Using Audiobooks to combat Mental Underload: How Traffic Density and Road Complexity affect Driving Performance while Multitasking in Virtual Environments

by

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ABSTRACT

USING AUDIOBOOKS TO COMBAT MENTAL UNDERLOAD: HOW TRAFFIC DENSITY AND ROAD COMPLEXITY AFFECT DRIVING PERFORMANCE WHILE MULTITASKING IN VIRTUAL ENVIRONMENTS

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Distracted driving (driving while performing a secondary task) is the cause of many collisions. Most research on distracted driving has focused on operating a cell-phone, but distracted driving can include driving while eating, conversing with passengers or listening to music or audiobooks. Although the research has focused on the deleterious effects of distraction, there may be situations where distraction (specifically audiobooks) improves driving performance. Mental underload is associated with an increased collision risk and it is possible that secondary tasks can help alleviate underload while driving. In my Master’s thesis, I conducted three experiments where licensed drivers were tested in a driving simulator on roads of differing complexity. Road complexity was manipulated by increasing traffic, scenery, and the number of curves in the drive. Participants either simply drove, drove while listening to an audiobook, and drove while engaging in a handsfree conversation. Driving performance was measured in terms of braking response time to hazards, average speed, standard deviation of speed, and standard deviation of lane positioning. Overall, driving performance was better in simple driving environments, where audiobooks were found to lead to lower hazard reaction time and speeds closer to the posted speed limit compared to simply driving and driving while engaging in a handsfree conversation. Furthermore, it was found that secondary tasks lead to lower reaction time to vehicles, but higher to pedestrians.
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Introduction

15.4 million Canadians commuted to and from work in 2011, and of these people, 74% drove a personal vehicle to work (Government of Canada, 2015). As metropolitan areas grow and develop, commute times are expected to increase. The average commuter in Toronto spends about 66 minutes on their daily commute, and over 29% of these drivers spend more than 90 minutes commuting (Government of Canada, 2015). Drivers can spend decades taking the same route to work, and often these commutes can be uneventful. Drivers become so accustomed to the commute that they may stop paying adequate attention to the road, leading to potential collisions. Often, individuals commute in the mornings and in the evenings, when they are more mentally and physically tired, or fatigued, which further increases their risk of collision (Du, Zhao, Zhang, Zhang, & Rong, 2015; Gershon, Ronen, Oron-Gilad, & Shinar, 2009). In my research, we intended to address a practical issue concerning the over 15 million daily commuters in Canada. Can we use audiobooks to improve driving performance? Under what specific road conditions? And who would benefit from audiobooks? To answer these questions, we conducted three experiments in a high-fidelity driving simulator that allowed full customization of the driving environments. In the sections that follow there is a discussion of the theoretical background, including defining what selective attention is, the idea of mental workload and cases when individuals experience mental overload (too many demands on attention and performance begins to deteriorate) and underload (too few attentional demands and performance begins to suffer). Finally, there is a discussion of the literature regarding listening to audiobooks and how audiobooks impact driving performance.
**Attention**

Before addressing how audiobooks affect driving performance, it is appropriate to understand what attention is. Broadly speaking, attention is the mechanism by which we organize and prioritize our perceptions, thoughts and actions in an environment, and attentional resources refer to the limited capacity of attention that can be allocated across sensory modalities (Duncan, 1984; Thompson et al., 2011; Trick, Enns, Mills, & Vavrik, 2004). We use selective attention to process information in an environment consisting of more information and stimuli than we can possibly react to. Selective attention refers to the goal directed allocation of attentional resources to different aspects of sensory information, actions amongst potential responses, and different thoughts and memories (Duncan, 1984; Fort et al., 2010).

Driving requires the individual to carry out many actions at once, such as maintain adequate steering control, monitor speed, respond to traffic, signs and street lights, and hazards and navigate the environment to reach their destination safety. Selective attention is required to select which parts of the driving scene to be aware of and what responses to make (Gold, Korber, Lechner, & Bengler, 2016).

Our understanding of selective attention and its limited capacity comes from experimental work on dual-task interference, where it was found that performance on a primary task begins to suffer when a secondary task is introduced, often, performance on both tasks begins to suffer. For example, driving is one kind of single task, and talking to someone on the phone is also a single task, dual task interference refers to the relative impairment on performance observed when they are done together rather than in isolation (Leroux et al., 2006). It was thought that primary task performance decreases as a function of the difficulty associated with the secondary task, and that there is a maximum attentional capacity; if performance on
either task suffers, then it must be because these tasks now have to share a limited resource between them (Kahneman, 1973; Wickens, 1991). However, there have been studies where the addition of a secondary task did not impair single task performance, especially when the tasks load on different sensory modalities (Wickens, 2002). Wicken’s (1991) multiple resource theory was developed in response to some of the limitations in the single resource theory. It states that different tasks and sensory modalities can have access to different pools of attentional resources. For example, a driver reading a set of instructions while driving (a task that requires vision for looking at the road), will experience greater interference than if the instructions were played over the speakers, since two visual tasks would interfere with each other more than a visual and auditory task. Attentional resources vary based on the modality (visual, spatial, verbal and auditory) and stage in processing (perception, cognition, response selection). According to multiple resource theory, controlled attentional resources are both limited and allocable (that is, they can be assigned to some particular perceptual object or action). Task performance is predicted by the capacity of available attention resources and the mental workload. Mental workload refers to the environmental/ task demands for resources and the ability to provide the required resources. Therefore, performance should be ideal when there is congruency between attentional resources and the mental workload. That is, performance should be ideal as long as the demands of the workload do not exceed the capacity for attentional resources. Mental workload is therefore the amount of information that is processed at once among various potential tasks and types of stimuli across various sensory modalities.

Mental Overload

Mental overload occurs when the ability to process and respond to data is impaired because of an incapacity to effectively organize attentional resources in a given environment due
to a limitation in attentional resources (Berka et al., 2007). Much of the literature regarding the limits of attention refer to instances of mental overload and the degree to which performance on tasks interfere with each other depends on degree to which each task contribute to the mental workload (Berka et al., 2007; Biondi, Turrill, Coleman, Cooper, & Strayer, 2015). Mental overload while driving often occurs when distractions, especially secondary tasks, interfere with driving performance. There is a large pool of literature demonstrating the usually harmful impact distracted driving, the most common of which are eating and drinking, talking to passengers, cell-phone conversations, staring at non driving relevant stimuli like accidents and browsing and texting on mobile devices (Bergmark et al., 2016; Biondi et al., 2015; Irwin, Monement, & Desbrow, 2014; Tian, Li, Chen, Chen, & Witt, 2013). The Government of Canada (2015) reported that there were 122,090 collisions in 2013, leading to 164,493 injuries and 1,908 fatalities. Furthermore, it is estimated that anywhere from 8% to 40% of collisions can be attributed to distracted driving (Rumschlag et al., 2015; Stavrinos et al., 2013), and that cell-phone use is responsible for a minimum of 28% of all crashes in the United States (National Safety Council, 2015).

**Distraction**

Although there are a wide variety of different secondary tasks that have been shown to interfere with driving, they can be classified into three types. *Visual distractions* occur when the driver’s eyes come off of the road onto buildings, traffic and pedestrians (Antonson, Mårdh, Wiklund, & Blomqvist, 2009; Larue, Rakotonirainy, & Pettitt, 2011; Paxion, Galy, & Berthelon, 2015), billboards (Decker et al., 2015) and in-car distractions like a cell phone or media console (Bergmark et al., 2016; Caird, Willness, Steel, & Scialfa, 2008; Horberry, Anderson, Regan, Triggs, & Brown, 2006; Irwin et al., 2014). Structural (motor) distractions (also called structural
interference) occur when the secondary task causes the hands/feet/body to be positioned in such a way that it is difficult to use the steering wheel or accelerator/brakes and occurs often with eating or drinking (Irwin et al., 2014) and texting (Caird, Johnston, Willness, Asbridge, & Steel, 2014). However, the most relevant form of distraction in our study is cognitive distraction, where the person is thinking about the secondary task to the detriment of the driver’s ability to think about the driving task, as these do not require the drivers to glance off of the road or take their hands off of the wheel. Examples include the processes involved in understanding what a person is saying or composing a response, as in the case of a conversation or a hands-free conversation (Beede & Kass, 2006; Caird et al., 2008; Strayer et al., 2015), or for that matter, when a person is just engaging in rumination, thinking about non-driving related tasks (mind-wandering) (Nijboer, Borst, van Rijn, & Taatgen, 2016), and when listening to music (Dibben & Williamson, 2007; Schwarz et al., 2012).

Mental Underload

Theories of attention effectively explain the effect of attentional workload and driving performance in the context of distracted driving (Kahneman, 1973; Wickens, 1991, 2002b). These theories however, have difficulty in explaining the concept of mental underload: a state associated with low levels of stimulation and arousal. It is when the demands of the task are far below the attentional capacity and is associated with under arousal. Arousal refers to degree of psychological excitation, physiological stimulation or sympathetic nervous system activation in response to task demands (Carrol, Zuckerman, & Vogel, 1982; Kahneman, 1973). Models of attention generally predict that as mental workload goes down, performance should improve because there are more attentional resources that can be directed toward to the task. However, evidence suggest that especially low demands, and therefore low arousal, are associated with
decrements in performance despite the presence of enough resources to carry on the task (Young & Stanton, 2002b). Malleable attentional resource theory (MART) views attention resources as changeable and allocable, as cognitive demands drop, so do attentional resources (Young & Stanton, 2002). It is especially relevant to commuters who drive the same route day in and day out. When environments are overly familiar, individuals lose interest in paying attention to that environment, contributing to mental underload (Heslop, Harvey, Thorpe, & Mulley, 2010). Mental underload restricts their attentional resources and impairs driving performance.

The dangers associated with mental underload are more apparent when an individual is feeling fatigued and individuals who commute are more likely to feel physically or mentally tired, or fatigued. Fatigue is common in individuals who engage in sustained physical and mental exertion, spend long hours at work, few hours sleeping, and who drive very early and late in the day. There is a great deal of literature regarding the dangers of driving while experiencing fatigue, which can lead to increases in speeding, swerving, and reaction time (Du, Zhao, Zhang, & Rong, 2016), impaired performance on complex behaviours like over-taking (Chen et al., 2016), and is associated with up to 30% of all collisions (Connor et al., 2002). The negative effects of fatigue are most likely to be experienced in conditions of cognitive underload. Under conditions of cognitive underload, fatigued individuals are at a heightened risk of falling asleep, which often has fatal consequences (Bunn, Slavova, Struttmann, & Browning, 2005).

The relationship between attentional resources, mental workload and performance follow the Yerkes/Dodson curve of arousal and performance (See Figure 1), where moderate arousal leads to optimal performance (Cohen, 2011; Kahneman, 1973; Watters, Martin, & Schreter, 1997). In this framework, mental workload, when not over- or underloaded, allows for the full utilization our attentional resources, leading to optimal performance. Many individuals who
experience underload are at heightened risk of experiencing boredom, which can be described as the aversive state of wanting to, but being unable to engage in a satisfying activity (Eastwood, Frischen, Fenske, & Smilek, 2012). When this happens, individuals tend to engage in secondary tasks or risky behaviours in attempt to alleviate the uncomfortable state of boredom (Nijboer et al., 2016). Engaging in dangerous secondary tasks while driving leads to mental overload (distractions), such as talking on the phone (Beede & Kass, 2006) or texting (Bendak, 2015) further increasing their risk of collision (Lee, Champagne, & Francescutti, 2013). However, there is research to suggest that some kinds of secondary tasks can increase driving performance without leading to mental overload in the driver, reducing the chances of boredom and fatigue related driving decrements, however, many of these tasks are experimental cognitive tasks (signal detection tasks) that a driver would never partake in (Desmond & Matthews, 1997; Matthews & Desmond, 2002). Other tasks like listening to music have been found to only have a minor effect on driving performance (Dibben & Williamson, 2007; Schwebel et al., 2012).

Executive Functioning

There is also a great deal of inter-individual variability in the degree to which distracting secondary tasks impact individual driving performance. People with a large executive working memory capacity have been found to perform concurrent tasks without experiencing a significant decline in performance. Working memory (WM) can roughly be described as the cognitive system concerned with the immediate conscious processing of information, it is limited both in terms of capacity and duration, though the capacity varies between individuals (Lambert, Watson, Cooper, & Strayer, 2010). Stimuli must first be brought into attention before it can be processed by WM, and once it is in WM, attention can move between tasks, thoughts, and stimuli. The Central Executives Systems model describes executive processes in their function to
direct attentional resources during task performance, dividing and switching resources between concurrent tasks or task information, and integrating information from working memory and long-term memory (Wongupparaj, Kumari, & Morris, 2015). Individuals with high scores on measures of executive functioning demonstrate superior performance in maintaining task goals while avoiding conflicting distractions (Sanbonmatsu, Strayer, Medeiros-Ward, & Watson, 2013). The Operation Span Task (OSPA) measures task switching. In the OSPAN participants are given letters to keep in working memory while concurrently answering simple math questions. Individuals who score well on the OSPAN are relatively unimpaired by multitasking while driving, while individuals poorer scores experience declines in their driving performance when multitasking (Watson & Strayer, 2010). Differences in OSPAN scores may be useful to predict who will and who will not be negatively affected by performing distracting secondary tasks while driving.

Audiobooks

We are interested in utilizing a type of mental stimulation that produces better driving performance without distracting the driver to the point where performance deteriorates. Such a task cannot be a visual or structural distractor, and must be moderately cognitively stimulating. We propose that listening to audiobooks may be a useful intervention for alleviating mental underload by increasing attention and performance while driving in under stimulating environments. In addition to addressing the general dearth of literature on the effect of audiobook use on driving performance, this topic warrants examination because audiobooks are quickly becoming an ever more available in-car distraction. Audiobook downloads made up to over 18% of all audio downloads, accounting for $2.1 billion in sales in 2015. It has been reported that 24% of all Americans had listened an audiobook in at least one time in 2015; a 22%
increase over the previous year (Milliot, 2017). Furthermore, over 83% of audiobook purchases are in digital format, optimal for listening to on cell phones and other personal electronic devices (Kozlowski, 2016). Audiobooks are a convenient way making driving more enjoyable and we need to understand the general risks and benefits involved with listening to audiobooks while driving (Webster, 2016). Strayer, et al. (2013) conducted a comprehensive study on cognitive distractions in cars where they compared listening to audiobook to other common cognitive distractions like listening to the radio, handsfree conversations and conversations with passengers; distractions that have been studied extensively. The results of a self-report distraction questionnaire indicated that audiobooks are less distracting than handheld conversations, handsfree conversations and conversations with passengers. More importantly, it was found that all conversations negatively impacted driving performance (lead vehicle following distance and eye movement data) to a greater degree than audiobooks. Furthermore, audiobooks led to poorer performance compared to listening to the radio, which did not differ significantly from simply driving (Strayer et al., 2015). In another experiment comparing simply driving to driving while listening to an audiobook, and driving while performing a simple visual task on the central media console, found no differences between the audiobook and the control condition on any driving measures, except for hazard detection, where audiobooks lead to faster response time (Hermannstädter & Yang, 2013). The above preliminary evidence gives us an understanding how listening to an audiobook affects driving, though, it is unclear as to whether this benefit of audiobooks would be replicated on different types roads and environments.

Listening to audiobooks may affect driving performance differently in response to the differing demands of the complexity of the drive. In our study complexity refers to the density of traffic, density of roadside scenery and complexity of road geometry. We need to know which
environments may benefit most from audiobooks, as far as we know, there have been no studies examining the effects of listening to audiobooks in driving environments of various complexity. We predict that the benefit of audiobooks occurs in driving environments that are simple, boring and repetitive so that they produce mental underload (Young & Stanton, 2002a) and has been found that straight roads with no traffic and low levels of visual scenery are more likely to produce underload (Paxion et al., 2015). Furthermore, high traffic density (Gold et al., 2016), dense and varied roadside scenery (Antonson et al., 2009), and the presence of curves (Du et al., 2015), are more likely to produce higher levels of mental workload. We also need to know which people are most benefited by listening to audiobooks. We suggest that the OSPAN task may make this apparent. In the following sections, we will present three experiments that investigate the impact of audiobooks on driving performance. In general, we hypothesize that the audiobooks will produce beneficial effects on performance, particularly in simple driving environments and among drivers with high executive working memory capacity as measured by the OSPAN task.

Combatting the negative effects of mental underload while avoiding distraction is a key challenge that many commuters face. It is possible that a common in-car cognitive distraction, listening to an audiobook, may be useful for improving driving performance in environments that provide low levels of cognitive stimulation. The following three experiments test these predictions and yield strong results consistent with our theoretical framework regarding attention and mental underload while driving.
Experiment 1

In Experiment 1, we looked at how listening to an audiobook affected driving performance in comparison to simply driving in simulated simple and complex road environments. Furthermore, we examined whether measures of executive working memory as measured by the OSPAN task influenced whether the audiobook had a positive or negative affect on driving performance. We measured driving performance by looking at hazard reaction time (HRT) to peripheral hazards, average speed, acceleration/ deceleration; standard deviation of speed (SD Speed), and standard deviation of lane positions (SDLP): the amount of variation in the car’s position as measured from the middle of the car lane. We also included self-report measures on how difficult the drive was, how well driving performance was perceived to be and how distracting the task was perceived to be. These measures were chosen because they offer a comprehensive set of parameters by which we can measure the degree to which our manipulation affected various aspects of driving performance compared to the baseline condition and between environments of different drive complexity.

Predictions

We predicted that the secondary task will improve hazard reaction time in the simple environment compared to the complex environment. This is because the cognitive secondary task will increase the pool of attention improving hazard detection in the simple environment, which is predicted by MART (Young & Stanton, 2002b). This will not occur in the complex environment because of the greater mental workload associated driving through traffic, with diverse scenery and frequent curves. In these environments, the addition of an audiobook is more likely to distract the driver, impairing performance. We also predict that individuals with low OSPAN scores will have poorer driving performance when engaging in a secondary task because
of their relative impairments in switching their attention between tasks. In regards to the self-report measures, we predict that the audiobook will only be perceived as distracting in the complex road environment, apart from this we expect the participants to rate their performance as better in the single task.

Method

Design

Our study was 2 x 2 x 2 mixed factorial design with the following factors: road environment level of distraction (single task, audiobook) x road complexity (simple road condition, complex road condition) x OSPAN score (low OSPAN, high OSPAN). Road complexity and OSPAN score were the between subjects variables while level of distraction was the within subjects variable. The dependent variables of interest were as follows: HRT, speed, SD speed, SDLP, and the self-report measures. For our analyses, we conducted a series of 2x2 ANOVAs in order to keep the sizes of our groups sufficiently large to ensure enough power for our analyses. Individuals were randomly assigned to either the simple or complex environment prior to entering the lab based on the order by which they scheduled their experiment times (switching between road complexity every six participants). The OSPAN group was determined by conducting a median split on the scores, with scores below the 57 in the low OSPAN group \( (M = 44.78, SD = 9.18) \) and scores above in the high OSPAN group \( (M = 65.58, SD = 5.98) \).

Participants

Participants were University of Guelph students recruited from the participant pool. All students were enrolled in an undergraduate Psychology course and were paid in course credit. Results were included from 40 participants (age: \( M = 18.94, SD = 1.35 \); male=10) with normal to
corrected to normal vision. 24 of the participants had at least their G2 driver’s license, which allows the individual to operate a vehicle without supervision in Ontario; the rest had a G license. 5 participants could not complete the study because they were feeling ill during the experiment. Intake questionnaire data can be found in Table 1.

**Materials, equipment and stimuli**

A number of questionnaires were used. For example, we used the Simulation Adaptation Syndrome (SAS) screening questionnaire (see Appendix A). This is a questionnaire that is designed to screen out participants who are at a heightened risk of SAS, which is a temporary condition characterized by fatigue, nausea and vertigo (Mollenhauer, 2004). This SAS screening questionnaire is not always accurate at predicting who will experience SAS as many people still succumb to these symptoms even though they obtained a perfect score on the questionnaire.

An intake questionnaire (see Appendix B) was given to participants consisting of items relating to their demographic characteristics and driving experience.

Furthermore, participants were required to complete an OSPAN task as a measure of executive function prior to completing the experimental drives. Each participant completed three trials in which they determined if a simple equation is true or false, followed by a letter that they must remember. For example, one stimuli pair could be: \((2+3)/2=2\) true or false), followed by a letter (L). In any given trial, a participant is presented with between 3-7 stimuli groups of equation-letter pairs. Participants must then recall the letters in the order that they appeared. Each trial has five stimuli groups corresponding to the number of letters to be remembered. Scores were calculated by their total recall out of 75 items. The OSPAN specifically measures how well individuals can effectively switch their attention between the memory and arithmetic tasks. It is
internally consistent with a Cronbach’s alpha=.78 (Bailey, 2012). An example of an OPSAN trial can be found in Figure 2.

The OKTAL driving simulator used is a fixed base simulator connected to the body of a Pontiac G6 convertible, which is surrounded by 300 degrees of wrap around projector screen. It is fitted with sound and vibration transducers that simulate a real driving environment. The simulator is run through six visual PC’s that are connected to six high definition projectors. OKTAL’s simulator software SCANER Studio 1.5 is the program used to run the experiment and it allows for full terrain and scenario customization (see Figure 3).

Participants were required to complete a four-item post drive questionnaire after each drive. The questions relate to the participant’s self-appraisal of their driving performance, the difficulty of the drive, how focused they were on the drive and how much they felt the distractions affected their driving performance.

For the audiobook condition participants were told to listened to an excerpt from chapter 4 “The Seven Potters” of the audiobook “Harry Potter and the Deathly Hallows” (Rowling & Dale, 2015). This section was chosen as it was an exciting section that didn’t require the participants to be familiar with the characters of the plot. The audiobook was played at 70% of max volume based on the reading from the media console and the segment from the audiobook played from the beginning of the drive until each participant finished the drive. There was no attempt to coordinate the occurrence of a hazard with any specific event in the story as individual differences in individual driving speed would make such organization difficult. We did not ask participants whether they had read the book, though this weakness was addressed in Experiment 3.
Two simple and two complex drives were designed for this study and are discussed in detail in the following paragraph (please refer to Figure 4). These drives differed in the locations of the hazards along with some modification of the visual stimuli used within each individual drive. The simple road condition consisted of straight drives on a country road with few peripheral visual stimuli like trees and buildings, and did not include any traffic. The complex drive consisted of a road segment with many curves and distinct environments such as forests, farming villages, towns, and big cities, and included moderate traffic (10 vehicles every 500m). There were ten times more building groups and over 200 times more trees in the complex road condition compared to the simple road condition. Each drive was about 30 km long and took approximately 20 minutes to complete. Each participant went on two 20-minute drives; one drive for the control condition and the other for the audiobook dual task. In each drive, participants reacted to five pedestrian hazards (see Figure 5) and five motor vehicle hazards (see Figure 6) that emerged from the periphery at randomly assigned places. Hazards were counter-balanced so that 10 hazards emerged from the left and 10 emerged from the right over the two drives. Participants were told to keep their speed at about 90 km/h. Conditions were counter-balanced to make sure that all the condition orders were tested. In the control condition, participants simply drove through the course without completing any secondary tasks or listening to anything through the speakers.

Procedure

Participants were given a consent form and orally informed of their role and rights as a participant in the experiment prior to starting the experiment. Prior to any testing, participants were screened for their likelihood of experiencing Simulator Adaptation Syndrome (SAS). Once it was determined that the participant was a good candidate for the driving simulator, the
participant was given the intake questionnaire while still in the waiting room. The intake questionnaire took about 10-15 minutes to complete. Following the completion of the intake questionnaire, the participant was invited into lab to complete the OSPAN task, which took about 15-20 minutes to complete. Once the OSPAN was completed, the participant was shown the driving simulator and told what would be required from them in the drive. The participant was accompanied into the vehicle for the practice drive, which lasted about 2-3 minutes and included one peripheral hazard that allowed the participant to get familiar with the brakes of the vehicle.

Once the practice drive was completed, the participant was told what was expected in the experimental drives. The participants were told to maintain driving speed at 90km/h, to completely stop for each hazard and to avoid swerving around hazards. Following each drive, the researcher approached the car, asked if the participant felt okay, and then presented the participant with the post-drive questionnaire. This was repeated one more time, corresponding to the final drive. After the experimental drives, the participant was invited back into the control room. The participant was then handed the debriefing form and we answered any question that they might have. The whole experiment lasted approximately an hour and a half.

Results

We conducted a series of 2x2 mixed factorial ANOVAs with between subjects variable road complexity (simple, complex) and the within subjects variable task load (single task, audiobook) and the between subjects variable OSPAN score (low, high) and the within subjects variable task load (single task, audiobook) on the dependant variables. The Greenhouse-Geisser correction was used to correct against violations of the sphericity assumption.
**Hazard Reaction Time**

We calculated HRTs using data taken from the simulator by subtracting the time when each hazard was activated from the first instance when brake pressure was first applied. This was done for every hazard. A Z-score analysis was completed using the data from each participant in each drive, any RT that was more than +/- 2.5 SDs away from the mean was removed amounting to 2.1% of the total data. Means were then calculated for each participant in each condition. These means were then used in the statistical analysis which was performed in SPSS statistical package.

We conducted a 2x2 ANOVA on road complexity and task load and there was no effect of task load $F(1, 35) = .01, ns$, partial $\eta^2 = .0$, this was however, qualified by the predicted interaction between road complexity and task load $F(1, 35) =12.32, p < .001$, partial $\eta^2 = .26$. We examined the interaction by examining the simple main effects of task load in the complex environment $F(1, 35) =7 p < .05$, partial $\eta^2 = .14$ which indicates lower HRTs in the single task compared to the audiobook. We then examined the simple main effects of task load for the simple environment $F(1, 35) =5.33, p < .05$, partial $\eta^2 = .16$, which indicates lower HRTs in the audiobook task than the single task. There was a main effect of road complexity $F(1, 35) = 20.13, p < .001$, partial $\eta^2 = .37$ indicating that HRTs were significantly higher in the complex environment compared to the simple environment. This suggests that the complex road environment demanded a higher mental load and interfered more with HRTs (see Figure 7.).

We conducted a 2x2 ANOVA on OSPAN group and task load and there was no effect of OSPAN group $F(1, 35) = .038, ns$, partial $\eta^2 = .00$, but an interaction between OSPAN group and task load emerged $F(1, 35) = 6.16, p < .05$, partial $\eta^2 = .15$, where low OSPAN group individuals had lower HRTs in the single task than in the audiobook condition, while those in the high
OSPAN group had lower HRTs in the audiobook condition. Simple main effects reveal no effect of task load for the low OSPAN group $F(1, 19) = 3.24, ns$, partial $\eta^2 = .15$, and no effect of task load for the high OSPAN group $F(1, 18) = 3.59, ns$, partial $\eta^2 = .16$. This supports our predictions, as it seems that despite road complexity, individuals with low OSPAN scores tend to have HRTs negatively impacted by the audiobooks, the opposite was true for high OSPAN individuals (see Figure 8).

**Speed and SD Speed**

We conducted a 2x2 mixed factorial ANOVA with road complexity and task load on speed using a 1.3 km segment of road. There was no main effect of task load $F(1, 34) = .847, ns$, partial $\eta^2 = .024$, but this was qualified by a significant interaction between task load and drive complexity $F(1, 34) = 4.93, p < .05$, partial $\eta^2 = .127$ with the single task leading to fast speeds in the simple environment, but the audiobook leading to faster speeds in complex environment. Simple main effects reveal no effect of task load in the simple environment $F(1, 19) = 3.89, ns$, partial $\eta^2 = .17$, and no effect of task load in the complex environment $F(1, 17) = 1.66, ns$, partial $\eta^2 = .09$. There was also a main effect of road complexity $F(1, 36) = 5.17, p < .05$, partial $\eta^2 = .126$, as average speed was higher in the simple environment compared to the complex environment. This is consistent with the literature, where underload causes individuals to be more likely to speed. In this case, the most under stimulating condition was the only one with significantly faster speeds (see Figure 9). We also conducted a 2x2 ANOVA on SD Speed and there was no effect of drive complexity $F(1, 36) = 1.98, ns$, partial $\eta^2 = .053$ between the simple environment ($M = 2.37, SE = .34$) and the complex environment ($M = 2.46, SE = .36$). There was also no main effect of task load $F(1, 36) = 2.68, ns$ partial $\eta^2 = .07$ between the single task ($M = 2.65, SE = .33$) and the audiobook ($M = 2.18, SE = .24$).
**SDLP**

We conducted a 2x2 ANOVA with road complexity and task load on SDLP. There was a main effect of drive complexity on SDLP $F(1, 34) = 5.74, p < .05$, partial $\eta^2 = .14$ with significantly higher SDLP in the simple environment than in the complex environment. There was no main effect of task load $F(1, 34) = .919, ns$, partial $\eta^2 = .028$, but this was qualified with a significant interaction between drive complexity and task load $F(1, 34) = 4.424, p < .05$, partial $\eta^2 = .115$ (see Figure 10). Simple main effects reveal no effect of task load in the simple environment $F(1, 19) = 3.34, ns$, partial $\eta^2 = .08$, and no effect of task load in the complex environment $F(1, 17) = 1.72, ns$, partial $\eta^2 = .09$. Therefore our simple main effects reveal a trend in the data regarding higher SDLP in the simple environment, but surprisingly, these analyses reveal that both simple main effects were not significant so these results should be interpreted with caution.

**Post-drive Questionnaire**

We conducted a preliminary analysis of the results and found no main effect of OSPAN score of self-report measures, therefore we collapsed across OSPAN score for all analysis and conducted 2x2 ANOVAs. There was a significant main effect of task load on self-reported level of distraction $F(1, 34) = 18.75, p < .001$, partial $\eta^2 = .36$ with the audiobook condition being significantly more distracting than the single task. In addition to this, there was a significant interaction between task load and drive complexity on self-reports of distraction $F(1, 34) = 7.74, p < .01$, partial $\eta^2 = .19$ (see Figure 11). Simple main effects reveal that the audiobook was much more distracting than the single task in the complex environment $F(1, 16) = 34.08, p < .001$, partial $\eta^2 = .68$, but there no difference between the tasks in the simple environment $F(1, 17) = .99, ns$, partial $\eta^2 = .05$. This is consistent with our predictions; it was found that audiobooks only
acted as a distraction in the complex environment.

There was a significant main effect of task load on the drivers’ ratings of the challenge of drive $F(1, 34) = 49.37, p < .001$, partial $\eta^2 = .60$, with the audiobook condition being assessed as more challenging than the single task condition (see Figure 12). There was a main effect of task load on self-rating of performance $F(1, 34) = 32.64, p < .001$, partial $\eta^2 = .50$ with drivers assessing their performance as better in the single task than in the audiobook condition (see Figure 13). Both above effects are consistent with our predictions; participants found that their driving performance was worse when listening to audiobooks compared to the single task. However, contrary to our predictions, there was no effect of task load on self-reported difficulty of the drive $F(1, 34) = 1.25, ns$, partial $\eta^2 = .04$ (see Figure 14). We did not find a main effect of road complexity for any of the above variables ($p > .05$).

**Discussion**

The purpose of this study was to investigate whether an audiobook could be used to improve driving performance in under-stimulating environments. All previous studies examining the effects of listening to audiobooks while driving compared listening to audiobooks to other common in car distractions such as having a hands-free conversation or texting, but they did not take driving complexity in consideration (Biondi et al., 2015; Strayer et al., 2015). We found support for our first hypothesis; that the audiobook will improve performance (specifically HRTs) in the simple environment but not in the complex environment. The presence of cityscapes, curves and traffic that made up the complex drive significantly contributed to the mental workload experienced by the driver, this made the addition of the secondary task more likely to become a distraction in the complex drive and impair driving performance in terms of
HRTs (Beede & Kass, 2006; Durantin, Gagnon, Tremblay, & Dehais, 2014; Strayer et al., 2015). The simple environment was designed to be boring and under-stimulating, making mental underload more likely and allowing the audiobook to improve driving performance in the case of both HRTs and speed (Gershon et al., 2009; Young & Stanton, 2002a). In addition to this, the post-drive questionnaire shows that the audiobook did not distract the participant in the simple drive, but was significantly more distracting in the complex environment.

Although we lacked an objective test of fatigue, boredom or mind wandering, our data suggests that our participants were indeed experiencing cognitive underload in the simple road due the significantly faster average speeds. Furthermore, the negative impact of mental underload was successfully remedied with the inclusion of a moderately stimulating cognitive distraction, the audiobook. We predicted the benefits of the audiobook in the simple environment, but the increase in SDLP was an unexpected finding; it seems that listening to the audiobook increased the ability to detect and react to peripheral hazards at the cost of an increase in swerving. This may be an artifact of the experiment; as in the case of the simple drive, there was no ambient traffic which made this increase relatively harmless. It would be interesting if this effect remained if traffic was included in the drive.

We also found support for our second hypothesis; low OSPAN scorers had higher HRTs when listening to the audiobook compared to simple driving. Individuals in the high OSPAN scores however, had lower HRTs when listening to the audiobook compared to the driving single task. Those with low OSPAN scores who had higher HRTS when listening to audiobooks but lower HRTs than the high OSPAN group in the single task condition. This finding is consistent with findings that higher OSPAN scores predicting better multitasking ability (Anstey, Wood, Lord, & Walker, 2005; Garavan, Ross, Murphey, Roche, & Stein, 2002; Unsworth et al., 2005).
Better executive functioning allows these individuals to focus on their attention on both the audiobook and on the road without experiencing an interference effect; it seems that the audiobook may have optimized their levels of arousal, and therefore their HRTs. This is consistent with what we know about multiple resource theory, MART and the Yerkes-Dobson curve of arousal and performance. It is also possible that high OSPAN scorers succumb to underload more easily than those with lower scores, which may be the case in our results as there was no overall difference in overall HRTS between our two OSPAN groups. It would be ideal if we compared individuals in the top and bottom quartile of OSPAN scores, however, due to our sample size, we did not have sufficient power for this analysis.

These findings suggest an interaction between executive working memory, the environment and the workload associated with engaging in a secondary task. Our simple environment was programmed to be uneventful, but it shares many features with rural roads, where the driver may benefit from listening to audiobooks. There is reason to suggest that these results may be relevant to daily commutes where the driver is familiar with the route may also benefit from the listening to audiobooks. We lacked the time and resources to sufficiently habituate participants to more complex environments, like highway commutes, to examine the degree to which this effect can be generalized to real drivers. Additionally, it was unclear if the participants were habituated to listening to the audiobook while driving. However, based on our theoretical framework, we can predict that this benefit may be applied to commuters as well.

Further studies need to be conducted to replicate this effect and understand which of the environmental factors contribute most to underload. We also need to compare the effect of the audiobook to another common cognitive distractor like a hands-free conversation. Future studies can also use longer stretches of roads from which to gather average speed, standard deviation of
speed and SDLP, as one of the weaknesses of this study is that the 1.3 km stretch may be too short to gather enough data. For our next study, we attempt to replicate the positive effect of listening to an audiobook, but also include a handsfree conversation where participants will be conversing throughout the whole drive.

Overall, our study shows that not all distractions affect driving the same way, and that audiobooks can be beneficial in certain environments. We still need to run additional studies to replicate the results with the inclusion of a handsfree conversation condition, to determine if this effect is specific to audiobooks or to any cognitive distraction in general. We also need to better understand which of the factors used in designing out environments contributed most to our effect. Furthermore, we need to consider that although our driving simulator is highly realistic, a real car provides additional stimuli that we could not manipulate in the simulator, including but not limited to haptic feedback, familiarity with the surroundings and strict deadlines in terms of arriving at a destination on time. Finally, we do not know if the observed effect would be replicated for different types of books, familiarity of the book and amongst individuals more or less experienced with listening to audiobooks while driving.
Experiment 2

Introduction

In my first experiment, we found that we can use audiobooks to improve driving performance in road environments that produce mental underload. Our data shows that listening to audiobooks while driving in simple road environments can lead to lower HRTs and slower speeds (average speed closer to the posted speed limit). Listening to audiobooks in complex environments, however, increased the already higher mental workload elicited by the environment, leading to higher HRTs. We also found that individuals who scored low on the OSPAN task had relatively higher HRTs when multitasking, while those with high scores had relatively lower HRTs. These findings are consistent with our understanding of attention and distraction, which is grounded in multiple resource theory and MART (Wickens, 2002; Young & Stanton, 2002). However, it is impossible to tell if this effect was the result of the audiobook or, of any cognitive distraction in general. We needed to compare the audiobooks conditions to a cognitive distraction that is known to have a negative effect. Driving simulators provide the driver with less overall sensory information than does driving a vehicle especially in terms of haptic feedback. It is possible that this lack of feedback increased the likelihood of mental underload to a greater degree than driving (Strayer et al., 2015). This issue was addressed by including a cognitive distraction known to impair driving performance: a handsfree conversation condition (Beede & Kass, 2006; Caird et al., 2008). Handsfree conversations are more attentionally demanding and contribute more to mental workload than listening to an audiobook (Törnros & Bolling, 2006). Instead of passively listening, the driver must listen, process the information, and respond while maintaining control of the vehicle and attending to the environment.
In a meta-analysis of cell phone use while driving, it was found that cell phone conversations reliably lead to slower reaction time, greater variability in lane positioning, and decreases in speed. Furthermore, when taking the type of conversation being held into consideration (handheld, handsfree, passenger), it was found that both handheld and handsfree conversation lead to similar increases in RT compared to baseline (210ms and 180ms increase from baseline respectively). There is also virtually no difference in these measures when comparing cell-phone conversations to conversations with passengers. Overall, in both meta-analysis of cell-phone use while driving and conversations while driving, it was found that engaging in secondary cognitive tasks (Caird et al., 2008) and texting (Caird et al., 2014) lead to the greatest decrements to driving performance compared to handsfree conversations, which have been found to impair driving performance more than listening to an audiobook (Strayer et al., 2015). Therefore, these meta analyses justify the inclusion of a handsfree conversation condition in our experiment as a common, well studied cognitive distractor that was used to examine whether the benefit of the secondary task was unique to listening to the audiobook, as it is a similar, but more demanding cognitive distraction.

Experiment 2 follows the same procedure and design as Experiment 1 with the addition of a new distraction condition: handsfree conversation. Each participant drove down either a simple or complex road environment, and in each environment; they simply drove, drove while listening to an audiobook, and drove while engaging in a handsfree conversation.

Predictions

Our predictions regarding the variables from Experiment 1 remained the same. However, in the case of the handsfree conversation, we predicted that the higher mental workload will lead to higher HRTs compared to the audiobook condition in the simple environment, and higher
HRTs compared to the single task condition in the complex road environment. We also predict that we will replicate our previous effect of the audiobook condition leading to higher SDLP than the single task. Our predictions regarding OSPAN scores are also the same, individuals with lower OSPAN scores will have poorer driving performance in the multitasking condition compared individual with higher scores. We expected that, consistent with the previous experiment, average speeds will be higher in simple road environment. In regards to the self-report measures, we predict that the audiobooks will be less distracting than the handsfree conditions in the simple road environment, but more distracting than the single task in the complex road environment. We also predict that participants will rate their driving performance best in the single task, and worst in the handsfree condition.

**Method**

*Design*

Our study was 2 x 2 x 3 mixed factorial design with: distraction (single task, audiobook, handsfree) x road environment (simple road condition, complex road condition) x OSPAN score (low OSPAN, high OSPAN). The dependent variables of interest were, HRT, speed, SD speed, SDLP and the self-report measures. For our analysis, we conducted a series of 2x3 ANOVAs in order to keep the sizes of our groups sufficiently large to ensure enough power for our analyses. Individuals were randomly assigned to either the simple or complex environment based on their participant ID and OSPAN group was determined by conducting a median split on the scores, with scores below the 59 in the low OSPAN group ($M = 50.89$, $SD = 6.38$) and scores above in the high OSPAN group ($M = 66.24$, $SD = 4.49$).
Participants

Participants were University of Guelph students recruited from the participant pool. All students were enrolled in an undergraduate Psychology course and were paid in course credit. Results were included from 39 participants (age: $M = 18.9$, $SD = 1.4$: male=10) with normal to corrected to normal vision. 23 of the participants had at least their G2 driver’s license, which allows the individual to operate a vehicle without supervision in Ontario, the rest had a G license. Power analysis conducted in G Power 3.0 revealed that we needed a minimum sample size of 28 to find our interaction between task load and road complexity. This is based on the effect size of our interaction of .26 with a power of .95 and a correlation amongst measures of .78. We did not gather data for 4 participants due to simulation adaptation syndrome throughout the whole period of data collection. Intake questionnaire data can be found in Table 2.

Materials

The same questionnaires were used as in Experiment 1: SAS (Appendix A), Intake questionnaire (Appendix B), and Post-Drive Questionnaire (Appendix C).

Using the same simple and complex environments from Experiment 1, we programmed an audiobook condition into each environment. This was done by inserting 10 peripheral hazards (in different location than the other two conditions) throughout the environments. We then programmed 30 questions into the drive, each question was between 30s to 60s apart, giving the participants ample time to elaborate and answer the question in detail. We decided on automated questions in order to keep the timing of the conversation consistent between participants. If the answer was interrupted by a following question, we asked the participants to simply address the new question being asked. The questions were primarily focused on the participant’s home life, school and favourite things: movies, TV shows, sports and music. We did not record the answers.
to the questions; rather, the purpose of the handsfree condition was to get the participant speaking for as long as possible during the drive. There was variability in the degree to which participants engaged in the conversations, with some participants talking the whole time, while others providing little more than one word answers despite prompting to go into more detail. However, we did not specifically record the degree to which participants engaged in the conversation, which made analysis based on verbosity impossible.

Procedure

Participants followed the same procedure as in Experiment 1, the only difference was that there were three experimental drives. It took a maximum time of 2 hours to complete the experiment, though most of the finished in under an hour and 45 minutes.

Results

We conducted a series of 2x3 ANOVA with between subjects variable road complexity (simple, complex) and the within subjects variable task load (single task, audiobook, handsfree), and, the between subjects variable OSPAN score (low, high) and the within subjects variable task load (single task, audiobook, hands free) on the dependant variables. The Greenhouse-Geisser correction was used to correct against violations of the sphericity assumption. Bonferroni tests were used for post-hoc comparisons between means.

Hazard Reaction Time

We calculated HRTs using data taken from the simulator by subtracting the time when each hazard was activated from the first instance when brake pressure was first applied. This was done for every hazard. A Z-score analysis was completed using the data from each participant in each drive, any RT that was more than +/- 2.5 SDs away from the mean was removed amounting
to 1.8% of the total data. Means were then calculated for each participant in each condition. These means were then used in the statistical analysis that was performance in SPSS statistical package.

We conducted a 2x3 ANOVA with road complexity and task load on HRTs. As predicted, there was a main effect of task load $F(1.94, 67.90) = 4.54, p < .05$, partial $\eta^2 = .12$ with audiobooks leading to the lowest HRTs and the handsfree condition leading to the highest. There was a main effect of road complexity $F(1, 37) = 9.49, p < .01$, partial $\eta^2 = .204$ indicating that HRTs were significantly higher in the complex environment compared to the simple environment (see Figure 15). This consistent with our prediction and a replication of the effect from Experiment 1 suggesting that participants were more likely to experience overload in the complex environment. There was also a significant interaction between road complexity and task load $F(1.94, 67.90) = 4.29, p < .05$, partial $\eta^2 = .11$. We examined the interaction by examining the simple main effects of task load in the simple environment $F(1.33, 22.56) = 9.15, p < .01$, partial $\eta^2 = .38$; post-hoc comparisons of means demonstrate that there is a significant difference between HRTs in all of the three condition with single task RTs ($M = 989ms, SD = 105$), hands-free RTs ($M = 1004ms, SD = 103$), and audiobook RTs ($M = 942ms, SD = 104$). These results are consistent with our predictions and suggest that audiobooks cause lower HRT performance while handsfree conversations lead to worse performance compared to the single task. We examined the simple main effects of task load for the complex environment but did not find any effects $F(1.42, 25.60) = .56 ns$, partial $\eta^2 = .033$, which demonstrates no differences between tasks in the complex road environment. This was contrary to our hypothesis as we predicted the secondary tasks to lead to decrements in driving performance in the complex road environment, instead there were no differences between the multitasking conditions and the single task. We
conducted a 2x3 ANOVA with OSPAN group and task load on HRTs. There was no main effect of OSPAN group $F(1, 35) = .39$, $ns$, partial $\eta^2 = .03$ and unlike our first experiment, there was no interaction between OSPAN group and task load $F(2, 72.40) = .23$, $ns$, partial $\eta^2 = .00$.

*Speed and SD Speed*

There was no effect of OSPAN group on any of the following analysis of speed, SD speed or SDLP. Therefore we conducted a series of 2x3 ANOVAs with road complexity and task load. There was no main effect of road complexity $F(1, 35) = 3.25$, $ns$, partial $\eta^2 = .085$ or task load $F(1.88, 65.90) = 1.71$, $ns$, partial $\eta^2 = .04$. The interaction between road complexity and task load approached significance $F(1.88, 65.90) = 3.07$, $p = .056$, partial $\eta^2 = .04$ (see Figure 17). We also conducted a mixed factorial ANOVA on SD Speed and there was no main effect of road complexity $F(1, 37) = 1.12$, $ns$, partial $\eta^2 = .03$ between the simple environment ($M = 2.20$, $SE = .24$) and the complex environment ($M = 2.58$, $SE = .25$). There was also no main effect of task load $F(1.82, 63.63) = 2.61$, $ns$, partial $\eta^2 = .066$, between the single task ($M = 2.64$, $SE = .31$), audiobook ($M = 2.23$, $SE = .20$) and the handsfree condition ($M = 2.56$, $SE = .24$).

*SDLP*

We conducted a 2x3 mixed factorial ANOVA on SDLP. There was no main effect of road complexity $F(1, 37) = 1.40$, $ns$, partial $\eta^2 = .03$ or of task load $F(1.88, 65.72) = 2.50$, $ns$, partial $\eta^2 = .06$. However, this was qualified by a significant interaction between task load and drive complexity $F(1.88, 65.72) = 6.94$, $p < .01$, partial $\eta^2 = .16$. Simple main effects reveal a significant effect of task load in the simple environment $F(1.33, 22.55) = 5.49$, $p < .01$, partial $\eta^2 = .24$ and post-hoc comparisons of means revealed that the hands free condition has significantly lower SDLP than both the single task and the audiobook, which were no significantly different from each other (see Figure 18). Simple main effects for task load in the complex environment
however, revealed no significant effect $F(1.42, 25.59) = 1.06, ns$, partial $\eta^2 = .05$. These results are consistent with our results from Experiment 1, though it is unclear whether this effect is due to the audiobook or the lack of traffic in the simple environment.

Self-report measures

We completed four 2x3 ANOVAs with road complexity and task load for each of the question in the post-drive questionnaire (see Figure 19). We failed to find a main effect of road environment or OSPAN group on any of the 4 questions ($p > .05$), therefore, we did not analyse these variables for any of the ANOVAs. We found a main effect of task load for how challenging the drives were $F(1.66,54.99) = 7.79, p < .001, \eta^2 = .19$. Pairwise comparisons reveal that, contrary to our hypothesis, participants found the audiobook condition more challenging the handsfree condition, which was more challenging than the single task. We found a main effect of task load on how good participants felt their performance was on each of the drives were $F(1.51,49.94) = 6.49, p < .01, \eta^2 = .16$ with participants feeling poorer performance in the audiobook conditions compared to the single task and handsfree condition. There was no main effect of task load on how difficult it was to focus on the drive $F(1.89,62.46) = .85, ns, \eta^2 = .02$

Lastly, consistent with our predictions, we found a main effect of task load on how much the distraction affected the participants’ driving performance $F(1,82,60.18) = 28.78, p < .001, \eta^2 = .47$ with handsfree conversations distracting the participants more than the audiobooks, which were more distracting than the single task.

Discussion

The current study was intended to be a replication of Experiment 1 with the addition of a handsfree-conversation within-subjects condition. This was done to see whether the positive effect of the audiobook in Experiment 1 was because of the audiobook specifically or of
cognitive distractions in general. We replicated our novel finding from Experiment 1, participants had lower HRTs when listening to an audiobook when driving in an under stimulating environment, which gives us further evidence that the simple environment contributed to mental underload, especially when simple driving. The key aspect of Experiment 2 was the addition of the handsfree condition, which showed us that the relatively low HRTs in the simple driving were only elicited by the audiobook and not the handsfree condition (Horberry et al., 2006; Strayer et al., 2015). Our unique finding however was that we found no difference in HRTs between the three different tasks in the complex road environment. There are several potential reasons as to why this was the case. The participants may have not paid attention to the audiobook or engaged in the hands-free conversation to a sufficient degree to have their driving performance impaired since we did not have the materials to check the degree of comprehension and engagement for each task respectively. There was tremendous variability in the degree to which participants engaged in the hands-free conversation, with some participants responding to the questions enthusiastically while others provided little more than one word answers despite prompting from the researcher to be more engaged. The same could be true of the audiobook condition, we had no objective measure to test whether the participants were paying attention to the audiobook so we don’t know the degree to which participants here paying attention. It may be that the added demands of the complex road environment made participants less likely to pay attention to the audiobook while the simple road environment allowed for enough attentional freedom for the participants to listen actively. This could be why there was a benefit to listening to the audiobook in the simple road environment and why there was no distraction effect of the audiobook condition in the complex road environment. These shortcomings were addressed in Experiment 3. However, these results may also suggest that the participants overcame mental
underload with the audiobook in the simple condition, but that they did not experience mental overload in complex road environment when engaging in the secondary tasks. There is a possibility that the higher OSPAN scores in Experiment 2 may have contributed to this effect, the overall better executive functioning could have allowed the drivers to multitask (and increase mental workload) in complex road environment, but not experience the negative effects of mental overload.

The differences between the effect of OSPAN scores on driving performance are likely influenced by the differences in average scores between the experiments, especially in the low OSPAN group, though there is reason to suggest that this may have to do with the timing of our experiment the first experiment was run during the final few weeks of the winter semester of 2016, while the second experiment was run during the first part of the fall semester of 2016. It could be that individuals with higher executive abilities simply choose earlier test dates than those with lower OSPAN scores. These differences in the OSPAN scores may also be the reason why we did not find the interaction between OSPAN scores and road complexity that we found in the first study; the differences between the high OSPAN group and the low OSPAN group was larger in Experiment 1.

Our first experiment showed that that high OSPAN scores are associated with better multitasking abilities (Watson & Strayer, 2010). Higher scoring individuals had lower HRTs across all multitasking conditions, though this effect was not significant. Post-hoc comparisons of means between the single task and audiobook condition however showed that high OSPAN individuals experienced lower HRTs in the simple road environment, and lower HRTs when listening to audiobooks in the simple road environment, though relatively higher HRTs when engaging in a handsfree conversations. These results can be interpreted in the context of MART
(Young & Stanton, 2002). The audiobooks increased attentional resources compared to the underloading single task, leading to lower HRTs. However, the handsfree conversation may have been too demanding leading to relatively poorer performance in terms of HRTs but still significantly faster than all the complex conditions where there was no difference in HRTs between conditions.

We partially replicated the results of Experiment 1 pertaining to SDLP. Consistent with what was found in the first study, SDLP was highest while listening to an audiobook in the simple road environment. In the first experiment, it was unclear if this is attributed to engaging in a secondary task while driving in simple road environment with no traffic. This study reveals that this is not the case since SDLP was lowest in the handsfree condition in the simple road environment. Therefore, there must be something about listening to an audiobook in simple road environments that leads to this increase in SDLP. There seems to a trade-off between lower HRTs and higher SDLP when it comes to listening to audiobooks in simple road environments that is not evident in the case of a handsfree conversation. There is evidence that conversations and turn taking activate many of the same brain areas as simply listening to a narrative, specifically: the striatum, amygdala, thalamus, cerebellum, dorsal frontal cortex, middle temporal and thalamic regions. However, the motor cortex is activated while engaging in a conversation while listening to narratives without responding leads to the inhibition in the same motor areas (Nummenmaa et al., 2014; Scott, McGettigan, & Eisner, 2009). Although there is a significant degree of overlap in the cortical activation between listening to narratives and engaging in a conversation, the relative difference in motor cortex activation may play a role in the interaction seen between SDLP in road complexity and the two secondary tasks. It may be that there is active inhibition of the motor cortices when listening to audiobooks, leading to
poorer steering control. However, this inhibition may be overridden in the complex road environment where the presence of traffic required greater motor control due to the risks associated with colliding with traffic.

A common response to researchers who find differences in HRT between different task loads is that maybe the participants slowed down or sped up when engaging in secondary tasks. We found no such differences, as these effects on HRT only emerge after 7-8km/h above the posted speed and there was no evidence of compensatory slowing. All participants drove very close to posted speed limit of 90 km/h, there was also no evidence of participants accelerating or decelerating at different rates between the different tasks. However, when comparing average speed in the audiobook and control condition, a significant interaction emerged. Consistent with our first experiment, listening to audiobooks in both simple and complex road environments led to speeds closer to the posted speed limit than when simply driving. This effect suggests that listening to the audiobook lead to lower HRTs in simple environments, but improves speed control in both simple and complex road environments. It seems that effect of the secondary task on driving performance also depends on the demands of the specific aspect of driving performance measured. Responding quickly to hazards contributes more to the mental workload than keeping average speed stable, therefore, our results reveal that the differing demands of the specific aspects of driving performance; in this case keeping speed stable and responding to hazards, may influence the degree and direction of the effect that listening to audiobooks has on driving performance.

Our results also demonstrate that participants’ self-reports of challenge of drive, distractions and performance differed from our observed measures of driving performance, just like in Experiment 1. The audiobook condition was reported to be more challenging and
perceived to affect driving performance more negatively than the other two conditions, even though the audiobook condition lead to the lowest HRTs in the simple environment, and across all conditions. However, consistent with our expected results, the handsfree condition was perceived to be significantly more distracting than both the single task and audiobook condition, and this was also apparent in measures of HRTs where the handsfree condition lead to the highest HRTs overall.

Our second experiment supported our initial hypothesis regarding the positive effects of listening to audiobooks in simple road environments, however it has several limitations. First, it would be better if the drives were longer and it would also be useful if we could truly investigate the effects of routine driving, by having drivers repeatedly traverse the same roads. As it is, it is possible that the driving alone condition did not elicit enough boredom/ mind-wandering to produce an effect. Second, the audiobook was “Harry Potter”, a children’s book that is familiar to many. It is possible that a book that was more difficult to understand would interfere more with driving. Furthermore, because the book was familiar, it is possible that the drivers did not pay close attention to the book. A post-drive measure of comprehension would have been a beneficial and was included in Experiment 3. Finally, because the simple and complex drives differ in terms of traffic, road curvature, and scenery, it is unclear which of these three factors is most important in determining when secondary tasks such as audiobooks begin to interfere.
Experiment 3

Our first two experiments yielded interesting results regarding the benefit of listening to an audiobook in conditions that are likely to produce mental underload. It was found that listening to audiobooks in simple road environments lead to lower HRTs than when simply driving. We also found that listening to audiobooks in complex road environments leads to higher HRTs than simple driving in Experiment 1, and no significant difference in HRTs in Experiment 2. Although these experiments reveal interesting effects, they suffer from drawbacks. We did not know which of the variables used in manipulating road complexity were responsible for the beneficial effects of listening to an audiobook in the simple environment. Furthermore, we were unable to compare pedestrian hazards to vehicle hazards due to a lack of a standardized distance between the road and the hazards. In addition to this, we were unable to test audiobook comprehension or ensure engagement in the handsfree conversation due to the lack of a comprehension questionnaire and sufficient prompts during the handsfree condition. We addressed these weaknesses by programing new driving environments that allowed us to better control over the key environmental variables used program our previous simple and complex road environment, we also standardized distances between the hazards and the road allowing us to look at each hazard type individually. Finally, we added a comprehension questionnaire and made sure to prompt the participants to elaborate more on the questions when it was apparent that there was a lack of engagement.

There is a great deal of inconsistency in literature in regards to how road complexity is operationalized. For example, some researchers manipulate complexity by increasing traffic density and the speed limit (Liu & Wu, 2009), including or excluding road curvature (Hamish Jamson & Merat, 2005,) and adding roadside scenery (Cantin et al., 2009; Paxion, Galy, &
Berthelon, 2015). These issues with correctly defining road complexity likely contribute to inconsistencies regarding how road complexity affects driving performance (Strayer et al., 2015; Törnros & Bolling, 2006b).

Many studies that fail to find significant differences on driving performance between simple and complex driving environments. One example is a study by Törnros and Bolling (2006) who manipulated road conditions across a number of variables including density oncoming traffic, number of traffic lanes, frequency of parked cars, frequency and density of houses and buildings, frequency of traffic lights, and frequency and density of pedestrians and cyclists in order to test the impact of road complexity on driving while multitasking. The authors designed five road environments with two rural sections of 70km/h and 90km/h, and three urban environments of low, medium and high complexity by manipulating the variables above. Each participant drove through the five environments two times, once while simply driving and one while operating a mobile phone. Overall, the presence of traffic decreased secondary task performance more than presence of peripheral visual stimuli, and the hands-free condition was detrimental to driving in all road conditions. Unlike other studies, the authors did not find a main effect of road complexity on driving performance and this may be attributed to some shortcoming in the methodology used. The authors included too many road environments to be used in a relatively short drive (7 minutes per environment per condition), and used a peripheral detection task as opposed to hazards to measure reaction time, much like the study by Strayer et al. (2015), where the 10 minute drives and the lack of peripheral hazards did not allow for the sufficient testing of each road environment to find an effect of road complexity. This is likely due to the author’s manipulation of drive complexity and the brevity of the drives. This has been an issue in a number of studies that have failed to find significant differences between simple and
complex road complexities, and part of this has to do with differences in the way these authors operationally define complexity (Strayer et al., 2015; Törnros & Bolling, 2006b).

These results are in stark contrast to the experiments that found significant differences between performance on simple and complex roads. In these experiments, researchers included long drives that were sufficiently varied on a number of dimensions including number curves, presence or lack of traffic, inclusion of intersections, inclusions of various hazards and the number of peripheral visual stimuli (Cantin, Lavallière, Simoneau, & Teasdale, 2009; Hamish Jamson & Merat, 2005; Horberry et al., 2006; Liu & Wu, 2009; Paxion et al., 2015). Road complexity is most effectively manipulated when the simple road condition can reliably induce mental underload, and when the complex road condition can reliably increase the mental workload of the driver. This is done by including traffic, roadside events, turns and curves, intersections and peripheral visual stimuli such as office buildings, strip malls, houses and parked vehicles (Cantin et al., 2009; Horberry et al., 2006). The successful manipulation of road complexity is important because the risks and benefits of using certain secondary distractions are directly related to the mental workload associated with complexity of the drive, and the difficulty of the secondary task.

In our first two experiments, drive complexity was established through the manipulation of road curvature (straight, and some curves), presence of peripheral visual stimuli such as the number and type of building groups (not including roadside signs) and the presence or lack of trees, and traffic (no traffic, moderate traffic). It is possible that the observed effect occurred due an interaction between two or three of the variables because these variables affect driving performance in different ways. Traffic density, for example, while contributing to road complexity and drive difficulty, can also be viewed as an additional distracter or as a hazard,
since as traffic density increases, so does the likelihood of a vehicular collision (Stavrinos et al., 2013). Simulated roadside scenery has been shown to increase driver arousal and reduce fatigue, but increases the frequency of off road glances (Heslop et al., 2010; Larue et al., 2011). In Experiment 3, we intended to understand how the combination of low traffic and low levels of roadside scenery caused the driver to have lower HRTs when listening to the audiobook compared to the control, and how moderate traffic, road curvature, and a high density of roadside scenery lead to audiobooks leading to higher HRTs.

Traffic density

Traffic density has been explored thoroughly in the literature. In general, high traffic density leads to impairments in driver speed control and lower situational awareness (Heenan, Herdman, Brown, & Robert, 2014). This is because as traffic increases, so does the number of potential hazardous situations on the road as there are simply more vehicles that the driver can collide with. Therefore, the driver must take extra care to not only avoid collisions but also to maintain good driving performance while doing so. The increased attentional demands that stem from manoeuvring through traffic restrict attentional resources and impair situational awareness and driving control since the driver must allocate more resources to responding to traffic conditions (Shakouri, Ikuma, Aghazadeh, Punniaraj, & Ishak, 2014; Teh, Jamson, Carsten, & Jamson, 2014).

In addition to this, high traffic density and the presence of parked cars on the roadside increases driver uncertainty, mental load and the potential risks associated with responding to the road environment leading to lower speeds and higher hazard reaction times to pedestrians (Edquist, Rudin-Brown, & Lenné, 2012). Researchers have examined how traffic density affects the driver’s ability to perform concurrent secondary tasks. Gold, Korber, Lechner and Bengler,
(2016) tested overall driving performance and successful overtaking manoeuvres in situations that required an evasive manoeuvre in three different traffic densities (no traffic, 10 vehicles per km and 20 vehicles per km), with some participants also completing a concurrent auditory 20-Question task (TQT). Increasing traffic lead to more longitudinal accelerations, lateral accelerations and poorer takeover performance leading to more critical situations leading to potential collisions. Traffic density was significantly more predictive of driving impairments than the TQT, which had only minor effects on driving performance. This study demonstrates that there are cases where higher traffic density can affect driving performance to a more significant degree than engaging in a secondary task.

Drivers are faced with greater uncertainty, higher risks and higher physical and cognitive demands as traffic density increases. These conditions require the driver to be more alert and take a more active approach in maintaining safe driving behaviours. It appears that traffic affects drivers in two ways, the first is by impairing selective attention through the increased visual clutter associated with increased traffic (Trick, Toxopeus, & Wilson, 2010). The second way that traffic affects driving is through increasing mental workload, that is, as traffic increases, the drivers must be more vigilant in the way they react and adapt to the ever changing road conditions due to constraints on their attentional resources (Edquist et al., 2012).

Roadside scenery

The presence of peripheral visual stimuli, or, roadside scenery in urban environments contributes to the mental workload of the driver, leading to lower roadway perception, higher SDLP and decreased performance on secondary auditory tasks (Kaber, Zhang, Jin, Mosaly, & Garner, 2012; Stinchcombe & Gagnon, 2010). Roadside scenery like buildings, landmarks, billboards and intersections contribute to increase mental load. A higher density of roadside
scenery make drivers less likely to execute full roadside scans and anticipatory glances, decreasing the likelihood of identifying potential hazards, increasing the risk of collision (Biondi et al., 2015; Garrison & Williams, 2013). Drivers also tend to slow down when approaching roadside scenery (Bella, 2013; van der Horst & de Ridder, 2007). Furthermore, the relative density of visual cues in driving simulations affects average driving speeds, with a lower density of visual cues leading to overall faster speeds (Kemeny & Panerai, 2003). This effect can be found in the research by Antonson, Mårdh, Wiklund and Blomqvist (2009), who examined the effect that roadside scenery and landscape affected SDLP and average speed. In their study, they included 3 landscapes of differing complexity: an open landscape with trees only far in the background, a varying landscape containing forested areas, farming land, buildings and farm relevant objects, and a densely-forested landscape. It was found that the open landscape had the highest average speed and SDLP while the forested landscape had the lowest average speed and SDLP. The above study suggests that in terms of speed and SDLP, the relative density and not variability of peripheral visual stimuli has the greatest impact of driving performance.

Tian et al. (2013) investigated the relative risk of collision based on traffic density and cumulative driver off-road glances. It was found that very frequent off-road glances had a very minor, yet significant effect on relative risk when traffic density is very low, however, high traffic density increases the risk when off road glances are low. The highest relative risk of collision occurred when both off-road glances and traffic density were both at the highest level. This experiment shows that while high cumulative off-road glances and higher traffic density have low to moderate risk of collision, both factors combined lead to a risk of collision significantly higher than each factor alone. These results support the hypothesis that high traffic
and road complexity each lead to different but consistent kinds of driving impairments, and that the combination of both increases the risk more than each factor in isolation.

**Road curvature**

In Experiment 1 and 2, we included road curvature in the complex environment, though the simple drive only consisted of straight road segments. In general, increased road curvature leads to increased vigilance, but lower average speeds and higher SDLP (Chen et al., 2016; Larue et al., 2011). As curve radius decreases (turn becomes tighter), so does speed variability and SDLP; this effect is even more pronounced when the driver is fatigued (Matthews & Desmond, 2002). They also found that adding curved segments to roadways significantly decreased the proportion of micro-sleeps that the driver experienced. Due to constraints in our potential sample size, we kept road curvature identical for all drives so that we were able to look at roadside scenery and traffic density without any potentially confounding variables affecting the results, as including differences in road geometry would require a significantly higher number of participants which we did not have access to.

These issues were addressed in Experiment 3 where we programmed realistic road environments that varied in terms of roadside scenery (Urban and Rural), in terms traffic density (no traffic, moderate traffic) and in terms of hazard type (pedestrian, vehicle). This allowed us to understand which aspects of road complexity lead to our observed effects in the first two experiments. Experiment 3 followed the same general procedure as Experiment 2, though we did not include OSPAN data into our analyses because of our focus on the environmental factors as including a distinction between OSPAN scores would lead to too many groups to run an analysis of sufficient power. We also added a 10-item questionnaire used to assess comprehension in the audiobook condition in order to prompt each participant to pay attention to the audiobook and to
see if there were any differences between conditions. Each participant simply drove, drove while listening to an audiobook, and drove while engaging in a handsfree conversation. Participants drove in either the urban-no traffic, urban-traffic, rural-no traffic, or, rural-traffic road environments due to time constrains. We also decided to run two separate analyses, one for pedestrian hazards and one for vehicle hazards. This was done with the intention of replicating our effects on both hazard types.

Predictions

Consistent with our predictions and results from the first two experiments, we predicted that audiobooks will be beneficial in environments that are most likely to produce cognitive underload, and they would have an interference effect in environments that contribute to a high mental workload. We also expect the handsfree condition to lead to poorer driving performance than audiobooks due to the higher mental workload associated with conversations. Traffic has been found to contribute more to individual mental workload than roadside scenery due to the higher attentional demands associated with paying attention to and responding to different traffic conditions (Shakouri et al., 2014; Teh et al., 2014). Therefore, we predicted an interaction effect; listening audiobooks will lead to lower HRTs in the no traffic and higher HRTs in the moderate traffic condition. Consistent with our previous predictions, we hypothesized that the low traffic condition will have significantly lower HRTs compared to moderate traffic because higher traffic is more likely recruit more attentional resources, and therefore contribute more to mental workload. In regards to road environment, we predicted that roadside scenery will affect HRTs to a lower degree than traffic density; since roadside scenery has been found to primarily affect average speed, we expected the rural environment to lead to higher average speeds than the urban environment. This is consistent with the literature where a lower density of visual cues,
specifically buildings and trees, have been found to lead to overall faster average speeds (Antonson et al., 2009; Kemeny & Panerai, 2003). Furthermore, we predicted that, just like in our previous experiments, the audiobook condition will lead to higher SDLP compared to the single task and handsfree condition because of the overall arousing nature of listening to an exciting segment of a story/audiobook (Trick, Brandigampola, & Enns, 2012). In regards to our self-report measures, we predicted the same trend of results as the previous studies.

Method

Design

Our study was a 2x2x3 mixed factorial design with: traffic (no traffic, moderate traffic) x environment (urban, rural) x task load (single task, hands-free, audiobook). Traffic and environment were the between subjects variables and task load was the within subjects variable. The dependent variables of interest were as follows: HRT, speed, SD of speed, SDLP, and the self-report measures. For our analyses, we conducted a series of 2x3 ANOVAs in order to keep the sizes of our groups sufficiently large to ensure enough power for our analyses. Individuals were randomly assigned to either the Urban or Rural environment, and the Traffic or no Traffic condition prior to entering the lab based on the order by which they scheduled their experiment times (switching between environment every 12 participants, and traffic density every 6 participants).

Participants

Participants were University of Guelph students recruited from the participant pool. All students were enrolled in an undergraduate Psychology course. We tested a total of 31
participants (age: $M = 18.72$, $SD = 1.13$: male = 13) with normal to corrected to normal vision. 15 of the participants had at least their G2 driver’s license, which allows the individual to operate a vehicle without supervision in Ontario, the rest had a G license. Power analysis conducted in G Power 3.0 revealed that we needed a minimum sample size of 72 to find our interaction between task load and our environmental variables. This sample size was calculated using the effect size .12 from the interaction between road complexity and task load from Experiment 2 with a power of .95 and a correlation amongst measures of .86. However, a separate power analysis was conducted using the effect size of .20 for the effect of road complexity with a power of .95 and a correlation amongst measures of .86 revealed that a minimum sample size of 28 was needed to find an effect for the environmental variables. 4 participants could not complete the study because they were feeling ill during the experiment, therefore, results were included for 27 participants. Intake statistics can be found on Table 3.

**Materials**

The same questionnaires were used as in Experiment 1: SAS (Appendix A), Intake questionnaire (Appendix B), Post-Drive Questionnaire (Appendix C). A 10-item comprehension test for the audiobook was added (Appendix D). Statistics regarding comprehension scores can be found in Table 3.

Prior to each drive, participants went on a unique 3-minute drive through a semi urban environment that allowed them to practice accelerating, turning, and responding to hazards. This practice drive was useful since out of the 31 participants who drove through the practice drive, only 4 managed to stop completely for the pedestrian hazard without a collision. Although we would prefer to have participants drive until they successfully stopped for a hazard, we ended to practice drive after the first hazard because of time constraints.
We designed four 32km long driving environment that consisted of four 1.5km curves between every 4km and 7 km interval. Each 4km interval had 3 intersections placed every 1km. In the urban environment (see Figure 20), these sections consisted of suburbs, shopping centers, downtown areas and government buildings. These sections simulated low density rural areas in the rural environments, which were primarily made up of farms, houses and churches (see Figure 21). After each 4km straight stretch and 1.5km curve we included a 7 km section containing 7 intersections; 4 of them being placed 1 km from each intersection, while the 3 center intersections were placed only 500m away from each other. These longer sections simulated small town centers with town halls and churches in the rural drive and dynamic high rise city centers reminiscent of Toronto and New York city in the urban drive. The curved sections were mostly empty of any roadside scenery in the rural drive, but were made up of a university campus, Canadian parliament buildings and shopping centers in the urban drive. We intentionally made the track longer than necessary as this allowed for less overlap between the different driving conditions. For example, participants started at the western most part of the track on the single task drive and drove 27km east, while participants in the hands-free condition started at the eastern most point of the track and drove 27km west. The direction which participants drove was changed between drives in order to prevent participants from becoming overly familiar with the driving environments. For the audiobook condition participants started 5km west of the eastern most part of the track and drove until the eastern end of the track. Therefore, when participants drove in the control condition and the audiobook condition, there was some overlap between the two drives, though extra care was taken to make sure that common part of the two drives was not identical by placing trees and buildings in slightly different places.
Each drive was programmed to have either no traffic, or moderate traffic (12 vehicles per km). Five vehicle and five pedestrian hazards were placed 2m away from the edge of the road and were occluded by the roadside scenery. In each drive, 8 of the hazards were placed on straight segments of the road while 2 of them were placed on a curved section of the road. It took each participant an average of 18.5 minutes to complete each drive. Although the exact number are hard to calculate, there were over 25-50 times more building groups in the urban road condition compared to the rural road. Every participant went on a 3-minute practice drive designed from the road environments from Experiment 1 and 2 prior to the experimental drives. This gave the participants an opportunity to learn how to operate the vehicle and respond to a pedestrian. Hazards were counter-balanced so that there were a total of 15 hazards emerging from the left and 15 emerging from the right over the three drives. Participants were instructed to keep their speed at 90 km/h; if participants were driving more than 30km over the limit, the researcher gave a prompt to slow down, since higher speed cause less precise HRT measurements; however, this only occurred 4 times. Conditions were counter-balanced to make sure that all the condition orders are tested. For the audiobook condition, participants were required to listen to an excerpt from the audiobook “Harry Potter and the Deathly Hallows” to keep the multitasking conditions consistent among experiments. We administered a short 10 question multiple choice quiz following the audiobook condition to ensure that the participants were paying attention to the story.

Procedure

Participants followed the same procedure as in Experiment 2. The experiment lasted a maximum time of 2 hours, though most of the participants finished in under an hour and 45 minutes. Participants were reminded 5 times throughout the pre-drive procedure about the
importance to avoid one word answers when driving in the hands-free condition. These repetitions lead to significantly more elaborate responses in the handsfree condition than we had in the previous two studies.

**Results**

We examined the effects of the between subjects variables road environment (urban, rural), traffic density (no traffic, moderate traffic) and the within subjects variable task load (single task, handsfree conversation, audiobook) on dependent variables. However, given that we were only able to analyze data for a sample of 27, we used the following strategy to ensure we could maximize group sizes to try to achieve as much reliability as we could. We did a preliminary scan of the data to find promising effects, and if there were none we collapsed across that variable. A preliminary scan revealed no significant effects or interactions involving the road environment factor in terms of hazard response times or SDLP ($p > .05$ for all), and consequently we collapsed across the road environment conditions to get a 2 x 3 analysis (task load was always a factor). Similarly, Traffic Density did not enter into any significant main effects or interactions when it came to driving speed, so we collapsed across and low and high density conditions in that analysis. Analyses were conducted using SPSS statistical software. Geisser-Greenhouse corrections to the degrees of freedom were used against potential violations of the sphericity assumption. Bonferroni tests were used for post-hoc comparisons between means.

*Hazard reaction time: Road environment and traffic density*

We calculated HRTs using data taken from the simulator by subtracting the time when each hazard was activated from the first instance when brake pressure was first applied. This was done for every hazard. For each participant and in each condition, any data point more than
2.5 standard deviations away from the mean was dropped from analysis. This resulted in the loss of 1.1% of the data. Means were then calculated for each participant in each condition. We then conducted 2 separate analyses on the HRT data, one for vehicle hazards and one for pedestrian hazards with task load (single task, handsfree conversation, audiobook) and traffic density (no traffic, moderate traffic) as factors.

The predicted main effect of task load emerged for vehicle hazards, $F(1.71, 42.69) = 4.81, p < .05$, partial $\eta^2 = .16$ (see Figure 22). Pairwise comparisons of means indicated that, in the audiobook condition, HRTs were lower than in the control condition ($p < .05$) but contrary to prediction the difference between the hands-free and audio conditions did not achieve statistical significance. Traffic density also had a significant effect $F(1,25) = 16.89, p < .001$, partial $\eta^2 = .40$, with lower HRTs in the no traffic conditions compared to the moderate traffic condition, but contrary to prediction, there was no Task Load X Density interaction, whereby the effects of the audiobook secondary task was beneficial in low traffic density and not in high ($F(1,25) = 1.47, p = 0.24$).

There was a main effect of task load: $F(1.76, 43.97) = 4.82, p < .05$, partial $\eta^2 = .16$ (see Figure 23). As with the vehicle hazards, there was also a significant main effect of traffic density on HRTs ($F(1,25) = 13.42, p < .001$, partial $\eta^2 = .35$), indicating that participants reacted to pedestrian hazards significantly faster in the no traffic condition compared to the moderate traffic condition. However, although we predicted that the audiobooks would be most beneficial in the low traffic density condition, the predicted Task Load x Density interaction did not achieve statistical significance ($F(1.76, 43.97) = 3.01, p = .066$, partial $\eta^2 = .11$). Moreover, tests of means indicated that the audiobook produced significantly worse performance than the control
condition (p < .05), with hazard RT almost identical to than in the Hands-free condition (p = 1.0). Thus, when it comes to pedestrian hazards, all secondary tasks lead to higher HRT.

We conducted a post-hoc analysis of the effect of hazard type on task load because of the drastically different trends in results. There was a main effect of hazard type $F(1, 44.78) = 169.820$, $p < .001$, partial $\eta^2 = .867$, and a significant interaction between hazard type and task load $F(1.72, 44.78) = 12.94$ $p < .001$, partial $\eta^2 = .33$, (in Figure 24).

**Speed and SD of speed**

For driving speed and speed deviation, we found that traffic density had no significant effects and did not enter into any significant interactions (p > .1), and consequently, we collapsed across density and looked at the effects of road environment instead (rural, urban). Road complexity had a robust effects on speed ($F(1,25) = 11.29$, $p < .055$, partial $\eta^2 = .31$, with faster speeds associated with rural environments which is consistent with our previous experiments (see Figure 25). We also found a main effect of task load ($F(1.75, 40.23) = 11.18$, $p < .001$, partial $\eta^2 = .33$), post-hoc comparisons of means revealed the Hands-free condition to be significantly faster than the other two (p < .05 for both). There was also a marginal effect of task-load on SD of speed ($F(1.76, 43.97) = 2.97$, $p = .068$, partial $\eta^2 = .11$), but the tests of means revealed that no significant differences between the single task ($M = 2.20, SE = .36$), the audiobook ($M = 2.07, SE = .22$) and the handsfree condition ($M = 2.92, SE = .42$).

**SDLP**

As with HRT, SDLP was measured as a function of task load and traffic density as there was no main effect of road complexity $F(1,25) = .04$, ns. There was a main effect of task load on SDLP, $F(1.62,40.56) = 6.64$, $p < .01$, partial $\eta^2 = .21$, which was consistent with our predictions
(see Figure 26). Post-hoc tests indicated that SDLP was significantly higher in the audiobook condition, compared to the control condition ($p < .05$) and marginally more than the hands-free condition ($p = .054$). Traffic density had no effect on SDLP.

**Self-report measures**

There were no effects for traffic and road environment on any of the 4 questions of the self-report, therefore we collapsed across those variables (see Figure 27). There was a main effect of task load on how much the distraction affected the participants’ driving performance $F(1.88,50.85) = 4.96, p < .05$, partial $\eta^2 = .21$. Post-hoc comparisons of means revealed that, consistent with our predictions, handsfree conversations distracted the participants significantly more than the audiobook and single task condition. There was main effect of task load for how challenging the drives were $F(1.72,46.48) = 12.35, p < .001$, partial $\eta^2 = .31$, which suggests that participants found both the audiobook and handsfree condition more challenging than the single task. There was a main effect of task load on how good participants felt their performance was on each of the drives were $F(1.86,50.31) = 15.57, p < .001$, partial $\eta^2 = .37$ with participants feeling significantly better for the single task, followed by the audiobook condition, and the handsfree condition, all differences were significant. There was a main effect of task load on how difficult it was to focus on the drive $F(1.83,49.50) = 15.38, p < .001$, partial $\eta^2 = .36$ with the single task being the least difficult and the hands-free condition being the most difficult. These results are consistent with our predictions.

**Discussion**

This study was designed to replicate the findings of our previous studies using a stronger experimental design. We added more realistic and diverse driving environments, two analyses of HRTs, longer stretches of road to gather dependant variables from and an increase in prompts to
make sure that the participants engaged fully in the secondary tasks while driving. These improvements have allowed us to address many of the weaknesses of the previous studies while also replicating some of the effects from the previous studies.

In our first two experiments, we investigated whether listening to audiobooks can be used to combat mental underload in simple road environments. We found significant interactions between task load and road complexity in both experiments, where audiobooks lead to lower HRTs compared to the single task and the handsfree condition in simple environments, but slower, or no difference in HRTs compared to both the single task and handsfree conditions in the complex road environment. In Experiment 3, we ran two separate analyses, one for pedestrian hazards and one for vehicle hazards. Both analyses revealed a main effect of task load, though not in the ways that we expected. As predicted, listening to audiobooks led to lower HRTs than the single task when reacting to vehicles, though unlike our predictions, there were no significant differences between the handsfree condition and our audiobook condition. Contrarily, both audiobook and the handsfree conversation lead to similar decrements in HRT compared to the single task when reacting to pedestrians. Therefore, audiobooks only had a positive effect on driving performance when reacting to vehicle hazards and a negative effect when responding to pedestrians. In addition to this, we failed to find an interaction between traffic density and task load for either vehicles or pedestrians. Specifically, the predicted effect of audiobooks leading to lower HRTs in the no traffic conditions and audiobooks causing interference in the moderate traffic condition. In the following paragraphs, there is a discussion on the different trends in HRT data for vehicles and pedestrians on the task load conditions. Finally, we will discuss the effects of traffic density and road environment on our dependant variables.
We did not find our predicted interaction between traffic density and task load, instead we found two different trends in results pertaining to the type of hazard encountered. This was an unexpected result; we intended our two analyses of HRTs to act as a replication factor. We were not surprised that there was a difference in HRTs between the vehicles and pedestrians. Vehicles are much more conspicuous than are pedestrians and vehicular collisions are much more likely cause the driver injury. Therefore, participants would be expected to have lower HRTs for vehicle hazards. What we didn’t expect, however, is that the secondary task conditions had opposite trends in terms of HRT data for the two hazard types and these results cannot be explained solely in terms of perceptual conspicuity. We interpret this effect to suggest that participants must have been “ready” to react to the vehicle hazards, and perhaps, less ready to react to the pedestrian hazards. The participants seemed to have increased their attentional resources in response to these environmental cues when engaging in the secondary tasks. In our driving environments, vehicle hazards only occurred on 5 of the 25 intersections. Pedestrian hazards on the other hands were scattered throughout the drive and hid behind buildings, which depending on the road environment, included several hundreds of potential hiding spots. Examination of the in-car recordings of participants’ drives revealed that participants took their foot off of the accelerator when approaching the intersections. This is further evidence that participants may have responded to the intersections and prepared for a potential vehicle hazards.

Participants drove about 60 minutes in total throughout the experiment, and these longs drives on relatively familiar terrain may have contributed to mental underload in both road environments. Therefore, it is possible that the secondary tasks may have led to overall higher arousal, which in response to potentially dangerous cues like intersections, allowed for a better utilization of attentional resources. In the case of pedestrian hazards, participants reacted fastest
when simply driving, with both secondary tasks leading to higher HRTs. This is likely because it was impossible to predict when a pedestrian would appear and even when they did appear, they were much smaller and less conspicuous than the vehicle hazards. It may have been difficult for participants to quickly reallocate their attentional resources from the secondary tasks to the sudden appearance pedestrians, leading to an interference effect. In the single task, there were no cognitive distractions to compete with pedestrian hazard leading to lower HRTs compared to the secondary tasks.

We replicated the effect of the audiobook condition leading to the highest SDLP in all three of our experiments. This is a difficult trend to interpret because of the inherent similarities between the audiobook and the handsfree condition. In both cases, participants drove while paying attention to a voice speaking through the speakers. The elaborate and often enthusiastic answers for the handsfree condition and the satisfactory comprehension scores on the audiobook condition contend that the participants were in fact paying attention to both secondary tasks. It is also interesting to note that despite the significant differences between the single task and handsfree task, both conditions yielded the same measures of SDLP. We replicated the observed trade-off between lower HRTs (with vehicle hazards) and higher SDLP in the audiobook condition as we did with the last two experiments. We proposed a potential explanation of these effects in Experiment 2 relating to different cortical activation between the two tasks, however, this interpretation would be difficult to verify using the data collected (Nummenmaa et al., 2014). Instead, a more likely explanation may be that the audiobook condition led to higher arousal because of the exciting and engaging nature of the story being told. Increased arousal has been found to lead to more body movements and fidgeting, and this can be seen in tasks across various modalities including, but not limited to, watching movies, listening to music, and playing video
games (Bianchi-Berthouze, Kim, & Patel, 2007). Unlike our last experiment, Experiment 3 did not show interaction between complexity and task load. This however, may be a result of the added comprehension questionnaire in Experiment 3, which likely motivated participants to pay closer attention to the story across all conditions. It is possible that participants were less likely to pay attention in our previous complex environments, making it less likely that they would experience this arousal effect.

We answered one of the primary questions that in many ways drove the design of this final study: which of the variables used to manipulate road complexity contributes observed effect of road complexity on HRTs in the previous two studies? Our data gives a very clear answer: traffic density. Despite the vastly more complex and realistic roadside scenery in both the rural and urban road environment, traffic density was the primary variable affecting hazard reactions time across all participants. This is consistent with much of the literature which consistently shows that increases in traffic lead to lower situational awareness (Heenan et al., 2014), increased attentional demands (Teh et al., 2014), higher HRTs (Edquist et al., 2012), and poorer multitasking (Stavrinos et al., 2013). As traffic increases, so does the number of objects the driver can collide with. Furthermore, higher traffic density leads to more potential objects that can compete with the hazards for attentional resources. Therefore, our observed effect of the moderate traffic density condition leading to higher HRTs compared to the no traffic condition is to be expected.

Road environment had no effect on HRTs and this goes against our predictions. We expected that at least some of the variance in HRTs in our first two experiments would be due to roadside scenery. The most likely reason for this is that we may have experienced a floor effect in terms of density of roadside scenery on HRTs in Experiment 3. Our intention was for the rural
environment to contribute more to underload than the urban environment. However, our rural environment was still significantly more complex than our simple environment from the first two experiments. Furthermore, considering the increase in the variability of roadside scenery in the rural environment, it is possible that the rural environment was more similar to our complex environment than the simple environment. This, along with the relatively low number of participants, may partially explain why we didn’t find an interaction between task load and any of the environmental variables; our intended underloading conditions were not simple enough to replicate the effects from the previous studies.

Despite this, we still replicated our main effect of road environment on average speed. We used much longer stretches of road in our analysis of speed, SDLP and deviation of speed in this experiment compared to the first two experiments, leading to more precise measurements and larger effect sizes. Road complexity was the primary environmental variable impacting average speed, contributing to most of the variance in average speed in Experiment 3. Participants drove significantly faster in the rural environment compared to the urban environment despite no differences in the placement of speed limit signs or any other instructions. These differences in speed likely emerge from a combination of the perception of the relative differences in the density of roadside scenery between the two environments and a potential carry over of real-world driving habits into the driving simulator. It has been found that individuals drive faster in driving simulators when there are fewer visual cues and a lack of haptic feedback, and this has been found across all of our experiments (Kemeny & Panerai, 2003). The significantly greater density of roadside scenery in our urban environment likely contributed to this effect. Another interpretation is that people tend to drive faster when they are driving on rural roads as they often have a posted speed limit of 80 or 90km/h while most urban
roads have a posted speed limit of 50-70km/h. Furthermore, urban environments contain many more potential hazards and unexpected events due to their sheer size and population density and participants likely compensated for these factors by reducing their speed to increase safety. Therefore it is possible that their speed was at least somewhat influenced by real word driving habits as well as in response to the lower density of visual cues in terms of peripheral visual stimuli. Another factor that may have driven these results is that participants could have driven slower in the urban environment because they slowed down to admire the roadside scenery, particularly in the downtown centers. This phenomenon was observed in both urban and rural environments; participants had a tendency of driving faster in the areas of low roadside scenery and slower in city/town centers or both roadside environments. Regardless of interpretation, the results of all 3 experiments demonstrate that as the density of roadside scenery increases, speeds tend to decrease.

In addition to the main effect of roadside scenery on speed, there was also a main effect of task load on average speed. Most of this was attributed to the handsfree condition, which was the variable responsible for the greatest proportion of variance in Experiment 3. The handsfree condition was the most engaging secondary tasks, as participants had to listen to the questions, think of an answer and then respond. Audiobooks while also engaging, only require the participant to passively listen. Participants had a tendency of directing their answers to me (the simulator technician) working in the control room since they recognized my voice. Many noted they felt awkward simply talking and not directing their answers to anyone. This behaviour means that they spent less time focusing on the speedometer compared to the other two conditions. It is also important to note that the simulator lacks haptic feedback, which means that participants could only rely on auditory feedback and the speedometer to keep their speed at the
required speed limit. This was especially true when the participants became engaged in the conversation; they had a tendency of accelerating while they were speaking, and slowing down while the question was being asked. However, it is difficult to generalize this finding to real-world driving behaviours since drivers rely on many sources of feedback in regulating speed.

The results of our Post-Drive questionnaire yielded the predicted results. In the case of how challenging the task was, the two secondary tasks yielded higher scores than the single tasks with the audiobook or the handsfree condition being the more challenging, though the two secondary tasks were not significantly different. Self-reports on difficulty followed the same trend as the above reports on the challenge of the tasks. The handsfree condition interfered most with participants’ focus, though not significantly more than the audiobook. In terms of performance, participants felt that their performance was best in the single task, followed by the audiobook and then the handsfree condition. In this case, there were significant differences between all the conditions. This demonstrates differences in how participants feel the secondary tasks affect their driving performance; it seems that the handsfree condition distracted participants from their driving performance the most, followed by the audiobook. This is consistent with the observation that the handsfree conversation task is the more engaging of the two secondary tasks and at least subjectively, affects the participant’s performance to the most significant degree. Lastly, when it comes to the level of distraction, the handsfree conversation is said to be the most distracting, followed by the audiobook, which is only marginally significant at $p = .052$. These analyses demonstrate that self-reports can differ significantly from the behavioural measures, and shows the weaknesses of utilizing self-report measures as the focus of simulated driving experiments.
All the self-report measures demonstrated that individuals felt that engaging in secondary tasks hurt their performance, increased distraction, increased the challenge of the drive and made them unconfident with their driving performance. The actual behavioural measures yielded much more varied results; this becomes especially apparent when controlling for road environment, traffic density and hazard type. Overall, participants felt that their driving performance was negatively impacted when they engaged in secondary tasks; although secondary tasks lead to lower HRTs when reacting to vehicles. The self-report measures also didn’t differentiate the difference in difficulty between the traffic condition and the road environment condition. This may be an artifact of the study since participants only drove in a road of one of the two road environments with either moderate traffic or no traffic. It is also possible that these higher levels of perceived difficulty caused the participants to be more vigilant, which may have contributed to the lower HRTs for vehicles across all conditions in Experiment 3.
General discussion

In this research, we intended to answer 3 specific questions: 1) can audiobooks be used to improve driving performance? Under what circumstances are they useful? and 3) who are they useful for? My three experiments provided answers to these questions. In regards to the first question, it was found that, listening to audiobooks can improve driving performance compared to simply driving, but only in certain environments and only on certain aspects of driving performance. Audiobooks had the greatest effect on hazard reaction time though this came at the expense of higher SDLP. Furthermore, audiobooks were only found to be useful in simple road environments. Based on our theoretical framework, we predicted that audiobooks would only be beneficial in an environment can induce mental underload. As a result, we created a simple road environment with this in mind. Based on MART, it has been shown than mental underload leads to reductions in attentional resources. It was predicted that adding a moderately stimulating cognitive distraction like an audiobook to the simple road environment would increase arousal and mental workload, therefore increasing their attentional resources without producing overload. Handsfree conversations on the other hand, were predicted to be more likely to produce cognitive overload and cause an interference effect, leading to higher HRTs compared to the single task condition in the simple environment.

However, there are situations where audiobooks led to poorer driving performance. We found that listening to audiobooks in the complex drive lead to higher HRTs compared to the single task in the first experiment, and we found no differences in HRTs amongst the 3 task load conditions in the second experiment. We addressed the negative effect of audiobooks in complex road environments in our predictions. Although audiobooks may be beneficial in environments that may produce underload, they should cause more interference in environments that contribute
more to the mental workload, leading to mental overload. We found support for this in our first experiment. As for our second experiment, it is possible that we were unable to replicate the effect due to a general lack of engagement in our secondary tasks since we had no objective measure of audiobook comprehension during this time. Nonetheless, our results demonstrate that the benefits of listening to audiobooks seem to occur only when the road environment reliably produces mental underload, and that audiobooks begin to interfere with driving once the attentional demands of the environment are greater.

Furthermore, we found that the benefits of listening to audiobooks only occur in certain kinds of people, specifically, those with higher levels of executive functioning as measured by the OSPAN task. There are many studies demonstrating superior multitasking abilities in individuals with high OSPAN scores (Biondi et al., 2015; Watson & Strayer, 2010). These individuals can perform two tasks concurrently without experiencing a significant interference effect due to their task switching abilities. We found support for this is our experiments. In Experiment 1, individuals in the high OSPAN group had lower HRTs in the audiobook condition compared the single task while those in the low OSPAN group had lower HRTs in the single task compared to the audiobook. We were unable to replicate this effect in Experiment 2. This is likely because our low OSPAN group had a significantly higher mean OSPAN score than the low OSPAN group in Experiment 1. Nonetheless, we found that high OSPAN individuals had their lowest HRTs in the audiobook condition, though higher HRTs in the handsfree condition in experiment 2. This may be because high OSPAN scorers may experience underload when simply driving in simulated environments, and can use a moderate cognitive distraction to optimize their attentional resources. Low OSPAN individuals on the other hand may experience overload when
engaging in any kind of moderate cognitive distraction, leading to optimal performance when simply driving.

In Experiment 3, we encountered a number of unexpected results. We failed to find our predicted interaction between task load and traffic density. Traffic density was identified as the variable that drove the differences in HRT between our simple and complex environments. Roadside scenery was expected to influence HRTs, though this was not the case. It is possible that this is a result of the way we programmed the new environments. In the first two experiments, we succeeded at creating simple road environment that produced mental underload, and complex road environments that contribute to a higher mental workload. In Experiment 3, our focus was on creating more realistic environments in terms of roadside scenery. Although we succeeded at creating realistic environments due to our inclusion of high resolution building models, it is possible that we observed a ceiling effect in terms of the influence that roadside scenery has on HRTs. The rural environment was still rather complex, and the added roadside scenery in the urban environment may have done little to increase the attentional demands of the drive. Despite environment not playing a role in HRTs, we replicated our previous results in the effect of environment on average speed, with faster speeds in the rural environment. This effect was likely driven by the lower density of roadside scenery in the rural environment, which leads to slower average speeds in driving simulators.

The most notable effect from Experiment 3 was that the main effect of task load changed direction when comparing pedestrian hazards to vehicle hazards. This was an unexpected result as we intended both hazard types to follow the same trend. This is despite vehicle hazards leading to lower HRTs than pedestrians, likely due to being larger and more perceptually conspicuous. Instead, it was found that increasing the mental workload though engaging in
secondary made vehicles HRTs lower than in the single task. This increase in workload however, leads to higher HRTs in response to pedestrian than the single task. This is a surprising effect since it appears that tasks that are advantageous to reacting to vehicles are a disadvantage when responding to pedestrians. This effect most likely has to do with the predictability of the hazards. The vehicles only appeared on 5 of the 25 intersections, while pedestrian hazard appeared throughout the drive and were impossible to predict. It seems that the secondary tasks increased attentional resources, especially in response to environment cues that suggested that a hazard would be likely to occur. Pedestrians were a more cognitively demanding hazard; the lower perceptual conspicuity along with the unpredictability of the hazards likely lead to overload, and there for an interference effect that lead to higher HRTs.

Our understanding of the Yerkes-Dodson Law of arousal and performance (Cohen, 2011) and MART drove many of our predictions regarding road environment and multitasking. In this model, optimal arousal leads to optimal performance, and this relationship varies tremendously between individuals. This model works well with the idea of mental workload (van Merriënboer & Sweller, 2005) where the over utilization of cognitive resources may lead to overall poorer performance. Our research reveals that this model seems sufficient to explain the observations, although, it does seem to have temporal restrictions; performance begins to suffer if the individual maintains “optimal” arousal for too long. This can be seen in the relative drop in HRTs between the predictable vehicle hazards in both environments, the less predictable pedestrian hazards. For this model to be work given our analysis, there needs to temporary increase in arousal only in situations with a relatively high probability of containing a hazard. Environments with a heavy traffic require the driver to be in a heightened state of arousal when traversing the complexities of an environment with heavy and unpredictable traffic; HRTs will
be negatively affected by mental overload in response to hazards. The constant stream of vehicles driving down the left side of the road, randomly turning at intersections would no doubt cause the participants to be in a prolonged state of over-arousal and therefore experience mental overload. This model is supported by our data, where participants reacted on average 150ms slower to all hazards in the presence of moderate traffic compared to no traffic.

It is difficult to make a sweeping generalization regarding the impact of engaging in secondary tasks on driving performance. Experiment 2 revealed no differences between the single task and the handsfree task on HRTs, while Experiment 3 revealed that the single task lead to significantly lower HRTs than both the handsfree and audiobook conditions for pedestrians, but higher HRTs than the audiobook condition for vehicles. Our results are both supportive and contrary to the general consensus on the general impact of cognitive distractions on driving performance (Caird et al., 2014; Lee et al., 2013; Trick et al., 2004). However, most studies tend not to report or differentiate between the type of hazards used, and it is possible that the use of either hazard type would significantly affect the outcome of the results. Therefore, though our results show that audiobooks lead to higher HRTs in simple environments (though less so than simply driving in complex environment), we observed lower HRTs in response to vehicles, and higher HRTs to pedestrians than the single task in our more realistic environments. Nonetheless, it would be useful to run further experiments with a greater variety of hazard types, including both peripheral and central hazards to better understand the effect of engaging in a handsfree conversation in a variety of different environments. In terms of interpreting the data, it is difficult to determine which of the two trends in HRT data should be our primary focus.
Limitations

Although our experiments yielded interesting results regarding how environmental factors influence the degree to which secondary task, specifically listening to audiobooks affect driving performance, our results were somewhat inconsistent across our three experiments. There were many limitations in our methodology that may have contributed to this inconsistency. In all our experiments, we were unable to recruit a large number of participants due to constraints on the participant pool. This lead to smaller than desired sample sizes, especially in Experiment 3, where the smaller number of participants restricted our ability to run a number of analysis due to limits in our observed power.

Furthermore, although fatigue and boredom are especially dangerous when individuals experience mental underload, we did not explicitly measure the degree to which participants experienced fatigue and boredom. It is likely that a questionnaire addressing these factors would have allowed for more careful analysis of the data, including post-hoc comparisons of the degree to which fatigue and boredom affected driving performance in our study. In retrospect, adding these questionnaires would have contributed much to our experiments without significantly changing the length and design of our experiments.

There were also limitations regarding the secondary tasks that we used. It would be useful to examine the effect of other kinds of audiobooks, perhaps ones that the participants would be less likely to be familiar with, as this would give us more information on the extent to which familiarity contributed to our effects. Given our analyses, we can only speak to the degree that the chapter of our selected book affected driving performance, it is possible that books on science or philosophy would be more cognitively demanding than a novel, and that the benefit of listening to audiobooks only occurs for novels. Furthermore, our handsfree condition was not
very realistic. Although programing the drive to have questions occur at specific locations in the drives allowed for some degree of control, the fact that participants were often interrupted by following questions took away for the realism of having a real conversation. Participants were unable to guide the conversation, rather they responded to a series of questions with no real naturalistic flow. This lack of realism may have contributed to the inconsistency of the results pertaining to the handsfree condition. In the future, it may be useful to see if actually speaking to the participants would yield similar results.

Another limitation is that, although much time was spent making the environments as realistic as possible, they still lacked many features of real driving environments including turns, street lights and dynamic pedestrian traffic amongst others. These factors could have contributed to the mental workload associated with driving through these environments. As it is now, we cannot generalize our results to real driving environments as in addition to the lack of haptic feedback and way finding, the above-mentioned factors are just as much a part of a real driving environment as is roadside scenery and traffic density. In addition to this, a significant flaw in Experiment 3 was that we did not test the effect that road geometry has on driving performance while multitasking. It is possible that road geometry had a significant impact on the results in the first two experiments, and the inability to replicate the key findings in Experiment 3 may be a result of controlling for road geometry between our different road environments. However, including road geometry as one of our environment factors would have increased the number of groups from 4 to 8, and given our small sample size, we would not have the power to run the appropriate analyses.
Concluding remarks

In our first experiment, we learned that multitasking can be good; listening to audiobooks improves hazard reaction time in “simple” rural environments with no traffic, however, this comes at the cost of an increase in SDLP. In Experiment 2 we learned that we can replicate the main finding of our first experiment using a more complex design, we also learned that the benefit of multitasking while driving only pertains to audiobooks; handsfree conversations lead to higher HRTs in simple environments. In experiment 3 we learned that hazard reaction time is primarily driven by the type of hazard encountered, and the level on traffic on the roads. We also learned that, when controlling for road geometry, road environment primarily affected driver speed, especially in the handsfree conversation. Experiment 3 contributed most to our understanding of the theory behind multitasking while driving, especially in the context of optimal arousal and MART theory. It seems that underload can be overcome through multitasking, but also in response to environmental cues like intersections though this is not the case for unpredictable hazards like pedestrians.

My research has many practical applications as well. It is important that we understand the degree of safety associated with multitasking in different environments. Despite the changing of laws regarding the use of portable electronic devices, distracted driving continues to be major safety issue. Our research shows that a nuanced approach is most appropriate when approaching legislation pertaining to the use of secondary tasks while driving. Beyond policy, it is important for drivers to understand the risks involved with engaging in certain kinds of secondary tasks and the environmental factors that either contribute or alleviate these risks of distracted driving. Audiobooks and podcasts are becoming ever more available; cell phones more numerous and commute times continue to rise. People spend a great deal of time in their vehicles and knowing
that there are situations where something like engaging in a handsfree conversation or listening to an audiobook won’t make their driving significantly worse, may alleviate some anxiety and maybe even promote relaxation and decrease HRTs during typically stressful commutes or long boring drives.

The research on this matter is still in its infancy, and there is a great deal more for us to discover. The rapid development of technology such as motion platforms, in-car EEGs and TMS can radically improve our understanding of the interaction between all the variables associated with driving. This line of research will be continued further at the University of Toronto as there are still many unanswered questions from Experiment 3. How does road geometry play a role in this relationship? Is it consistent across times like dawn, evening and night? And would we be able to replicate these results if we placed our participants in an actual dynamic environment where they must navigate complex cities and towns. In all our experiments, participants drove without a clear goal in mind, they simply drove until the simulator technician told them to stop. The goal of reaching a destination is primary variable associated with why people drive. Future research must take this into consideration and test these variables in an environment with a clearly defined goal or target. It is possible that our results would turn out very differently with this extra added dimension of complexity.


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Figure 1. The Yerkes/Dodson curve of arousal and performance
**Figure 2.** Example of a trial in the OSPAN task

**Figure 3.** Photograph of OKAL’s hi fidelity driving simulator in a Pontiac G4 body
Figure 4. Differences between the simple and complex road environment from various angles and segments from each drive.
Figure 5. Example of a pedestrian hazard from the view of the driver.

Figure 6. Example of a vehicle hazard from the view of the driver.
Figure 7. Effect of task load on HRTs for simple and complex road environments. Error bars are ± 1 SE. Listening to audiobooks lead to lower HRTs compared to the single task in the simple road environment but not in the complex road environment.

Figure 8. Effect of OSPAN group on HRTs for simple and complex road environments. Error bars are ± 1 SE. A significant interaction shows that multitasking leads to lower HRT for HighOSPAN participants but not for LowOSPAN participants.
Figure 9. Effect of task load on speed for simple and complex road environments. Error bars are ± 1 SE. A significant interaction shows that individuals drove slower in the simple road environment when listening to an audiobook compared to the single task.

Figure 10. Effect of task load on SDLP for simple and complex road environments. Error bars are ± 1 SE. A significant interaction shows higher SDLP in the single task compared to the audiobook in the simple road environment.
**Figure 11.** Effect of task load on self-reported distraction in simple and complex road environments. Error bars are ± 1 SE. There was no difference between the tasks in the simple environment, conversely, audiobooks were significantly more distracting than the single task in the complex environment.

**Figure 12.** Effect of task load on self-reported challenge of drive in simple and complex road environments. Error bars are ± 1 SE. Audiobooks lead to a more challenging drive in both conditions.
Figure 13. Effect of task load on self-reported performance in simple and complex road environments. Error bars are ± 1 SE. Audiobooks lead to a poorer perceived performance in both conditions.

Figure 14. Effect of task load on self-reported difficulty of drive in simple and complex road environments. Error bars are ± 1 SE. No significant effects emerged.
Figure 15. Effect of task load on HRTs for simple and complex road environments. Error bars are ± 1 SE. Listening to audiobooks lead to lower HRTs compared to the single task in the simple road environment but not in the complex road environment.

Figure 16. Effect of task load on speed for simple and complex road environments. Error bars are ± 1 SE. Simple main effects reveals a main effect of task load, road complexity, and interaction between the two, but only for those with high OSPAN scores.
Figure 17. Effect of task load on speed for simple and complex road environments. Error bars are ± 1 SE. No Significant effects emerged.

Figure 18. Effect of task load on SDLP for simple and complex road environments. Error bars are ± 1 SE. Participants had the highest level of swerving when listening to audiobook in the simple road environment.
Figure 19. Self-report questionnaires for task load. Error bars are ± 1 SE. There was a main effect of task load on every question except difficulty.
Figure 20. Screenshots from various sections of the urban environment.
Figure 21. Screenshots from various sections of the rural environment.
Figure 22. The effect of task load and traffic density on vehicle HRTs. Error bars are ± 1 SE. There is a main effect of task load and traffic density.

Figure 23. The effect of task load and traffic density on pedestrian HRTs. Error bars are ± 1 SE. There is a main effect of task load and traffic density.
**Figure 24.** The effect of task load and hazard type on HRTs. Error bars are ± 1 SE. Secondary tasks lead to lower HRTs for vehicles but higher HRTs for pedestrians.

**Figure 25.** The effect of task load and road environment on speed. Error bars are ± 1 SE. Participants drove faster in the rural environment, especially in the handsfree condition.
Figure 26. The effect of task load and road environment on SDLP. Error bars are $\pm 1 \ SE$. Participants had higher SDLP in the audiobook condition across both environments.

Figure 27. Self-report questionnaires for task load. Error bars are $\pm 1 \ SE$. There was a main effect of task load on every question.
Table 1

*Participant Intake Questionnaire Statistics*

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Appendix A.

Pre-Experiment Manual of procedures and screening questionnaire for SAS

Simulator Adaptation Syndrome (SAS): Lab Procedures

MANUAL (For researchers).

Whenever people are exposed to simulated environments, there is a chance that simulator sickness may occur. Also known as simulator adaptation syndrome, it is characterized by a range of complaints and discomfort, such as:

- Visuomotor dysfunction (eye strain, blurred vision, difficulty in focusing),
- Mental disorientation (difficulty in concentrating, confusion, apathy)
- Nausea including vomiting
- Drowsiness, fatigue, eye strain, headache
- Sweating, extreme pallor (palloriness)

In order to increase our understanding of this phenomenon, and to reduce the occurrence, it is necessary that the following procedures be followed.

Before The Testing Session

1. When the potential participant is contacted about the study, it is necessary that they are aware of the risks involved before agreeing to take part. Therefore, each person needs to provide informed consent that he/she is willing to participate in the simulation, before coming in for the study.

2. Certain factors can predict the likelihood that an individual will experience simulator sickness. In order to assess whether the potential participant is at particular risk, the SAQ must be administered. This questionnaire asks about driving related history, as well as general and specific factors associated with simulator sickness. Let them know if something on their questionnaire indicates they may be at a slightly higher risk, and let them choose for themselves if they would like to participate. This should be done at least 24 hours before the participant is scheduled to use the simulator. SEE APPENDIX A FOR A COPY OF THE QUESTIONNAIRE.

3. The day before a participant is scheduled to use the simulator, it is necessary to call him/her. Not only do we want to remind them of their appointment, but we also need to assess their current
well-being. In order to participate in a simulation, an individual must be in their regular state of health.

- If a participant is experiencing fatigue, an upset stomach, hangover, flu, ear infection, or cold then they should not participate. Tell the participant they can reschedule when they are feeling normal again.
- We need to know what medication the person is taking. The following medications should not be taken if someone is using the driving simulator:
  
  i. Decongestants/ cold medications (e.g. diphenhydramine)
  
  ii. Antihistamines / allergy medications
  
  iii. Some prescription anxiety medications (benzodiazepines, such as Ativan)
- Participants should be encouraged to avoid alcohol, caffeine, drugs, and cigarettes at least the night before the simulation.

**During The Testing Session**

1. When the participant arrives, it is necessary that they give consent again. We also need to confirm what medications they are taking.

2. Administer the SSQ (to be done both before and after the simulation). This can act as a baseline to give you an idea of how much the simulator has affected the participant. SEE APPENDIX B FOR A COPY OF THE QUESTIONNAIRE AND SCORING INFORMATION.

3. Some research has indicated that increased ability at mental rotation decreases likelihood of simulator sickness. In order to find out if mental rotation ability can successfully predict simulator sickness, we will administer a mental rotation test. SEE APPENDIX____

4. Administer the Postural Stability Test (used in Mourant & Thattacherry)
   
   - Instruct the participant to stand on one foot, eyes closed, arms crossed over chest.
   - Time the participant for a maximum of 30 sec.
   - 2 trials – average the 2 times.

**Additional things to do to reduce the chances of simulator sickness:**

- Make sure the room is cool
- Don’t let the participant think they will definitely get sick. Although they should be aware of the risk, they should not feel it is inevitable. Other simulation labs suggest that there is an element of suggestion in simulator sickness. People who expect to feel sick, begin to feel sick. Furthermore, do not allow a participant to see someone else get sick.
- Offer the participant some ginger tea (this settles the stomach) before exposure to the simulator.
- Have some cookies (e.g. ginger snaps – ginger helps the stomach) and crackers for people to snack on if they are feeling uneasy.
- Always have cold water available.
- Make sure the participant is set and ready to begin before turning on the simulator.
- If possible, use low light intensity.
• Take lots of breaks. People will often want to keep going, but you need to ensure that frequent breaks are taken. Some research has shown that symptoms of simulator sickness increase as a function of time spent in the simulator so it is important to have brief periods of exposure.

• Encourage participants to concentrate. Research suggested that when someone is concentrating this can reduce the incidence of simulator sickness.
• If someone is feeling unwell, advise him or her to close his or her eyes or look at the floor.
• Find other tasks for them to do, or prepare short explanations of various perceptual phenomena (e.g. vection) to keep them interested while they rest.
• Check in with the participant every few minutes. Ask them how they are feeling on a scale of 1 to 10 (1 is awful, 10 is great). Keep track of these responses and how they vary as time passes.
• Monitor their faces for any changes (redness, increased swallowing).

Factors associated with the actual simulator that can increase the chances of simulator sickness:

- Bright images
- Wide fields of view
- Motion at 0.2 hz
- CRT systems (rather than dome projection systems).

If a person displays signs of simulator sickness follow this protocol:

• **Mild Symptoms** (uneasiness, flush, increased temperature)
  - Ask the participant how he/she is feeling.
  - Determine if the participant wants to continue.
    - If no, end the scenario immediately.
    - If yes, ask if the participant wants to take a break.
      - If they say no, continue with the simulation when the person is ready.
      - If they say yes, stop the simulation, turn on all the lights in the room, and escort the person to a chair. Make sure they are steady on their feet before getting up. Make sure the person is back to normal before resuming simulation.
      - Indicate to the person that these feelings will soon pass.

• **Medium Symptoms** (uneasiness, flush, increased temperature, dizziness, mild nausea)
  - Ask the participant how he/she is feeling.
  - Determine if the participant wants to continue.
    - If no, end the scenario immediately.
    - If yes, encourage the participant to take a short break. Turn on all the lights in the room, and escort the person to a chair. Make sure they are steady on their feet before getting up. Make sure the person is back to normal before resuming simulation. Resume simulation only if the participant again indicates that they want to continue.
    - Indicate to the person that these feelings will soon pass.
Simulator Adaptation Syndrome Pre-screening Questionnaire (SAQ)

Because it is critical that we are sure that the participant is really understanding the items, it is critical that this we READ this to the participant and have them answer orally rather than in writing. We the experimenters will write down the responses for them.

TO BE READ TO THE PARTICIPANT

This study will require that you drive in a driving simulator. We need to first find out a little about how often you drive in order for us to help understand how you will adapt to the simulator. Some participants have felt uneasy after participating in studies using a simulator. To help identify people who might be prone to this feeling, we would like to ask the following questions.

Specific predictors
1. Do you experience migraine headaches?  Yes  No

2. Do you experience claustrophobia (fear of closed in spaces)?  Yes  No

3. Do you have a history of motion sickness?  Yes  No

If yes, please describe (where: car, boat, train, airplane) and when (recently vs. when a child):
4. Have you ever experienced dizziness or nausea while watching a movie in a wide-screen (e.g. Silver City or Omnimax Theatre)?

   Yes  No

If yes, please describe ________

5. Do you experience dizziness or nausea while reading in a moving car?

   Yes  No

6. Do you prefer to be the driver, compared to the passenger, because otherwise you experience dizziness or nausea?

   Yes  No

Note to Researcher: If a participant answers yes to any of these questions, tell them that they may be at higher risk for problems resulting to simulator exposure. In particular, viewing a computer screen may cause eye-strain and eye-strain triggers migraines for some migraine sufferers; the confined space may be a challenge for claustrophobics; people who have had experiences of dizziness or nausea as a result of motion (especially if these are recent experiences) or viewing wide screen movies may experience similar symptoms in a simulator. However, the motion sickness experienced on a boat is much more typical in the population. We are especially worried about people who get carsick or train sick.

General Medical history questions.

1. Do you have heart problems or have you had a heart attack?  
   Yes  No

2. Do you experience lingering effects from stroke, tumor, or head trauma?

   Yes  No

3. Do you have any inner ear problems (vertigo)?

   Yes  No
4. Do you have diabetes for which insulin is required?  
   Yes  
   No

5. Do you have problems with low blood sugar (hypoglycemia)?  
   Yes  
   No

6. Do you have epileptic seizures?  
   Yes  
   No

7. Are currently taking medications that make you feel extremely nauseated or dizzy?  
   Yes  
   No

   Such as:  
   Decongestants/ cold medications (e.g. diphenhydramine)  
   Antihistamines / allergy medications  
   Prescription anxiety medications (benzodiazepines, such as Ativan)

8. How are you feeling today? __________

Note to researcher: If a participant answers yes to any of these questions, or if the participant indicates that they are sick (in particular, hungover, nauseated) they may be at higher risk for problems resulting to simulator exposure and ask them if they want to continue. If participants answer yes to 2 of these questions, do not permit them to go on into the second phase of the study. If they indicate that they are already nauseated try to reschedule the appointment to a time when they are feeling better.
Appendix B

Subject Code _________
Condition: _________

Intake Questionnaire: Participant characteristics questionnaire

General Questions

1. Gender: Male  Female  Other (please specify) _______

2. How old are you? __________

3. Have you ever been diagnosed with any problems with your eyes or vision?
   Yes / No
   If yes, what type of eye or vision problems? _______________

4. Have you ever been diagnosed with any problems with your ears or hearing?
   Yes / No
   If yes, what type of ear or hearing problems? ____________

5. Have you ever been diagnosed with Attention Deficit Hyperactivity disorder (ADHD)?
   Yes/No

6. If so, are you currently taking any medications for ADHD? Yes/No Which ones_______

7. How are you feeling today? __________

8. How many hours of sleep did you get last night? _______

9. How tired are you feeling right now?
Experience with distraction, Mp3 players

1. When you are studying, do you find it is sometimes easier to concentrate when you study in a busy environment (e.g. a coffee shop, a study hall with other students) than studying by yourself in complete silence?

   1  2  3  4  5  6  7  8  9
   Not at all tired  Extremely tired

2. Do you sometimes feel that having a distraction (something else to do, something else to listen to) makes it easier for you to focus your attention and concentrate when you are performing other activities (activities other than studying)?

   1  2  3  4  5  6  7  8  9
   Not at all  To a great extent

3. Do you have an IPOD or MP3 player to play music?  Yes/No

4. Do you currently use any other portable device to play music? Yes/No

5. If so what do you use to play music? ______________________________

6. How long have you had portable music player?  __________ (years)

7. How many days a week do your portable music player?  __________ (max 7)

8. How many hours a day do you use your portable music player?  _______ (max 24)
9. How often do you use your portable music player while walking?

Never______________
Very Rarely (Once or twice in your life) ______
Occasionally (Several times a year ) ________
Several times a month _________
Every day ____________
Several times a day ____________

10. How often do you use your portable music player while driving?

Never______________
Very Rarely (Once or twice in your life) ______
Occasionally (Several times a year ) ________
Several times a month _________
Every day ____________
Several times a day ____________

**Cell phones, Smart Phones, and Other in-vehicle technologies**

1. Do you own a cell phone or Smart phone for phone calls? Yes/no

2. How long have you been using it or other cell or Smart Phones? ___________ (years)

3. If you have a cell phone or Smart phone, how many days a week do you use it? ___ (max 7)

4. If you have a cell phone or Smart phone, how much time do you spend on it per day? ___ (minutes)

5. How often do you use your cell phone or Smart Phone while walking? (Put an X in front of the appropriate answer).

Never______________
Very Rarely (Once or twice in your life) ______
Occasionally (Several times a year ) ________
Several times a month ________
Every day ____________
Several times a day ____________
6. How often do you use a cell phone or Smart phone to make phone calls while driving?  
(Put an X in front of the appropriate answer).

Never ______________
Very Rarely (Once or twice in your life) ______
Occasionally (Several times a year) ________
Several times a month ________
Every day __________
Several times a day ____________

7. How often do you text while walking?

Never ______________
Very Rarely (Once or twice in your life) ______
Occasionally (Several times a year) ________
Several times a month ________
Every day __________
Several times a day ____________

8. How often do you text while driving?

Never ______________
Very Rarely (Once or twice in your life) ______
Occasionally (Several times a year) ________
Several times a month ________
Every day __________
Several times a day ____________

9. Do you have an in-vehicle system that requires you to type in commands? Yes/No

10. If so, what type of system is it? _______________________

11. Which type of voice control device do you currently own? (Circle all that apply)
    Vehicle / Smartphone / Tablet / Media Player / Other (describe below)

__________________________________________________________________________

Driving Questions

1. At what age did you first start driving? ______
2. At what age did you first get your license? _____

3. What level of driver’s license do you currently have? _____ (G1, G2, G)

4. Do you own a car? _____

5. How many days ago did you last drive? _____ (days)

6. How many days a week do you drive on average? _____ (Maximum = 7)

7. How much time do you spend driving on an average day? _____ (minutes)

8. How far do you drive on an average day? _____ (kilometres)

9. What kind of driving do you do most often? Urban _____ Rural _____ Highway _____

10. Have you ever been in an accident when you were a passenger? Yes / No
    If so, how many? _____

11. Have you ever been in an accident, when you were a driver? Yes / No
    If so, how many? _____

12. Have you ever had a speeding ticket? Yes / No
    No
    If so, how many? _____

13. Have you been charged with reckless driving? Yes / No
    No
    If so, how many times? ________

14. Have you ever been charged for distracted driving? Yes/No
    If so, how many times? _________________

15. Have you ever had any other tickets when driving? Yes/No
    If so, what kind________________________________

16. Do you currently have some sort of Driver Assistance system in your car? Yes/No
    *(Driver assistance includes Adaptive Cruise Control, Collision avoidance systems, etc.)

17. If so, what type of system do you have?__________________________________________________________________________
Subject Code _________
DRIVE NUMBER ________
CONDITION ____________

POST-DRIVE QUESTIONNAIRE

Please answer the following questions to the best of your ability using the 1-9 scale. Circle the number that indicates your response. (If you are uncomfortable with any of the items, you feel free to leave it blank.)

These are questions about the most recent drive?

1. How challenging a drive do you feel this drive was? (Circle one number)
   1  2  3  4  5  6  7  8  9
   Not at all challenging          Extremely challenging

2. How would you rate your driving performance on this drive?
   1  2  3  4  5  6  7  8  9
   Worst possible               Best possible

3. How challenging did you feel it was to stay focused on driving on this drive?
   1  2  3  4  5  6  7  8  9
   Extremely easy               Extremely hard

4. To what extent do you think distraction may have had an effect on your driving performance in this drive?
   1  2  3  4  5  6  7  8  9
   Not at all                   To a great extent

5. Is there anything you would like to add about your experiences with the last drive? ____________