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HOW MUCH DO IN-VEHICLE TASKS WITH SWAPPING, SWITCHING AND SPILLOVER EFFECTS INTERFERE WITH DRIVERS' ABILITY TO DETECT AND RESPOND TO THREATS ON THE FORWARD ROADWAY?

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A Dissertation Presented

By

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DEDICATION

To my loving parents.

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ABSTRACT

HOW MUCH DO IN-VEHICLE TASKS WITH SWAPPING, SWITCHING AND SPILLOVER EFFECTS INTERFERE WITH DRIVERS' ABILITY TO DETECT AND RESPOND TO THREATS ON THE FORWARD ROADWAY?

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Distractions have long been associated with crashes. A review of the literature shows drivers engaging in secondary tasks to be three times as likely to crash as compared to attentive drivers. Although several studies report that excessively long glances away from the forward roadway elevate the risk of crashes, little research has been conducted to determine how long a driver needs to glance towards the forward roadway in between glances inside the vehicle to perform a secondary task in order to detect threats present in or emerging from the forward roadway. To determine this, drivers were asked to perform simulated in-vehicle tasks requiring glances alternating inside and outside the vehicle. The glance inside was limited to 2 s. The glance outside was varied between 1 and 4 s. Eighty five participants were evaluated across two experiments involving one continuous view and three alternating view (baseline, low load and high load) conditions. Drivers in all alternating conditions were found to detect far more hazards when the forward roadway duration between two in-vehicle glances was the longest (4 s). The decrease in hazard detection at the shorter roadway durations was a combined consequence of

the drivers having to devote more resources to their driving (swapping), and having to switch their attention between the primary (driving) and secondary (in-vehicle) tasks (switching). There was an additional carry over effect of load observed in the alternating high load condition when drivers were loaded even while looking at the forward roadway (spillover). There was an effect of type of processing (bottom up versus top down) and eccentricity (central versus peripheral). The asymptotic estimation of the threshold duration indicated that the drivers' minimum glance duration on the forward roadway be at least 4 seconds when engaged with an in-vehicle task that elicits swapping effects and at least 7 seconds when engaged with an in-vehicle task eliciting switching effects.

EXECUTIVE SUMMARY

Distractions have long been associated with crashes. A review of the literature shows drivers engaging in secondary tasks to be three times as likely to crash as compared to attentive drivers. It's been shown that brief glances away from the forward roadway actually decrease crash risk if they are safety related (e.g., checking the side mirrors). However, glances exceeding a 2 second threshold were found to accelerate crash risk by twice as much as compared to control conditions. Although several studies have indicated that excessively long glances away from the forward roadway are responsible for elevating the risk of crashes, very little research has been conducted to determine how long a driver needs to glance towards the forward roadway in between glances inside the vehicle to perform a secondary task in order to detect and respond to threats present in or emerging from the forward roadway.

It is extremely important to obtain this information as we currently do not know how long glances directed towards the forward roadway need to be in the midst of a sequence of alternating glances inside and outside the vehicle while the driver is performing a parallel, in-vehicle secondary task in order for the driver to capture all of the critical information. The intuition would lie in assuming that very short glances (e.g., glances under 500 ms) are too short to capture the existence of potential hazards as the traffic environment constantly changes (i.e., is dynamic). However, it is not known just how short is too short. In my work, I am primarily interested in the detection of potential hazards which are not visible (or cued) before the driver takes the first glance away from the forward roadway.

Throughout my dissertation, I intend to answer two general questions that compare the performance of drivers when glancing continuously at the forward roadway (*continuous condition*) with drivers that alternate their glances between the forward roadway and the inside of the vehicle (*alternating condition*). (i) First, what is the minimum time in general that a

driver in in the alternating conditions needs to detect a threat as well as a driver in the continuous condition and, related to that, how does the minimum time vary as a function of: (a) the way in which the initial threat is processed (top down or bottom up), (b) the location of the potential threat (fovea or periphery), and the (c) the level of cognitive load (high or low) imposed by the secondary task when the driver is glancing on the forward roadway. This minimum time will be referred to as the *threshold duration*. When the cognitive load is low (defined here as the drivers being loaded only while performing the in-vehicle task), the primary causes of the difference between the alternating and continuous conditions are due to the *swapping* of the view of the forward roadway for a view inside the vehicle and the *switching* of attention from driving to the in-vehicle task. Experiment 1 has been designed so that I will be able differentiate between the separate effects of swapping and switching. When the cognitive load is high (i.e., the drivers are performing aspects of the in-vehicle task even while glancing at the forward roadway), the primary cause of this difference comes not only from the swapping of views and the switching of attention, but also from the *spillover* from the secondary task of any ongoing demands associated with that task. Experiment 2 has been designed so that I will be able to identify not only the separate effects of swapping and switching, but also so that I can identify any additional effects of spillover. (ii) Second, does the hazard anticipation performance decline as the duration of the glance on the forward roadway decreases in the alternating conditions and, related to that, when the period of time during which the driver glances at the forward roadway (the *window*) is less than the threshold duration, how does the difference in the likelihood that drivers in the alternating and continuous condition detect a threat vary as a function of the above three factors (a – c).

When performing a secondary, in-vehicle task a driver cannot see the forward roadway. In both Experiments 1 and 2, a secondary, in-vehicle task requiring multiple in-vehicle glances was simulated by alternating between displays on the center screen of the forward roadway (for varying lengths of time) and of the search task which contained 15 characters, one or more of which were the letter t (always displayed for 2s). The forward roadway on the center screen was not visible when the search task was displayed. The driver had to count the number of times the letter t appeared in the target display. In Experiment 1, the driver simply reported this number after the presentation of each target display on the center screen (low load). In Experiment 2, the driver had to perform a task while glancing at the forward roadway that was based on the number of targets (high load).

Using this method, the duration of an alternating sequence of glances on the forward roadway and away from the forward roadway (towards the target display) could be controlled. Four sequences were used: 1 s on the forward roadway and 2 s inside the vehicle (1-2), 2 s on the forward roadway and 2 s inside the vehicle (2-2), 3 s on the forward roadway and 2 s inside the vehicle (3-2), and 4 s on the forward roadway and 2 s inside the vehicle (4-2). Each sequence (simulated in-vehicle task) began with a glance inside the vehicle (i.e., the forward roadway on the center screen replaced by the search task) and then, in alternation, a glance on the forward roadway, a second glance inside the vehicle, a second glance on the forward roadway, a third glance inside the vehicle, a third glance on the forward roadway, a fourth glance inside the vehicle, and then the final glance up. For example, in the 1-2 sequence, the durations of the alternating glances inside and outside the vehicle would be, respectively, 2 (inside), 1 (outside), 2 (inside), 1 (outside), 2 (inside), 1 (outside), and 2 (inside). In each drive, participants were given a number of pseudo-secondary tasks like this. The percentage of latent hazards recognized was recorded (as indicated by an eye movement in the direction of the latent hazard) when the driver was performing the pseudo-secondary tasks.

In Experiment 1, drivers were assigned to one of three conditions: continuous (control), alternating baseline (alternating completely blank center screen and forward roadway center screen), and alternating low load (alternating center screen with display of search tasks and forward roadway) conditions. In the alternating baseline and alternating low load conditions, the four alternating sequences described above were used (1-2, 2-2, 3-2, 4-2). In all three conditions, two other factors, type of processing (a) and location of threat (b), were varied. Task switching involves both an interruption (the forward roadway is not visible and is replaced, i.e., swapped, with a view inside the vehicle of whatever task is being performed) and a redirection of attention (enumerating the number of targets). By comparing the alternating baseline and continuous conditions, one can determine whether a task interruption by itself has a detrimental effect on hazard anticipation (this is referred to as an effect of swapping). By comparing the alternating low load and alternating baseline conditions, one can determine whether a redirection of attention to a low load task has an effect above and beyond task interruption.

Forty-five participants were evaluated in the Experiment 1 across the continuous, alternating baseline and alternating low load conditions. (i) Forward Roadway Duration. The results indicated a strong effect of the duration of the forward glance on drivers' ability to detect latent hazards. Drivers in both alternating conditions were found to detect more hazards when the forward roadway duration between two in-vehicle glances was 4 s as compared to when the durations of the forward glances were 1 s, 2 s or 3 s. Because the participants in the continuous condition performed better than the participants in the alternating low load 4-2 condition, the threshold duration had to be estimated. It was determined that the threshold duration was approximated 6 s. (ii) Swapping and Switching. There was no significant difference in the alternating baseline (swapping) and low load conditions (switching), though the percentage of hazards detected in the low load condition was lower than this percentage in the baseline condition. Overall accuracy and tasks attempted, as well as accuracy for just those tasks attempted, were measured for the alternating low load condition. The participants were clearly performing the target task. Thus, the load was higher in the low load condition than the baseline condition. This would appear to indicate no effect of switching, but only an effect of swapping. However, the percentage of hazards anticipated on the last glance in a sequence in the alternating low load condition when the task was not attempted was much higher than this percentage when the task was attempted. This suggests an effect of switching above and beyond that of swapping. The alternating baseline condition was modified slightly to reduce a possible confound in Experiment 2 which could have decreased the difference in the alternating baseline and low load conditions leading to the failure to find a significant difference in the alternating baseline and low load conditions (and therefore a failure to find an effect of switching independent of swapping). (iii) Type of Processing. There was an effect of type of processing, with a larger percentage of the hazards detected in scenarios involving bottom up processing (compared to top down). (iv) Eccentricity. There was no significant effect of location of threat (central versus peripheral) on the percentage of hazards detected across scenarios. (v) Velocity. Finally, velocity was analyzed as a vehicle measure. Perhaps drivers in the alternating low load condition slowed appreciably and therefore effectively had more time than drivers in the alternating baseline or continuous conditions to view the latent hazards. However there was no difference in the average velocities among the three conditions either during the 15 s preceding a hazard or the 5 s preceding a hazard.

In Experiment 2, the cognitive load while the driver was glancing on the forward roadway was varied along with the other factors (i.e., all three factors, a – c, are varied). Forty participants were evaluated in Experiment 2 across the control (C), baseline (B), low load (E) and high load (H) experimental conditions. Only 3 alternation sequences were considered for the alternating baseline (B), low load (E) and high load (H) experimental scenarios (3/2 was omitted). A cognitively demanding secondary task was used in the high load condition which required effort while the driver was glancing on the forward roadway to determine if there were spillover effects from secondary task performance on drivers' ability to detect latent hazards. (i) Forward Roadway Duration. The results indicated a strong effect of the duration of the forward glance on drivers' ability to detect latent hazards. Drivers in all three alternating conditions were found to detect more hazards when the forward roadway duration between two in-vehicle glances was 4 s as compared to when the durations of the forward glances were 1 s or 2 s. It was determined that there was no forward glance duration in the alternating high load which would ever produce hazard anticipation performance equal to that observed in the continuous condition. (ii) Swapping, Switching and Spillover. Significant swapping, switching and spillover effects were observed. There were significant differences in the alternating baseline (swapping), low load (switching) and high load conditions (spillover). The percentage of hazards detected in the alternating high load condition was the lowest (C> B > E > H). Overall accuracy and tasks attempted, as well as accuracy for just those tasks attempted, were measured for the alternating low load and high load conditions. The participants were clearly performing the target task. Thus, the load was higher in the low load condition than the baseline condition and similarly the load was higher in the high load than in the low load condition. This would appear to indicate an effect of swapping, switching, and spillover. Combined swapping and switching effects and combined switching and spillover effects were observed. The modification of the alternating baseline condition in Experiment 2 to address a potential confound in Experiment 1 served the purpose and clear and significant differences were obtained for all conditions. (iii) Type of Processing. There was no effect of type of processing, though a larger percentage of the hazards were detected in scenarios involving bottom up processing (compared to top down). (iv) Eccentricity. There was a clear benefit to latent hazard anticipation for centrally located threats (e.g., lead vehicle braking) as opposed to peripherally located latent hazards (e.g., pedestrian at a crosswalk). (v) Velocity. Finally, velocity was analyzed as a vehicle measure. As noted above, perhaps drivers in the alternating low load and high load conditions slowed appreciably and therefore effectively had more time than drivers in the alternating baseline or continuous conditions to view the latent hazards. However there was no difference in the average velocities among the four conditions either during the 15 s preceding a hazard or the 5 s preceding a hazard ruling out the possibility.

The results of my experiments indicated that across conditions, the threshold duration is shortest in the alternating baseline condition (4 s), longer in the alternating baseline condition (6 - 7 s), and nonexistent in the alternating high load condition. More specifically, when the in-vehicle task requires swapping, a threshold duration of about 4 s is critical. This duration increases as the in-vehicle task requires switching (6 – 7 s) and when the in-vehicle task is cognitively loaded and requires spillover (loading even when the driver is glancing at the forward roadway), the threshold duration is nonexistent indicating that under spillover effects, no amount of time can manifest safety. Alternatively, tasks that induce spillover effects should not be performed while driving as the persistent effects of load outweigh the benefit of even the longest forward roadway glances.

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CHAPTER 1

INTRODUCTION

1.1 The Problem

The recent past has seen an increase in the research focusing on the impact of driver distraction on crash and near crash risk. In a study reported by Klauer et al. (2006), the authors attempt to determine the relationship between driver inattention and crash/near-crash risk. They concluded that drivers engaging in secondary visually or manually complex tasks had a three times higher near crash/crash risk than drivers who were attentive (i.e., not engaged in a secondary task). The article states that brief glances away from the forward roadway for the purpose of scanning the driving environment using the forward and side view mirrors are safe and actually decrease crash/near-crash risk. However, glances in excess of 2 seconds for any purpose were seen to increase near-crash/crash risk by at least twice as much as the baseline condition.

Other studies indicate that excessively long glances away from the forward roadway elevate the risk of crashes (Horrey& Wickens, 2007). However, very little research has been conducted to answer the equally important question of how long a driver needs to glance towards the forward roadway in order to detect and respond to threats present/emerging in the forward roadway. Why is this question important? Consider as an example the following scenario. Suppose that a driver takes three glances to complete a simple in-vehicle task, tasks which do not require the driver to process information gathered during the in-vehicle glance when the driver returns his or her gaze to the forward roadway. None of the driver's glances away from the forward roadway are in excess of 2 seconds (the safe threshold as established by Horrey and Wickens, 2007). However, suppose that the driver only glances at the forward roadway for 500 ms in between glances inside the vehicle while performing the secondary tasks. In this case, it will almost always be true that the time the driver has to analyze information in the forward roadway is too short to provide enough time to assimilate information from the environment required for hazard detection and response (since a great many hazards will require two glances, each glance on the order of 300 or more ms) (Underwood et al., 2002).

The first question I am asking is how long at a minimum drivers need to glance on the forward roadway in order to detect various different types of hazards (Crundall at el., 2012) when they are alternating glances on the forward roadway and inside the vehicle performing secondary tasks. The smallest duration at which the hazard detection performance of drivers alternating glances between the inside of the vehicle and the forward roadway equals the hazard detection performance of drivers continuously glancing on the forward roadway will be defined as the *threshold duration*. Thus the first question can be restated as follows: what is the threshold duration for different types of hazards. It needs to be made clear here that I am interested in the detection of potential hazards which are not visible (or cued) before the driver takes the first glance away from the forward roadway. This will be labeled *initial hazard detection*. One can contrast this with a situation in which a potential hazard was recognized before the first glance inside the vehicle, something which will be labeled *interrupted hazard detection* (Borowsky et al., 2013).

The threshold duration is likely to vary with a number of factors including the type of processing (bottom up or top down), the location of the hazard (central or peripheral), and the cognitive load placed on the driver. The type of processing is important to consider because some threats are cued by stimuli which attract attention (bottom up, e.g., brake lights) and some are cued by stimuli which require the allocation of attention (e.g., a complex intersection).

It is well known that behaviors vary as a function of the type of processing (e.g., Crundall, Van Loon & Underwood, 2006).

The location of the threat is important because some hazards are located centrally (e.g., a lead vehicle braking) and some are located to the side (e.g., a bicyclists approaching quickly from a side street). It is known that location of a stimulus can influence the time to detect the stimulus (e.g., Posner, Snyder & Davidson, 1980).

Finally, the cognitive load is important to consider because the level of the load varies among in-vehicle tasks (Adamczyk & Bailey, 2004). Presumably it will take longer for the drivers in the alternating condition to detect a hazard than it will drivers in the continuous condition for any given threat, holding performance constant, both when the load is small (present only when the driver is glancing at the in-vehicle) and when the load is high (present both when the driver is glancing at the in-vehicle task and when the driver is glancing on the forward roadway), but the effect will be larger when the load is high. When the load is small (or nonexistent) the cause of the difference in performance between the alternating and continuous conditions will presumably be the result of both the swapping of one scene (the view of the forward roadway) with the view of another scene (the in-vehicle task) and the switching of attention between the primary task of driving and the secondary in-vehicle task. These will be referred to, respectively, as the *swapping effect* and the *switching effect*. It is known that low load in-vehicle tasks (which have both swapping and switching effects) will interfere with hazard anticipation in the case of interrupted hazard detection. In particular, Borowsky et al. (2013) showed that a hazard which was cued before a first glance inside a vehicle was less likely to be detected when the driver glanced back up on the forward roadway than were the driver to be glancing continuously on the roadway (in continuous condition the hazard was obscured by the built and natural environment). In this study the drivers were performing a low load in-vehicle task. However, it is not known whether swapping and switching effects will be present in the case of initial hazard detection. More importantly, it is not known how long the glance on the forward roadway needs to be in order for these effects to dissipate.

When the load is high, in addition to the effects of swapping and switching on the threshold duration, there will be arguably be an effect of the concurrent cognitive load imposed by the secondary task on the threshold duration. This increment I will refer to this as the *spillover effect* (i.e., the effect of the secondary, in-vehicle task spilling over into the primary driving task – specifically initial hazard detection -- even when the driver is glancing at the forward roadway). The spillover effect requires further discussion. Specifically, consider what effect performing a secondary, cognitively demanding in-vehicle task might have on the initial hazard detection time when the driver is alternating glances inside the vehicle and on the forward roadway. The existing research suggests that secondary tasks which do not require the driver to take his or her eyes off the forward roadway -- such as use of a cell phone -- do interfere with both top down processing (Taylor et al., 2012) and bottom up processing (Strayer and Johnston, 2001) in the detection of initial hazards. If the cognitive load imposed on the driver by an in-vehicle task while the driver is glancing inside the vehicle also carries over (spills over) to the processing of information while the driver is glancing at the forward roadway, one would expect that it would take drivers longer to detect an initial hazard when performing a cognitively demanding secondary task which has spillover effects than when performing either a secondary task with no spillover effects or no secondary task whatsoever. As above, the equally important question is just how long the glance on the forward roadway will need to be in order for the effects of swapping, switching and spillover to dissipate. Given that spillover is ongoing, there may be no glance on the forward roadway that is long enough to reduce complete the effect that a concurrent load has on hazard anticipation.

The second question I am asking is whether hazard anticipation performance deteriorates in the alternating conditions as the duration of the glance on the forward roadway decreases and, if so, how the difference between drivers who glance continuously on the forward roadway and drivers who alternate glances varies as a function of the above factors (type of processing, location, and load) when the time which the hazard is visible is less than the threshold duration. The time that the forward roadway is visible (the time between when the driver glances up from the secondary, in-vehicle task to the forward roadway and back down into the vehicle) will be defined as the *window*. This situation is critical to consider because one cannot guarantee that after a driver first glances back up on the forward roadway the window will be equal to or greater than the threshold duration. A potential hazard may only have become visible when the driver was glancing down inside the vehicle. Thus, in order to understand the effects of the safety of secondary, in-vehicle tasks it is critical to determine just what effect alternating glances have on hazard detection likelihoods with windows smaller than the threshold duration.

1.2 Aims

The aim of this dissertation research is to be able to successfully answer the above two questions. To begin, several definitions are needed, some of which have been given previously (but are noted here for completeness). First, define am *alternating condition* generically as any situation in which the driver alternates glances inside the vehicle and outside the vehicle on the forward roadway. We will analyze three alternating conditions: alternating blank screen (alternating baseline), alternating low load, and alternating high load. Second, define a *continuous condition* as the situation in which the driver glances continuously outside the vehicle. There is only one continuous condition. Third, define the *threshold duration* as the minimum time it takes the driver glancing back up on the forward roadway to detect a latent threat with the same likelihood that he or she does when glancing at the forward roadway continuously. Fourth, define the *window* as the length of time that a latent hazard is visible when the driver glances back up on the forward roadway after performing a secondary in-vehicle task. Fifth, for a given forward roadway duration, define the *swapping effect* as the difference in the average percentage of hazards detected in the alternating baseline and continuous conditions; define the *switching effect* as difference in the average percentage of the hazards detected in the alternating low load and alternating baseline conditions; and define the *spillover effect* as the difference in the average percentage of hazards detected in the alternating low and high load conditions. Finally, define the *alternation sequence* as the sequence of durations of the glances on the forward roadway and inside the vehicle. There are four alternation sequences used in the experiment: 1-2 (1 second outside, 2 seconds inside), 2-2, 3-2 and 4-2.

Given the above definitions, I can frame the two questions as follows: (a) what is the threshold duration on average in the alternating conditions and how does it vary as a function of the type of processing, the location of the threat, and the cognitive load; and (b) does hazard anticipation performance decline as the duration of the glance on the forward roadway in the alternating conditions decreases and, if so, how does the difference between the detection likelihood of drivers in an alternating and continuous conditions vary as a function of each of the above factors when the window is less than the threshold duration. In Experiment 1, I address the two questions when there are no spillover effects from the secondary, in-vehicle task in the alternating conditions (i.e., there is no load that carries over from the secondary task). The only effects are due to switching and swapping. In Experiment 2, I address the two questions when there are spillover effects from the secondary, in-vehicle tasks (i.e., cognitive load is present from the secondary task while the driver is glancing on the forward roadway).

Experiment 1: Experiment 1 uses the RTI simulator in the Arbella Insurance Human Performance Laboratory which contains three screens, a center screen and a screen on the left and the right sides. With the above definitions in mind, there are two related aims. The first aim is to determine the average threshold duration and how this duration varies in the alternating conditions as a function of: (a) how the threat is processed (top down or bottom up); (b) where the threat is located (fovea or periphery); and (c) the cognitive load placed on the driver. Pursuant to understanding the effect of load is the question of whether in the low load condition there are effects just of swapping or of both swapping and switching. The second aim is to determine whether hazard anticipation performance declines as the duration of the glance on the forward roadway decreases and, if so, how the difference between the likelihood that drivers in the alternating and continuous conditions detect a threat when the window is less than the threshold varies as a function of the above factors.

The experiment uses a mixed design. Consider first those factors that were varied between participants. Participants either drive scenarios in the continuous glance control condition (where the forward roadway is constantly visible), alternating baseline condition (where at certain points the center screen alternates between views of the forward roadway and a blank, black screen) or the alternating experimental low load condition (where at certain points the center screen alternates between views of the forward roadway and the search task). The period of time during which the information was visible on the forward roadway was varied across participants. The exact visible forward roadway times were 1 s, 2 s, 3 s and 4 s. The maximum visible time of 4 s was selected so that the likelihood the initial hazard would be identified in a single glance was near ceiling (ceiling being defined here as the likelihood that the hazard was detected when the roadway is continuously visible). The invisible time was chosen as 2 s based on previous studies indicating 2 s as the threshold for in-vehicle glances before safe driving performance starts decreasing dramatically (Klauer et al., 2006; Horrey & Wickens, 2007). So, for example, in a 1 s outside/2 s inside subsequence, the simulated drive would be visible for 1 s and not visible for 2 s. The alternating glance sequence used was always the same one for each participant.

Consider next those two factors that were varied within participants. They were discussed above and include: the location of the latent threat (central or peripheral) and the type of processing (bottom up or top down).

When the forward roadway is not visible, in the alternating low load condition the participant is asked to complete an in-vehicle task which places no load on the driver during the period of time when the task is visible. Specifically during this condition, the center screen alternates between a view of the forward roadway and a view of a visual search display with a 5 x 3 matrix of 15 random characters of the English alphabet. Drivers need to search for and count the number of times the character 't' appears on the display. In the alternating baseline condition, the center screen alternates between a view of the forward roadway and a black, blank display.

Eye behavior was tracked throughout, as was driver and vehicle behavior. Measures were made both of how likely a driver is to detect a potential threat under the different threat conditions (latent hazard detection) and of the drivers' response (velocity).

The threshold duration was estimated in the alternating conditions. For example, suppose in the continuous condition 90% of the drivers detect the threat. If in the alternating low load 4 s/2 s condition 90% of the drivers detect the threat, but in the alternating low load 3 s/2 s condition only 60% of the drivers detect the threat then, crudely, the threshold duration is 4 s. The threshold duration will also be estimated in the alternating baseline condition. Suppose that in the alternating baseline 4 s/2 s condition 90% of the drivers detect the threat and in the alternating baseline 3 s/2 s condition 80% of the drivers detect the threat. The switching effect in this case is 20 percentage points at a forward roadway duration of 3 s (80% - - 60%). The swapping effect if 10 percentage points at a forward roadway duration of 3 s (90% - 80%).

Experiment 2: Experiment 2 also uses the RTI simulator. This experiment differs from the above experiment only in terms of the additional load that the secondary task places on participants while the forward roadway is visible. I chose a variation of the previous task where drivers search for and count the number of times 't' appears on the search display. In the high load condition, unlike the low load condition, the drivers continue to count forward by 3 during the period of time that the forward roadway is visible until the next such search display is presented. A different arrangement of characters in the search display was used each time the target display was presented. The forward roadway appeared for a predetermined length of time. The participant during this interval would need both to complete the secondary task (search) as well as continue to compute arithmetically (count forward by 3) thereby exerting a load on the verbal working memory.

With this in mind, like Experiment 1, there are two aims of Experiment 2. The first aim is to determine how long is the average threshold duration of drivers and how this threshold duration varies as a function of: (a) how the threat is processed (top down or bottom up); (b) where the threat is located (fovea or periphery); and (c) the load (continuous, alternating baseline, alternating low load, alternating high load). As with Experiment 1, pursuant to understanding the effect of load is not only the question of whether in the low load condition there are effects just of swapping or of both swapping and switching, but also the question of whether in the high load condition there are effects of spillover in addition to those of swapping and switching. The second aim is to determine whether hazard anticipation performance declines as the duration of the glance on the forward roadway decreases and, if so, to identify how the difference between the likelihood that drivers in the alternating and continuous conditions detect a threat when the window is less than the threshold varies as a function of the above three factors.

There were four conditions: a continuous glance control condition, an alternating baseline condition (the alternation is a black screen with a '+' sign that the drivers need to fixate upon), an experimental low load condition where the views of the forward roadway and secondary task are alternately displayed as described above and the driver is not cognitively loaded when glancing on the forward roadway, and an experimental high load condition where the views of the forward roadway and secondary task are alternately displayed as described above and the driver is cognitively loaded with the arithmetic task. As in Experiment 1, eye, driver and vehicle behaviors were measured and analyzed.

CHAPTER 2

LITERATURE REVIEW

Crashes are due to a number of different reasons. One of these reasons is a failure to detect potential hazards. The primary focus of my dissertation will be on failures to detect latent hazards which occur while the driver is looking at the forward roadway that are caused both by the alternation of glances inside the vehicle and on the forward roadway in and of itself and of the additional cognitive load created by the use of in-vehicle devices. This additional cognitive load exists in those cases where the secondary, in-vehicle task: (a) requires the driver to maintain a spatial or visual memory of information gathered inside the vehicle while glancing up at the forward roadway or (b) requires the driver to execute actual cognitive operations while glancing up at the forward roadway. With the advent of technological improvements in in-vehicle devices, the levels of in-vehicle distraction have reached a new zenith. This winds up being a safety concern most critically because in-vehicle distractions lead to degradation in driving performance when the drivers' eyes are away from the forward roadway. But it may also be the case that in-vehicle technologies take a toll on driver performance even when the driver is glancing at the forward roadway due both to task switching and spillover effects. The literature review below covers a range of topics relevant to the distractions caused by in-vehicle devices.

First, the relation between driver performance and the durations of glances inside the vehicle (in-vehicle glance durations) and on the forward roadway (forward-roadway glance of in-vehicle glance durations) is discussed. This discussion makes it clear that glances too long away from the forward roadway are a clear cause of crashes. Of more relevance, it makes clear that as the roadway demands increase, the driver needs to glance for a longer period of time on the forward roadway. However, it does not bear on an answer to the critical question of how cognitive load will influence drivers' ability to gather information from brief glances on the forward roadway. The research on occlusion may provide insight into swapping effects that occur in the alternating baseline condition where a blank screen interruption is initiated within the alternation sequence.

So, second, I will turn to a review of the literature on change and inattention blindness. The discussion of change blindness is of clear relevance to the aims of the dissertation because the view out the forward roadway will change every time the driver glances inside and outside the cabin of the automobile. The discussion of inattention blindness is significant because it reminds us that drivers focused on one aspect of the scene may not detect another salient, but unexpected aspect of the scene which is at the same location. Put slightly differently, just because an individual fixates a given location does not mean that that individual processes all relevant information in that location. Measures in addition to the fixation location are needed when it is critical to understand whether information at a particular location is processed. Especially relevant here is the extent to which a secondary task influences change and inattention blindness outside of the driving task.

Third, I turn to a discussion of the impact of in-vehicle tasks on driving performance. Texting is a model example of such a task.

Fourth, I discuss the literature about cell phones and their effect on distraction and crashes. The impact of cell phones on driver performance by itself is not directly related to the topic at hand since the driver is always glancing at the forward roadway (not alternating glances inside and outside the cabin of the automobile). But it can potentially yield insights into the effects that the carryover cognitive load of a secondary in-vehicle task might have on driver performance. Additionally, I seek to understand the effects of performing in-vehicle tasks that require switching and swapping on drivers' ability to detect latent hazards.

Finally, I discuss just how ubiquitous are the various secondary tasks (e.g., texting, talking on a cell phone) and what factors influence how likely drivers are to engage in such tasks. Understanding more broadly whether this will be a continuing problem is of general importance.

2.1 Relation Between Duration of Glance Durations On and Off the Forward Roadway and Crashes

2.1.1 Glances off the Forward Roadway

For many years, investigators have focused primarily on mean glance durations inside the vehicle as a measure of driver distraction. In a recent study, Horrey and Wickens (2007) examined not only the relation between mean glance durations and crashes, but also the relation between the tails of a distribution of glance durations and crashes. In their experiment, participants were asked to perform in-vehicle tasks of varying complexities. The experiment had 11 younger drivers. The driving environment consisted of a single-lane city road with a single opposing lane. The road environment included buildings, parked vehicles and ambient traffic. Furthermore, there was simulated wind turbulence exerted on the simulator vehicle.

There were several critical hazard events included in the form of incursion objects. These include: pedestrians, animals, bicyclists or other vehicles. Time-based triggers were used to initiate the critical hazards. Drivers were provided with 2.5 seconds to avoid a collision. The frequency of the incursions was limited to 6 events over the course of 8 3-minute blocks to prevent learning effects or predictive tendencies of the driver.

Participants had to perform two concurrent tasks: driving and an in-vehicle task over the duration of the experiment. The in-vehicle tasks were designed to maintain high levels of cognitive load on drivers. Drivers were asked to determine if there were more odd or even digits in a 5-digit or an 11-digit string of numbers presented on the display. The purpose was to have two levels of task complexity. The numerical digits were salient and hence, their detectability via peripheral vision was almost impossible. Thus drivers needed to glance inside the cabin of the automobile in order to perform the secondary task. The main measure of driving behavior collected was the in-vehicle glance duration. Horrey and Wickens define a glance as the amount of time that the eye is directed towards a certain area of interest until it moves to a new area. Glances can include multiple fixations.

The authors analyze the data in two ways. One way involves the analysis of the means of the distribution while the other analysis involves examination of the tails of the distribution. The eye data is filtered by setting a minimum criterion for a glance at 100 milliseconds.

For the analysis of means, extreme values which fell beyond +/- 2 standard deviations were removed. Four percent of glances were lost in this process. A 2x2 repeated measures ANOVA was performed. One of the factors was wind frequency (low, high) and the other task complexity (simple, complex). There were no significant effects of wind or task complexity. This finding suggests that the average in-vehicle glance durations did not experience fluctuations due to increasing task demands. The mean glance duration was discovered to be well below the 1.6s safety threshold described by Wierwille (1993) in his research. Thus from this method of analysis, it could be concluded that drivers performing complex in-vehicle tasks weren't exposed to a higher crash risk, at least on the basis of their mean in-vehicle glances. It was also determined that participants fixated on the display more frequently during a complex in-vehicle task. This suggests that complex in-vehicle tasks expose drivers to more risks.

The second analysis technique employed by the authors looked at the tails of the glance distributions. Examination of the tails showed that there were more long-duration glances in the complex in-vehicle condition. To illustrate this, Horrey and Wickens examined responses to critical hazard events. In-vehicle glances exceeding 1.6 s were found to result in an average response time of 2 s. As the glance duration increased, the response times were shown to increase as well ($r = 0.81$, $p < .05$). The likelihood of getting into a collision also increased ($r = 0.74$, $p < .05$). The likelihood of drivers looking down at the onset of an event was the same across conditions. The complex in-vehicle condition resulted in 21% of fixations in excess of 1.6 s. A repeated measures ANOVA for proportion of glances over 1.6s indicated that there was a large difference in the proportion of glances longer than 1.6s in the simple (6%) and complex (21%) conditions. Importantly, they find that some 80% of the crashes on a driving simulator were caused by the 21% of the glances that are longer than 1.6 s. Consistent with this, Summala (Nieminen & Summala, 1994) finds that longer than average glances were more relevant from a safety view than the average glances. Longer than normal glances are definitely more problematic.

Based on the results of their experiment (Horrey & Wickens, 2007), Horrey and Wickens proposed a revised crash risk model that describes crash risk as a function of the proportion of long duration in-vehicle glances. The earlier crash risk model exclusively looked at the means of the glance distributions. The authors emphasize the importance of the tails of the distribution by considering the example of two distributions that may have similar means but varying robustness with respect to their tails. (The tail of one distribution may indicate 12% glances above 1.6s while the tail of the other shows 5% glances longer than 1.6s. In this case the identical means of the distribution conveyed no significant information whatsoever but the tails indicated a remarkable observation.)

The old crash risk model is displayed in Figure 1. According to this model, visual attention could be directed either towards the forward roadway or within the vehicle towards an in-vehicle device. Crash risk could hence be defined as a function of the mean glance durations and the frequency of driving events. Events were classified as either potential collisions or as control events which required steering inputs. Control events were defined to arise from three sources: road curvature, turbulence and general lane maintenance requirements. Three parameters in the model below are moderated by vehicle velocity while turbulence is the only exception. Collision events and the two control events, road curvature and lane maintenance, both are a function of density of objects and are hence a function of vehicle speed.

Subsequently, Horrey and Wickens argue that mean glance durations may not be the best measure to determine crash risk. This is especially true considering the importance of the tail end of a distribution as identified by the authors in their paper. To address the said concern, the authors re-evaluated the model and modified it to define crash risk as a function of both the characteristics in the local traffic environment as well as the proportion of longer duration glances. The modified crash model is indicated in Figure 2.

$$\text{crashrisk} = \text{MDD}_{\text{IVT}} \times \left[\text{vel}\left(\text{colevent} + \text{curve} + \text{steer} \right) + \text{turb} \right] \quad (1)$$

where

MDD_{IVT} = the mean dwell duration to a given in-vehicle display,
colevent = collision events,
curve = defined in relation to density per unit distance (as is colevent),
steer = a constant (whose effect is proportional to velocity),
turb = expressed in perturbations per second, and
vel = the vehicle velocity.

Figure 1: Old Crash Risk Model

$$\text{crashrisk} = P\left(\text{GD} > 1.6s\right) \times \left[\text{vel}(\text{colevent} + \text{curve} + \text{steer}) + \text{turb} \right] \quad (2)$$

where

$P(\text{GD} > 1.6\ \text{s})$ = proportion of glances that exceed 1.6 s (threshold can be adjusted),
vel = vehicle speed (m/s),
curve = rate of curvature (per m),
steer = steering remnant (per m) [see McRuer (*32*) for details],
turb = disturbance inputs (per s) (e.g., wind), and
colevent = potential collisions or obstacles (per m).

Figure 2: Modified Crash Risk Model

At this point, I would like to describe a study conducted by Klauer et al. (2006) that aimed to look at glances off the forward roadway and their direct relation to crash risk. Klauer et al. conducted a 100 car naturalistic study to evaluate the impact of driver inattention on crash/near-crash risk. The results indicated that drivers engaged in visually or manually complex tasks have a three times higher crash/near-crash risk than drivers who aren't distracted. The study identified specific environmental conditions like intersections and areas of high traffic density which were more dangerous to drivers engaged in secondary tasks. For every six seconds of video data, the authors collected data around the event, five seconds before the event and one second after it. Risk increased significantly if the driver glanced for a total of more than two seconds inside the vehicle within the six second window. The authors report that short, brief glances away from the forward roadway are safe and contribute towards reducing crash/near-crash risk. Their analysis indicated that tasks requiring single short glances elevated risk if any minimally. At the same time, glances longer than 2 seconds for any purpose was found to increase crash/near-crash risk by at least twice as much as baseline driving (Klauer et al, 2007).

For the purpose of analysis, the authors used two reduced databases: the 100-car study event database that includes reduced crashes, near-crashes and incidents; and the baseline database. The baseline database was created via stratified sampling of the entire 6.3 Terabyte (total digital volume of information sampled) dataset based upon the number of crashes, near-crashes and incidents each vehicle was involved in followed by random sampling of 20,000 6-sec segments from the data. According to the report, a vehicle involved in over 3 percent of all total crashes, near-crashes and incidents would also represent 3 percent of the baseline data. The authors performed this stratification to create a control dataset with multiple baseline epochs per each crash or near-crash event to allow for more accurate calculation of odds ratios.

The study analyses indicated that “high involvement” drivers were significantly younger (30 vs. 38), lacked driving experience (13 years vs. 25 years) and reported more moving violations (2.2 vs. 1.4) on average than low involvement drivers. Any driver who had an involvement in four or more inattention related crashes/near-crashes was labeled as a “high involvement driver”. Analyses showed a high correlation of 0.72 between the frequency of a driver’s involvement in attention-related crashes and near-crashes. Baseline epochs indicated a direct correlation between the frequency of involvement in such distractive activities and the associated frequency of crashes and near-crashes.

2.1.2 Glances on the Forward Roadway

In a study conducted a while ago by Tsimhoni & Green (1999), the authors attempted to determine the visual demand on driving using visual occlusion. Previous research shows the relationship between crashes, roadway-based geometries and driver workload. Assessing driver workload is key to assessing the abovementioned relationship. Hence, the authors decided to use visual occlusion as the primary means of workload measurement. The previous research that was conducted didn’t examine the effect of road curvature while driving in a simulator. The authors investigated where drivers looked when they drove under visual occlusion. The experiment examined several questions, the most important (to our current point of discussion) of which is: “when the driver’s vision is intermittently occluded while driving in a simulator, where does the driver look when the scene is visible?”

		Curve Radius [m]			
		582	291	194	146
Deflection Angle	20°	D	F	G	A
	45°	H	E	J	M
	90°	B	L	C	K

Figure 3: The Geometry of the curves (Adapted from Tsimhoni & Green, 1998)

In the visual occlusion method, drivers pressed a switch to get a half second glimpse of the road. The roadway remained occluded rest of the time. The authors defined visual demand as the proportion of time the road was visible. The experiment had 24 participants across three age groups (18-24, 35-54, 55+). The participants were asked to drive a simulated single-lane road composed of 12 curves of 4 curve radii (582m, 291m, 194m, 146m) and 3 deflection angles (20, 45, 90) (Figure 3). The experimental design had two between-subject factors (age and sex) and four within-subject factors (curve radius, deflection angle, curve direction and three repetitions). The curve order was fixed across participants. Curve directions were randomized throughout the road (half of the curves in each direction during each run). The test course (Figure 4) for the study was 8.7 km long and took about 7 minutes to drive at a speed of 72.5 km/h.

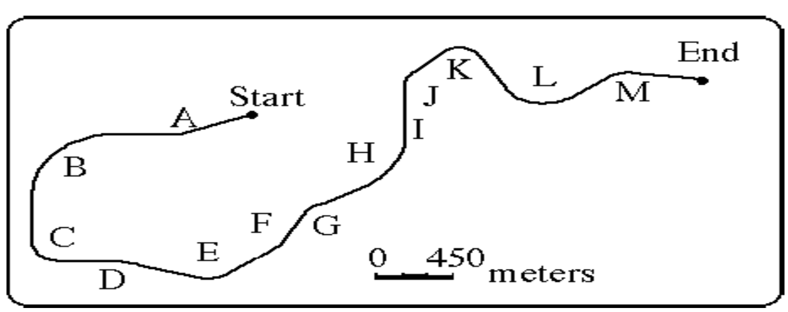

Figure 4: Test Course Layout (Adapted from Tsimhoni & Green, 1998)

The results reported by the authors indicated that the mean visual demand (visual demand was estimated as the mean of all the observations within the first half of the curve) didn't vary considerably as a function of the deflection angle of the curve. As expected by the authors, visual demand was found to be higher for sharper curves (curves with shorter radii). The paper reports that age wasn't a significant variable either.

Additionally, the study yielded useful information as to where participants look (within the scene) when their vision is intermittently occluded while driving in a simulator. The results report that, in general, participants preferred looking at the imaginary focus of expansion while navigating straighter sections of the roadway. In curved sections, drivers whose vision was not occluded were found to fixate on one of the edges of the roadway. The participants continued to perform backward sequences (saccade forward, and then several attempts backward) till the curve ended. However when their vision was occluded, participants focused on the edges of the curved roadway performing forward sequences till the curve ended. The participants were found to prefer looking towards the inside the curve for large radius curves. Contrariwise, participants preferred looking towards the outside the curve for sharper curves. The preference described above was found to be higher for left curves as compared to right curves.

2.1.3 Implications for Research

It is clear that especially long glances off the forward roadway are dangerous (Horrey and Wickens, 2007; Klauer et al., 2006). The most obvious reason that they are dangerous is that a situation can develop while the driver's eyes are off the road that cannot be avoided when the driver glances back up on the road. There simply is not enough time. Horrey and Wickens' work with tails of glance distributions showed that longer than average glances were more critical and relevant from a safety perspective than average glances. What is not clear immediately is whether especially long glances would have an equally negative effect on initial hazard detection. If that were the case, then some of the crashes one sees when the glances are especially long may be a consequence of an increase in the time it takes to identify a latent hazard.

The research by Tsimhoni and Green is indicative of how visual demand varies as a function of road geometry. As expected, the demand is higher in the tightly radiused curves. The implication is that drivers performing a secondary, in-vehicle task would have a more difficult time identifying a latent hazard and take longer to identify it when they were negotiating tightly radiused curves as opposed to more gently radiused curves. Interestingly, the results on glance patterns complement this. Drivers whose vision is not occluded on a curve alternate glances between one far downstream and then several more upstream. Drivers whose vision is occluded take a continuous sequence of successive downstream glances towards the near point of the vehicle. The implication is that drivers who are performing a secondary task would behave similarly and therefore would be more likely to fail to identify a latent hazard. There is also the important question of how the threshold duration would influence detection probabilities as window size varies as a function of cognitive load exerted by a secondary task performed in conjunction with the primary task (driving). More specifically, the work on occlusion points to the existence of effects persisting from the mere occlusion of the forward roadway without the involvement of a secondary task. This is especially useful in my attempt to understand swapping effects in my first experiment. Swapping is defined by me as a change in the focus of attention. The performance decrements experienced by drivers when navigating an alternation sequence with a blank screen occlusion compared to the continuous glance condition is similar to that experienced by just replacing the background that one was focusing upon.

2.2 Change Blindness & Inattention Blindness

In a task where the driver alternates glances between the forward roadway and the cabin of the automobile, objects may appear that were not previously present. Additionally, if the driver's attention is on a secondary task, the driver may fail to process information upon which he or she is fixating. Any kind of failure to detect an object when looking in the direction of the object can be categorized as a kind of visual blindness. Jensen (2011) refers to two types of visual blindness: *change blindness* and *inattention blindness*. In layman's terms, these types of blindness are classic illustrations of scenarios wherein people fail to detect a simple change or to see something right in front of their eyes.

2.2.1 Change Blindness

Jensen defines change blindness as the failure to detect any substantial visual change to an attended object (Levin & Simons, 1997). Change detection has been used as a task for decades. Change detection occurs only when a change draws attention. It fails otherwise. Usually when visual changes occur, the variation in luminance is fairly noticeable. Change blindness ensues when other luminance changes or visual variations mask the change signals.

Jensen et al mention five steps for successful change detection (Jensen et al, 2011):

- There has to be direct attention to the location where the change is bound to happen;
- The item that was at the target location before the change has to be memorized;
- The new feature at the target location has to be memorized following that;
- Comparison between the two features in memory occurs after this; and
- A recognition that there is a discrepancy in the two features has to occur and is the final step.

Failures to detect a change (i.e., change blindness) could occur because the pre-change representation was never encoded in memory (Beck & Levin, 2003). Or, they could occur because there was difficulty comparing the first encoded object and the newly encoded object (Mitrof et al, 2011). Earlier research tried to account for change blindness by conducting reading-related studies. Jensen et al. changed the case of words while the participants made a saccade between words to see if the case changes affected their ability to comprehend the meaning. There were no effects of case changes. Flicker tasks have also been used to explain change blindness. Experimenters alternate an original and changed image back and forth by using a brief blank screen. For example, participants reading lines of mixed case text (e.g., 'The fLoRiDa eVeRgLaDeS' do not notice when all the letters change case (e.g., 'The FlOrIdA EvErGlAdEs') during an eye movement. Observers indicated no changes at all and did not seem to face any disruption while reading. Previous research says that participants require multiple alternations of the original and changed images to localize a change. Several studies show that changes during eye movements go unnoticed, and are minimally disruptive to reading, word naming or picture calling.

2.2.2 Inattention Blindness

The term 'inattention blindness' originates with the book with the same title (Mack & Rock, 1998). Inattention blindness is defined as a failure to notice an unexpected but fully visible item when attention is diverted to other aspects of the display (Jensen et al., 2011). Selective attention was studied extensively in earlier research as one possible explanation of the occurrence of inattention blindness. Previous studies have shown that attention can be object focused instead of space focused and hence it's likely that even when unattended information (Object 1) appears at the same spatial location as attended information (Object 2), participants may not notice Object 1 if attention is on Object 2 (Goldstein & Fink, 1981). Table 1 below lists the primary differences between change blindness and inattention blindness.

Dichotic listening tasks were popular in earlier literature and these tasks were used to study selective attention. In dichotic listening tasks, participants are asked to repeat every word that is spoken in their attended ear (the attended ear can be the left or right ear) as part of an ongoing audio stream (Moray, 1959). While the participants shadow the stream in their attended ear, the experimenter presents another stream in the unattended ear. It was noticed that participants typically failed to notice the semantic content of the unattended stream even when that information is unexpected, distinctive, or semantically meaningful.

Later studies attempted to determine whether selective attention was confined to the auditory modality (Neisser & Becklen, 1975). To make this determination, Neisser and colleagues designed a visual analog of dichotic listening known as the selective looking paradigm. The studies were designed to explore the nature of focused visual attention: do people focus attention on regions of space or do people focus attention on objects? Neisser et al. filmed two separate events and then combined them into a single display using a half-silvered mirror. In the composite display, all actors and events were partially transparent and overlapping, occupying the same locations on screen. As with the dichotic listening task, subjects could selectively listen to one video and ignore the other, even though the events occupied the same space in this case. As with dichotic listening tasks, subjects often missed a random event in the stream they weren't paying attention to. Further critically, these random unexpected events were obvious to those observers not performing a task requiring focused attention.

Table 1: Differences between Change Blindness & Inattention Blindness

Sl. No.	**Change Blindness**	**Inattention Blindness**
1.	Failure to notice an obvious change.	Failure to note the existence of an unexpected item.

2.	Change Blindness requires two displays to induce the phenomenon.	Inattention blindness requires a single display of the unattended target object.
3.	Inattention can be a cause of change blindness but it cannot be the only cause.	Engagement in multiple tasks can contribute to inattention blindness.
4.	Change blindness tasks can have multiple trials as participants are maintaining their attention on a specific task that is obviously present.	Inattention blindness task trials cannot be repeated as a learning effect will create ambiguity in results.
5.	There is a possibility of generalization especially when utilizing selective looking tasks	There is no scope for generalizability.

2.2.3 Relation between Change and Inattention Blindness

Both change blindness and inattention blindness are similar in the sense that the observer is blind to the changes occurring in either case. But the difference lies in the fact that change blindness usually refers to a failure to notice an obvious change while inattention blindness refers to a failure to note the existence of an unexpected item (Levin & Simons, 1997).

While the cause of inattention blindness is clearly due to inattention, change blindness may be the result of inattention with other accompanying factors. Change detection has been known to fail even when people focus all their attention on the object being changed. Change blindness can also occur when participants fail to clearly recollect the initial object placed in memory. In this scenario, when the object changes, participants can't retrieve the previous object from memory to compare with (Scott-Brown et al, 2000). This could simply mean that there was no information stored and therefore nothing with which to make a comparison after the change has occurred. Change detection can also fail when participants fail to compare the two encoded objects (Mitroff et al, 2004). However Jensen goes on to say that in most scenarios, change blindness occurs as a result of a combination of representation and comparison failures. We could therefore conclude that inattention blindness could be a special case of change blindness in which inattention to an object is a possible reason but not the only reason for the occurrence of the phenomenon.

Change blindness however cannot be classified as a special case of inattention blindness because in inattention blindness the participants fail to note the existence of an unexpected item (Levins& Simons, 1997). For change blindness to be classified as inattention blindness, it seems necessary that participants fail to note an *obvious* change. Expectation of an event leads people to allocate resources to the object even if it's not the primary task. This implies that the object representations in inattention blindness tasks are truly unexpected (Most et al, 2005). Hence, we can safely conclude that change blindness is definitively different form inattention blindness. In other words, change blindness is not a form of inattention blindness.

2.2.4 Implications for Research

Clearly, change blindness and inattention blindness could explain – at least in part – why alternating glances inside the vehicle and on the forward roadway (the *alternating glance condition*) could make the initial detection of a latent hazard more difficult than a continuous glance on the forward roadway (the c*ontinuous glance condition*). For both conditions, the location and content of the information projected on the retina is changing moment by moment. First, consider the effects of change blindness. The location of successive glances on the roadway is probably going to be on different areas of the scenario when the driver is alternating glances. Thus, the driver will have a vague memory at best of what appeared previously at the area of the scenario which is fixated when the driver glances back again on the road. If it is information changing over time that defines an area in a scenario as a latent hazard, then the change is very likely to go unnoticed in the alternating condition because different areas of the scenario are fixated in successive glances. However, the change could be more noticeable in the alternating condition than the continuous if the driver in the alternating condition fixates the location of the scenario when the latent hazard is developing. Specifically, if the change in the scenario between glances that identified a location as one which could contain a latent hazard was relatively dramatic, then the performance of drivers when they alternated glances could better than the performance of drivers when they glanced continuously at the roadway. This implies that it will be necessary to consider where the driver glanced on the roadway before glancing inside the vehicle in order to predict whether change blindness could be the cause of the occasional instance where drivers were actually faster to detect a latent hazard.

Inattention blindness explains the failure of a person to identify or detect the presence of an unexpected item. Engagement in multiple tasks contributes to inattention blindness and in my work, I intend to examine how the performance of a secondary task in conjunction with driving (multi-tasking) affects an individuals' ability to detect potential threats especially in the alternating glance condition where the forward roadway is periodically interrupted. It could be surmised that the performance of two non-related tasks involving different mental processes could compound the crash risk associated with multi-tasking. The performance of drivers in the alternating condition is likely to be better than that of drivers in the continuous glance condition if indeed inattention blindness attributes to quicker saccading and hence, more sensitive to changes in the visual environment. Change blindness can additionally explain swapping effects.

Swapping effects occur due to a substantial visual change (replacement of the forward roadway with a blank screen) to the attended object (for my experiments the forward roadway). Swapping effects are different from switching effects in that the latter involves attending to a specific secondary task, albeit one that places minimal load on the driver when he attends to the forwards roadway.

2.3 Secondary In-Vehicle Tasks: Texting and Other Tasks

The influence of a number of in-vehicle tasks on driving performance has been studied. Texting is arguably the task that puts drivers most at risk (Lee, 2007) and therefore is given the most attention below. The influence of other in-vehicle tasks on driving performance has also been studied. However, there has been no real effort to separate out the effects of the secondary, in-vehicle task on the information that is processed while the driver is glancing up at the forward roadway when that information requires initial hazard detection.

2.3.1 Texting and Crashes

It has been well documented in simulator studies that cell phones have a negative impact on a number of different measures of driving performance (Strayer et al., 1999, Reed & Robbins, 2008), though the evidence is mixed when one considers the evidence from epidemiological studies (McEvoy et al. 2005; Klauer, 2006) and naturalistic studies (Young, 2012). It is very clear from naturalistic studies that text messaging greatly inflates the risk of crashing, by a factor of almost 23 (Klauer, 2006). The exact reasons why this is the case have been examined in the following studies.

2.3.2 Texting: Effect on Driver Behaviors

In 2006, Strayer et al. conducted research to investigate the effects or negative impairment associated with conversing on a telephone while driving (Strayer, Drews & Crouch, 2006). The study design employed by them had 40 adult participants ranging in age from 22 to 34 with an average age of 25. The study required the participants to be social drinkers (3 to 5 alcoholic drinks a week). Of the 40 participants, 78% owned a cell phone and 87% of the cell phone owners self-reported phone use while driving. The authors employed a within subject design wherein the order of subsequent alcohol and cell phone sessions were counterbalanced across participants. The experiment entailed a brake response task where the lead vehicle released its brake and accelerated to normal highway speed. Failure to depress the brake would result in the participant colliding with the lead vehicle. In the alcohol session, participants drank a mixture of orange juice and vodka calculated to achieve a blood alcohol level of 0.08. The cell phone condition consisted of three 15-minute counterbalanced conditions: baseline driving, driving while conversing on a handheld cell phone, and driving while conversing on a hands-free cell phone. The researchers found out that drivers using a cell phone exhibited a delay in their response to events in the driving scenario and were identified to be more likely to commit a traffic infraction or be involved in an accident. Drivers in the alcohol condition exhibited a more aggressive driving style, driving closer to the vehicle immediately in front of them. While alcohol impaired drivers had shorter following distances, cell-phone distracted drivers exhibited longer reaction durations. Cell phone drivers were also found to be more likely to be involved in accidents. Also of note was that the differences in impairments between hand-held and hands free drivers were barely significant indicating that the conversations themselves were sufficient to cognitively load the individual enough to render him or her impaired in crucial driving instances. The authors compared a drunk driver to a person using a cell phone with the goal to establish a benchmark for assessing risks related to impairment.

The Monash University Accident Research Center (MUARC) conducted a study to evaluate the effects of text messaging on the driving performance of young novice drivers

(Hosking, Young & Regan, 2009). Researchers at MUARC hypothesized that there would be a decrease in mean speed and increased variability in speed when drivers were texting. They also predicted increased lane excursions and poor lane positioning. The study involved twenty students aged between 18 and 21 years. All participants were chosen to have familiarity with the Nokia interface as well as significant familiarity with predictive texting. The study was conducted on a driving simulator and the simulation involved an 8 km long dual lane stretch with speed limit between 50 to 80 km/hr. There were two experimental drives with the same 8 test scenarios. The drives were counterbalanced, with 4 scenarios in the first drive serving as a control section for subjects when they performed the predictive text sending/receiving task while the second drive was balanced to have the subjects perform their predictive entry task on the other four scenarios. The results of the study indicated that drivers tended to significantly vary their lane positioning when sending or receiving text messages. A chi-square-goodness-of-fit test indicated a direct correlation between lane excursions and text messaging. Text messaging was found to cause drivers to inadvertently traverse across lanes more often. An analysis of visual demands by the authors indicated that the duration of drivers' off-road glances were half a second more in the text messaging condition than in the baseline (non-texting) condition. Finally, the results also revealed that when drivers were text messaging, the variability of their time headway in lead-vehicle following tasks doubled at the least.

2.3.3 Texting: Effect on Vehicle Behaviors

Reed & Robbins (2008) conducted a study that in which the hypothesis was tested that performance would be worse while writing a text message than while reading a text message. The authors hypothesized that performance of text messaging tasks while driving would affect drivers' ability to react (increased reaction time, slower response times), following (headway) distance, lane maintenance metrics (lateral lane positioning) and speed (reduced speed). The results of this study demonstrated impairment by concurrent text messaging tasks. Reaction times, car following ability, lane control, and driver speed were used as measures of driver performance. The study recruited 17 participants aged between 17 and 24. All participants were regular users of cell phones and the text messaging application. Only alphanumeric keypad users were included in the study. Participants drove two identical drives as a part of the study: the first while text messaging and the second without any distractions. The reaction times to task un-related trigger stimuli were found to be higher when participants were involved in a text messaging task. The authors also noted a general failure to detect hazards by distracted drivers. Drivers engaged in the secondary text messaging task were found to detect hazards at a much lesser rate than non-distracted drivers. Engaged drivers displayed speed modulation especially in attempts to mitigate accident risks. In my work, I intend to determine if extremely brief threshold durations are a contributor of hazard detection impairment. Furthermore, the alternating glances condition serves to mimic real-time change blindness encountered by clueless, careless drivers. The study observed that drivers tended to reduce their speed in text messaging conditions. As surmised by the study, the failure to detect hazards, increased response times to hazards, and exposure time to that risk have implications for driver safety. The authors also suggest the possibility that the drivers were aware of the impairment whilst engaged in text messaging tasks and hence chose to reduce their speeds in order to mitigate accident risk. This study found that reading messages resulted in a 12.7% increase in lateral position variability whilst that for writing a message increased by 91.4% (Reed & Robbins, 2008).

In their study, Sexton et al. (2000; 2002) attempted to investigate the effects of cannabis on driving. Their attempt was to validate previous studies that showed severe an impact on performance of simulated and actual driving and divided attention tasks under the influence of alcohol. Previous cannabis studies indicated that task performance involving all psychomotor involvement and continuous attention suffered impairment. The study under discussion (Sexton, 2000) was conducted on a driving simulator at TRL and involved experienced cannabis and alcohol users of the male gender. There were two cannabis conditions: placebo and the low dose cannabis condition and the drivers were expected to carry out laboratory tasks and drive the simulator under both conditions. There were two additional alcohol conditions: placebo and a dose leading to a Blood Alcohol Concentration of 50mg of alcohol per 100ml of blood (This is an alcohol plus cannabis condition in which the alcoholic drink was administered before smoking to maximize simultaneous impairment). There were a total of four groups: - placebo, alcohol only, cannabis only and alcohol plus cannabis conditions. The results of the study showed a reduction in average driving speed and an increase in the minimum time headway when participants had an active dose of cannabis, regardless of the alcohol dose. Measurements from an adaptive tracking task indicated significant performance deterioration as the dose level increased. Sexton et al. concluded that cannabis had a measurably worsening effect on psychomotor performance, especially tracking ability. Influenced drivers tried to compensate for their impairment by driving more slowly however, they were found to suffer from severe lane control issues. Sexton et al. (2000) found that drivers displayed an increase of around 35% in lateral position variability with high doses of cannabis whilst Sexton et al. (2002) found an approximate 14% increase in SDLP for the cannabis and cannabis + alcohol conditions.

2.3.4 Other Secondary In-Vehicle Tasks

Blanco et al. (2006) comment on the impact of secondary task cognitive processing demand on driving performance. Blanco et al. investigated the characteristics of in-vehicle information system tasks that could hinder driving performance due to uncertainty build up and cognitive capture. While driving, participants were presented with in-vehicle information system tasks with various information densities, decision-making elements, presentation formats and presentation modalities (visual or auditory). The study was conducted on the road using an instrumented 1995 Oldsmobile Aurora and a 1997 Volvo Heavy Truck with a 48-foot trailer. The study involved thirty six truck drivers across both genders. Six different route selection tasks were presented to the drivers. There were two groups of drivers: light vehicle drivers and heavy vehicle drivers. The results from the study showed that the addition of one or more decision making elements to a search task substantially adds to the attention demand related to automotive secondary tasks. Another important finding was that even a simple search only task presented as a secondary task while driving provided a higher cognitive loads than a conventional secondary task like activating a turn signal, adjusting the power mirrors, etc. The experiments conducted by Blanco were aimed at investigating the characteristics of in-vehicle information systems that could hinder driving performance (Blanco, Biever, Gallagher and Dingus, 2006).

2.3.5 Implications for Research

It is clear from the above that increasing the cognitive load on drivers by imposing secondary, in-vehicle tasks has an effect on crashes (e.g., texting, Klauer et al., 2006), driver behaviors (e.g., brake response times, Strayer et al., 2006) and vehicle behaviors (e.g., SDLP, Sexton et al., 2002). However, only one study actually looked at the effect of secondary, in-vehicle tasks on hazard detection (Reed and Robbins, 2008).

They found that drivers were less likely to detect hazards when performing an in-vehicle task. The types of potential hazards evaluated included loops, and car following events. Reaction times to task un-related stimuli was observed to be higher when reading or writing a text message. Reed and Robbins also reported a failure by drivers to respond to stimuli when engaged in concurrent text messaging. The increased stopping distance (12.5 m) would have easily made the difference between a crash and an avoidance.

In my work, I attempt to understand for what threshold duration, the likelihood of detecting a potential hazard remains maximum. It is clear that at non- optimal threshold durations involving alternating glances between the forward roadway and the inside of the vehicle while engaged in a loaded or non-loaded secondary task (while driving), the likelihood of successfully detecting a potential hazard drops exponentially. Furthermore, it is also important to understand if when the window is lesser than the threshold duration, load as a result of secondary task contributes to a spillover effect on the primary task of driving thereby further reducing the likelihood of detecting a potential hazard. In the alternating glances condition, the alternation between the forward roadway and the inside of the vehicle is likely to cause drivers to fixate on a visible area pre-task which in turn may lead them to cautiously scan for potential unmaterialized hazards. However, in the continuous glance condition, drivers are presented with a continuous view of the forward roadway and the intuition here is that successful initial hazard detection by the drivers in this group will lead to a higher likelihood of scanning for potential hazards (Since change blindness is limited by the continuous non-interrupted presentation of the forward roadway.

2.4 Secondary Forward-Roadway Tasks: Cell Phones and Other Tasks

An understanding of the effects of cell phone use on driving performance gives us direct knowledge of the effects of cognitive load on driving performance when the driver is glancing ahead at the forward roadway. This knowledge can be used to infer the effects that the load imposed by a secondary, in-vehicle task might have on the driver while he or she was glancing up at the forward roadway.

2.4.1 Cell Phones and Crashes

Titchener et al. report driver distraction as the leading cause of traffic crashes worldwide. They conducted a survey that indicated 30 percent of crash victims who attended a hospital in Perth, Western Australia, identified at least one distracting activity at the time of their crash. And cell phones are reported to be a significant contributor to these in vehicle distractions (Titchener, White & Kaye, 2009). McEvoy et al. mention that a few epidemiological studies have assessed the risk of crashes associated with phone use (McEvoy, Stevenson, McCartt, Woodward, Haworth, Palamara & Cercarelli, 2005). They suggest that police crash reports have only been vaguely helpful in this regard since the information on the driver's phone use is unreliable. They used a case-crossover design, a variation of a case-control design that is appropriate when a brief exposure causes a transient rise in the risk of a rare outcome. The drivers' phone use at the estimated time of crash was compared to his or her phone use at some other time period. The authors found that a person using a cell phone while driving was four times more likely to have a crash that would result in hospital attendance. They reported that sex or age group didn't influence the increased likelihood of a crash.

Consistent with the findings reported by McEvoy et al. (2009), Redelmeier and Tibshirani (1997) studied 699 drivers who had cellular phones and were involved in motor vehicle collisions resulting in damages. The study employed an epidemiological method, the case-crossover design, to study whether using a cell phone while driving increases the risk of exposure to a motor vehicle collision. Each participants' cell phone calls for the week prior to the collision were analyzed via the use of billing records. The authors concluded that the risk of a collision when using a cellular phone is four times higher than when the cell phone is not in use. Calls placed close to the time of collision were found to be extremely hazardous: the relative risk for calls placed within 5 minutes of the collision was 4.8 as compared to only 1.3 for calls placed more than 15 minutes before the collision. The study also found no safety advantages for hands free cell phones over hand-held phones.

Stutts et al. report that one-fourth of vehicle crashes result from a driver being inattentive or distracted (Stutts, Reinfurt, Staplin & Rodgman, 2001). The goal of their study was to identify the major sources of driver distraction and the relative importance of the distractions as potential causes of crashes. The study used data from the Crashworthiness Data System (CDS) which is an annual probability sample of approximately 5,000 police-reported crashes involving at least one passenger vehicle that has been towed from the crash scene. The two variables keyed for the analysis include: (a) the attention status of the driver (attentive, distracted, looked but did not see, sleepy, or unknown), and (b) the specific distracting event for each distracted driver. The overall data indicated that 48.6 % of the drivers were identified as attentive at the time of crash while 8.3% were identified as distracted and 5.4% as "looked but did not see" (about 14% of crashes occurred as a result of distraction or non-detection). Young drivers were found to be most likely to be involved in distraction-related crashes. There were higher proportions of adjusting radio/CD events occurring in nighttime crashes while there were higher proportions of moving object, in vehicle events occurring in crashes on non-level grade roadways.

A recent study by Richard Young (2012) examines the possibility of a relative positive bias in epidemiological studies. Young argues that recent epidemiological studies (McEvoy et al., 2009; Redelmeier and Tibshirani, 1997) have estimated little or no increased risk of automotive crashes as a result of driver distraction, whereas earlier case-crossover designs estimated a relative risk of about four times. Young attempted to determine if earlier studies had introduced a positive bias in relative risk estimates by overestimating driver exposure in the control segments. The study design involved tabulating driver exposures in a "control" window and a “case” window across 100 days for 439 instrumented vehicles. Young reported that driving exposure for control windows was about one-fourth that of case windows containing at least some driving. After further adjustment for imbalance in window populations, Young re-estimated the relative risk in earlier case-crossover studies, reducing that estimate from 4 to 1. Young concluded that earlier case-crossover studies must have likely overestimated the relative risk for cell phone conversations while driving by implicitly assuming that driving during a control window was full time when it may not have been the case (Young, 2012).

2.4.2 Cell Phones: Effect on Driver Behaviors

Strayer et al. conducted a study in 2001 that reported perceptual impairments associated with using cell phones while driving. The study had 64 participants with an average age of 21.2. The design had four groups: radio control, book-on-tape control, hand-held cell phone, or hands-free cell phone groups. The participants had to perform either a tracking task while driving or had to perform a conversation task in addition to the tracking task while driving on the simulator. They reported that subjects engaged in cell phone conversations missed twice as many simulated traffic signals as otherwise and they had longer reaction times (Strayer, Drews, Albert & Johnston, 2001). Reaction time is one of the most important factors that help us distinguish a safe driver from an unsafe one. For a task like driving that involves a large cognitive workload, it is important for drivers to have fast reaction times to act rapidly in case of possible hazard materialization.

Consistent with this, Strayer et al. (2003) has conducted research that examines the effect of hands free conversations on simulated driving. This particular study had 40 participants with an average age of 23.6 and the study was conducted on a driving simulator. The simulated route consisted of a 40-mile multilane beltway with on- and off- ramps and two-lane traffic in each direction separated by a grassy median. Participants drove the highway in four sections of

10 miles each. Half the scenarios were used in the single task condition while the other half were used in the dual task condition involving both the driving task and a cell phone task. They determined that participants looking at objects in the driving environment were less likely to create a durable memory of those objects if they were conversing on a cell phone. In-vehicle conversations are said to be less distracting than cell-phone conversations because of easier cognitive processing loads (Strayer & Drews, 2007). This is consistent with the research that suggests that conversations impair driver's reactions to vehicles braking in front of them (Strayer, Drews & Johnston, 2001).

A recent paper by Transport Canada (2002) discusses the cognitive demands of cell phones and the impact of that demand on driver performance. The authors suggest that though the introduction of hands-free operation for cell phone devices is intended to reduce the distraction due to manual operation of cell phones, in the first place the distraction may not have resulted from manual manipulations but may have been due to the cognitive demands of cell phones. The authors performed a study that investigated the effects of cognitive distraction on driver behavior while the drivers were carrying out tasks that varied in cognitive demand. The study had 21 participants aged 21 to 34 with an average age of 26.5. The experiment was on-road in nature and participants drove a 1999 Toyota Camry. The test route was a 4 km stretch of a busy 4-lane city road on which the driver drove north and south for a combined 8 km. Each participant completed three runs: easy task condition (e.g., easy addition), difficult task condition (e.g., difficult addition) or no additional task. The results of the experiment and further analysis revealed that the drivers made fewer saccades, spent more time looking centrally and spent less time looking to the right periphery under conditions of increased cognitive load. The authors identified a larger number of hard braking incidents and changes in inspection patterns of the forward view when drivers performed the more demanding tasks. The study recommended that a better understanding of driver-device interaction methods could result in improved designs that minimize the amount of distraction (Harbluk and Noy, Transport Canada 2002).

Although some few studies show that some aspects of driving are unaffected by a secondary task (Brookhuis et al., 1991; Engstrom et al., 2005), a recent meta-analysis study suggested definite costs are associated with cell phone use while driving (Horrey & Wickens, 2006). Horrey and Wickens reported significant deterioration in driving performance in the presence of secondary tasks. Conversational tasks in general have greater costs than information-processing tasks (a typical information processing task would involve the use of multiple mediums to interact, understand and respond to the data at hand; text messaging is an excellent example of an information processing task. Texting involves reading a message (visual, cognitive), comprehending the message (cognitive) and composing a message (motor, visual, cognitive) and very often these subsequences are performed in a semi-parallel manner) when those costs are measured in terms of their impact on driving performance (Horrey & Wickens, 2006). This may be attributed to the “greater engagement” associated with actual conversations. Although information processing tasks involve perceptual resources and working memory, they do not share the same degree of engagement. Importantly, information processing tasks have a detrimental impact on driving performance but with smaller costs. Text messaging could be defined as an information processing task (Horrey & Wickens, 2006).

Consistent with the above, Matthews at al. tried to determine the effect of different types of cell phones on total subjective workload. The types of cell phones examined include hand held, hands free with an external speaker and personal hands free. The total subjective workload was measured using NASA-task load index (TLX) and the modified rhyme test (MRT). The experimenters concluded that the physical demand wasn’t a high contributor to the workload and they determined that the personal hands free cell phone would interfere the least with cognitive demands of driving.

2.4.3 Cell Phones: Effect on Vehicle Behaviors

The dangers of phone use while driving are the distractions induced by taking the driver's attention away from the driving task and the road ahead. The driver is expected to monitor and control the vehicles' lateral and longitudinal position along a safe path. Obvious side-effects/consequences of internal distractions like cell phones include poor lane positioning and greater speed variability. (Brookhuis et al., 1991; Burns et al.2002).

Just et al. report a decrease in brain activation associated with driving when listening to someone speak (Just, Keller & Cynkar, 2008). The study that they conducted used functional magnetic resonance imaging (MRI) to investigate the impact of concurrent auditory language comprehension on the brain activity associated with a simulated driving task. Participants were asked to steer a vehicle along a curved road while listening to spoken sentences that they judged as true or false. The dual-task condition caused a significant deterioration in driving accuracy which presumably was due to the processing of auditory sentences. The study identified language comprehension performed concurrently with driving draws mental resources away from driving and produces deterioration in driving performance.

It has long been regarded important to maintain attention to the forward roadway. Lack of attention has been determined to contribute heavily to crashes (Just et al., 2008). There are several sources that indicate distraction to be a severe problem for novice drivers. These sources include police crash reports, naturalistic studies, field experiments, simulator studies and studies of older drivers (Chan et al., 2009). Researchers have also examined the effects of cell phone distractions on younger and older drivers. Their findings reported reaction times 18 percent slower, following distances 12 percent greater and speed recovery (following braking)

17 percent longer (Just et al., 2008). Cell phone induced effects were reported to be similar for younger and older adults (Strayer & Drews, 2004). Similar conclusions may be drawn for a text messaging perspective too.

2.4.4 Other Forward Roadway Secondary Tasks

Recarte et al. performed experiments to study the effects of mental workload on detection and discrimination capacities. Mental workload was manipulated by having the participants perform several mental tasks while driving. The performance criteria were set by using a simultaneous visual-detection and discrimination test. The study involved 12 participants and the results of the study showed that mental tasks induced visual-detection impairment and produced spatial gaze concentration. Ocular behavior analysis showed that this impairment was due to late detection and poor identification. The results also indicated that increased workload resulting from mental tasks produced endogenous distraction, thereby affecting the capacity to process visual stimuli. Further, performance of mental tasks was found to prevent application of top –down processes as exhibited by a driver involved in a collision who said, for example, “I didn’t expect it,” “I looked but failed to see, “ or “I saw it too late.” Their results reflected incremented pupil size, indicating additional mental effort and spatial gaze concentration (Recarte and Nunes, 2003).

2.4.5 The Role of Experience

There is recent research that talks about eliminating the impairment induced (due to cell phones) by practice (Shinar, Tractinsky & Compton, 2005; Cooper & Strayer, 2008). Shinar and colleagues found out that 96 minutes of simulator-based practice spread over 5 days was sufficient to eliminate driving impairment from cell phone use in a group of relatively experienced drivers. Shinar et al. observed dual task learning on the mean and standard deviations of lane position, steering angle, and speed. Additionally there was evidence of learning being greatest when driving was coupled with a math task rather than naturalistic conversation.

At the same time Cooper and Strayer (2008) conducted a study that examined the effect of practice on concurrent driving and phone conversations. Their study involved 60 participants. The average age was 24.8 years. The experiment was conducted on a driving simulator and involved four unique scenarios, two each from a city database and highway database. The scenarios differed in terms of direction of travel, location of braking events, and vehicle model. The results indicated that drivers conversing on a cell phone responded more slowly to lead vehicle braking. Repeated scenario exposure during the practice phase of the experiment did not result in significant improvement in performance for drivers using a cell phone. Overall, the study findings were consistent with the findings of the skill acquisition literature (The concurrent performance of two unpredictable, attention-demanding tasks will exhibit persistent impairment, As stated by Kramer et al., 1995).

2.4.6 Implications for Research

The review and discussion of studies in the section above provide an understanding of how cognitive load exerted by secondary cell-phone task affects driver and vehicle behavior when the driver looks up at the forward roadway, after having glanced within the vehicle to perform an in-vehicle secondary task (or a unit of such a task). Titchener et al., 2009 and McEvoy et al., 2009 used case –crossover designs to report that cellphone usage increased risk of exposure to a motor vehicle collision. Stutts et al., 2001 reported that one-fourth of vehicle crashes resulted from a driver being inattentive. Recently, Young, 2012 examined the possibility of a positive bias in epidemiological studies and argued that recent studies may have estimated little or no increased risk of automobile crashes as a result for driver distraction.

Studies by Strayer (2001, 2003) and Harbluk (2002) highlighted the effect of cell phones on driver behaviors. Reaction times were found to be slower and a high number of hard braking events indicated the negative influence of cell phones on driver behaviors critical to safety. Conversational tasks and information-processing tasks were found to have a detrimental impact on driving performance due to high "engagement" associated with such tasks.

The impact of cell phones and associated cognitive load on vehicle behaviors was reported by Brookhuis (1991), Burns (2002), Just (2008) and Strayer (2004). The obvious consequences included poor lane positioning and greater speed variability. Slower reaction times, closer following distances and slower braking recovery all indicate the de-marginalized impact of secondary tasks such as cell phones when performed concurrently with driving. In my work, I attempt to investigate the spillover effects of such secondary tasks (both loaded and non-loaded) on the primary task while the driver attempts to alternate his glances between the forward roadway and the inside of the vehicle. The effects of task switching compounds the detrimental effect.

Recarte, 2003 specifically tried to determine the effects of mental workload on detection capacity and found that mental tasks induced visual-detection impairment and produced spatial gaze concentration. Late detection and poor hazard identification was confirmed via the use of eye tracking. I intend to do the same in my research so as to distinguish between the effects of cognitive load and cognitive spillover resulting from secondary tasks. Shinar (2005) and Cooper (2008) both discuss the elimination of impairment via practice. Shinar reports success at practice while Coopers' results were found to align with that proposed by Kramer in 1995 (The concurrent performance of two unpredictable, attention-demanding tasks will exhibit persistent impairment). This inconsistency in findings might be due to the difference in the average experience of the population investigated (seems like Shinar used more experienced drivers while Cooper used less experienced drivers. Further, the tasks used differed significantly. While Shinar used math tasks, Cooper used a cell phone task and it could be argued that cell phones as a secondary task can never be mastered while tasks that involve learning could exhibit some form of practice or learning effects thereby indicating a false trend observed in post-training performance.

2.5 Secondary Driving Tasks: Prevalence and Engagement

Secondary tasks have become so prevalent in society that it takes more than simple outreach and education to get drivers to understand the true risk of multitasking. The existing literature talks about the prevailing attitudes regarding multitasking and public opinion regarding the same. Although, engagement in a secondary task is almost always voluntary, it is not necessarily a conscious decision. This makes it all that much harder to regulate.

2.5.1 Texting Prevalence

Over 7 billion text messages are sent each day throughout the world (The GSM Association, 2007). In 2010, the Pew Research Center conducted a project that, interestingly, concluded that adults were just as likely as teens to have text messaged while driving and were substantially more likely to have talked on the phone while driving (Pew Research Center, 2010). As reported by Pew Research Center, forty-nine percent of adults and teens said that they have been passengers in a car when the driver was sending or reading text messages on their cell phone. The Pew research Center also determined that over 47% of all texting adults admitted to having sent or read a text message while driving. This compares to one in three texting teens who said they had "texted while driving", in a September 2009 survey (Pew Research Center, 2010).

In 2009, the AAA Foundation for Safety conducted a nationally representative telephone survey that found over two out of every three drivers admit to talking on cell phones while driving in the past month, and over one in five admitted to reading or sending text messages while driving. Rates of self-reported text messaging while driving were found to be highest amongst teenage drivers. Data from the National Highway Traffic Safety Administration (NHTSA)'s observational studies report that 6% of drivers were talking on handheld cell phones, an estimated additional 5% were talking on hands-free cell-phones, and 1% were "visibly manipulating hand-held devices" at any given daylight moment in 2008 (AAA Foundation for Traffic Safety Survey).

2.5.2 Cell Phone Prevalence

Lamble, Rajalin and Summala, (2002) reviewed road-user surveys on the use of cell phones on the road in Finland where the mobile phone ownership rate is the highest in the world (70% in 2000). The proportion of drivers that chose to use a cell phone while driving rose from 56% in 1998 to 68% in 1999, while the proportion of drivers experiencing dangerous situations rose from 44% to 50%. Over 48% of the interviewees believed that the government should ban the use of hand-held mobile phones while driving, and another 27% believed that all types of mobile phone use should be banned while driving. Those drivers who used their phones regularly were more likely to want some form of restriction than those who had lower usage. Three in four cell-owning adults said they had talked on a cell phone while driving while just over half the teens reported talking on a cell phone while driving (Pew Research Center, 2010)

2.5.3 Secondary Task Engagement

Factors influencing intentions to use a cell phone while driving are many. Walsh et al. conducted a study where they examined the factors associated with "dialing and driving", as they termed it (Walsh, White, Hyde & Watson, 2008). Their intention was to examine the efficacy of the Theory of Planned Behavior (TPB) in predicting intentions to use cell phones while driving amongst peers and other cohorts of drivers.

Nemme et al. employed the TPB in examining peoples' driving behavior. According to this model, behavior is determined by the individual's attitude, subjective norm, and perceived behavioral control. Attitude refers to the drivers' evaluation of performing the behavior (a secondary, in-vehicle task in the current situation; e.g. the driver's evaluation of whether it is OK to text at a particular point in space and time on the road because there is little or no chance of risk); subjective norm refers to the social pressure to perform the behavior; and perceived behavioral control indicates the level of difficulty perceived by the driver in performing or not performing the behavior. The primary aim of their study was to examine the utility of TPB in predicting both the intention to and the subsequent act of text messaging while driving amongst Australian drivers. Their findings were consistent with their hypothesis (Nemme & White, 2010).

Drews et al (2009) suggest human factors improvements in cell phone interfaces as a possible reason for the popularity of text messaging. Drews says that the emergence of simpler and potentially more convenient methods of text entry like the "text on nine keys" (T9) predictive text entry system may have contributed towards popularizing text messaging. T9 uses a built-in dictionary to predict an entry according to the most likely phrase for the current entry based on earlier inputs. The T9 entry system has proved to be far more convenient than the old alphanumeric mode that uses the same number of keys but warrants multiple key-presses to ensure expected input.

2.5.4 Implications for Research

Studies conducted by Pew Research Center, 2010 and AAA Foundation for Safety, 2009 conducted representative surveys to identify texting prevalence amongst the driving population. Pew Research Center reported that adults were just as likely as teens to text while driving. While, AAA Foundation reported teens as the population most actively involved in text messaging while driving. The difference in conclusions could be attributed to the fact that data collected was self-reported and hence, the results may include the judgment of the individual (he/she willfully admitting to text messaging while driving). Self-reported variables always have a larger room for standard error and deviation.

Summala (2002) reported that regular high volume users of cellphones were likely to want stricter regulations and enforcements curbing phone use, as opposed to lower usage individuals. This potentially implies that regular users of cell phones (while driving) are well aware of the risks associated with multitasking but prefer some form of enforcement to boost prevalent user mentalities. Nemme (2010) attempted to predict intentions to use cell phones while driving (amongst teens and older drivers) using the Theory of Planned Behavior. The model describes behavior as determined by individuals' attitude (a secondary task), subjective norm (social pressure to perform a behavior) and perceived behavioral control (level of task difficulty as perceived by the driver). The results reported were consistent with intuition that individuals were willing to engage in a task, either under peer pressure or perceived social norms, especially if the perceived task difficulty is low). In my dissertation, as I attempt to understand glance patterns as a factor of cognitive load, it is equally important to understand basic underlying social perceptions and associated norms of accepted behavior. It is counterintuitive to assume that drivers in the continuous glance condition are likely to allocate more resources to hazard detection to mitigate the effect of the distraction from the secondary task since, prevalent user mentalities suggest that the biggest culprits of distracted driving are often the ones who are aware of the risks and knowingly choose to seek risk in a less than ideal dynamic traffic environment. However, in the alternating glance condition drivers are more likely to suffer from the spillover effects of the secondary task both as a result of task switching and as a compounded effect of multi-tasking.

CHAPTER 3

EXPERIMENT 1

There are two goals of Experiment 1, each related to understanding how glances away from the forward roadway interfere with hazard anticipation. To begin, consider the various definitions that have been given above (the definitions are broadened to include terms used in both Experiments 1 and 2). They will be needed below and are redefined in **Table 2** for the reader's convenience.

Table 2: Terminology

Sl. No.	Terminology	Definition
1.	*Threshold Duration*	The minimum length of time in an alternating sequence of glances inside and outside the vehicle a latent hazard needs to be visible after a driver returns his or her gaze from inside the vehicle to the forward roadway in order for the driver to identify the hazard with the same likelihood that the driver would were he or she to be looking continuously at the roadway. (Note that for the alternating high load condition in Experiment 2 there may be no threshold duration.)
2.	*Window*	The duration of the glance on the forward roadway in an alternating sequence of glances inside and outside the vehicle. The threshold duration is then equivalent to the minimum duration of the window at which the driver can identify a hazard with the same likelihood as he or she does when glancing continuously at the roadway
3.	*Alternating Condition*	Any situation in which the driver alternates glances between the forward roadway and an in-vehicle task. These include both the alternating baseline and alternating low load conditions in Experiment 1 and the alternating baseline, low load, and high load conditions in Experiment 2.

4.	*Continuous Condition*	The situation in which the driver glances continuously on the forward roadway.
5.	*Swapping Effect*	The effect of replacing a view of the forward roadway with a blank center screen on hazard anticipation.
5.	*Switching Effect*	The effect of switching attention from driving to a secondary task on hazard anticipation above and beyond whatever effect swapping has.
6.	*Spillover Effect*	The existence of an effect on a driver's ability to detect hazards when glancing at the forward roadway that is generated by a load placed on the driver by an in-vehicle secondary task not only during the period of time the driver is glancing inside the vehicle, but also during the period of time that the driver glances back up at the forward roadway.

With these definitions in mind, there are two related aims for Experiment 1. To repeat, the first aim is to determine the average threshold duration in the alternating conditions and how the threshold duration varies in the alternating conditions as a function of factors which influence the likelihood that a threat will be detected, including: (a) how the threat is processed (top down or bottom up); (b) where the threat is located (fovea or periphery); and (c) the load (continuous, alternating baseline, alternating low load). The second aim is to determine whether hazard anticipation performance decreases as the duration on the forward roadway decreases in the alternating conditions and, if so, how the difference between the likelihood that the threat is detected in the alternating and continuous conditions when the window is less than the threshold duration varies as a function of the above factors.

3.1 Method

Drivers in this experiment perform a secondary in-vehicle task as they navigate through various sections of a virtual world involving two-lane and four-lane roads in a suburban environment.

Participants were divided into three groups. Drivers in the *alternating baseline condition* were alternately shown at various points in a driver a blank center screen (for 2 s) and the forward roadway (for 1, 2, 3 or 4 s). Drivers in the *alternating low load condition* were alternately shown at various points in a drive a target center screen (for 2 s) and the forward roadway (for 1, 2, 3 or 4 s). They were asked to complete a task which places a load on the driver only when the driver is glancing inside the vehicle. Spillover effects were designed to be nonexistent or minimal, i.e., no aspect of the secondary task should require processing during the period of time the driver is glancing on the forward roadway. Only switching and swapping (alternating low load) or just swapping (alternating baseline) effects should be present. Drivers in the continuous (*control*) condition were asked to navigate the virtual world without being shown a blank center screen at any point in the drive.

3.1.1 Participants

In this experiment, the driving performance of younger drivers was evaluated on the driving simulator. A total of forty five younger drivers (between the ages of 18 – 20) with an average age of 19.3 (SD = 0.831) and average driving experience of 2.3 years (SD = 0.492) were recruited as participants for the study from the University of Massachusetts Amherst and surrounding areas.

3.1.2 Secondary Task

The secondary task for this experiment was chosen with the criterion that when the forward roadway is visible, it (the secondary task) must place no load on the driver during the period of time in which the road is visible. The secondary task used for this experiment is listed in **Table 3** below.

Table 3: Secondary Task for Experiment 1

Task
The center simulator screen displays a 5x3 search matrix of 15 random characters (alphanumeric and special, e.g., “*”), where the driver was required to count and report verbally the number of times the character ‘t’ appeared on each occurrence of the search display (See **Figures 5&6**).

The task was chosen keeping in mind that the experimenter had to be able to control the time that the driver was looking at the center-screen task so that the different combinations of in-vehicle and forward roadway glance times could be maintained. Note that the different combinations of forward roadway and in-vehicle glance durations (1-2, 2-2, 3-2, 4-2) while the driver is performing the secondary task were controlled by the simulation software.

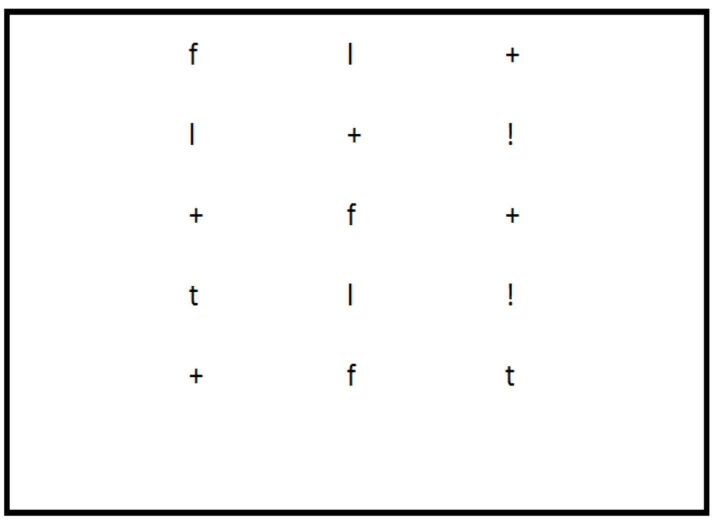

Figure 5: Secondary Visual Search Task: Alternating Low Load Condition ('t' present)

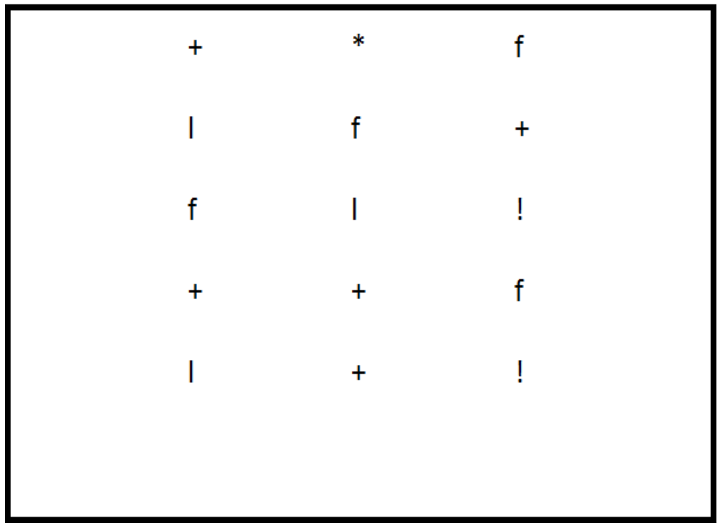

Figure 6: Secondary Visual Search Task: Alternating Low Load Condition ('t' absent)

The alternating baseline center screen interruption is depicted in Figure 7 below.

Figure 7: Black Screen Interruption for Alternating Baseline condition

3.1.3 Scenarios Used for Evaluation: Four Combinations

The scenarios were designed to determine how the type of processing (top down or bottom up) and the location of the threat (central or peripheral) would affect the threshold duration and, when the window is less than the threshold duration, how these factors would affect the likelihood that an individual detects a threat. There are thus four combinations:

central/top down, central/bottom up, peripheral/top down, and peripheral/bottom up. There were a total of 8 scenarios, two each for the four *combinations*. The scenarios have been arbitrarily labeled and the scheme used is indicated in the table below (Table 4). They will be discussed in more detail after making some general remarks.

Table 4: Type of Processing and Location of Threat: Labeling of Eight Scenarios (A, B, C, D, E, F, G, and H)

Location of Threat / Type of Processing	Top-Down	Bottom-Up
Peripheral	• Four Way Uncontrolled Intersection [B] • Looking across a Curve – No Movement Cues [E]	• Truck parked on the right side of a Crosswalk [D] • Looking across a Curve – Movement Cues[H]
Central	• Mullins Center [C] • Truck Left Turn [G]	• Lead Vehicle Braking – Brake Lights [A] • Work zone [F]

Each scenario is unique in design, logic, and road geometry and traffic density. The scenarios are situated either in a suburban environment or in a semi-city setting. The average speed limit is 30 mph. For each scenario, I indicate where the secondary task will be initiated with respect to the potential threat. For the top-down tasks, the secondary in-vehicle tasks are initiated 12 s before the location of the potential threat (assuming that driver is maintaining the speed limit). This is far enough ahead so that all drivers start with some, but not a great deal of information, about the upcoming potential threat. For bottom-up tasks, the question of when to initiate the secondary, in-vehicle tasks required a more concentrated attention to detail. The bottom-up tasks are characterized by sudden onsets, for example the sudden onset of motion or of brake lights. I am interested in learning how drivers in the alternating condition process information on the forward roadway when they are gazing on the forward roadway, not inside the vehicle. Thus, it was critical to ensure that the secondary task was not initiated at a point in time when the driver needed to glance on the forward roadway in order to anticipate a hazard. The particulars of when to initiate the bottom-up task will vary with the scenario, as described below. Most importantly, the timing was such that for the 1/2, the hazard appears on the forward roadway during the relevant glance upwards for 1s, for the 2/2 the hazard appears during the relevant glance up for 2 s and so on.

Finally, it should be noted how the threshold duration is defined for the different dependent variables. When eye behavior (glance location) is the dependent measure of threat detection, the threshold duration is defined for an in-vehicle glance of a given length as the glance duration on the forward roadway in which the likelihood of detecting the threat in the alternating condition (baseline or low load) is equal to what it is in the continuous condition. When vehicle behaviors are the dependent variable, the threshold duration will be defined for an in-vehicle glance of a given length as the glance duration on the forward roadway in which the measure of vehicle behavior in the alternating condition is the same as the measure of behavior in the continuous condition. For example, assume that in the continuous condition the driver brakes on average 500 ms after a lead vehicle brakes. And assume that in the alternating low load condition the driver brakes on average 700 ms after the lead vehicle brakes in the 2 s/2 s condition, 600 ms after the lead vehicle brakes in the 3 s/2 s condition, and 500 ms after the lead vehicle brakes in the 4 s/2 s condition. Then 4 s would be set to the threshold duration in the alternating low load condition.

- Lead Vehicle Braking – Brake Lights [A]: Central/Bottom-Up – The basic design of this scenario involves a lead vehicle which is programmed to decelerate from 30 mph for 2 seconds (Figure 8). The brake lights are activated throughout the deceleration. The lead vehicle accelerates after braking. The lead vehicle is programmed to maintain a headway of 30 m from the subject vehicle. This scenario involves bottom up processing (a sudden onset of a bright stimulus attracts attention) and the potential threat is located in the foveal region. The lead vehicle starts braking 100 ms after the driver looks up from the in-vehicle task the first, second or third time. It is assumed that the threat is detected if the driver takes his or her foot off the accelerator and, possibly, brakes. The threat only materializes when the driver looks up on the forward roadway.

Figure 8. Lead Vehicle Braking (A).

- <u>Four Way Uncontrolled Intersection [B]: Peripheral/Top-Down</u> – This scenario involves a suburban environment and a typical four way intersection with no stop sign compliance or traffic signal regulations (Figure 9). The driver needs to be cautious about cross traffic and other potential hazards especially due to line of sight obstructions on the left and right hand sides of the road (e.g., horizontal or vertical curvature) thereby necessitating secondary looks to either side after entering the intersection. This scenario involves top-down processing and the threat requires peripheral scanning. The in-vehicle task starts 14 s before the driver enters the intersection. Thus, all drivers start with the same information about the forward roadway before they begin the in-vehicle task. It is assumed that the driver detects the potential threat if he or she looks to the cross roads before and after entering the intersection. Only if a driver made all four glances (to the left and right before and right after entering the intersection) was the driver scored as anticipating the hazard.

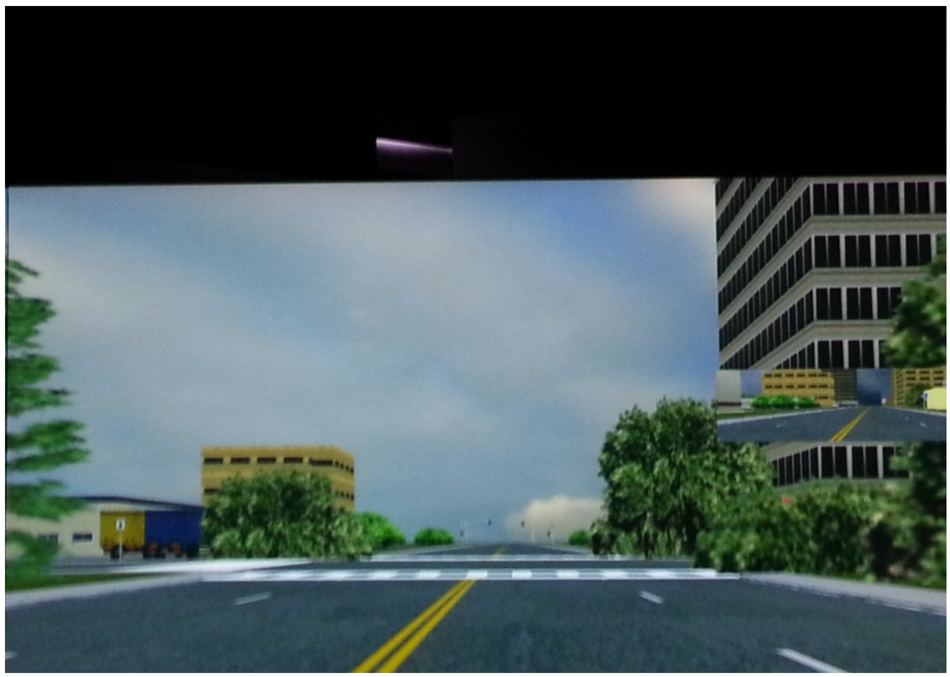

Figure 9. Four Way Uncontrolled Intersection (B).

- Mullins Center Scenario [C]: Central/Top-Down – This scenario is representative of the traffic pattern at the Mullins Center situated on Commonwealth Ave. in Amherst, MA. There is a mid-block crosswalk in the middle of the four lane two-way road (two travel lanes in each direction). The driver needs to scan for potential pedestrians or bicyclists crossing from either sides which are visible (Figure 10). There is also a need for the driver to realize the risk posed by a truck driver stopped in the left travel lane (our driver is travelling in the right travel lane) for a pedestrian proceeding to cross, thereby obscuring the potential line of sight for the participant driver. The Mullins Center scenario is an example of a scenario which requires top down processing with a foveal threat. The in-vehicle task was started 14 s before the driver reaches the crosswalk. It is assumed that the driver detects the threat if he or she looks to the right in front of the stopped vehicle before traveling over the crosswalk.

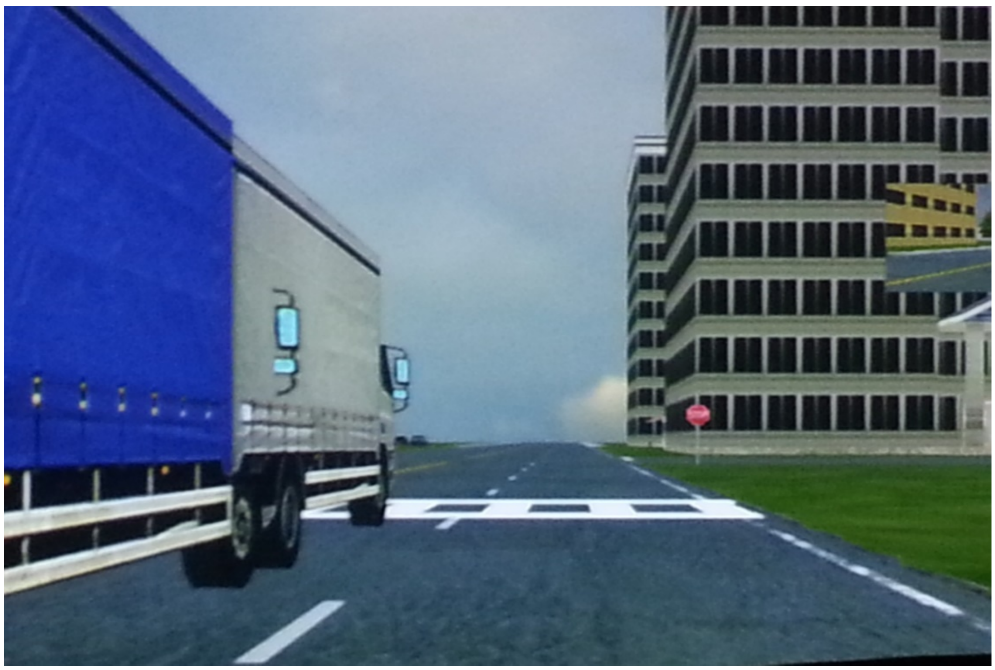

Figure 10. Mullins Center Scenario (C).

- Truck parked on the right side of a crosswalk [D]: Peripheral/Bottom-Up – This scenario involves a truck stopped in the travel lane on the right hand side of a midblock crosswalk (Figure 11). The scenario begins on a four lane road and as the driver approaches the midblock crosswalk (100 feet down), two pedestrians start walking towards the crosswalk on the right hand side (one pedestrian walking north – in the same direction the participant driver is traveling -- from 15 feet south of the crosswalk with the second pedestrian moving simultaneously in a lateral direction 15 feet west of the crosswalk). They both reach edge of the crosswalk on the right hand side as the driver approaches the midblock crosswalk. There is also a pedestrian standing on the left hand side of the crosswalk who starts moving towards the crosswalk after the driver has navigated the first alternation in the alternating conditions. There is no actual materialization of the crossing event. This scenario involves bottom up processing (the quick and odd movement of the pedestrians in the periphery should attract the participant driver's attention) and the potential threat requires peripheral detection to successfully identify the hazard (looking to the right in front of the truck was the measure of hazard anticipation). This in-vehicle task is more difficult to time in this bottom up scenario because one wants the information on the forward roadway to be equally available to participants in all conditions and one wants the movement of the pedestrian to start 100 ms or so after the driver glances up from the forward roadway.

Figure 11. Truck Parked in front of Crosswalk (D).

- Looking across a Curve – No Movement Cues [E]: Peripheral/Top-Down – Participants drive along a right winding curve with a mid-block crosswalk emerging about 50 feet after the curve straightens out. There is a truck parked horizontally on the edge of the curb on the right extremity of the crosswalk while an agricultural tractor obscures the potential presence of a pedestrian at the left extremity of the crosswalk (Figure 12). This scenario involves top down processing as attention has to be allocated to the extremities of the crosswalk for potential peripheral latent hazards. The secondary task was initiated 10 s before the apex of the curve is reached and 16 s before the crosswalk is reached. The question here is what the minimum threshold needs to be on the forward roadway for the driver to glance towards the edges of the crosswalk with the same likelihood in the alternating conditions as he or she does in the continuous condition.

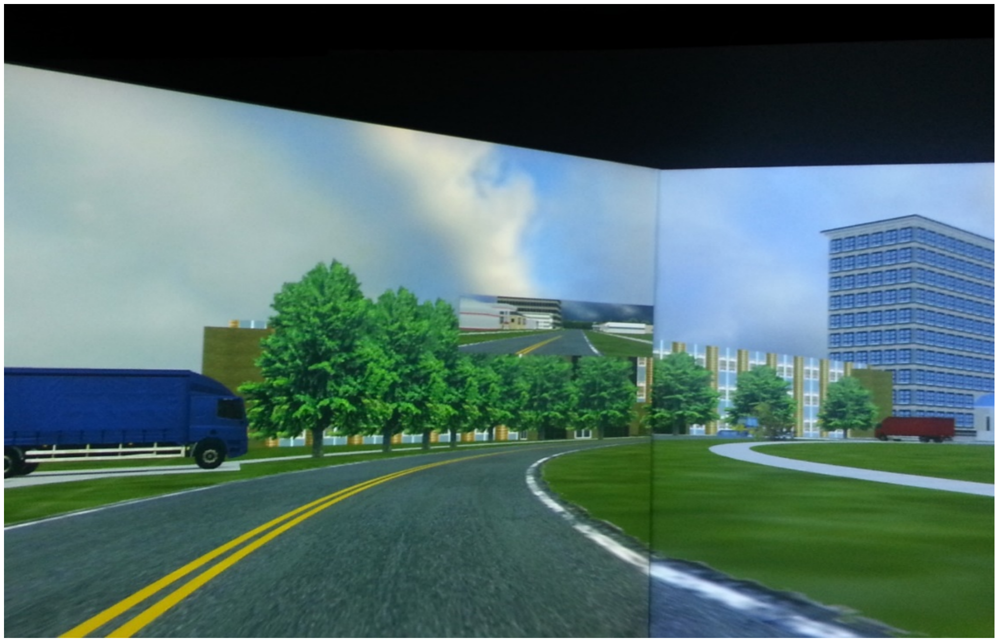

Figure 12. Looking Across a Curve – No Movement Cues (E). (Crosswalk located just upstream of brown truck on right at end of curve.)

- Work zone [F]: Central/Bottom-Up – In this particular scenario, the driver begins driving on the rightmost lane on a four lane road with two travel lanes in either direction but has to switch to the left lane because of a work zone in the right lane (the cue for which is provided by a work zone ahead sign). As the scenario progresses, there is a jeep parked with emergency flashers stopped in the left lane (Figure 13). The flashers indicate that there may be something happening ahead in the left lane (there is in fact a second work zone in the left lane that is cued by the motion of the brake lights of the stopped jeep). This scenario is processed bottom up with the potential threat emerging from the foveal region. The secondary task will be initiated at a time when the driver is glancing on the forward roadway 14 s prior to the emergence of the latent hazard, which is the potential existence of a pedestrian at the midblock crosswalk in front of the jeep and the second work zone. All drivers see the visual motion of braking lights prior to the first in-vehicle center screen interruption. The question here is with respect to a potential threat that is cued from the bottom up. The dependent variables are the average velocity of drivers while navigating this scenario in addition to the eye measure examining drivers' ability to detect a latent hazard as a function of the alternation, load, and the type of processing and location of threat.

Figure 13. Work Zone (F). (Midblock crosswalk ahead of second work zone just in front of jeep.)

- <u>Truck Left Turn [G]: Central/Top-Down</u> – This particular scenario unwinds on a four lane road, with two travel lanes in each direction. As the scenario progresses, the driver is forced to move into the left lane (just as the scenario begins, the driver turns right onto a four-lane road with a truck parked in the wrong direction on the edge of the rightmost lane) to turn left at a four way intersection (Figure 13). Additionally, there is a truck waiting across the intersection in the opposing left travel lane waiting to turn left at the intersection in front of the participant driver. It is imperative that the driver scan for potential cars emerging from the lane adjacent to opposing truck that may decide to continue straight or turn right thereby posing a risk to our driver intending to turn left. This scenario is a typical example of one requiring top down processing with the threat emerging from the foveal area. The secondary task was initiated 12 s before the driver entered the intersection. The dependent variable is whether the driver glances towards possible turning cars in the opposing lane across the intersection.

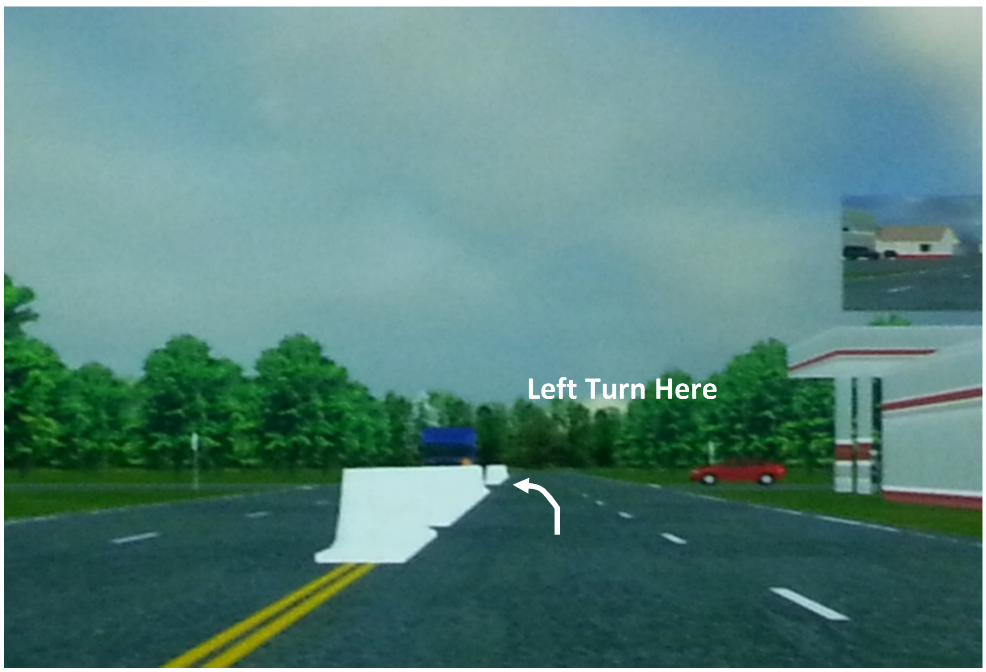

Figure 14. Truck Left Turn (G)

- Looking across a Curve -- Movement Cues [H]: Peripheral/Bottom-Up – In this scenario, the participants drive along a right winding curve. As the scenario progresses, a mid-block crosswalk with a 2-way stop sign and guard rails at the crosswalk extremities for pedestrian safety is visible about 60 feet after the curve straightens out (Figure 15). There is dense vegetation (bushes) at the extremities of the crosswalk. As the driver approaches the apex of the curve, a pedestrian starts moving towards the crosswalk from the right side. Drivers in all conditions see the initial movement of the pedestrian at the same point in time. The final destination point of the pedestrian is behind a short bush located in front of the stop sign. This scenario involves bottom up processing as attention is attracted by motion on the extremities of the crosswalk for potential peripheral latent hazards. The secondary task was initiated 12 s before the apex of the curve is reached and 16 s before the crosswalk is reached. The question here is what the minimum threshold needs to be on the forward roadway for the driver to notice the stop sign at the crosswalk with the same likelihood in the alternating condition as he or she does in the continuous condition. The dependent variable is whether the driver glances at the pedestrian stopped behind the bush (or at the bush itself thereby indicating driver has noticed the movement of the pedestrian).

Figure 15. Looking Across Curve – Movement Cues (H).

Turn instructions were provided on the center screen for all scenarios.

3.1.3.1 Control, Alternating Baseline and Alternating Low Load Scenarios

The control scenarios differ from experimental scenarios in the sense that the forward roadway is continuously visible in these scenarios while the feedback from the forward roadway is visually interrupted in the alternating scenarios according to the window size used. The interruption is initiated in advance of the scenario and continues past the scenario, the exact initiation time depending on the scenario. In those control scenarios where the potential hazard is not visible, a determination of how frequently the group of drivers are able to recognize a hazard is made. A predetermined *launch zone* and *target zone* are defined for every scenario and the scoring rubric is designed to assign a binary value of hit or miss (0 or 1) to each fixation recorded towards potential target zones throughout scenarios.

The alternating baseline scenarios replace the center screen with a blank screen (Figure 7). The alternating low load scenarios replace the center screen with a target screen in which a target is either present (Figure 5) or absent (Figure 6). The secondary task for the alternating low load scenarios involves a visual search task where participants had to count and then report the number of times the target character ('t') appears on a visual search display on the center screen. During the specified interruption window (alternating baseline or alternating low load), the center screen is blacked out to mimic how drivers obtain hardly any information from the forward roadway when engaged in a distracting in vehicle secondary task in concurrence with driving.

The intuition here was that one would observe switching effects if there was a difference between the hazard anticipation performances of the alternating low load and alternating baseline conditions at the shorter forward roadway glance durations (at the longer forward roadway durations there may well be no switching effects). Similarly, one should observe swapping effects if there is a difference between the hazard anticipation performance of the alternating baseline and continuous conditions at the shorter forward roadway glance durations.

3.1.4 Experimental Design

The drives developed for evaluation were designed using a relatively new method of mini-scenarios. All three drives - control (Drive 1), alternative baseline (Drive 2) and alternating low load (Drive 3) drives - required for this experiment consisted of 8 scenarios each (the actual scenarios in each drive were described in detail above). During the alternating low load drive, the driver was asked to perform a secondary task. The driver's view of the forward roadway that was displayed on the screens outside the window of the cabin of the simulator was alternated, as a function of the window durations, with a view of the secondary task. When the view of the forward roadway was displayed, the secondary task was not visible. Conversely, when the view of the secondary task was displayed, the view of the forward roadway was not visible. The alternation baseline drives involved a similar switching between views of a black screen and the forward roadway. However there was no secondary task.

3.1.4.1 Alternating Sequences

Based on prior research I used a sequence of visible (1, 2, 3, 4 s in which the forward roadway was visible) and not visible (2 s in which the forward roadway was not visible) times to identify the threshold durations. Prior research suggests that the majority of drivers' glances inside the vehicle are 3 s or less (Chan et al., 2011). Since glances greater than 2 s inside the vehicle are considered unsafe, it made sense to consider displaying the secondary task for 2 s (making the forward roadway always disappear for 2 s). The distribution of glance durations on the forward roadway when a driver is performing a secondary task is not known. However, experience suggests that these glances are typically less than 5 s. Thus, it made sense to display the forward roadway for 1, 2, 3 and 4 s. The time when the secondary task was displayed and the forward roadway was not visible will be referred to as the *invisible time*. The time when the roadway was displayed and the secondary task was not visible will be referred to as the *visible* *time*. An *alternating sequence* is defined as an alternation of unchanging durations of invisible displays and unchanging durations of visible displays of the forward roadway. Each sequence began and ended with an invisible display (i.e., a display of a blank screen or the secondary task). This leads to the following four sequences of invisible and visible times:

- Sequence A - Invisible time (2 sec) & Visible time (1 sec)
- Sequence B - Invisible time (2 sec) & Visible time (2 sec)
- Sequence C - Invisible time (2 sec) & Visible time (3 sec)
- Sequence D - Invisible time (2 sec) & Visible time (4 sec)

It still needs to be said how long the sequence will be presented. An alternating sequence begins when the secondary task is first displayed and ends when the secondary task is last displayed (five displays of the secondary task and four displays of the forward roadway for the 1/2 alternation (14 s total); four displays of the secondary task and three displays of the forward roadway for the 2/2 alternation (14 s total); three displays of the secondary task and two displays of the forward roadway for the 3/2 alternation (12 s total); and three displays of the secondary task and two displays of the forward roadway for the 4/2 alternation (14 s total). The intention was to ensure that the overall interruption duration be as similar as possible across alternation sequences. The secondary tasks were designed to be completed in a total of 10 s. As noted above, the number of times the interruptions occur vary as a function of the window size. And as noted above, a 1/2 alternation has a task duration of 14 seconds as does the 2/2 and 4/2 alternations while the 3/2 sequence has a task duration of 12 s.

The study employs a mixed design (factors are varied both between and within subjects). The type of processing and location of threat are within subject factors while the alternation sequence and type of load (continuous, alternating baseline, and alternating low load) are between subject factors. Specifically, every participant receives either the control drive (drive 1), one of the four alternating baseline drives (drives 2a, 2b, 2c, 2d) or one of the four alternating low load drives (the four experimental drive 3a, 3b, 3c and 3d) where each drive consists of eight scenarios (the eight scenarios in each drive are described above; see Figure 8 - Figure 15). The participant navigates only a single drive in order to minimize both learning effects as well as simulator sickness resulting from prolonged exposure.

3.1.4.2 Counterbalancing Control Drive, Baseline Drive and Experimental Drive Sequences Across Participants

The eight mini scenarios in each drive each take about 2 minutes on average to navigate. Participants were randomly allocated to one of the nine treatment conditions: the continuous condition (drive 1), the alternating baseline condition (drive 2a, 2b, 2c, or 2d, where the four versions represent the four alternating sequences) or the alternating low load condition (drive 3a, 3b, 3c, or 3d, where again the four versions represent the four alternation sequences, namely, 1/2, 2/2, 3/2 and 4/2). Specifically, the assignments for the first 18 participants are given in **Table 5**:

Table 5: Drive Counterbalancing

Participant	Drive Sequence	Participant	Drive Sequence
1.	1	10.	2d
2.	2a	11.	2a
3.	3b	12.	2c
4.	2b	13.	3c
5.	3c	14.	2a
6.	2c	15.	2b
7.	3a	16.	1
8.	3d	17.	3a
9.	2d	18.	3d

The scenarios in each of the drives were counterbalanced as well across drives. Within drives, however, the same order was used across participants (**Table 6**).

Table 6: Counterbalancing of Scenarios (A, B, C, D, E, F, G, H)

across Drives (1, 2a, 2b, 2c, 2d, 3a, 3b, 3c, 3d)

Participant No.	First Drive
1	1 (A, B, C, D, E, F, G, H)
2	2a (C, D, E, F, G, H, A, B)
3	3b (C, D, E, F, G, H, A, B)
4	2b (B, G, H, E, A, F, C, D)
5	3c (B, G, H, E, A, F , C, D)
6	2c (A, B, C, D, E, F, G, H)
7	3a (F, C, D, B, G, H, E, A)
8	3b (F, C, D, B, G, H, E, A)
9	2d (C, D, E, F, G, H, A, B)

3.1.4.3 Counterbalancing Combinations of Threat Factors within and Across Participants

Finally, note that it is important to counterbalance the combination of the types of processing and the location of the threat. The table below shows how the combinations are counterbalanced for the first subject for the two seed sequences –A, B, C, D, E, F, G, H and F, C, D, B, G, H, E, A. Note that scenarios with bottom up processing never occur adjacent to each other in the seed sequences, though occasionally they will occur together in the other sequences generated from the seed (**Table 7**).

Table 7: Counterbalancing Across Scenario Sequence Type of Processing and Location of Threat

Scenario Sequence	Combination	Scenario Sequence	Combination
A	Central/Bottom Up	F	Central/Bottom Up
B	Peripheral/Top Down	C	Central/Top Down
C	Central/Top Down	D	Peripheral/Bottom Up
D	Peripheral/Bottom Up	B	Peripheral/Top Down
E	Peripheral/Top Down	G	Central/Top Down
F	Central/Bottom Up	H	Peripheral/Bottom Up
G	Central/Top Down	E	Peripheral/Top Down
H	Peripheral/Bottom Up	A	Central/Bottom Up

3.1.5 Apparatus

3.1.5.1 Driving Simulator

The driving simulator setup consists of a fully equipped 1995 Saturn sedan placed in front of three screens subtending 135 degrees horizontally. The virtual environment is projected on each screen at a resolution of 1024 x 768 pixels and at a frequency of 60Hz (Figure 16). The images themselves are updated 60 times a second using a network of four advanced RTI simulator servers which parallel process the images projected to each of the three screens using high end, multimedia video chips. The participant sits in the car and operates the controls, just like he or she would in a normal car. These controls move him or her through the virtual world according to his or her inputs to the car. The audio is controlled by a separate system which consists of two mid/high frequency speakers located on the left and right sides of the car and two sub woofers located under the hood of the car. This system provides realistic wind, road and other vehicle noises with appropriate direction, intensity and Doppler Shift.

Figure 16: Driving Simulator (RTI)

3.1.5.2 Eye Tracker

A portable lightweight eye tracker (Mobile Eye developed by ASL) was used to collect the eye-movement data for each driver (Figure 17). It consists of a pair of goggles that contain miniaturized optics – a camera for viewing the eye, another for viewing the scene ahead, an ultraviolet light source, and a small reflective spectacle to allow the eye camera to record an image of the eye without being directly in front of the participant's eye. The images from these cameras are interleaved and recorded on a remote system, thus ensuring no loss of resolution. The interleaved video can then be transferred to a PC where the images are separated and processed. The eye movement data is converted into a crosshair, representing the driver's point of gaze, which is superimposed upon the scene recorded during the drive. This provides a record of the driver's point of gaze on the driving scene while in the simulator. The remote recording system is battery powered and is capable of recording up to 90 minutes of eye and scene information at 60 Hz in a single trial.

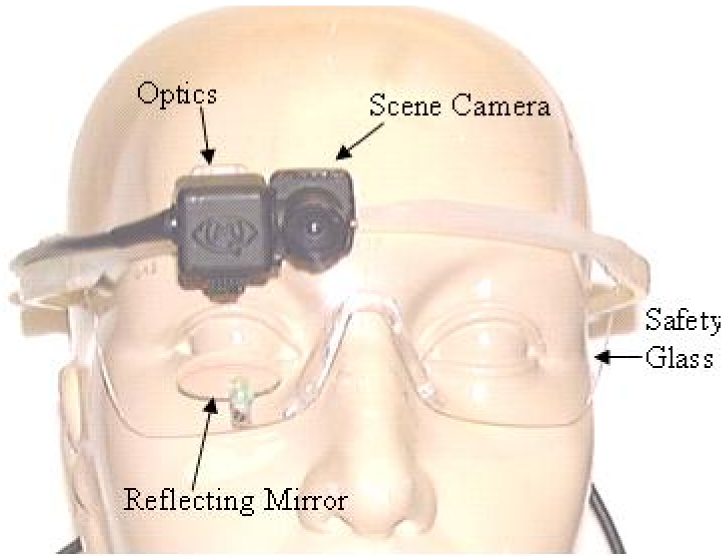

Figure 17: ASL Mobile Eye Tracker

3.1.6 Procedure

Participants were given a brief overview of the study at the onset following which they were asked to read an Informed Consent form and provide written consent to participate in the experiment as per the Institutional Review Board norms. Participants were then provided a Demographic questionnaire that collects participants' driving history and some demographic information like age, sex, and race following which the participants were fitted with an eye tracker which was calibrated within the simulator. After calibration, participants were given a practice drive to familiarize them with the driving simulator. The practice drive included no hazard anticipation scenarios so that participants did not become sensitized to them. This drive is intended to familiarize the participants with the new world of simulated driving. Subsequent instructions were provided to participants at the onset of each experimental drive sequence.

3.1.7 Dependent Variables

The Arbella Insurance HPL (Human Performance Laboratory, University of Massachusetts Amherst) Advanced Driving Simulator is extremely flexible in its ability to provide both frequently measured and less frequently measured types of data to the researchers using it. Typical *vehicle behaviors* collected include throttle position, velocity, lane position, and braking for the participant's vehicle (*ownship*). The eye tracking equipment was used to collect *eye behaviors* including fixation and glance data from participants. Glance duration is a variable measured via the use of the eye tracker. Glance durations on the forward roadway and within the vehicle are collected over the course of the 8 scenarios. Fixation locations are scored 0 or 1 to determine participants' ability to detect or anticipate potential hazards when faced with interruption sequences in the experimental drives.

3.1.8 Statistical Analyses

3.1.8.1 Threshold Duration

The threshold duration was defined above as that duration of the forward view of the roadway where the dependent measure of threat detection (e.g., probability that a threat is detected) in the alternating low load condition is equal to or greater than the same measure in the continuous condition. One can actually get a finer grained analysis of the threshold duration as follows.

An example can make clear what needs to be done. Consider scenario A (central/bottom up) and its conceptual equivalent, scenario F (central/bottom up also). There are four low load alternating sequences: 1/2, 2/2, 3/2, and 4/2. Five drivers will be exposed to each sequence. The average will be computed across the two exemplars (A and F in this case) of each scenario. Thus, there will be 10 data points (5 subjects times two scenarios) for each alternating sequence. The probability of the threat being detected will then be computed from the eye movements. Suppose one observed at each of the four alternating sequences the following probabilities: 0.30, 0.50, 0.60, and 0.60. Label these o_1, ..., o_4. And suppose one found that in the continuous drive the threat for scenarios A and F was anticipated with probability 0.60. Then the threshold duration is somewhere between 2 s and 3 s.

Let Δ equal the observed threat detection probability in the continuous condition. Then the following function has an asymptote of Δ and a minimum of 0:

$$\Delta \times \left(1 - e^{-\lambda t}\right)$$

It is simple enough to find a value of λ, λ', which minimizes the sum of the squared deviations between the four predicted measurements and the four observed measurements:

$$\lambda' = \min\left\{\lambda > 0, t > 0; \sum_{i=1}^{4}\left[\Delta\left(1 - e^{\lambda t}\right) - o_i\right]^2\right\}$$

The threshold duration will be then be selected as that time *t*, *t', for* which it is the case that the predicted probability of detecting the threat in the alternating condition is equal to 95% of the observed probability in the continuous condition.

$$t' = \left\{t > 0, 0.99 \times \Delta = \Delta\left(1 - e^{-\lambda' t}\right)\right\}$$

3.1.8.2 Swapping and Switching Effect

As discussed above, the swapping effect for a given window will be set equal to the difference in the average hazard anticipation performance of the alternating baseline and continuous conditions. The switching effect for a given window will be defined as the difference in the average hazard anticipation performance of the alternating low load and alternating baseline conditions. As noted, above, it is expected that the swapping and switching effects will get smaller as the window approaches the threshold duration because the participant, by definition has more time to glance on the forward roadway.

3.2 Results & Analyses

3.2.1 Latent Hazard Anticipation

In order to analyze whether drivers successfully anticipated latent hazards, I decided to determine whether or not a participant had glanced towards the target zone while in the launch zone. A *target zone* was defined as the area where a potential hazard might appear, and the *launch zone* was defined as the area wherein the participant should glance at the hazard. Therefore, the dependent variable (number of hazards anticipated) was binomially distributed (1 -- a participant glanced at the target zone while in the launch zone; 0 -- the participant did not glance at the target zone while in the launch zone). The launch zone and target zone areas for each scenario were based on the zones in other studies using the same scenarios (e.g., Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; Pradhan A. , Pollatsek, Knodler, & Fisher, 2009).

The observed proportions for the percentage of hazards detected across the various treatments are represented in Figure 18. As predicted, drivers in the continuous condition anticipated the largest percentage of hazards (83%) while drivers in the 1/2 alternation sequence performed worst in terms of latent hazard detection, both in the alternating baseline and in the alternating low load conditions (43% and 35% respectively). The 4/2 alternation sequence elicited a much higher proportion of glances critical to hazard anticipation in both alternating baseline and low load conditions (75% and 68% respectively). The observed percentage of hazards detected followed predictions and decreased as the glance time on the forward roadway was decreased (the percentage of hazard detected decreased as the forward roadway glance decreased from 4 s to 1 s). Overall, drivers in the continuous condition anticipated 83% of the hazards, those in the alternating baseline condition anticipated 60% of the hazards, and those in the alternating low load condition anticipated 54% of the hazards. In summary, there appears to be an effect of both the duration of the glance on the forward roadway in hazard anticipation and the type of load.

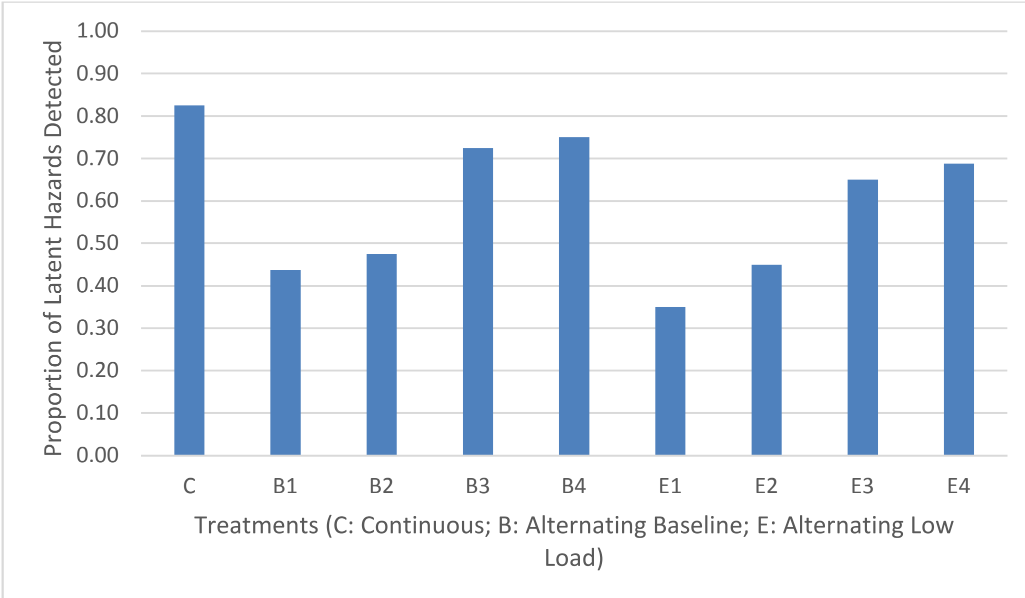

Figure 18: Percentage of Hazards Detected

In order to analyze the latent hazard anticipation skills across the different alternating conditions in the first experiment, I utilized a logistic regression model within the framework of Generalized Estimating Equations (GEE). The model included the participants as a random effect, two between subjects factors -- (a) Type of Load: Baseline or Low Load and (b) Alternation Sequence: 1/2, 2/2, 3/2, 4/2 -- and the three within subjects factors -- (c) Location of threat: Peripheral or Central; (d) Type of Processing: Bottom Up or Top Down, and (e) Scenarios (8 unique scenarios described in Section 3.1.3). All second and third order interactions were also included. Using a backward elimination procedure to winnow the models, the final model included highly significant main effects for Type of Processing [Wald X_1^2=8.977; p=0.003] and Alternation Sequence [Wald X_1^2=23.780; p=0.000]. There was no significant effect for Type of Load [Wald X_1^2=1.465; p=0.226] or any of the other remaining factors or second and third order interactions. The estimated marginal means averaged across the alternating baseline and alternating low load conditions are presented in **Figure 19**.

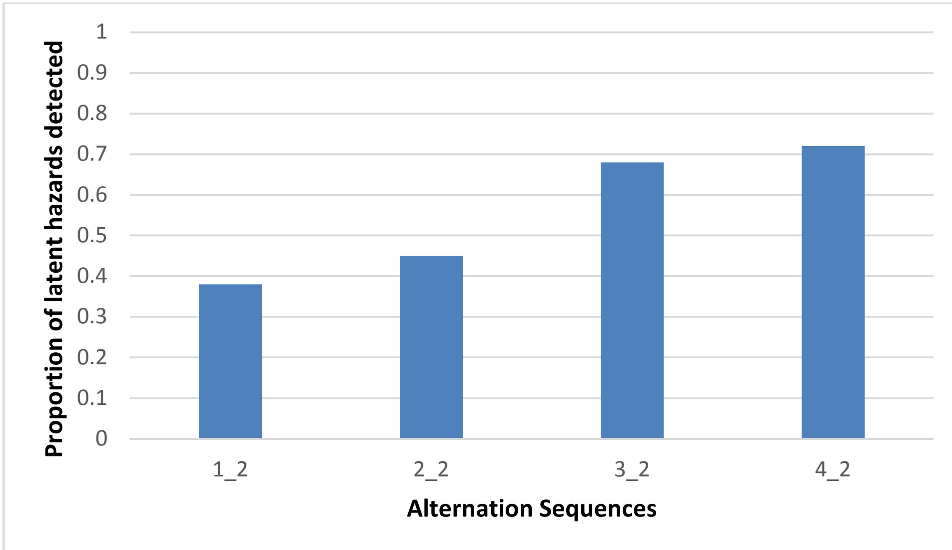

Figure 19: Estimated Marginal Means (Alternating Baseline and Low Load Conditions)

As predicted, performance in the 4/2 sequence is better than the performance in the 1/2 condition (almost twice as good). In order to further understand whether latent hazard detection performance was significantly different across the alternation sequences, a post hoc pairwise comparison using a Bonferroni correction ($p = 0.001$) on the estimated means was performed. The difference in performance between the 1/2 and 4/2 alternating sequences was found to be highly significant ($p < .01$). As expected, the drivers in the 4/2 alternating sequence were much more likely to glance towards a potential latent hazard as compared to drivers in the 1/2 alternation sequence.

3.2.1.1 Type of Processing

The type of processing involved in the scenarios was either top down (TD, those scenarios where attention needs to be allocated to a potential target zone to acquire information) or bottom up (BU, those scenarios where the processing of information is a function of attraction by motion or sudden visual onset). As hypothesized and described above, there was a significant main effect of Type of Processing. Specifically, the latent hazard detection performance of the drivers in the scenarios with bottom up processing is better than their performance in those scenarios with top down condition (four scenarios each), approaching near perfect performance when the view is continuous. The difference is 35 percentage points (see **Figure 20**).

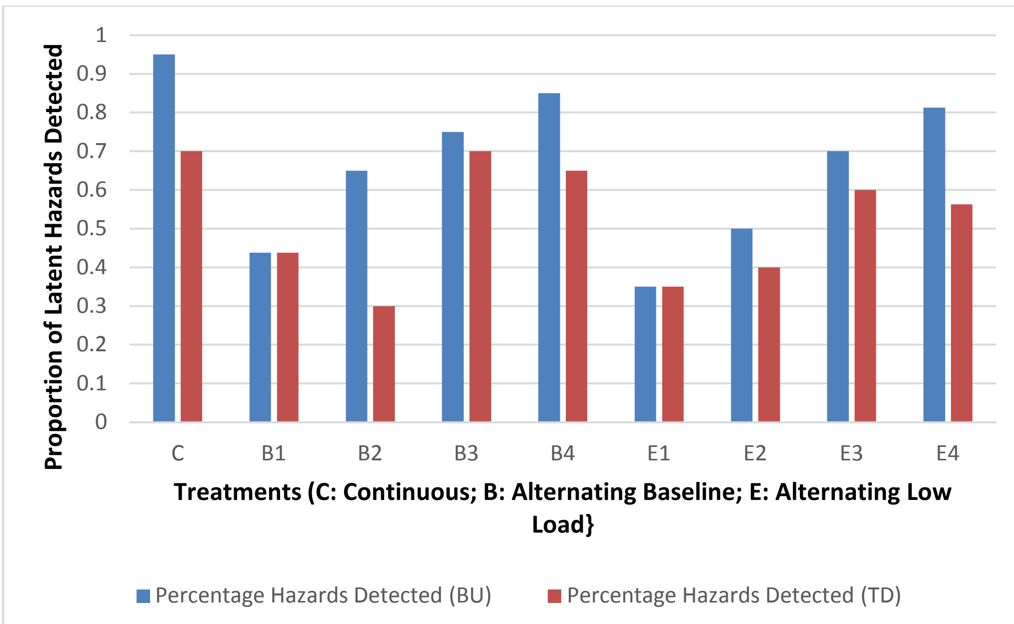

Figure 20: Percentage Hazards Detected (BU vs. TD)

Drivers across all conditions detect more hazards when the processing involves bottom up automatic attraction of attention as opposed to top down processing involving effortful allocation of attention and this particular result is most striking in alternating conditions at the longest forward roadway glance durations (95% for BU vs. 70% for TD in control condition; 85% for BU vs 65% for TD in alternating baseline 4/2 condition; 81% for BU vs 57% for TD in the alternating low load 4/2 condition). Note that in the alternating baseline and low load conditions the top down and bottom up detection rates are identical (although there was no interaction). This suggests that at the shortest glances upwards detection of anything is new is at floor.

3.2.1.2 Location of Threat

Contrary to the relevant hypothesis, as noted above there were no significant effects found for Location of Threat. The observed proportion of hazards detected as a function of the Location of the Threat (Peripheral or Central) is plotted in **Figure 21**.

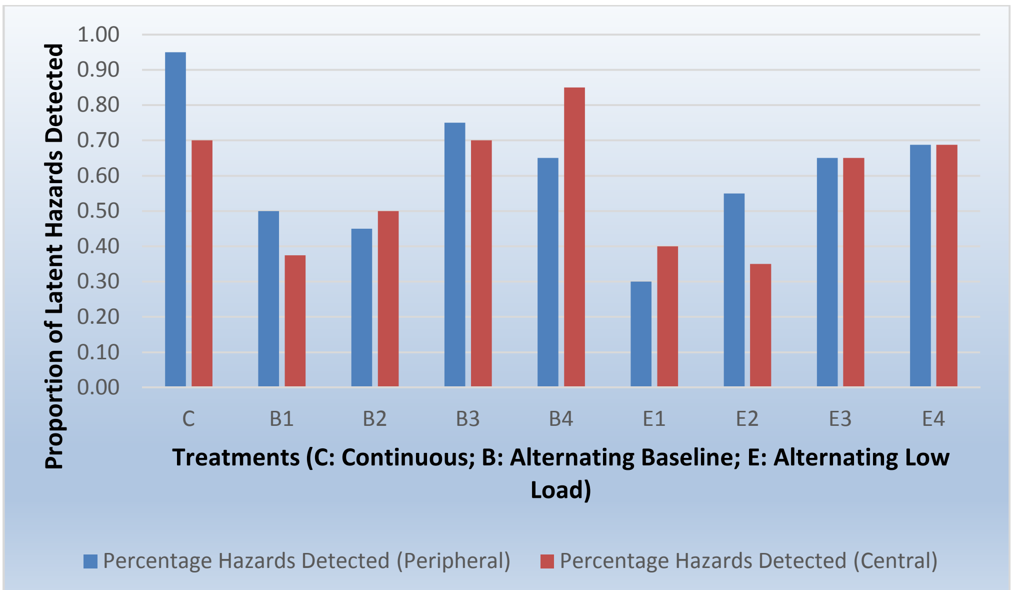

Figure 21: Percentage of Hazards Detected (Peripheral vs. Central)

3.2.1.3 Swapping and Switching Effects

The use of a visual search task as an alternating low load cognitive task elicited average hazard detection rates worse than the alternating baseline condition, however the difference overall between the two conditions was not statistically significant. But the overall analysis is not necessarily the only one. Swapping and switching effects may exist at shorter durations that do not exist at longer durations because participants reach asymptotic performance at the longer forward roadway durations. Thus, a series of pairwise comparisons were carried out and listed below (Table 8).

Table 8. Analysis of Swapping and Switching Effects. (One-tailed t-test)

Comparison	t(8)	p	Comparison	t(8)	p	Comparison	t(8)	p
C vs B1	5.519	0.001	**C vs E1**	6.938	0.000	**B1 VS E1**	0.915	0.193
C vs B2	6.261	0.000	**C vs E2**	3.536	0.004	**B2 VS E2**	0.224	0.414
C vs B3	1.265	0.121	**C vs E3**	4.427	0.001	**B3 VS E3**	0.973	0.179
C vs B4	0.688	0.256	**C vs E4**	2.829	0.011	**B4 VS E4**	0.000	0.500

There is clear evidence of a swapping effect for alternating baseline sequences 1-2 (B1) and 2-2 (B2) (a Bonferroni correction of $\alpha = 0.0133$ was used for multiple comparisons yielding $p = 0.1$). There is also clear evidence of a combined swapping and switching effect for all alternating low load sequences (E1 – E4). However, the differences between the alternating low load and baseline conditions are too small to find evidence of a statistically significant difference.

There are several reasons that the difference between the alternating baseline and low load conditions might be attenuated, raising the performance of participants in the alternating low load condition and lowering the performance of those in the alternating baseline condition. For example, factors that could increase the performance of participants in the alternating low load condition include, especially, the number of tasks attempted and the accuracy of those tasks that are attempted. If participants were not attempting the tasks or were doing so only half-heartedly, it would not be the case that the alternating low load condition would be placing the load upon participants for which it was designed. Thus performance would be above what was expected. Similarly, several factors could decrease the performance of participants in the alternating baseline condition that need to be considered. These include especially drivers who glance away from the center blank screen. If they did such, then they would not be focused on the forward roadway when the latent hazard appeared. Thus, their performance would be depressed. If both sets of factors were operating (increases in performance in the alternating low load condition and decreases in performance in the alternating baseline condition), this would have the net effect of decreasing any difference between the two conditions, thereby making it more difficult to analyze the switching effect. The existence of these moderating effects is explored below.

3.2.2 Secondary Task Accuracy and Tasks Attempted

The task accuracy and number of tasks completed was computed only for the alternating low-load condition. *Task accuracy* is defined as the proportion of search tasks across all scenarios that drivers correctly completed while driving. This was indicated by a correct numeric response to a target display. Task accuracy is displayed by itself in **Figure 22**. The *percentage of tasks attempted* identifies the percentage of secondary tasks that the drivers attempted while driving. This was indicated by a verbal response to a target display, correct or incorrect. The percentage of tasks completed is displayed along with task accuracy in Figure 23 in order to get a sense of how closely they track one another.

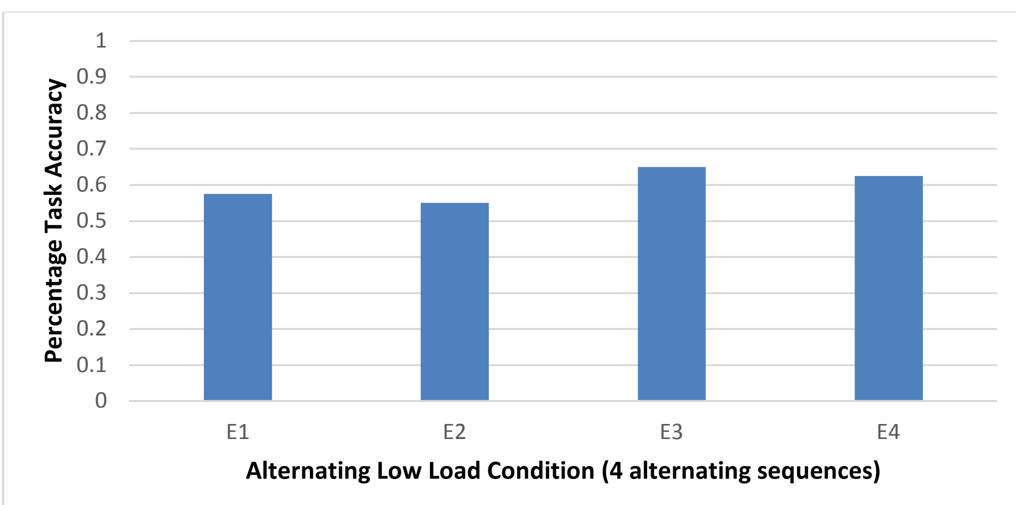

Figure 22: Percentage Task Accuracy (Alternating Low Load Condition)

As noted above, it was important to analyze the effects of task accuracy and number of tasks attempted on hazard anticipation in order to understand if the participants were actually performing the secondary task in the alternating low load condition. From the data displayed in Figure 22 and Figure 23 it would appear that the performance in the low load conditions in alternating sequences 1-2 and 2-2 may be artificially increased because the drivers are attempting fewer tasks and are less accurate overall.

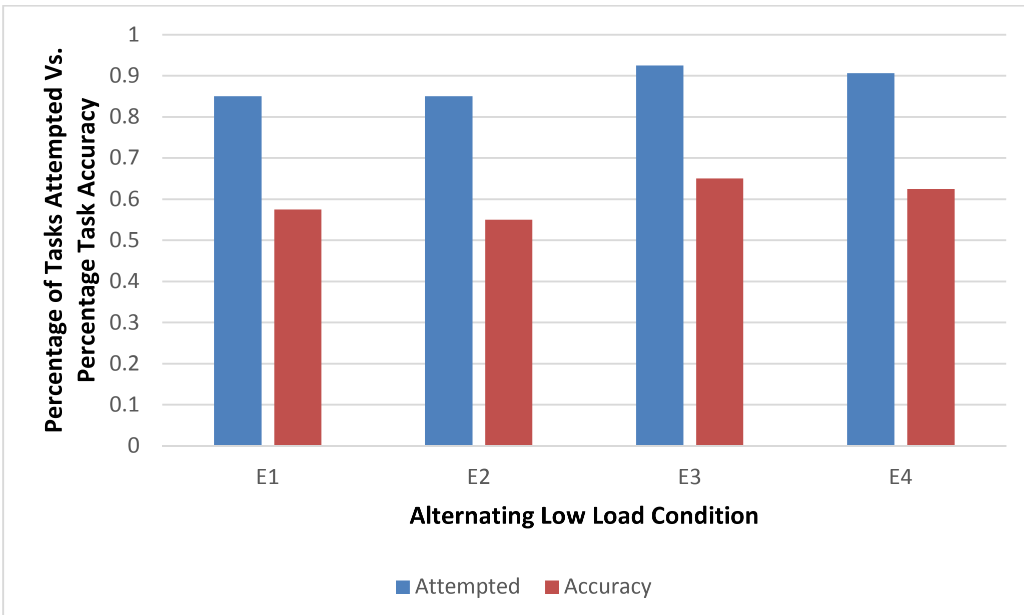

Figure 23: Percentage Tasks Attempted vs. Task Accuracy

In order to get a better handle on the relation between hazard anticipation on the one hand and tasks attempted and task accuracy on the other, I analyzed the effects of secondary task accuracy (observed proportions represented in Figure 18) and proportion of tasks attempted (Figure 23) on hazard anticipation across the alternating low load sequences. I utilized a logistic regression model within the framework of Generalized Estimating Equations (GEE) with the percentage of hazards detected as the dependent variable. Secondary task accuracy and percentage of secondary tasks attempted were included as covariates in the model. The model included the participants as a random effect along with the following factors:

(a) Scenarios (8 unique scenarios described in Section 3.1.3), (b) Alternation Sequence: 1/2, 2/2, 3/2, 4/2, (c) Location of threat: Peripheral or Central, and (d) Type of Processing: Bottom Up or Top Down. All second and third order interactions were also included. The final model included a significant main effect for Alternation Sequence [Wald X_1^2=582.011; p=0.000] and a significant effect of the covariate, Tasks Attempted [Wald X_1^2=72.640; p=0.000] (see Figure 23 for percentage of tasks attempted vs. task accuracy). In addition there was one highly significant second order interaction between Alternation Sequence and Tasks Attempted [Wald X_1^2=188.813; p=0.000]. Figure 24 illustrates the latent hazard detection probabilities of drivers as a function their task attempts.

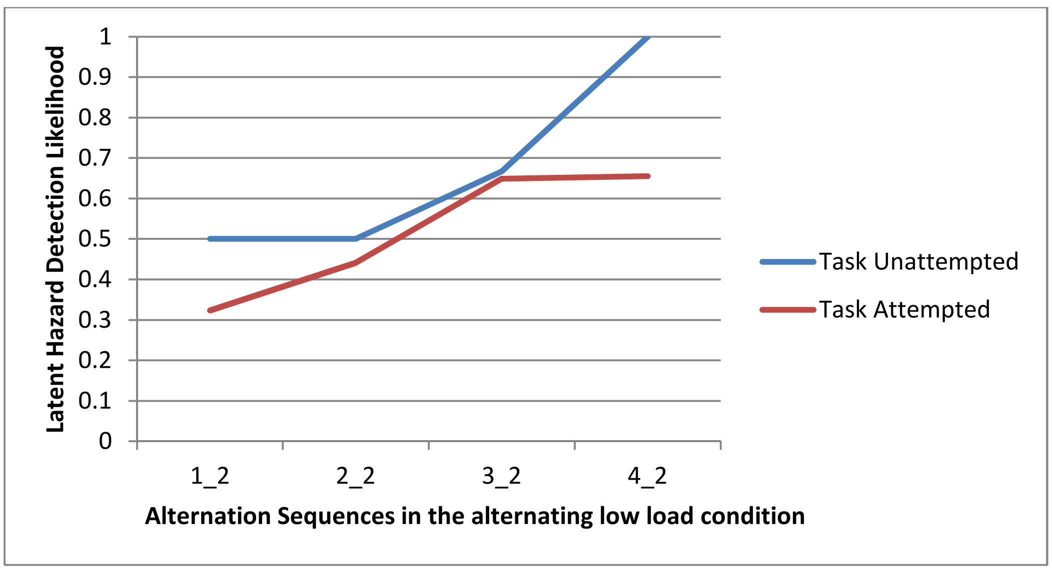

Figure 24: Latent Hazard Detection Likelihood across the various alternation sequences as a function of Task Attempted

There are four things of significance to note. First, the number of tasks attempted was very high. Specifically, drivers attempted 88% of tasks across all the alternation sequences while only 12% of tasks were left un-attempted. This suggests that participants were trying to perform the task and that, indeed, they were paying attention in the alternating low load conditions. Second, task accuracy is above chance (chance performance for the alternating low load condition in the first experiment was 1/7), indicating that not only were participants paying attention, but they were able to pay enough attention to get the task accurate most of the time. Together, these findings indicate the participants were loaded cognitively by the secondary task. Third, there was a significant effect of the number of tasks attempted on the hazard anticipation scores. And fourth, as Figure 24 makes clear, there is a strong relation between hazard anticipation performance and attempts at a task, especially in the 4-2 condition. Together, these latter two facts suggests that participants' performance was higher than it would have been had they attempted every task. In summary, the secondary task did load participants, but not by as much as it might have if they had attempted every task.

3.2.3 Vehicle Measures (Velocity)

Velocity was the primary vehicle measure analyzed. It was analyzed in order to determine whether drivers in the continuous condition were traveling faster than drivers in either or both of the alternating conditions. If such were the case, then the performance of drivers in the alternating conditions could be artifactually inflated because they had more time to scan for a latent hazard.

The velocity was collected for a 15 second period prior to the potential latent hazard for all subjects across all scenarios. The velocity was also collected for the immediate 5 seconds preceding the hazard. The average velocity was then computed for both periods. Decreases in velocity would be an indicator of drivers trying to mitigate the load placed on them by secondary tasks and the alternation sequence. There was no clear pattern for average velocity as a function of the alternation sequence. The average velocities across the continuous and alternation conditions for the 15 s preceding the hazard and 5 s preceding the hazard are plotted, respectively, in **Figure 25** and **Figure 26**.

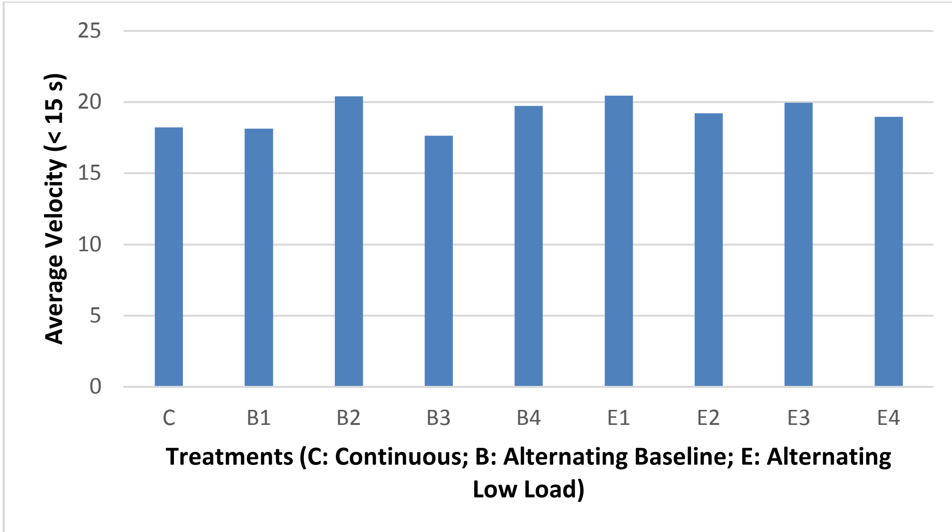

Figure 25: Average Velocity (< 15 s)

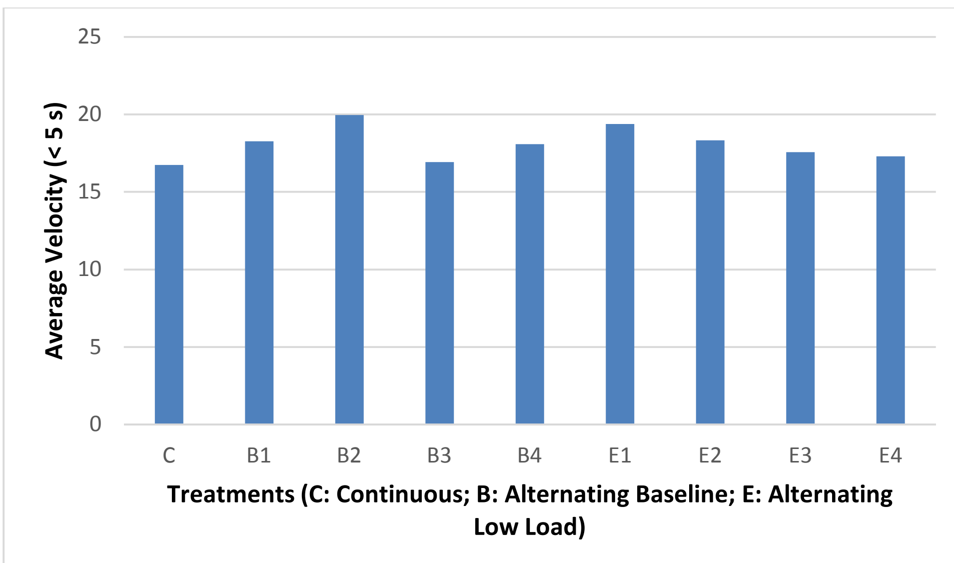

Figure 26: Average Velocity (< 5 s)

An analysis which compares the average velocity across the continuous and two alternating conditions was undertaken in order to determine whether drivers in the alternating conditions travel more slowly, a finding which would increase their performance compared to the control condition. I ran a Univariate ANOVA within General Linear Models to determine whether differences in average velocities (15 s and 5 s) were significant across conditions. The analysis for average velocity (15 s) revealed no significant effect for treatment (F (2) = 0.577, P =

0.566). The analysis for average velocity (5 s) also revealed no significance for treatment (F (2) = 0.630, P = 0.538). The average velocities and standard deviations for the 3 treatments are in Table 9 and Table 10 below.

Table 9. Average Velocity Across Conditions. (5 s before hazard)

Average Velocity (5 s)		
	Mean	SD
C	16.744	2.67
B	18.312	3.55
E	18.19	1.92

Table 10. Average Velocity Across Conditions. (15 s before hazard)

Average Velocity (15 s)		
	Mean	SD
C	18.22	3.48
B	19.01	3.19
E	19.68	2.43

Separate analyses were run for sequence in both the alternating baseline and alternating low load conditions. A Univariate ANOVA was performed on the individual alternating baseline and alternating low load conditions to test for effects of sequence on velocity. Again, there was no significant effect for sequence in either the alternating baseline or the alternating low load conditions.

3.2.4 Estimation of Threshold Duration

Finally, an estimate was made for the low load alternating condition of the threshold duration. The threshold duration is defined as the amount of time in the alternating low load condition that the forward roadway would need to be displayed between glances inside the vehicle in order for the percentage of hazards detected to be equal to 95% of the hazard detection rate in the continuous condition (78.85%). There were four low load conditions. Let *p* (*t*) be the proportion of hazards detected when the window of time is equal to *t*, *t* = 1 – 4. A least squares estimate of λ was found such that it minimizes the sum of squared deviation:

$$\text{minimize}\left\{\sum_{t=1}^{4}\left(p(t)-0.95\times 0.83\left(1-e^{-\lambda t}\right)\right)^{2}\right\}.$$

Table 11: Observed (Alternating Low Load) and Predicted Accuracy as a Function of Window Duration. (The value .789* is the asymptotic value that is 95% of the continuous condition).

time	Lambda = 0.7	
	Observed	Predicted
1	0.44	0.397
2	0.48	0.594
3	0.73	0.692
4	0.75	0.741
5		0.765
6		0.777
7	0.789*	0.783

The estimate (starting with λ = 0.1 and moving up in units of 0.1) of λ that minimized the sum of squared deviations, say λ*, was 0.7. The observations and predictions are presented in **Error! Reference source not found.Table 11** above.

3.3 Discussion

My first experiment reveals several unique findings. The results on hazard anticipation showed that drivers in the continuous condition anticipated the largest percentage of hazards while drivers in the 1/2 alternation sequence anticipated the lowest percentage of hazards in both the alternating baseline and the low load conditions. The results indicate the importance of the forward roadway duration in an alternation sequence. There definitely exists a benefit to glancing at the forward roadway for a duration greater than the preceding in-vehicle glance especially when the preceding in-vehicle glance is at least 2 s. The percentage of hazards detected by drivers dropped by almost half in the 1/2 alternation sequence as opposed to the 4/2 sequence. Clearly when distracted (manipulated via an alternation sequence), drivers are not able to obtain sufficient critical information from the forward roadway for latent hazard anticipation, especially when the forward roadway glance is less than 2 s.

The findings of my experiment could prove to be a critical contribution towards complementing and completing NHTSA's Distracted Driving Guidelines (NHTSA, 2012). The proposed guidelines recommend the design of in-vehicle devices such that: tasks should be completed by the driver with a mean in-vehicle glance duration of 2 sec or less; 85% of glance durations away from the forward roadway should be 2 seconds or less; and the cumulative time spent glancing away from the forward roadway should be 12 seconds or less.

What the guidelines lack is a component specifying how long at minimum drivers need to glance at the forward roadway when engaged in an in-vehicle task. My research address this question. The criticality of the forward roadway glance cannot be overstated simply because of the constantly changing dynamics on the open road. When extrapolated to the real world, my findings would indicate that the importance of significantly long forward roadway durations is amplified even further considering that the latent hazard anticipation required on the road is often more complex.

Practically, my findings could provide initial estimates of the framework for adding to the NHTSA guidelines similar information about the forward roadway duration. The numbers are apt to change, but the format should not vary greatly for the duration of forward roadway glances. For example, one might have the following as guidelines after suitable research had been completed:

- Drivers mean glance duration on the forward roadway must be at least 6 seconds (asymptotically estimated) when engaged with an in-vehicle task (similar to the alternating low load condition leading to switching effects);
- At least 85% of the forward roadway glances must be 6 seconds or more;
- And, the cumulative time spent glancing at the forward roadway should be at least 3 (visible to invisible time ratio in the alternation sequence) times the time spent glancing away from the forward roadway.

3.3.1 Type of Processing and Location of Threat

Upon taking a closer look, an effect of the type of processing on hazard perception was observed. As hypothesized, I observed a greater benefit to bottom up processing compared to top down processing. When the type of processing involves allocation of attention to a potential target zone, drivers performing a secondary task detect a much lower proportion of latent hazards as opposed to when the processing involved is bottom up. Even the performance of a simple, low load secondary task leads to performance decrements impacting safety and negatively impacts hazard detection which is explained by swapping and switching effects in the subsequent paragraphs. As predicted, drivers' performance in the bottom up condition is better than their performance in the top down condition, approaching near perfect performance when the view is continuous. The difference is 35 percentage points in this condition. In both of the alternating conditions, the effect of the bottom up cues are attenuated on average and especially at the shorter durations. This points to the critical importance of taking long glances on the forward roadway because the effect of even the most obvious of bottom up cues is considerably lessened. It is critical to note the impact of longer forward roadway glances in aiding hazard detection as a function of the type of processing.

The results did not indicate a benefit to centrally located threats as opposed to peripherally located threats and thus the null hypothesis could not be rejected. It becomes clear why this is the case when one looks at the continuous condition. There the peripheral threats were detected more frequently (95%) by some considerable margin than the central threats (70%). Thus, one would not expect centrally located threats to be detected better than peripherally located threats in the two alternating conditions. In fact, in 5 of the 8 alternating conditions, the detection of the peripheral threat was at least as good as the detection of the central threat. In retrospect, different types of bottom up cues were used as central (sudden onset of brake lights) and peripheral (sudden onset of motion) stimuli. Thus, the type of stimulus associated with the sudden onset was confounded with the location of the stimulus. Regardless, it is important to note that shorter forward roadway durations within an alternation sequence lead to the detection of a lower percentage of hazards across both types of threats. This result further underlines the importance and criticality of the duration of the forward roadway glance within an alternation sequence.

3.3.2 Swapping and Switching Effects

The use of a visual search task led to performance decrements in latent hazard detection in the alternating low load condition compared to the alternating baseline condition. The simple effect of swapping the center screen lead to performance decrements in drivers in the alternating baseline condition compared to the continuous condition. The former is explained by the switching effect which is the difference in latent hazard detection likelihoods between the alternating low load and baseline conditions while the latter is explained by the swapping effect which is the difference in latent hazard detection between alternating baseline and continuous conditions. There is clear evidence of a swapping effect for alternating baseline sequences 1-2 (B1) and 2-2 (B2) with shorter forward roadway durations (1 s and 2 s) in the alternation sequence. This is a critical result as it further strengthens the criticality of the forward roadway duration in an alternation sequence. There is also clear evidence of a combined swapping and switching effect for all alternating sequences (E1 – E4). However, the differences between the alternating and baseline conditions are too small to find evidence of a statistically significant difference. However, it may be the case that the difference between the alternating baseline and low load conditions may have been attenuated on average leading to better performance of participants in the alternating low load condition and worse performance of those in the alternating baseline condition. This motivated the evaluation of percentage of tasks attempted and task accuracy.

The eye tracker data from some participants in the alternating baseline condition in Experiment 1 indicated that while the black, center screen was presented there was a tendency to glance towards the side. This may have occurred as the alternating baseline condition task lacked an element that compelled drivers to fixate their glance on the center screen. Non fixation on the center screen even by a few participants could potentially diminish the observed effects if the participants were not fixating on the center screen when the latent hazard appeared on this screen. This is an issue that can be corrected and is addressed in the next experiment by presenting a fixation cross on the black, center screen in the alternating baseline condition to restrict participant drivers' tendency to glance at the side screens when in an alternation sequence.

There was a significant effect of the number of tasks attempted on the hazard anticipation scores. The results suggest that the size of the benefit for non-task performance would be minimal for the 4/2 alternation sequence while the benefits would be maximal when the sequence is 1/2. This follows because the percentage of tasks attempted is smaller in the 1/2 sequence than it is in the 4/2 sequence (Figure 23). Thus, there may well have been an effect of switching had participants completed more tasks in the 1/2 sequence. As it was, their performance in the 1/2 sequence could have been artificially inflated because they were not attempting all tasks.

The results of evaluating task accuracy as a function of the alternation sequence indicate that drivers are more likely to detect latent hazards when provided with longer forward roadway durations. However, this was largely because they attempted more tasks, not because, given they attempted a task, they were more accurate (Figure 23). Upon careful examination of the data, it was interesting to note that for the 12% of tasks that were un-attempted, the proportion of hazards detected in such instances was significantly higher across all the four alternation sequences thereby showing a clear benefit to non-performance of any kind of secondary task (Figure 24). This suggests that performance was also artificially inflated in the 4/2 sequence as well as the 1/2 sequence.

However, it is clear that participants were attempting the secondary task and most often getting it right. Specifically, participants were attempting the great majority of tasks in all sequences and task accuracy was above chance (chance was defined as 1/7), indicating that not only were participants paying attention, but they were able to pay enough attention to get the task accurate most of the time. These findings indicate that the participants were loaded by the secondary task.

At this point, it would be safe to state that there exists clear combined swapping effects and switching effects (since it is evident that drivers are attempting tasks and not ignoring the secondary task thereby boosting hazard detection rates). However, it is not possible to determine whether the combined effects are due just to swapping or to both swapping and switching. As one would expect, both effects are predominant when the forward roadway glances are either 1 s or 2 s within an alternation sequence. It would appear that the simple requirement to maintain the lane position and velocity (swapping) elicits worse hazard detection rates by itself. This is consistent with similar findings reported by Borowsky et al. (2014). Requiring a driver then to perform a task when the forward roadway is not visible does add extra load, but the decrement in performance compared to that observed when just a blank screen is present does not prove significant. A slight elevation in the performance in the alternating low load condition may explain this failure to find differences since the number of tasks attempted was smaller in the alternating low load condition when the forward roadway was visible for the shortest periods of time, exactly where one would expect the greatest switching effects to occur.

3.3.3 Velocity

Examination and analyses of velocity data yielded some valuable conclusions. The velocity was collected for a 15 second period prior to the potential latent hazard for all subjects across all scenarios. The velocity was also collected for the immediate 5 seconds preceding the hazard. It was analyzed in order to determine whether drivers in the continuous condition were traveling faster than drivers in either or both of the alternating conditions. If such were the case, then the performance of drivers in the alternating conditions could be artifactually inflated because they had more time to scan for a latent hazard. However, the average velocities did not differ across conditions. Drivers across all conditions drove at an average velocity (during the task duration) not exceeding 21 mph thereby eliminating a potential confound that could have existed if it was observed that drivers in the different treatments had different velocities (that vary greatly).

The velocities were also analyzed within each of the two alternating conditions as a function of the alternation sequences. If it was observed that say, the 1/2 sequence had an average velocity much faster than the 4/2 sequence, then it would be hard to determine if it was the slowing of the vehicle in the 4/2 sequence leading to better hazard detection or if it was the length of time the forward roadway is visible that is leading to better hazard detection. In fact, there was no change in velocity across alternation sequences in either of the two alternating conditions. This further strengthens the two key findings, a positive effect of longer forward roadway glances within an alternation sequence on hazard anticipation and the presence of swapping and switching effects proving detrimental to latent hazard anticipation when drivers are merely subjected to a change in the focus of attention (swapping) or diversion of attention using a visual search task (switching).

3.3.4 Summary

To summarize, the results of my Experiment 1 are consistent with the hypothesis that longer forward roadway glances within an alternating sequence have a larger benefit to latent hazard detection. Specifically, when driving with the views of the forward roadway alternated with the center screen task, drivers are much more likely to better detect hazards when they allocate more time on the forward roadway (4 s as opposed to 1 s, 2 s, 3 s). There is a benefit to longer forward roadway glances when the type of processing is bottom up compared to top down. The average velocity data rules out several potential alternative explanations of why there might be differences in the continuous and alternating conditions and why there might be differences within the alternating conditions. There is the presence of separate swapping and combined swapping and switching effects. When not attempting tasks, drivers anticipate a larger proportion of the hazards. However, the drivers were definitely paying attention to the alternating low load secondary task, ruling out one potential explanation of why separate effects of switching were not observed. The asymptotic estimation of the threshold duration predicted 7 seconds as the minimum duration required for an informative forward roadway glance when involved in an alternation sequence under switching effects (alternating low load condition) and 4 seconds when subjected to swapping effects (alternating baseline condition).

The type of alternation sequence had a clear effect where the longest forward roadway duration – 4/2 - within an alternation sequence elicited the highest percentage of hazards detected. Additionally I observe clear swapping effects, and significant combined effects of both swapping and switching. The difference between the likelihood that the threat is detected in the alternating and continuous conditions when the window is less than the threshold duration varies as a function of the type of processing and the alternation sequence. Additionally, the threshold duration was estimated in the alternating conditions. For the alternating baseline condition, the threshold duration was estimated at about 4 s. What this means is that under swapping effects, the optimal threshold duration is closer to 4 s. And this duration increases as a function of the load. It appears that 7 s would be the safest minimum forward roadway duration threshold to elicit safe driver behavior when the drivers perform an in-vehicle task that requires switching in the alternating low load condition.

In my second experiment, I address the presence of potential spillover effects by using a secondary task which cognitively loads the participant not only during the glance inside the vehicle but also during the glance on the forward roadway (alternating high load condition). Thus, in Experiment 2 there are four conditions, the continuous condition and three alternating conditions: baseline, low load, and high load. I also investigate the above factors across the additional high load condition in Experiment 2. The alternating baseline condition in the next experiment will be tweaked to ensure that drivers fixate on the center screen.

CHAPTER 4

EXPERIMENT 2

Experiment 2 also uses the RTI simulator. This experiment differs from the first experiment in two important respects. First, the secondary task given to participants while the forward roadway is not visible includes an alternating high load and as well as alternating low load condition. The alternating high load condition is included in order to investigate the effects of spillover in addition to those of swapping and switching. The details of this condition are discussed more thoroughly below. Second, the alternating baseline condition now requires drivers to fixate on the center screen. The eye tracker data from some participants in the alternating baseline condition indicated that while the black screen was presented they would occasionally glance to the side. With the fixation cross present on the black screen in Experiment 2, they can no longer look to the side screens. If drivers were looking at the side screens in Experiment 1 during the alternating baseline condition, they may not have been focused centrally when the hazard to be anticipated appeared. This could have artificially decreased performance in the baseline condition.

Similar to the first experiment, the second experiment has two aims as well. The first aim is to identify how the threshold duration varies in the alternating conditions as a function of: (a) how the threat is processed (top down or bottom up); (b) where the threat is located (fovea or periphery); and (c) the type of load (alternating baseline, low load, high load). The second aim is to determine how the difference between the likelihood that the threat is detected in the alternating and continuous conditions when the window is less than the threshold duration varies as a function of the above factors.

4.1 Method

Drivers in this study performed a secondary in-vehicle task as they navigated through various sections of the roadway involving two-lane and four-lane roads in a suburban environment. The scenarios in the various sections of roadway incorporated latent hazards. There are four experimental groups of drivers in Experiment 2: A continuous (control) group as in Experiment 1, an alternating baseline group (as in Experiment 1 but with a fixation task), an alternating low load group (as in Experiment 1 performing a secondary task which loads the driver only while glancing at the secondary task), and an alternating high load group (a group engaging in secondary task which loads the driver both while glancing at the secondary task and while glancing at the forward roadway). Specifically, drivers in the alternating high load condition will be asked to complete a secondary task which places a load on the driver during the period of time both when the task is visible and when the forward roadway is visible.

4.1.1 Participants

In this experiment, the driving performance of younger drivers was evaluated on the driving simulator. A total of 40 younger drivers (between the ages of 18 – 21) with an average age of 20.1 (SD = 0.819) and average driving experience of 2.8 years (SD = 0.351) were recruited as paid participants for the study from the University of Massachusetts Amherst and surrounding areas.

4.1.2 Secondary Task

There are two secondary tasks for this experiment. The first low load secondary task was chosen with the criterion that when the forward roadway is not visible, it (the task) places no load on the driver during the period of time in which the task is visible. Effects of switching and swapping are possible, making the threshold duration in the alternating low load condition longer than it is in the continuous condition. But there should be no effects of load while the driver is glancing at the forward roadway. It is identical to the alternating low load task in Experiment 1.

The second, high load secondary task, as noted above, places a load on the driver while he or she is performing the primary task. There are several tasks which could serve in this regard. I have chosen a cognitive arithmetic task that adds to the load of the secondary task chosen in Experiment 1 thereby providing me with a baseline for task comparison. As with the low load task, drivers in the high load task have to search the number of times the letter ‘t’ appears on the visual search display and report the count (e.g. 0,1,2,3,4,5,6) (Figure 27). However, after the number of targets has been reported the driver needs to count forward by 3 until the next visual search display appears For example, if the target count is 3, then the participant would verbally count aloud 3, 6, 9,…. until the next search display appears where the count may be a 2 leading to a verbal count of 2, 5, 8, 11… and so on. In this task, participants are loaded even when they look at the forward roadway since they need to mentally compute arithmetic sums. Addition is a fairly difficult cognitive process especially when combined with the primary visual task of driving.

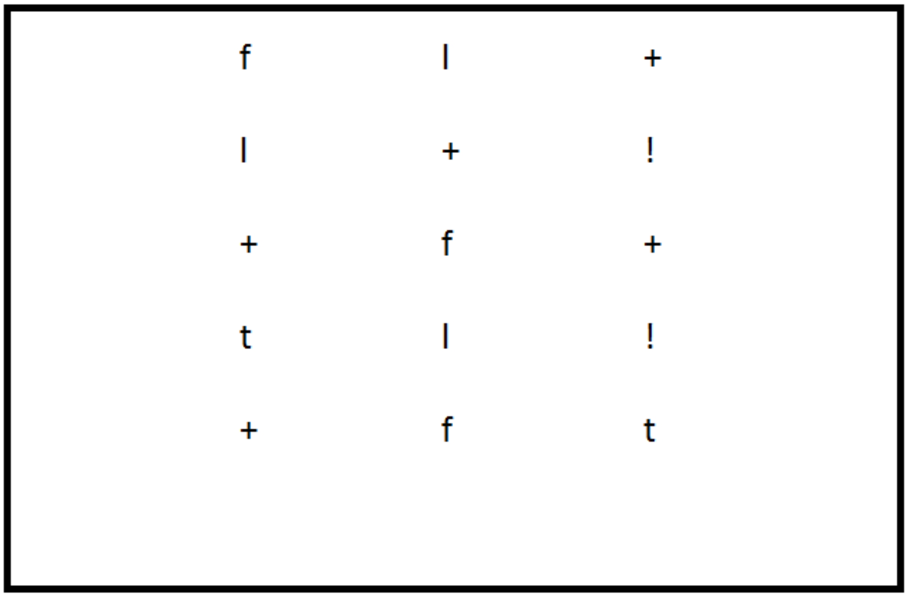

Figure 27: Example of Secondary Loaded Task

The alternating baseline condition in Experiment 2 was slightly modified from Experiment 1 in terms of the interruption. As discussed above, it was determined that it was necessary to control for where the participants would glance during the interruption and hence, the decision was taken to utilize a target fixation task on the black screen as an interruption (depicted in Figure 28 and Figure 29 below). Recall that in Experiment 1, it was observed that drivers had a choice to look at the periphery on either side of the center screen which was blanked out and thereby making it hard to control sufficiently for what drivers observed across treatment conditions. Therefore, I utilized a fixation task where I asked my participants to fixate on a '+' sign that appears on the black screen during the periodic alternations. The location of the '+' target was changed every time to ensure that drivers had some reason to glance at the blank screen.

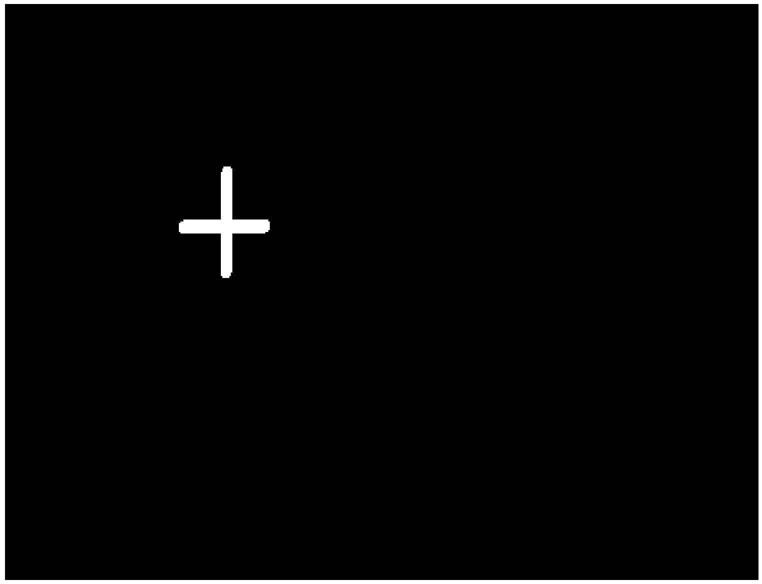

Figure 28: Fixation Task

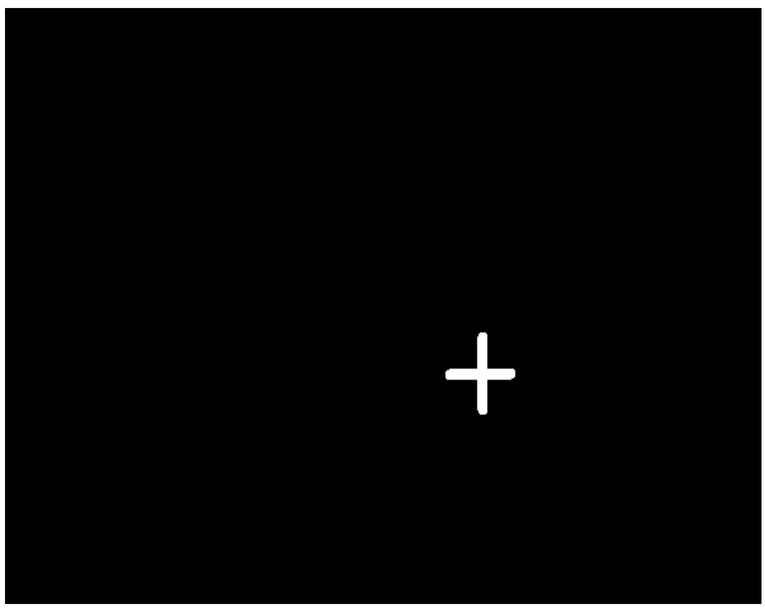

Figure 29: Another example of the fixation task with the target at a different location.

4.1.3 Scenarios used for Evaluation: Four Combinations

The scenarios used in Experiment 2 were identical to those used in Experiment 1. Briefly, they were designed to determine under different loading conditions how the type of processing (top down or bottom up) and the location of the threat (central or peripheral) affect the threshold duration and, when the window is less than the threshold duration, how these factors affect the likelihood that an individual detects a threat. There are thus four combinations: central/top down, central/bottom up, peripheral/top down, and peripheral/bottom up. As with Experiment 1, there were a total of 8 scenarios, two each for the four combinations.

4.1.3.1 Control and Alternating Baseline, Low Load and High Load Conditions

The same scenarios are seen across all four conditions. The continuous (control) condition differs from alternating conditions in the sense that the forward roadway is continuously visible in the control scenarios while the feedback from the forward roadway is visually interrupted in the alternating scenarios according to the window size used. In the alternating baseline, low load and high load conditions, the first interruption is initiated in advance of the scenario and the last interruption can occur after the latent hazard has been passed, the exact initiation time depending on the scenario.

The alternating baseline scenarios differ from the alternating loaded scenarios in the nature of secondary task used. The interruptions are initiated just like in the alternating loaded scenarios according to the various window sizes.

The secondary "in-vehicle" task for the loaded scenarios involves a visual search task where the participant is asked to count the number of times the letter 't' appears on a visual search display on the center screen while the baseline secondary task mimics an automated fixation task. During the specified interruption window, the center screen is blacked out to determine the psychomotor load associated with maintaining the lane position and speed when no information is available from the forward roadway (the situation when drivers are engaged in a distracting in vehicle secondary task in concurrence with driving).

There are two alternating loaded conditions: one with a secondary task where the load occurs only during the glances at the in-vehicle portion of the task and a second with a secondary task which loads the driver both while glancing at the in-vehicle portion of the task and while glancing on the forward roadway.

It was hypothesized drivers in the alternating high load condition would anticipate hazards less well than drivers in the alternating low load condition because the former condition includes effects of spillover, switching and swapping while the latter includes effects only of switching and swapping. And, as in Experiment 1, it was hypothesized that drivers in the alternating low load condition would anticipate hazards less well than drivers in the alternating baseline condition because the former condition includes effects of switching and swapping while the latter condition includes effects only of swapping. The differences between the alternating baseline and alternating low load conditions may now be significant, assuming that performance is the alternating baseline condition was artificially depressed in Experiment 1.

4.1.4 Experimental Design

The experimental design was largely the same as in Experiment 1 except for an additional condition involving an experimental high load condition where the secondary task utilized invokes cognitive load on the driver and the loading occurs even when the driver is gazing at the forward roadway and not only when performing a center screen task.

4.1.4.1 Alternating Condition

In the alternating condition, the combinations of times that the in-vehicle task is displayed (always 2 s) and times that the forward roadway is displayed (1 s, 2 s, and 4 s) were the same as in Experiment 1, except that the 3 s forward roadway duration was not used for Experiment 2. This was done because hazard anticipation performance seemed not much different between the 3 and 4 s glances at the forward roadway and the threshold duration could be computed from three points almost as easily as it could from four.

4.1.4.2 Overall Design

The study employs a mixed design (factors are varied both between and within subjects). Every participant receives either the control drive (drive 1), one of the three alternating baseline drives (drives 2a, 2b, 2d; the numbering is described above in Experiment 1), one of the three alternating low load drives (the experimental drives 3a, 3b and 3d) or one of the three alternating high load drives (drives 4a, 4b, 4d) where each drive consists of eight scenarios (the eight scenarios in each drive are described above). The participant sees only a single drive in order to minimize both learning effects as well as simulator sickness resulting from prolonged exposure. The drives vary from each other in terms of type of alternation sequence and type of load. The type of processing and location of the threat are within subject factors while the alternation sequence and type of load (continuous, baseline, low load, high load) are between subject factors.

4.1.3.2 Counterbalancing Conditions and Drive Sequences across Participants

The eight mini scenarios in each drive are each about 2 minutes on average. Thus each drive took about 16 minutes. The 40 participants were pseudo randomly assigned to one of the ten conditions (Table 12; example assignment for first 20 participants):

Table 12: Counterbalancing Conditions (Drives) Across Participants. (First 20 participants)

Subject	Drive
1	1
2	2a
3	2b
4	2d
5	3a
6	3b

7	3d
8	4a
9	4b
10	4d
11	1
12	2a
13	2b
14	2d
15	3a
16	3b
17	3d
18	4a
19	4b
20	4d

4.1.3.4 Counterbalancing Order of Scenarios across Participants

The order of scenarios (A – H) in each of the drives was counterbalanced across conditions (drives) and, within conditions, across participants (Table 13) in order to minimize order effects.

Table 13: Counterbalancing of Scenarios (A, B, C, D, E, F, G, H) across Drives (1, 2a, 2b, 2d, 3a, 3b, 3d, 4a, 4b, 4d)

Participant No.	First Drive
1	1 (A, B, C, D, E, F, G, H)
2	3a (C, D, B, G, H, E, A, F)
3	2b (C, D, E, F, G, H, A, B)
4	2d (B, G, H, E, A, F, C, D)
5	3b (E, F, G, H, A, B, C, D)
6	2a (H, E, A, F, C, D, B, G)
7	4b (G, H, A, B, C, D, E, F)
8	4d (A, F, C, D, B, G, H, E)
9	4a (C, D, B, G, H, E, A, F)
10	3d (E, F, G, H, A, B, C, D)

4.1.3.5 Counterbalancing Combinations of Threat Factors within and Across Participants

Finally, note that within drivers it is important to counterbalance the combination of types of processing and location of the threat (Table 14).

Table 14: Counterbalancing Across Scenario Sequence Type of Processing and Location of Threat

Scenario Sequence	Combination	Scenario Sequence	Combination
A	Central/Bottom Up	F	Central/Bottom Up
B	Peripheral/Top Down	C	Central/Top Down
C	Central/Top Down	D	Peripheral/Bottom Up
D	Peripheral/Bottom Up	B	Peripheral/Top Down
E	Peripheral/Top Down	G	Central/Top Down
F	Central/Bottom Up	H	Peripheral/Bottom Up
G	Central/Top Down	E	Peripheral/Top Down
H	Peripheral/Bottom Up	A	Central/Bottom Up

4.1.5 Apparatus

4.1.5.1 Driving Simulator

The driving simulator was described in Section 3.1.5.1.

4.1.5.2 Eye Tracker

The eye tracker was described in Section 3.1.5.2.

4.1.6 Procedure

The procedure for Experiment 2 is the same as that in Experiment 1.

4.1.7 Dependent Variables

The dependent variable for Experiment 2 are the same as in Experiment 1. See Section 3.1.7.

4.1.8 Statistical Analyses

4.1.8.1 Threshold Duration

The threshold duration was described in Section 3.1.8.1.

4.1.8.2 Effect of Swapping, Switching and Spillover

As discussed above, the swapping effect at each window size will be set equal to the difference in the average hazard anticipation performance of the alternating baseline and continuous conditions. The switching effect will be defined as the difference in the average hazard anticipation performance of the alternating low load and alternating baseline conditions at a given window size. And the spillover effect will be defined as the difference in the average hazard anticipation performance of the alternating high load and the alternating low load conditions at a given window size.

4.2 Results & Analyses

4.2.1 Latent Hazard Anticipation

In order to analyze whether drivers successfully anticipated latent hazards, similar to Experiment 1, I decided to determine whether or not a participant had glanced towards the target zone while in the launch zone. A *target zone* was defined as the area where a potential hazard might appear, and the *launch zone* was defined as the area wherein the participant should glance at the hazard. Therefore, the dependent variable (number of hazards anticipated) was binomially distributed (1 -- a participant glanced at the target zone while in the launch zone; 0 -- the participant did not glance at the target zone while in the launch zone).

The observed proportions for the percentage of hazards detected across the various treatments are represented in Figure 30. As predicted, drivers in the continuous condition anticipated the largest percentage of hazards (81.3%) while drivers in the 1/2 alternation sequence performed worst in terms of latent hazard anticipation, in all three alternating conditions, baseline, low load and high load conditions (69%, 63% and 44% respectively). The 4/2 alternation sequence elicited a much higher proportion of glances critical to hazard anticipation, in all three alternating conditions, baseline, low load and high load conditions (81%, 72% and 66% respectively). The observed percentage of hazards detected followed predictions and decreased as the glance time on the forward roadway decreased (the percentage of hazards detected decreased as the forward roadway glance decreased from 4 s to 1 s). Overall, drivers in the continuous condition anticipated 81.3% of the hazards, those in the alternating baseline condition anticipated 68% of the hazards, while those in the alternating low load and high load conditions anticipated 60% and 49% of the hazards.

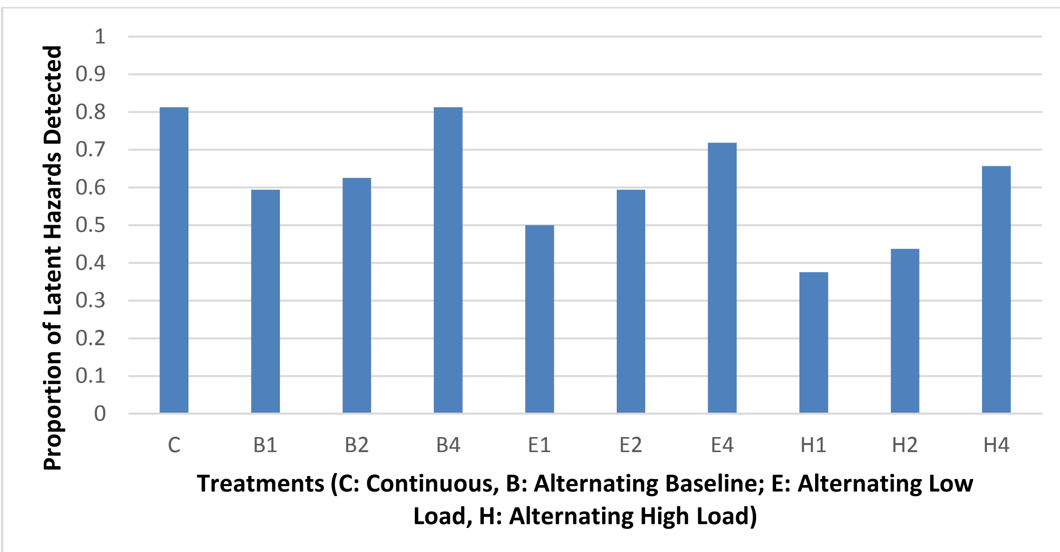

Figure 30: Percentage of Hazards Anticipated

In order to analyze the latent hazard anticipation skills across the different alternating conditions in the second experiment, I utilized a logistic regression model within the framework of Generalized Estimating Equations (GEE). The model included the participants as a random effect, two between subjects factors -- (a) Type of Load: Baseline, Low Load or High Load and (b) Alternation Sequence: 1/2, 2/2, 4/2 -- and the three within subjects main effects -- (c) Location of threat: Peripheral or Central; (d) Type of Processing: Bottom Up or Top Down, and (e) Scenarios (8 unique scenarios described in Section 3.1.3). All second and third order interactions were also included. Using a backwards elimination procedure, the final model included highly significant main effects for Location of Threat [Wald X_1^2=4.300; p=0.038], Type of Load [Wald X_1^2=7.410; p=0.025] and Alternation Sequence [Wald X_1^2=12.207; p=0.002]. There was no significant effect for Type of Processing. The estimated marginal means averaged across the alternating baseline and alternating low load conditions are presented in Figure 31.

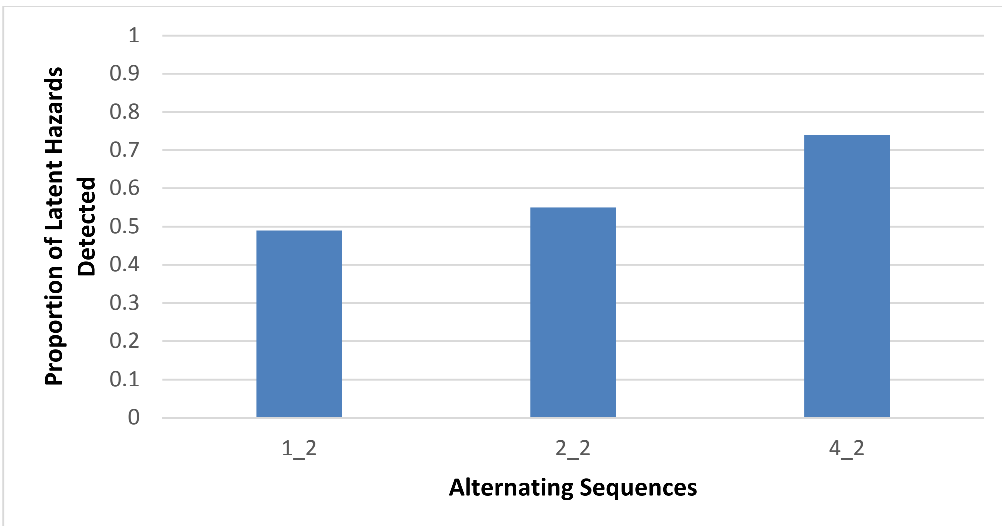

Figure 31: Estimated Marginal Means (Alternating Baseline, Low Load and High Load Conditions)

In order to further understand whether latent hazard detection performance was significantly different across the alternation sequences, a post hoc pairwise comparison using a Bonferroni correction (p = 0.001) on the estimated means was performed. The difference in performance between the 1/2 and 4/2 alternating sequences was found to be highly significant (p < .01). As expected, the drivers in the 4/2 alternating sequence were much more likely to glance towards a potential latent hazard as compared to drivers in the 1/2 alternation sequence.

The results obtained in Experiment 2 further reinforce the existence of benefits to glancing at the forward roadway for a duration greater than the preceding in-vehicle glance especially when the preceding in-vehicle glance is at least 2 s. At this point, it is important to look at what role the other factors may have played in the participants' ability to detect potential latent hazards.

4.2.1.1 Type of Processing

There was no significant effect for Type of Processing. There appears to be an increase in the percentage point difference between TD and BU processing in each of the three different loading conditions as the duration of the glance on the forward roadway decreases. However, the analyses (logistic regression within the GEE framework) did not indicate any interaction between alternation sequence and the type of processing. In order to determine whether the failure to find an effect of Type of Processing in Experiment 1 on hazard anticipation was a function of the inclusion of the alternating high load condition, the model was run with only the alternating baseline and low load conditions in Experiment 1. The final model included highly significant main effects for Type of Processing [Wald X_1^2=6.245; p=0.015]. Thus, it does appear that the effect of the Type of Processing in both Experiments 1 and 2 for the same alternating conditions was observed. Why the effect might not be observed when the alternating high load condition is included is discussed later.

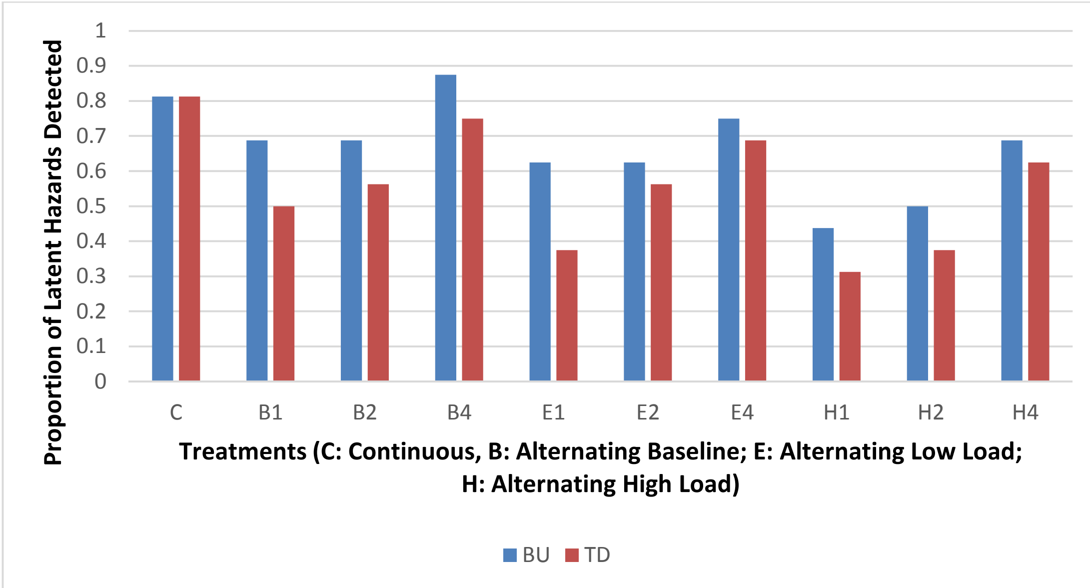

Figure 32: Percentage Hazards Detected (BU vs. TD)

4.2.1.2 Location of Threat

As noted above, the final model analyzed using logistic regression within the GEE framework included highly significant main effects for Location of Threat [Wald X_1^2=4.300; p=0.038]. The observed proportion of hazards detected as a function of the Location of the Threat (Peripheral or Central) is plotted in Figure 33. There was a clear benefit to latent hazard anticipation for centrally located threats (e.g., lead vehicle braking) as opposed to peripheral latent hazard (e.g., pedestrian at a crosswalk). The observed results matched my predictions. Across all conditions, there was a benefit for centrally located threats and this is specifically interesting when noting that even when examining across conditions, as the forward roadway durations within an alternating sequence increase, the benefit to centrally located threats still exists. This suggests that peripheral detection is bad to begin with and suffers even more when allocating brief glances at the forward roadway when distracted.

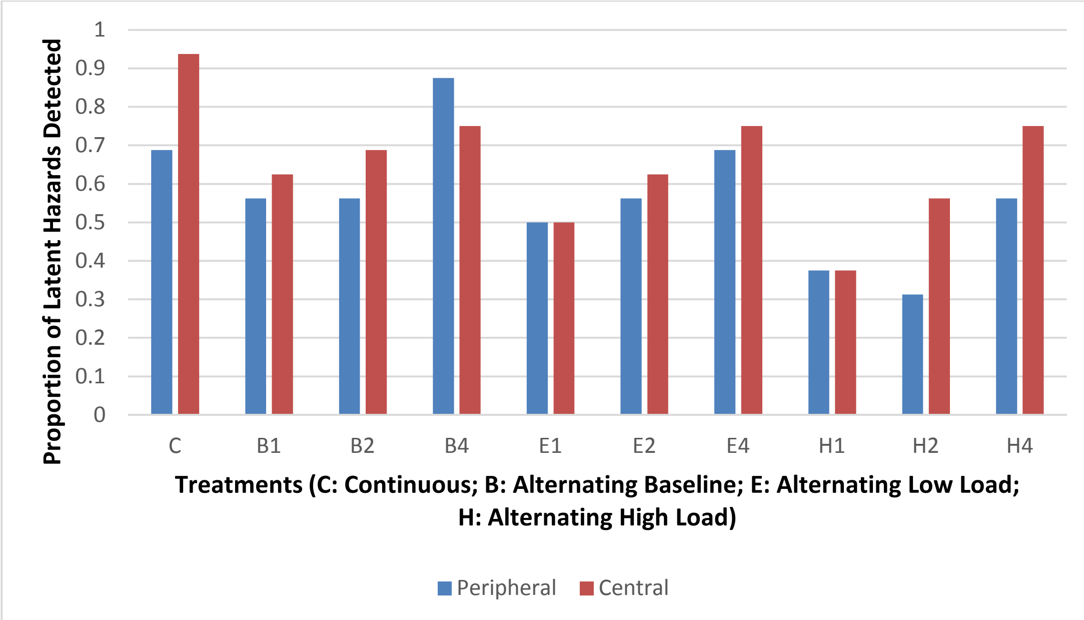

Figure 33: Percentage of Hazards Detected (Peripheral vs. Central)

The estimated marginal means for peripheral and central threats are presented in Figure 34

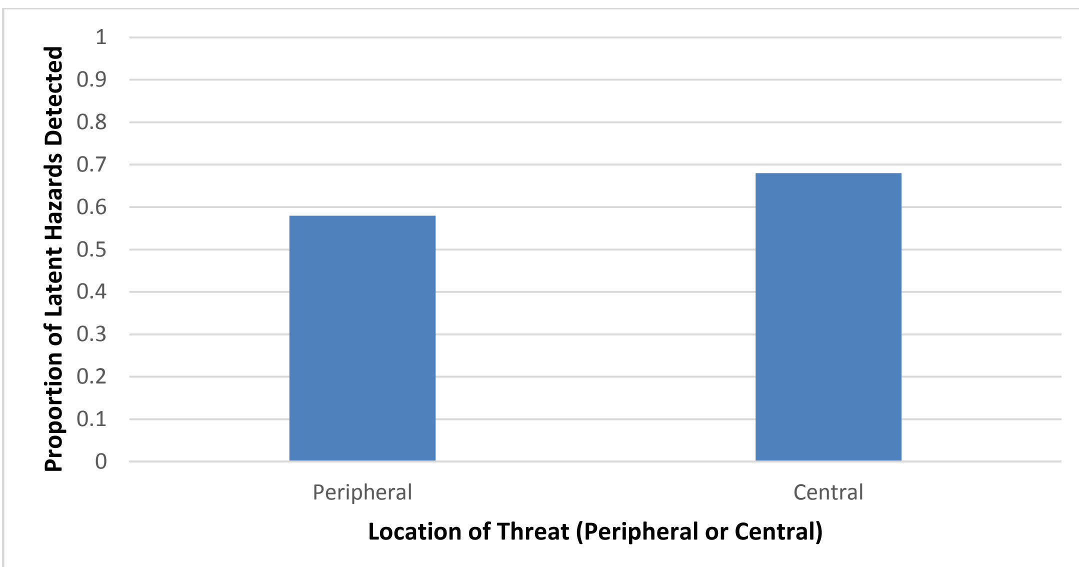

Figure 34: Estimated Marginal Means (Location of Threat)

4.2.1.3 Swapping, Switching and Spillover Effects

Given a significant effect of load, a post hoc analysis was performed to identify separate effects for swapping, switching and spillover. I ran a Univariate analysis under the General Linear

Model utilizing Least Square Difference for post hoc analysis. A statistically significant difference was obtained for the continuous condition (M = 0.813, SE = 0.161) compared to the alternating baseline condition (M = 0.68, SD = 0.135), M = 0.135, 95% CI [0.047, 0.318], F (3) = 5.331, p = 0.014, a difference indicating the existence of *swapping* effects.

A statistically significant difference was obtained for the alternating baseline condition [B (M = 0.68, SD = 0.135) compared to the alternating low load condition (M = 0.60, SD = 0.175), M = 0.073, 95% CI [0.057, 0.203], F (3) = 5.331, p=0.026, a difference indicating the existence of *switching* effects.

A statistically significant difference was obtained for the alternating low load condition (M = 0.60, SD = 0.175) compared to the alternating high load condition (M = 0.49, SD = 0.155), M = 0.155, 95% CI [0.015, 0.244], F (3) = 5.331, p = 0.018, a difference indicating the existence of *spillover* effects.

Further, a statistically significant difference was obtained for the alternating baseline condition (M = 0.68, SD = 0.135) compared to the alternating high load condition (M = 0.49, SD = 0.155), M = 0.188, 95% CI [0.058, 0.317], F (3) = 5.331, p=0.006, a difference indicating the existence of combined *switching and spillover* effects. Additionally, a significant difference was obtained for the continuous condition (M = 0.813, SE = 0.161) compared to the alternating low load condition (M = 0.60, SD = 0.175), M = 0.208, 95% CI [0.024, 0.391], F (3) = 5.331, p = 0.027, a difference indicating the clear existence of combined *swapping and switching* effects as well.

In summary, the use of an arithmetic cognitive task as an alternating high load cognitive task elicited average hazard detection rates worse than the alternating low load condition, and the difference between the two conditions was statistically significant, indicating the existence of spillover effects. The use of a visual search task as an alternating low load non cognitive task elicited average hazard detection rates worse than the alternating baseline condition and the difference overall between the two conditions was significant, indicating the existence of switching effects. There was a significant effect of swapping effect observed between the continuous and alternating baseline conditions. In short, there exists evidence for all three effects, namely, swapping, switching and spillover. The analysis further indicates combined effects of swapping and switching and switching and spillover as well.

4.2.2 Secondary Task Accuracy and Tasks Attempted

The task accuracy and number of tasks completed was computed only for the alternating low-load and high load conditions. As in Experiment 1, *task accuracy* is defined as the proportion of search tasks across all scenarios during the last in-vehicle glance that drivers correctly completed while driving. This was indicated by a correct numeric response to a target display. Task accuracy is displayed by itself in Figure 35. The *percentage of tasks attempted* identifies the percentage of secondary tasks that the drivers attempted while driving. This was indicated by a verbal response to a target display, correct or incorrect.

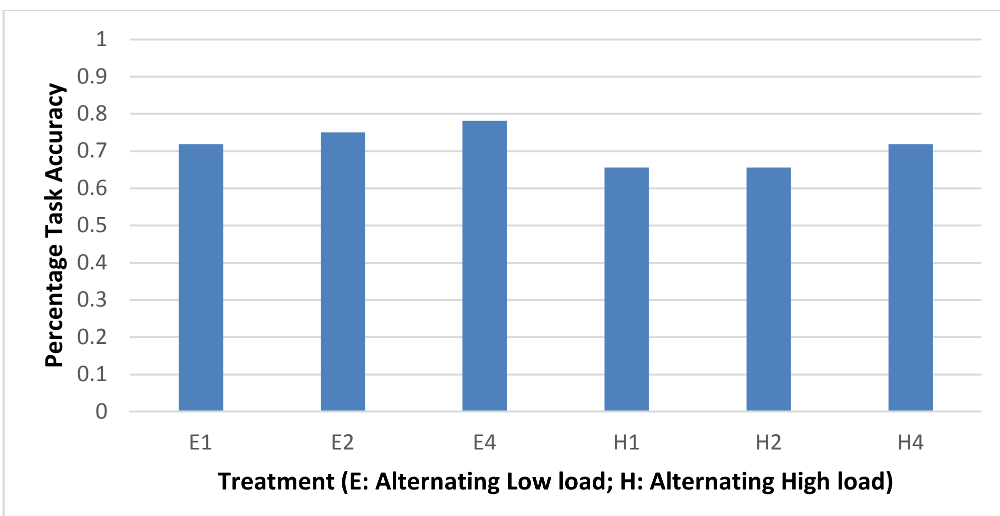

Figure 35: Task Accuracy

As noted above, it was important to analyze the effects of task accuracy and number of tasks attempted on hazard anticipation in order: (a) to understand whether the participants were actually attending to the secondary task in the alternating low load and high load conditions; (b) to understand if the participants were actually performing the secondary task as often in the alternating low load condition as they were in the alternating high load condition; and (c) to understand if the participants were performing the task as often in the long forward glance sequences as they were in the short forward glance sequences. From the data displayed in Figure 35 and Figure 36, it is clear that participants' performance on the secondary task is well above chance (14.3%) in both alternating conditions, so the secondary task is requiring some of the participants' attention, as intended. It would appear that participants in the alternating low load condition are attempting slightly more tasks than participants in the alternating high load condition; thus, if anything, performance in the high load condition would have been even worse than it was had more secondary tasks been attempted. Finally, if anything participants in the long forward glance sequences are performing more tasks than in the short forward glance sequences; thus performance in the short forward glance sequences would have been even more depressed had they attempted the same number of tasks in the short forward glance sequences as they attempted in the long forward glance sequences.

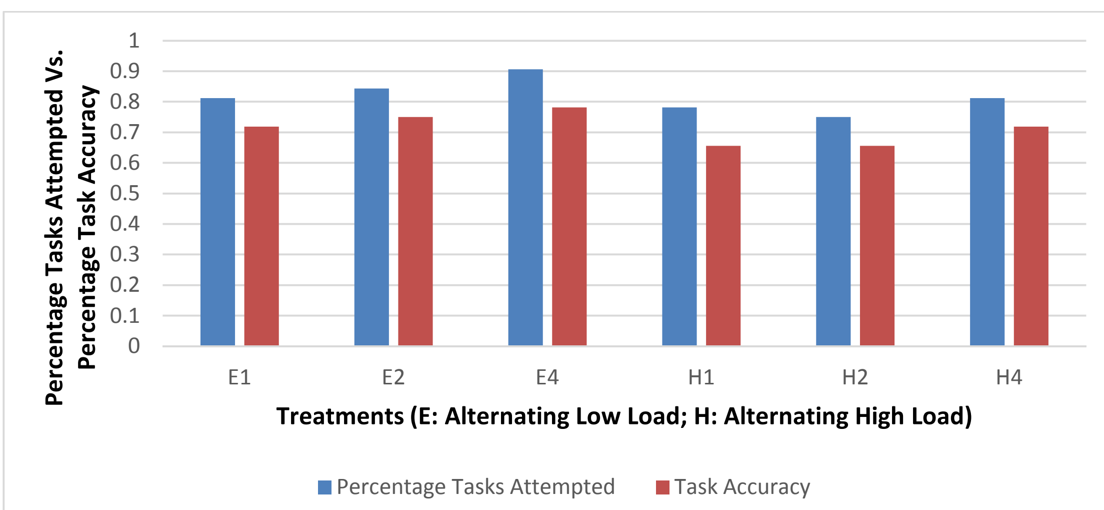

Figure 36: Percentage Tasks Attempted vs. Task Accuracy

In order to get a better handle on the relation between hazard anticipation on the one hand and tasks attempted and task accuracy on the other, I analyzed the effects of secondary task accuracy (observed proportions represented in Figure 35) and proportion of tasks attempted (Figure 36) on hazard anticipation across the alternating low load and high load sequences. I utilized a logistic regression model within the framework of Generalized Estimating Equations (GEE) with the percentage of hazards detected as the dependent variable. The model included the participants as a random effect. Secondary task accuracy and percentage of secondary tasks attempted were included as covariates in the model. Finally, the analysis model included the following factors: (a) Scenarios (8 unique scenarios described in Section 3.1.3), (b) Alternation Sequence: 1/2, 2/2, 4/2, (c) Location of threat: Peripheral or Central, and (d) Type of Processing: Bottom Up or Top Down. All second and third order interactions were also included. The final model included a significant main effect for Alternation Sequence [Wald $X_1^2=9.468$; $p=0.009$] and a significant effect of the covariate, percentage of tasks attempted [Wald $X_1^2=4.320$; $p=0.038$] (see Figure 36 for percentage of tasks attempted vs. task accuracy). In addition there were two highly significant second order interactions between Location of Threat and Tasks Attempted [Wald $X_1^2=4.459$; $p=0.035$] and Location of Threat and Task Accuracy [Wald $X_1^2=4.712$; $p=0.030$]. Figure 37 illustrates the latent hazard detection probabilities of drivers as a function of the tasks attempted.

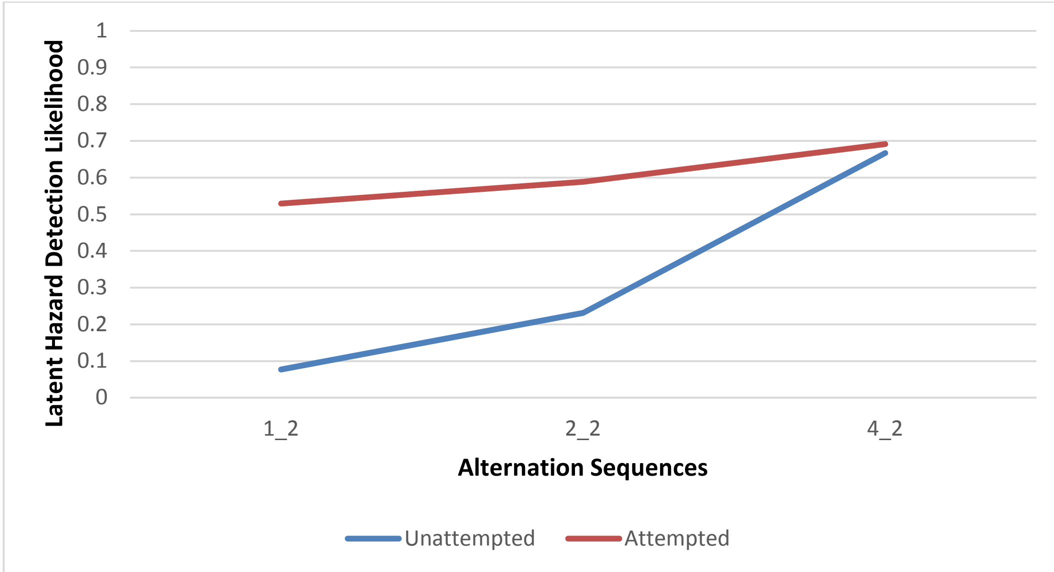

Figure 37: Latent Hazard Detection Likelihood across the various alternation sequences as a function of Tasks Attempted and Unattempted

There are three things of significance to note. First, the number of tasks attempted was very high. Specifically, drivers attempted 82% of tasks across all the alternation sequences while only 18% of tasks were left un-attempted. This suggests that participants were trying to perform the task and that, indeed, they were paying attention in the alternating low load and high load conditions. In addition, task accuracy is above chance (14.3%), indicating that not only were participants paying attention, but they were able to pay enough attention to get the task accurate most of the time. An analysis was performed to identify if task accuracy was significantly above chance. A Univariate ANOVA indicated that the chance probability lies outside the lower and upper bounds of the 95% confidence interval and hence the obtained task accuracy is above chance. Together, these findings indicate the participants were loaded cognitively by the secondary task both in the alternating low load condition indicating switching effects and in the alternating high load condition indicating spillover effects. Second, as noted above more tasks were attempted in the alternating low load condition than in the alternating high load condition. I ran a Univariate ANOVA within General Linear Models to test the hypothesis that number of tasks attempted in the high load condition is not greater than the number of tasks attempted in the alternating low load condition. The analysis revealed a significant effect for load ($F(1) = 5.674$, $p = 0.026$). This confirms that drivers in the alternating low load condition attempted significantly more tasks than drivers in the high load condition. Therefore, the fact that participants are performing better in the alternating low load condition cannot be because they are attempting fewer tasks. Third, there was a statistically significant increase in the number of tasks attempted as the duration of the forward glance increased. A Univariate ANOVA revealed a significant effect for alternation sequence ($F(2) = 5.981$, $P = 0.024$) indicating that as the duration of the forward glance in a sequence increased, participants attempted more tasks. This means that the participants are not doing worse in the shorter forward glance alternation sequences because they are attempting fewer tasks.

4.2.3 Vehicle Measures (Velocity)

As in Experiment 1, velocity was the primary vehicle measure analyzed. It was analyzed in order to determine whether drivers in the continuous condition were traveling faster than drivers in one or more of the alternating conditions. If such were the case, then the performance of drivers in the alternating conditions could be artifactually inflated because they had more time to scan for a latent hazard. The velocity was collected for a 15 second period prior to the potential latent hazard for all subjects across all scenarios. The velocity was also collected for the immediate 5 seconds preceding the hazard. The average velocity was then computed for both periods. Velocity would be an indicator of how drivers respond to the secondary tasks and the alternation sequence. There was no clear pattern for average velocity as a function of the alternation sequence. The average velocities across the conditions 15 s and for 5 s preceding the hazard are plotted in Figure 38 and Figure 39.

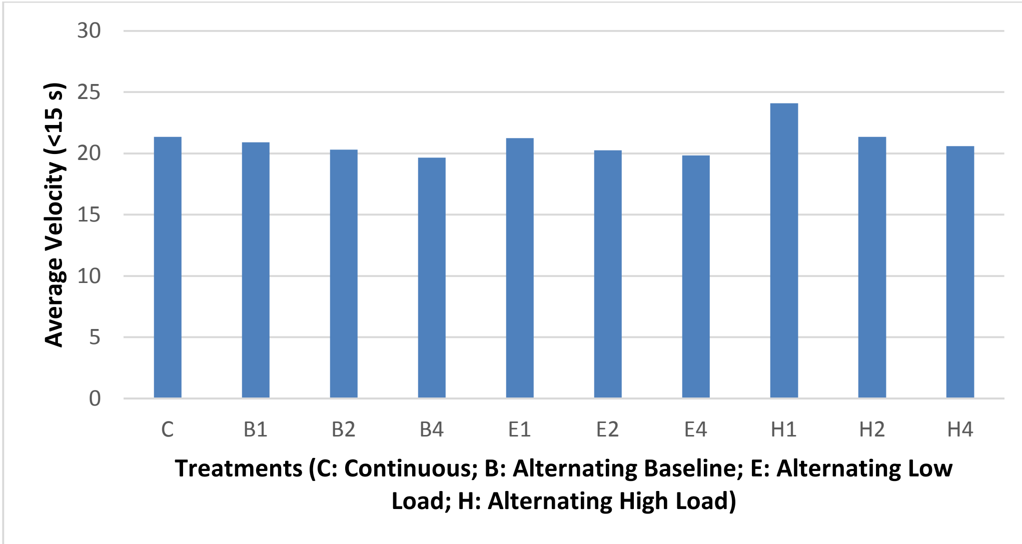

Figure 38: Average Velocity (< 15 s)

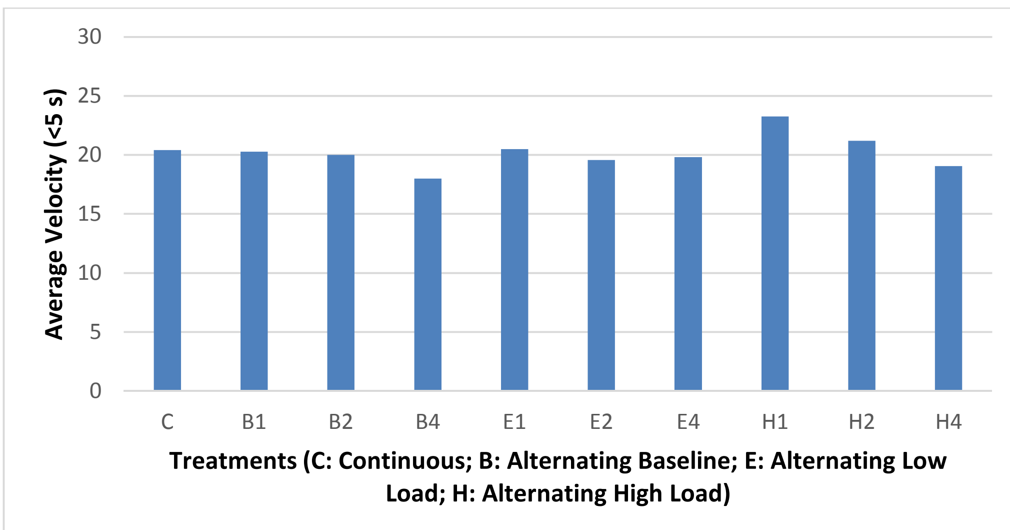

Figure 39: Average Velocity (< 5 s)

The average velocities were in the range of 21 – 22 mph. An analysis which compares the average velocity across the continuous and two alternating conditions was undertaken in order to determine whether drivers in the alternating conditions travel more slowly, a finding which could increase their performance compared to the control condition. I ran a Univariate ANOVA within General Linear Models to determine whether differences in average velocities (15 s and 5 s) were significant across conditions. The analysis for average velocity 15 s before the hazard revealed no significant effect for treatment ($F(3) = 0.835$, $p = 0.483$). The analysis for average velocity 5 s before the hazard also revealed no significance for treatment ($F(3) = 1.405$, $p = 0.257$). The average velocities and standard deviations for the 4 treatments are in Table 9 and Table 10 below.

Table 15: Average Velocity Across Conditions. (5 s before hazard)

Average Velocity (5 s)		
	Mean	SD
C	21.353	1.90
B	20.290	1.75
E	20.44	3.00
H	22.007	2.06

Table 16: Average Velocity Across Conditions. (15 s before hazard)

Average Velocity (15 s)		
	Mean	SD
C	20.400	4.27
B	19.429	2.79
E	19.956	2.77
H	21.178	2.26

The analysis which compares the average velocity across the continuous and three alternating conditions was undertaken in order to determine whether drivers in the alternating conditions travel more slowly, a finding which would increase their performance compared to the control condition. Separate analyses were run for alternation sequence in both the alternating baseline and alternating low load conditions. A Univariate ANOVA was performed on the individual alternating baseline, alternating low load and alternating high load conditions to test for effects of alternation sequence. Again, there was no significant effect for sequence in either the alternating baseline, alternating low load or alternating high load conditions. The analysis for average velocity 15 s before the hazard revealed no significant effect for alternation sequence, ($F(3, 38) = 1.557$, $p = 0.257$). The analysis for average velocity 5 s before the hazard also revealed no significance for alternation sequence ($F(3, 38) = 1.783$, $p = 0.168$).

4.2.4 Estimation of Threshold Duration

The data obtained was fitted using Excel Solver. I fitted a two parameter (λ, Δ) logistic function with the formula. To decide if the predicted data is close to the actual values a function was required to measure how good the fit was. I utilized the Least Square Difference approach and calculated the difference between the predictions and actual values and then squared it. The sum of these squares tend to 0 when the predictions are an exact match to the actual values and get larger as the predictions are further away.

Following the initiation of the solver, the objective was set to the sum of squares value approaching minimum, as we want this value to be as small as possible. The 2 parameter values were selected to permit the solver to adjust these values to minimize the sum of squares as per our requirement. These optimized values were then used to obtain the predicted threshold durations across the various conditions setting the performance in the continuous condition as a baseline. The value of ‘t’ obtained asymptotically provides me with the threshold duration required for participants to achieve/attain a level of performance in the alternating conditions approaching that in the continuous condition (81%). The threshold durations for each alternating condition was expected to be influenced by the type of load (alternating baseline, low load and high load). This helps me understand how larger effects (both in magnitude and nature) require longer threshold durations to attain levels of performance observed in the continuous condition.

An estimate was made for the baseline, low load and high load alternating conditions of the threshold duration. The threshold duration is defined as the amount of time in the alternating low load condition that the forward roadway would need to be displayed between glances inside the vehicle in order for the percentage of hazards detected to be equal to 95% of the hazard detection rate in the continuous condition (78.85%). There were four low load conditions. Let $p(t)$ be the proportion of hazards detected when the window of time is equal to t, $t = 1 – 4$. A least squares estimate of λ was found such that it minimizes the sum of squared deviation:

$$\text{minimize}\left\{\sum_{t=1}^{4}\left(p(t)-0.95\times 0.83\left(1-e^{-\lambda t}\right)\right)^{2}\right\}.$$

The estimate (starting with λ = 0.1 and moving up in units of 0.1) of λ that minimized the sum of squared deviations, say λ*, was 0.7.

The asymptotic estimation indicated that when swapping effects are present (alternating baseline condition), the threshold duration for the forward roadway glance is at least 4 s. When the in-vehicle task performed elicits switching effects (alternating low load condition), the threshold duration of the forward roadway glance increases to 5 s. Engagement in in-vehicle tasks leading to spillover effects (alternating high load condition) requires at least 6 s. The threshold durations were not separately estimated for type of processing and location of threat as opposite effects were observed in both experiments for these factors. The same method would be employed to obtain those durations.

4.3 Discussion

The results from my second experiment are partly consistent with the findings of my first experiment, revealing effects on alternation sequence and load, in addition to revealing spillover effects. Most importantly, the results on hazard anticipation showed that drivers in the continuous condition anticipated the largest percentage of hazards while drivers in the 1/2 alternation sequence anticipated the lowest percentage of hazards across all three conditions, alternating baseline, alternating low load and alternating high load conditions. The results hammer home the importance of the forward roadway duration in an alternation sequence.

In Experiment 2, I evaluated drivers across the same conditions I utilized in Experiment 1 in addition to using an additional alternating high load condition with a cognitively loaded visual search task. The secondary task in the alternating high load condition not only loads the driver during the center screen interruption but also when he/she is glancing at the forward roadway. There are several interesting points of note here similar to Experiment 1.

First, there definitely exists a benefit to glancing at the forward roadway for a duration greater than the preceding in-vehicle glance especially when the preceding in-vehicle glance is at least 2 s. The 4/2 alternation sequence elicited a much higher proportion of glances critical to hazard anticipation, in all three alternating conditions, baseline, low load and high load conditions (81%, 72% and 66% respectively). The percentage of hazards detected by drivers dropped by 25 percent in the 1/2 alternation sequence (across all alternation conditions) as opposed to the 4/2 sequence.

Second, in addition to an effect of the forward roadway glance duration, there is also an effect of the type of load. Drivers detected a larger percentage of the hazards in the continuous condition (81.3%) than in the alternating high load condition (44%). The percentage of hazards detected consistently decreased across the treatment conditions (69% for the alternating baseline and 63% for the alternating low load condition). The observed differences in hazard detection suggest that there are separate swapping and switching effects as well as strong spillover effects. Consider first the effect of swapping. In the second experiment, I tweaked the center screen alternation display for the alternating baseline condition by adding a '+' symbol upon which drivers had to fixate. This was done to ensure that drivers weren't electing to ignore the center blank screen and, instead, attend to the driving by glancing away from the center screen which was blanked towards the side screens which contained a view of the forward roadway. The results of my experiment confirmed that there were visible swapping effects when drivers no longer had forward roadway cues to maintain lane position and velocity. Next, consider the issue of separate effects for switching. The use of a visual search task led to performance decrements in latent hazard detection in the alternating low load condition compared to the alternating baseline condition. This is explained by the switching effect which it is hypothesized is due to the fact that attention must be switched from the driving task to the secondary search task, thereby decreasing the capacity available to maintain information on the forward roadway in short term memory.. There is also clear evidence of a combined swapping and switching effect for all alternating low load sequences (E1 – E4). Finally, the use of a cognitively loaded search task leads to a decrement in hazard detection performance for drivers in the alternating high load condition. The difference in latent hazard detection between the alternating high load and alternating low load conditions may be explained by the spillover effect. There was a clear evidence for combined switching and spillover effects for all alternating high load sequences (H1 – H4).

Third, when including all three alternating conditions in the model, there was no effect of type of processing, contrary to Experiment 1. However, upon taking a closer look, an effect on the type of processing was observed when just the alternating baseline and low load conditions were included in the model (consistent with Experiment 1). As predicted, drivers' performance in the bottom up condition is better than their performance in the top down condition, approaching near perfect performance when the view is continuous. The difference is 10 percentage points. The difference in the hazard anticipation performance of the participants on the bottom up and top down scenarios in the alternating high load condition is also in the right direction. In summary, in all three of the alternating conditions, the effect of the bottom up cues is attenuated on average as the duration of the view of the forward roadway decreases (Figure 34). This points to the critical importance of taking long glances on the forward roadway because the effect of even the most obvious of bottom up cues is considerably lessened at the shorter forward roadway durations.

Fourth, experiment two showed a significant effect for location of threat while experiment 1 did not. This difference may be attributed to the lighting factor. In Experiment 1, the lack of functional dashboard lights may have influenced participants' latent hazard detection performance across location of threat. While, in experiment 2, the presence of functional dashboard lights may have aided participants' ability to detect threats (explaining why performance across centrally located threats is better than performance across peripherally located threats). Lighting is a key factor towards being able to detect latent hazards and hence is a plausible enough reason for a reversal in performance across experiments.

Fifth, the question arose as to whether the participants could be performing better in the alternating low load condition than the alternating high load condition because they were performing fewer tasks in the alternating low load condition. In fact, the participants' average number of tasks attempted was larger in the low load condition than it was in the high load condition.

Sixth, the results on secondary task accuracy indicate that drivers were less accurate when spillover effects were present (alternating high load condition) than when just switching effects (alternating low load condition). This pattern was consistent with the percentage of tasks attempted on the last in-vehicle glance (center screen interruption). I find it interesting that as the magnitude of the load increases, the secondary task accuracy suffers in addition to latent hazard detection. It appears that when the load is constant as it is in the alternating high load condition, there is not only a cost to the primary task, but also a cost to the secondary task.

Seventh, what is also significant is that the task accuracy and percentage of tasks attempted decrease as the forward roadway duration within an alternation sequence decreases. These patterns are consistent across both experiments. This means that the measure of tasks attempted is a good measure of effort. Such would not have been the case had accuracy and the number of tasks attempted not been correlated. It also implies that participants are not performing better in the 1/2 condition than the 4/2 condition because they are simply completing fewer tasks in the 1/2 condition – quite the opposite.

Finally, the velocity was analyzed in order to determine whether drivers in the continuous condition were traveling faster than drivers in the three alternating conditions. Examination and analyses of velocity data yielded some valuable conclusions. The velocity was collected for a 15 second period prior to the potential latent hazard for all subjects across all scenarios. The velocity was also collected for the immediate 5 seconds preceding the hazard. It was analyzed in order to determine whether drivers in the continuous condition were traveling faster than drivers in either or both of the alternating conditions. If such were the case, then the performance of drivers in the alternating conditions could be artifactually inflated because they had more time to scan for a latent hazard. The average velocities were in the range of 21 – 22 mph. There were no significant differences in the average velocities across treatment conditions. Drivers across all conditions drove at an average velocity (during the task duration) not exceeding 21 mph thereby eliminating a potential confound.

To summarize, the results of Experiment 2 are consistent with the hypothesis that longer forward roadway glances within an alternating sequence have a larger benefit to latent hazard detection, at least for the hazard anticipation scenarios that were analyzed. Specifically, when driving with the views of the forward roadway alternated with the center screen task, drivers are much more likely to better detect hazards when they allocate more time on the forward roadway (4 s as opposed to 1 s, 2 s). There is a benefit to centrally located threats as compared to peripherally located threats across the alternation conditions, (however as explained above, opposite effects were observed in Experiment 1). Drivers anticipate a higher proportion of hazards when the type of processing is bottom up (attraction by motion, e.g., lead vehicle braking) as opposed to top down (allocation of attention, e.g.; 4 way uncontrolled intersection). When attempting tasks, drivers anticipate a much fewer proportion of the hazards in Experiment 1. However, the opposite was observed in Experiment 2. This may have resulted from drivers being loaded while looking at the forward roadway following an in-vehicle glance in the alternating high load condition in which case it would stand to reason that a subsequent task attempt was not necessary for a decrement in drivers' latent hazard detection ability. The analysis of data indicates a strong presence of all three effects, namely, swapping, switching and spillover. There is evidence for separate as well as combined effects.

Last but not the least, the results of my experiments suggest a threshold duration of about 4 s for in-vehicle tasks with swapping, 6 – 7 s for in-vehicle tasks that only require switching and most importantly indicate that for in-vehicle tasks that require spillover, the threshold duration is 6 s (see Section 4.2.4). What this implies is that a driver requires at least 4 seconds for in-vehicle tasks with just swapping and 5 s for tasks with switching. The threshold duration is highest for tasks with spillover since the spillover effect always lowers performance even when the driver is glancing at the forward roadway. That is, there is insufficient time for secondary, in-vehicle tasks with spillover to obtain sufficient information from the forward roadway critical to safe behavior when engaged in a sequence of alternating glances between the inside of the vehicle and the forward roadway, where the in vehicle glance is no longer than 2 s.

CHAPTER 5

SUMMARY

5.1 Summary

To summarize, there were two aims to the experiment. To repeat, the first aim was to determine the size of the threshold duration and how the threshold duration varies in the alternating conditions as a function of factors which influence the likelihood that a threat will be detected, including: (a) how the threat is processed (top down or bottom up); (b) where the threat is located (fovea or periphery); and (c) the load (continuous, alternating baseline, alternating low load). The second aim was to determine whether the likelihood of detecting a threat decreases as the duration of the glance on the forward roadway decreases and, if so, how the difference between the likelihood that the threat is detected in the alternating and continuous conditions when the window is less than the threshold duration varies as a function of the above factors. The first experiment addressed these two aims when the driver was performing an in-vehicle task which placed a load on the driver during the glance down but not during the glance up (the alternating low load condition). The second experiment addressed these two aims when the driver was performing an in-vehicle task which placed a load on the driver both during the glance down and during the glance up (the alternating high load condition).

The following general conclusions follow from Experiments 1 and 2 as described above. Briefly:

- Across conditions, the threshold duration is shortest in the alternating baseline condition (4 s), longer in the alternating baseline condition (6 - 7 s), and nonexistent in the alternating high load condition.

- The threshold duration is higher across all alternating conditions when the threat is processed top down. This duration does not appear to be affected by whether the threat is located centrally or peripherally.
- Across all alternating conditions, the shorter the forward roadway duration the less likely is the participant to anticipate a hazard.
- At forward glance durations less than threshold, there are separate effects of swapping, switching and spillover.
- At forward roadway durations near threshold there are effects of the type of processing; however these effects disappear when the glances on the forward roadway are especially short.
- At all forward roadway durations analyzed there are no effects of the location of the threat.
- Finally, potential alternative explanations of the results such as participants attempting fewer tasks in the alternating low load condition than they do in the alternating high load condition, attempting fewer tasks at the shorter forward roadway durations than they do the longer forward roadway durations, or traveling slower in the alternating conditions than they do in the continuous condition could be ruled out.

5.2 Limitations & Future Work

My research successfully addressed several questions. At this point, I would like to note several limitations of my study, all of which may be addressed via future research and subsequent experiments.

- Only a small set of the total set of hazard anticipation scenarios was used, limiting generality to other scenarios.

- No measurement was made of hazard mitigation, yet ultimately it is the ability of drivers to mitigate crashes that is important.
- Relevant to the above point, no measure was made of the effect of the alternation sequence on the likelihood of a crash.
- The experiment was performed in a driving simulator. The results do not necessarily generalize to the open road.
- The alternation sequences could not be selected by the participants. Drivers may be much savvier in the real world and glance forward for longer durations when necessary. They were given no chance to increase or decrease the duration of their glances either down or up during the experiments.
- There was no test of whether the load in the low load task actually carried over into the forward glance. In fact, the driver did have to report the number of target t's, so there was some carry over.
- As a next step, it would be interesting to see how actual in-vehicle tasks (tuning the radio, searching for a street on the GPS, searching for changes in the glove box) map on to the various effects (swapping, switching and spillover) I simulate via my pseudo-secondary tasks in both experiments. The advantage of pseudo-secondary tasks was the control afforded to the experimenter in determining precisely the in-vehicle and forward roadway glance durations in the different alternation sequences and identifying the various threshold durations. Given that the safe threshold durations have now been estimated, it becomes much simpler to utilize in-vehicle tasks to see the performance of these in-vehicle tasks exceeds the estimated threshold durations.

5.3 Implications for Practice

The findings from the above experiments may have an impact on framing of additional policies directed towards addressing motor vehicle casualties due to driver distraction. These findings could prove critical towards complementing and completing NHTSA's Distracted Driving Guidelines (NHTSA, 2012). The proposed guidelines recommend the design of in-vehicle devices such that tasks be completed by the driving with: a mean in-vehicle glance duration of 2 sec or less; 85% of eye duration away from the forward roadway being 2 seconds or less; and a cumulative time spent glancing away from the forward roadway of 12 seconds or less. What the guidelines lack is a component specifying how long at minimum drivers need to glance at the forward roadway when engaged in an in-vehicle task? My findings would provide a framework for a similar set of guidelines for the duration of the glances on the forward roadway. As an example, the set of guidelines for forward roadway durations might read like the following:

- Drivers mean glance duration on the forward roadway must be at least 4 seconds when engaged with an in-vehicle task requiring swapping (similar to alternating baseline condition) and at least 7 seconds (asymptotically estimated) when engaged with an in-vehicle task requiring switching (similar to the alternating low load condition leading to switching effects). There is no estimable threshold duration when engaged in an in-vehicle task requiring cognitive spillover (similar to the alternating high load condition).
- At least 85% of the forward roadway glances must be 4 seconds or more.

- And, the cumulative time spent glancing at the forward roadway should be at least 3 (visible to invisible time ratio in the alternation sequence) times the time spent glancing away from the forward roadway.

These findings are useful and would provide a tighter framework for in-vehicle device manufacturers and policy makers in general.

CHAPTER 6

SUPPORT

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APPENDIX: SCENARIO PERSPECTIVE VIEWS

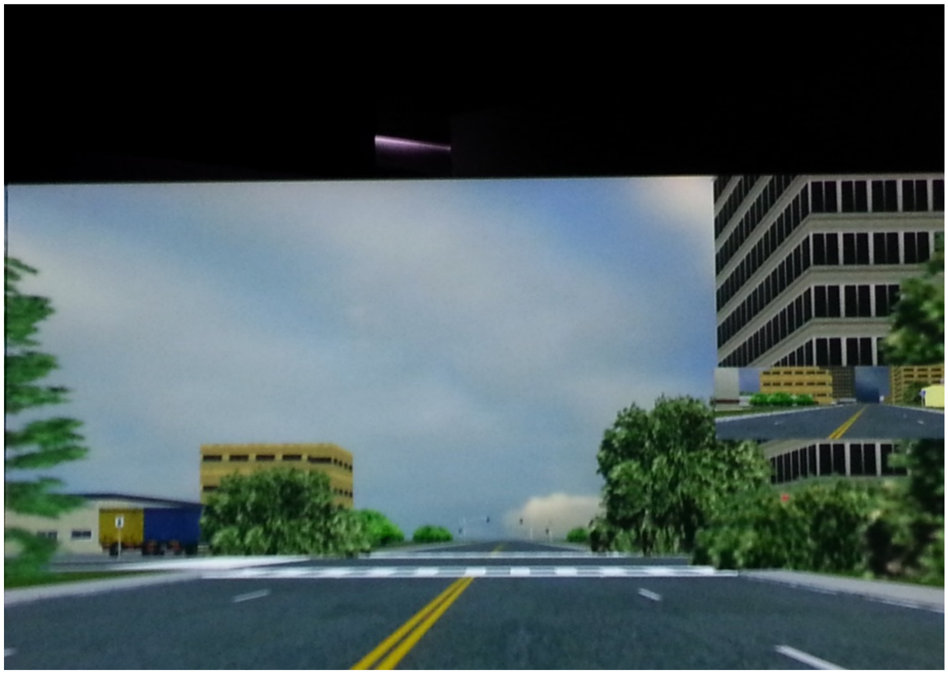
Truck Left Turn [G]

Mullins Center [C]

Work zone [F]

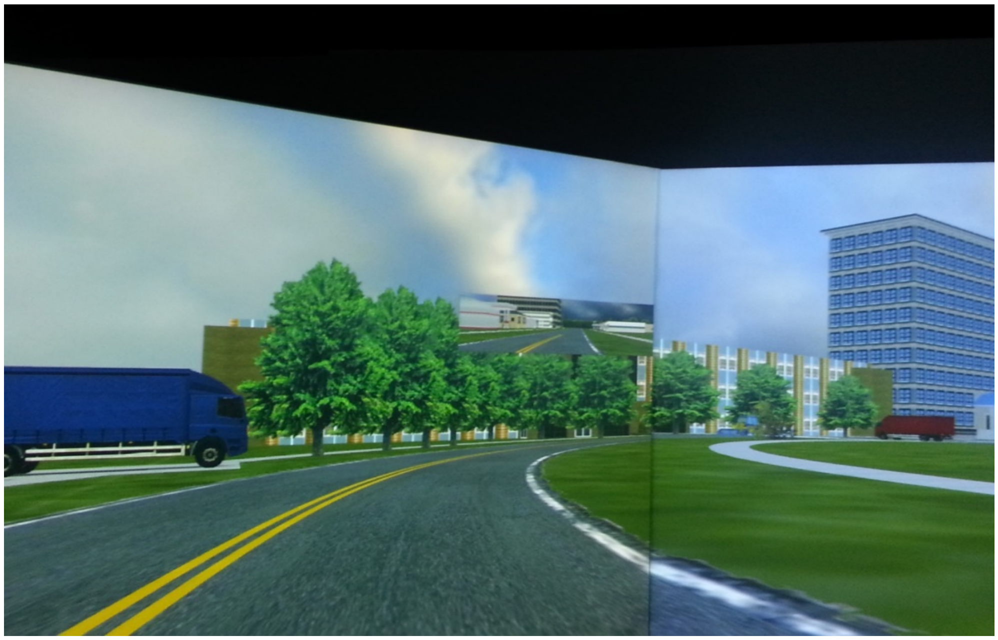
Truck parked on the right side of a crosswalk [D]

Four Way Uncontrolled Intersection [B]



Looking across a curve _ Bottom Up [H]

Looking across a curve _ TD [E]



Lead Vehicle Braking – Brake Lights [A]

BIBLIOGRAPHY

AAA Foundation for Traffic Safety. (2009). Traffic Safety Culture Index telephone survey of 2501 U.S. residents ages 16+, conducted April 15 - May 12,2009 by Abt SRBI Inc. Washington DC: AAA Foundation for Traffic Safety.

Adamczyk, P. D., & Bailey, B. P. (2004, April). If not now, when? The effects of interruption at different moments within task execution. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 271-278). ACM.

Beck MR, Levin DT. (2003). The role of representational volatility in recognizing pre- and post-change objects. *Perception and Psychophysics*, *65*, 458–468.

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

Borowsky, A., Horrey, W., Yulan, L., Garabet, A., Simmons, L. and Fisher, D.L. (June 2013). The effects of momentary visual disruption on hazard anticipation. *Proceedings of the 7th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, Lake George, NY. Iowa City: Public Policy Center, University of Iowa.

Borowsky, A., Horrey, W., Liang, Y., Simmons, S., Garabet, A. and Fisher, D. L. (October 2014). The role of working memory in driving related hazard anticipation. *Proceedings of the Human Factors and Ergonomics 2014 International Annual Meeting*, Chicago.

Brookhuis K.A., de Vries, G., de Waard D. (1991). The effects of mobile telephoning on driving performance. Accid Anal Prev 1991; 23:309-316.

Burns, P.C., Parkes, A., Burton, S., Smith, R.K., & Burch, D. (2002). How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol (TRL Report RL547). Berkshire, United Kingdom: TRL Limited.

Cooper, J.M. & Strayer, D.L. (2008). Effects of Simulator Practice & Real world experience on cell-phone related driver distraction. Human Factors 2008; 50; 893.

Crundall, D., Chapman, P., Trawley, S., Collins, L., van Loon, E., Andrews, B., Underwood, G. (2012). Some hazards are more attractive than others: drivers of varying experience respond differently to different types of hazard. *Accident Analysis and Prevention, 45*, 600-6009.

Crundall, D., Van Loon, E., & Underwood, G. (2006). Attraction and distraction of attention with roadside advertisements. *Accident Analysis & Prevention*, *38*(4), 671-677.

Drews, F.A., Yazdani H., Godfrey C.N., Cooper J.M. & Strayer D.L. (2009). Text Messaging During Simulated Driving. Human Factors.

Goldstein EB, Fink SI. Selective attention in vision: recognition memory for superimposed line drawings. *J Exp Psychology Hum Percept Perform* 1981, 7:954–967.

Harbluk, J.L. & Noy, Y.I (2002). The impact of Cognitive Distraction on Driver Visual Behavior and Vehicle Control. Transport Canada 2002, TP# 13889E

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

Horrey, W.J. & Wickens, C.D. In-Vehicle Glance durations: Distributions, Tail and Model of crash risk. *Transportation Research Record: Journal of the Transportation Research Board, No. 2018,* Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 22–28. DOI: 10.3141/2018-04.

Horrey, W.J. & Wickens, C.D., (2006). Examining the Impact of Cell Phone Conversations on Driving using Meta-Analytic Techniques. HUMAN FACTORS, Vol. 48, No. 1, spring 2006, pp. 196-205.

Hosking, S., Young, K., & Regan, M. (2006). The effects of text messaging on young novice driver performance. Monash University Accident Research Centre, Report No. 246.

Hosking, S., Young, K., & Regan, M. (2009). The effects of text messaging on young drivers. Human Factors: Journal of the HFES. 2009. 51:582. DOI: 10.1177/0018720809341575.

Jensen, M.S., Yao, R., Street, W.N., & Simons, D.J. (2011) Change Blindness and Inattention Blindness. John Wiley & Sons Ltd. Volume 2. Pg. 529-546. September/October 2011.

Just, M.A., Keller, T.A. &Cynkar, J., (2008). A decrease in brain activation associated with driving when listening to someone speak. Brain Research, Apr 18, 1205, 70-80.

Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., & Ramsey, D.J. The Impact of Driver Inattention on Near-Crash/Crash Risk: An analysis using the 100-Car Naturalistic Driving Study Data. Technical Report. US DOT. National Highway Traffic Safety Administration. DOT HS 810 594. April 2006.

Lamble, D., Rajalin, S. & Summala, H. (2002). Mobile phone use while driving: public opinions on restrictions. Transportation 29:223-236

Lee, J.D., (2007). Technology and teen drivers. Journal of Safety Research 38: 203-213

Levin DT, Simons DJ. Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin Review*1997, 4:501–506.

Mack A, Rock I. *Inattentional Blindness.* Cambridge, MA: MIT Press; 1998.

Madden, M. &Rainie, L., Pew Internet & American Life Project, Pew Research Center (2010). Adults and Cell Phone Distractions. [http://pewinternet.org/Reports/2010/Cell-Phone-Distractions.aspx [June](http://pewinternet.org/Reports/2010/Cell-Phone-Distractions.aspx) 18, 2010]

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

McEvoy, S.P., Stevenson, M.R., McCartt, A.T., Woodward, M., Haworth, C., Palamara, P. &Cercarelli, R., (2005). Role of Mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. BMJ 2005; doi:10.1136/bmj.38537.397512.55.

McGwin Jr, G., & Brown, D. B. (1999). Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis & Prevention*, *31*(3), 181-198.

Mitroff SR, Simons DJ, Levin DT. Nothing compares2 views: change blindness can occur despite preserved access to the changed information. *Percept Psychophys*2004, 66:1268–1281.

Moray N. Attention in dichotic listening: affective cues and the influence of instructions. *Q J Exp Psychology*1959, 11:56–60.

Most SB, Scholl BJ, Clifford ER, Simons DJ. What you see is what you set: sustained inattentional blindness and the capture of awareness. *Psychol Rev* 2005, 112:217–242.

Neisser U, Becklen R. Selective looking: attending to visually specified events. *Cognitive Psychology*1975, 7:480–494.

Nemme, H.E., & White, K.M., (2010). Texting while driving: Psychosocial influences on young people's texting intentions and behavior. Accid Anal Prev 2010; 42:1257-1265.

Nieminen, T., & Summala, H., (1994). Novice and experienced drivers' looking behavior and primary task control while doing a secondary task. Proceedings of the Human Factors and Ergonomics Society Annual Meeting October 1994 38: 852-856.

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of experimental psychology: General*, *109*(2), 160.

Pradhan, A. K., Pollatsek, A., Knodler, M. and Fisher, D. L. (2009). Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous? *Ergonomics, 62,* 657-673.

Recarte, M.A. & Nunes, M.L. (2003). Mental Workload While Driving: Effects on Visual Search, Discrimination and Decision Making. Journal of Experimental Psychology: Applied 2003; Vol. 9, No. 2, 119-137.

Redelmeier, D.A., & Tibshirani, R.J. (1997). Association between cellular telephone calls and motor vehicle collisions. N Engl J Med 1997; 336: 453-8.

Reed, N., & Robbins, R., (2008). The Effect of Text Messaging on Driver Behavior. A Simulator Study. September 2008. PPR 367. Published Project Report for RAC Foundation. TRL.
Rock I, Schauer R, Halper F. Form perception without attention. *Q J Exp Psychology*1976, 28:429–440.

Romoser, M. and Fisher, D. L. (2009). The effect of active versus passive training strategies on improving older drivers' scanning for hazards while negotiating intersections. *Human Factors, 51*, 652-668.

Scott-Brown KC, Baker MR, Orbach HS. Comparison blindness. *Visual Cognition (Special Issue: Change Blindness and Visual Memory)* 2000, 7:253–267.

Sexton, B.F. (1997) Validation trial for testing impairment of driving due to alcohol. TRL Report 226, Crowthorne: TRL Limited.

Sexton, B.F., Tunbridge, R.J., Brook-Carter, N., Jackson, P.G., Wright, K., Stark, M.M., Englehart, K. (2000). The Influence of Cannabis on Driving. TRL Report 477, Crowthorne: TRL Limited.

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

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

Strayer, D.L., Drews, F.A. & Johnston, W.A. (2003). Cell-Phone Induced Failures of Visual Attention during Simulated Driving. Journal of Experimental Psychology: Applied 2003; Vol. 9, No.1, 23-32.

Strayer, D.L. &Drews, F.A. (2004). Profiles in Driver Distraction: Effects of Cell Phone Conversations on Younger and Older Drivers. Human Factors, Vol. 46, No. 4, winter 2004, pp.640-649.

Strayer, D.L. &Drews, F.A. (2007). Cell-Phone – Induced Driver Distraction. Current Directions in Psychological Science 2007; Vol. 16, No. 3.

Strayer, D.L., Drews, F.A. & Crouch, D.J. (2006). A comparison of the cell phone driver and the drunk driver. Human Factors, 48, 2, pp. 381-391.

Strayer, D.L., Drews, F.A., Albert, R.W. & Johnston, W.A. (2010). Cell phone induced perceptual impairments during simulated driving. Driving Assessment, nsc.org

The GSM Association (2007). 20 Year Fact Sheet. Available from: http://www.gsmworld.com/documents/20_year_factsheet.pdf [Accessed 9 June 2008]

The RAC Foundation (2008). Almost half of Britain's motorists TXT + DRV. http://www.racfoundation.org/index.php?option=com_content&task=view&id=530&Itemid=35 [Accessed 10 June 2008]

Titchener, K., White, M. & Kaye, S. (2009). In-vehicle driver distractions: characteristics underlying drivers' risk perceptions. In proceedings, 10-12 November 2009, Sydney Convention and Exhibition Centre, Sydney, New South Wales.

Tsimhoni, O. & Green, P.A. Visual Demand of Driving Curves as determined by Visual Occlusion. 1999. The University of Michigan Transportation Research Institute, 2901 Baxter Road, Ann Arbor, Michigan 48109-2150, USA.

Underwood, G., Chapman, P., Bowden, K., & Crundall, D. (2002). Visual search while driving: skill and awareness during inspection of the scene. *Transportation Research Part F: Traffic Psychology and Behaviour*, *5*(2), 87-97.

Walsh, S.P., White, K.M., Hyde, M.K. & Watson, B. (2008). Dialing& Driving: Factors influencing intentions to use a mobile phone while driving. Accid Anal Prev 2008; 40:1893-1900.

Wierwille, W.W. (1993). Visual and manual demands of in-car controls and displays. In B. Peacock & W. Karwowski (Eds.), *Automotive Ergonomics*, pp. 299-320. Washington, DC: Taylor & Francis.

Wierwille, W. W., and L. Tijerina. (1998). Modeling the Relationship between Driver In-Vehicle Visual Demands and Accident Occurrence. In *Vision in Vehicles—VI* (A. G. Gale, I. D. Brown, C. M. Haslegrave, and S. P. Taylor, eds.), Elsevier Science, Amsterdam, Netherlands, 1998, pp. 233–243.

Young, R.A., (2012). Cell Phone Use and Crash Risk. Epidemiology; 23 (1): 116 DOI: 10.1097/EDE.0b013e31823b5efc.