that obtained in this thesis.

Finally, as was noted in Chapter 2, the resource depletion associated with mind wandering does not seem to be associated with any compensatory driving behaviour (slowing down, and increasing following distance). In contrast, compensatory behaviours are often observed when drivers are in a dual-task

situation (driving while conversing on a cell-phone). In dual tasking, the driver must attend to both tasks simultaneously, thus dividing the available attentional resources to the requirements of the two tasks. In so doing, the driver tends to compensate for the depletion in attentional resources by increasing the margin of safety (Strayer et al., 2003). This results in slower speeds and increased following distance.

This lack of compensatory behaviour might stem from the fact that mind wandering often occurs without explicit awareness (Schooler, Reichle & Halpern, 2004; Smallwood & Schooler, 2006). The idea being that one is unlikely to compensate if one is unaware of any distraction. It could be that driving behaviour while mind wandering with awareness (termed *tuning out*) may differ fundamentally from driving behaviour while mind wandering without awareness (termed *zoning out*; Schooler et al., 2004). It could be that, using the paradigm in Chapter 2, the incidence of zoning out may exceed the incidence of tuning out. Indeed, it has been shown that zoning out can account to up to 67% of mind wandering episodes (Schooler et al., 2004). Given the fact that zoning out can occur more often than tuning out, the lack of compensatory behaviour observed in the present work may reflect the fact that drivers were unaware of any cognitive distraction.

This raises an interesting research question. Will a driver compensate for the increased attentional demands associated with mind wandering when aware that mind wandering is occurring? Being aware of the mind wandering distraction, a driver may try to compensate for the increase attentional demand by increasing following distance and decreasing velocity. If so, the opposite effect (as observed in the present work) should be in evidence when a driver is mind wandering without awareness. Future research should endeavor to test this hypothesis.

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