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Effect of Occupational Demands on Driving Safety in Surgical Residents

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EFFECT OF VIGILANCE ON DRIVING PERFORMANCE IN COMMERCIAL MOTOR VEHICLE DRIVERS

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EFFECT OF VIGILANCE ON DRIVING PERFORMANCE IN COMMERCIAL MOTOR VEHICLE DRIVERS

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Abstract

Driving is a complex task requiring constant information processing made possible by attention. Because there are 5.7 million commercial motor vehicle (CMV) drivers in the United States, it is imperative to investigate factors affecting driving performance as well as methods to reduce motor vehicle collisions (MVCs) with the primary goal of eliminating transportation-related unintentional fatal and nonfatal injuries. Vigilance is a cognitive processing component that may play an important role in CMV driving safety. Two experiments were conducted to examine the effect of vigilance on simulated driving performance in varying conditions. Experiment 1 focused specifically on the effect of vigilance on CMV driving in general, and while distracted in particular. Fifty CMV drivers completed a 10 minute vigilance task (the Psychomotor Vigilance Task [PVT]) and drove in a CMV driving simulator for 4 drives while presented with 1 of 4 possible secondary tasks (no secondary task, cell phone conversation, text messaging interaction, and on-board emailing device interaction). Generalized estimating equations (GEE) and mixed models indicated marginal evidence that PVT mean reaction time is predictive of CMV driving performance. CMV driving experience also had a strong effect on CMV driving performance. Experiment 2 considered the differential impact of secondary tasks on visual attention in CMV driving performance, as different tasks have been associated with different effects on visual attention towards the roadway in previous work. Findings causally linked secondary tasks to visual attention, in turn affecting CMV driving performance. The mediating effect of visual attention significantly differed among different levels of vigilance. Given the unique demands of CMV driving, namely long driving distances and travel time, the ability to maintain attention during a sustained task (vigilance) requires further investigation as it applies to information processing in the context of CMV driving. Future research should assess vigilance over time in CMV drivers and examine how vigilance develops with CMV driving experience.

Keywords: commercial motor vehicle, vigilance, information processing, attention, safety, driving

DEDICATION

This work is dedicated to the memories of my dad, grandmother, and grandfather. I also dedicate this thesis to my nieces - my Monkey and Weasel – and their mother, as long as she has eaten recently. My thesis work is also dedicated to my mother, who has been through more battles than most ever will, and who despite my best attempts, I have become more like than I ever intended. This thesis is also dedicated to Al’s Deli and Grill, who has supplied me with grilled chicken salads throughout this process. I also dedicate this work to Selena Gomez, just because. Finally, I dedicate this to Dessie, who has always gone above and beyond as a mentor, has had the patience to endure me for years now, and has always pushed me to do my best.

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LIST OF ABBREVIATIONS

CDC	Centers for Disease Control and Prevention
CI	Confidence interval
CMV	commercial motor vehicle
FMCSA	Federal Motor Carrier Safety Administration
GEE	generalized estimating equations
MPG	miles per gallon
MPH	miles per hour
MVC	motor vehicle collision
NHTSA	National Highway Traffic Safety Administration
OpCon	Operator's Console
PVT	Performance Vigilance Task
RR	Rate ratio
RT	Reaction time
USDOT	United States Department of Transportation

Introduction

Commercial Motor Vehicle Collisions

Motor vehicle collisions (MVCs) are the leading cause of unintentional injury deaths (Centers for Disease Control and Prevention [CDC], 2015). According to the United States Department of Transportation (USDOT) and National Highway Traffic Safety Administration (NHTSA), commercial motor vehicle (CMV) fatalities increased by 17% from 3,380 to 3,964 and injuries increased by 28% from 74,000 to 95,000 from 2009 to 2013 (National Highway Traffic Safety Administration [NHTSA], 2015b). Because there are 5.7 million CMV drivers in the United States, it is imperative to investigate factors affecting driving performance as well as methods of reducing MVCs with the primary goal of eliminating unintentional fatal and nonfatal injuries and in transportation.

There is a greater proportion of MVCs in CMVs than in light passenger vehicles. In 2013, there were .0001 fatalities per registered passenger vehicle (National Highway Traffic Safety Administration [NHTSA], 2015b), while there were .0004 fatalities per registered CMV (National Center for Statistics and Analysis, 2015). MVCs involving CMVs resulted in costs of $78 billion in 2012, $6 billion more than the previous year (USDOT & FMCSA, 2015).

To highlight the importance of examining factors and methods of mitigating CMV MVCs as it pertains to development across the lifespan, it is important to consider that over 23% of CMV MVC fatalities involved drivers over the age of 55 in 2012 (National Highway Traffic Safety Administration [NHTSA], 2014a). Increasing age is associated with cognitive declines that result in difficulties with the task of driving

(Owsley et al., 1998). These declines influence driving by affecting information processing, specifically through bottom-up processes (Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998). Bottom-up processes are driven by information from the environment (Theeuwes, 1993), such as visual information in the roadway environment. In older adults, perceptual and cognitive processes reflect diminished bottom-up processing capacity (Ball, Owsley, Sloane, Roenker, & Bruni, 1993). Models of perception in driving highlight the high cognitive workload due to the great variability of information being processed as a basic feature of the task of driving (Endsley, 1995). To better understand the role cognitive processes and declines have in the context of CMV driving, information processing must be investigated.

Information Processing

Driving is a complex task requiring a constant processing of information fueled by attention. Information is processed from both the driving environment and modulated by the driver's motivation, interests, and expectations (Castro, 2009). Information is processed through a series of stages and mental operations as tasks are performed. Wickens 1980) developed an influential conceptual model of human information processing that highlights this processing of information through stages as illustrated in Figure 1.

Information found in the environment is first processed by senses (e.g., sight, sound, touch), and then perceived. Sensory information is vast, but only a small amount may be perceived (Wickens et al., 2013c). Perception involves not only sensing environmental information, but also determining the meaning of the sensory stimuli (Wickens et al., 2013c). For example, a driver sees a forward vehicle's brake lights (sensing) and knows the illumination of the brake lights indicates the driver of the forward vehicle is applying his or her brakes.

Following perception, the information may trigger an immediate response, or the information may utilize working memory to retain the initial environmental stimuli while scanning the environment for additional information to inform decisions for future action (Wickens et al., 2013c). When a response is executed in the processing of the information, the response alters the environment and in return, a new and different pattern of information is sensed. Information processing follows a feedback loop where the stimulus, sensation, perception, cognition, and response continually change (Wickens et al., 2013c).

Attention acts as: 1) a filter of information, and 2) a fuel of mental resources in the processing of information (Wickens & McCarley, 2008). Information that is sensed and then perceived is filtered by selective attention (Wickens et al., 2013c). Selective attention is necessary to the task of driving, because there is simply too much information in the driving environment to perceive and respond to at once (Castro, 2008). Factors related to selective attention are the best predictors of crash risk in older drivers (Ball & Owsley, 1991). Certain elements of the information are selected for further processing, while other elements of the information are suppressed. While on a divided highway, a driver can visually see the vehicles travelling in the opposite direction, but may limit to visually scanning only the traffic travelling in the lanes on the driver's direction of travel. Thus, perception has a larger input of information than output of information to the consequent stages of processing.

Attention is necessary for the various stages of information processing, but much like fuel in automotive vehicles, is a limited resource. Some stages of processing require more attention in certain tasks than other stages of processing. Since attention is a finite and limited cognitive resource, the collective resources necessary for any given task may not allow enough for another task occurring concurrently. This results in multi-tasking failure. If an individual allocates, or "pays" attention to the necessary tasks needed for safe driving, he or she is limited in how much attention can be allocated, or "paid" towards any other task (e.g., talking on a cellular phone, daydreaming, adjusting the radio) (Wickens, Hollands, Banbury, & Parasuraman, 2013d).

As indicated in Wickens' model (2013c), the appropriate allocation of attentional resources is necessary for the effective processing of information. A misdirection of attention can result in selecting wrong sensory information, misperceiving information, poor working memory or cognition, and/or response selection or execution (Wickens et al., 2013c). Attentional resources are limited, so attention must be properly monitored so that it can be directed to the stages of information processing. Otherwise, relevant stimuli in the environment may be undetected or misperceived, such as a vehicle ahead in the forward roadway coming to a sudden stop, and as a result, the appropriate response may not be selected or executed.

An Examination of Wickens' Model of Information Processing

The current study is guided by Wickens' information processing model, and examined vigilance's effects on information processing at the stages in Wickens' model as illustrated in Figure 2. Because driving involves both the processing of information presented by the roadway environment and from the driver's experiences and knowledge related to driving (Castro, 2009), the task of driving is affected by both top-down processes (processes driven by experience and knowledge (Wickens & Hollands, 2000)) and bottom-up processes. While driving requires processing from top-down and bottom-up processes (Castro, 2009), the current study focused on vigilance's effects on bottom-up information processes as displayed in Figure 2 (Wickens et al., 2013c).

Attention must be monitored to be properly directed to information processing stages. Because the requirements of CMV driving often entail long hours of driving, it may be difficult for CMV drivers to monitor their attentional resources. The effect that long travel hours may have on attention and fatigue in CMV drivers needs further investigation, specifically examining vigilant attention's role in driving.

Vigilant Attention

Vigilant attention, or vigilance, is defined as the sustained attention to monotonous tasks (Robertson & Garavan, 2004) and is supported by both stimulus-triggered "bottom-up" processing and a supervisory "top-down" processing system (Ocasio, 2011). Vigilance is an application of signal detection theory (Wickens, Hollands, Banbury, & Parasuraman, 2013e). There are many factors that affect vigilance in the context of driving. These factors include: 1) fatigue and the theories underlying fatigue (arousal theory, effort-compensation theory, and resource theory) and, 2) inattention, including driver distraction and inattention due to fatigue. These factors will be briefly discussed below.

Driver Fatigue. A possible factor for the greater proportion of fatalities and injuries in CMVs compared to passenger vehicles is the amount of time and distance travelled. FMCSA data showed that on average in 2012, there were 11,705 miles travelled by each registered passenger vehicle. Meanwhile in 2012, each registered CMV averaged travelling 25,172 miles – over twice the average mileage travelled by passenger cars (USDOT & FMCSA, 2013). There are three facets of fatigue: physical, mental, and sleepiness (Yoshitake, 1978). The focus herein is sleepiness.

Recent research has indicated that sleepiness is most severe on the first night of a long-haul CMV trip (Pylkkonen et al., 2015). While sleepiness and fatigue are two different states, sleepiness precedes fatigue (Morriss, Wearden, & Battersby, 1997), and both decrease arousal and in turn, human performance (Wickens, Hollands, Banbury, & Parasuraman, 2013b). Driver fatigue has been termed as a disinclination to continue performing the task of driving along with a progressive withdrawal of attention from the roadway and traffic demands (Brown, 1994). A minimum of seven hours is the amount of sleep time typically associated with safe driving (Neri, Dinges, & Rosekind, 1997), but given the demands of the CMV driving occupation, including expectations regarding on-time delivery and irregular schedules, CMV drivers are particularly at risk for chronic sleep deprivation and in turn, fatigue as well (Belzer, 2000; Ouellet, 1994). As a result of fatigue over long sustained drives, CMV drivers may exhibit declines in vigilant attention, reducing alertness to levels that increase the risk of errors (Philip & Akerstedt, 2006). Cummings, Koepsell, Moffat, and Ivara 2001) found a distinct relationship among long-distance driving, increasing fatigue, and increased crash risk; drivers who travelled in excess of 600 miles in a single drive had over 10 times increased crash risk. Driving fatigue may result in long periods of decreased attention to the task of driving, and the primary component of safe driving is vigilant attention (Williamson, 2009).

An operator's ability to detect signals from the environment decreases over time – a finding replicated many times since the first studies on vigilance conducted by N. H. Mackworth (1948). Environmental signals are intermittent, unpredictable, and usually of low salience (Wickens et al., 2013e), and the operator is required to detect these stimuli. When on watch for stimuli in the environment, the steady-state level of vigilance is lower than desirable. The vigilance level declines steeply during the first half hour of watch, and this has been experimentally replicated and observed in industrial inspectors (Harris & Chaney, 1969; Parasuraman, 1986), but remains to be thoroughly investigated in the context of CMV driving. The implications of this in the context of CMV driving suggest that detecting unpredictable events in the driving environment (e.g., a vehicle in the forward roadway suddenly stopping) decreases over a trip, possibly beginning within the first half hour of the trip. Despite driving being a complex multitask effort, the long durations of drives covering long distances (often on monotonous interstates) travelled by CMV drivers may render the task of driving as fatiguing. Sustaining attention to a monotonous task-vigilance-is perceived as effortful and highly demanding, inducing fatigue and strain over the course of the task (Grier et al., 2003; Szalma et al., 2004; Warm, Parasumaman, & Matthews, 2008). The decrease in vigilance level is known as vigilance decrement (Wickens et al., 2013e).

Vigilance decrement may occur as a result of a decrease in sensitivity to environmental signals (J. F. Mackworth & Taylor, 1963), which has several influences in the context of driving. Sensitivity to stimuli decreases when there is uncertainty about the time or location where a signal will appear (e.g., a vehicle in the forward roadway suddenly stopping), and uncertainty is especially great when there are long intervals between such signals. Low sensitivity to stimuli may result in missing relevant sensory information from the roadway or misperceiving it. The driver's resulting action in reaction to the stimuli may be inappropriate or too late. Because CMV drivers often cover long distances in a single drive, they may be susceptible to the aforementioned decreased sensitivity to stimuli due to the long intervals between possible stimuli. These considerations make vigilant attention a worthwhile factor to investigate in CMV drivers.

The theories of driving fatigue relate mainly to vigilance along with the monotonous nature of the task of driving (Williamson, 2009). The theories primarily underlying driving fatigue include arousal theory, effort-compensation theory, and resource theory and will be reviewed briefly below.

Arousal Theory. Arousal theory maintains that decrements in driving performance are a result of the decreases in arousal due to high monotony of stimulus presentation, i.e., the roadway environment (J. F. Mackworth, 1969). A primary concern in long-haul CMV driving is that the long distances can induce the experience of monotony and boredom in the driver. Boredom can then lead to mind-wandering by the driver. Subjective negative experiences in prolonged, simple tasks have been interpreted as reflecting the experience of boredom (Pattyn, Neyt, Henderickx, & Soetens, 2008; Scerbo, 1998), which in turn is associated with increased mind-wandering (Cheyne, Solman, Carriere, & Smilek, 2009; Smallwood et al., 2004). When in this state of mind-wandering, cognitive processing is directed away from the primary task at hand, driving, towards internally oriented goals, such as recalling previous experiences or simulating future experiences and actions (e.g., "daydreaming," or planning). This reallocation of attention and cognitive processing is responsible for performance detriments in any given primary task at hand (Manly, Robertson, Galloway, & Hawkins, 1999) and is a concern in CMV driving safety when considering the long distances and hours CMV drivers travel, the size of the vehicle and load, and the high-speed interstates often travelled by CMV drivers. Another theory of driving fatigue that is related to the prolonged driving required in CMV driving is effort-compensation theory.

Effort – Compensation Theory. Effort-compensation theory suggests that the effects of fatigue are related to stress effects and occur because the prolonged effort required to remain vigilant is stressful; over time this depletes capacity to complete the task with high levels of performance (Hockey, 1997; Matthews, 2001). Maintaining attention to a monotonous yet attention-demanding task - long haul CMV driving in this instance - requires constant self-regulation by the driver. The driver must regulate between the subjective costs (i.e., effort exertion) and benefits (i.e., intrinsic rewards) of maintaining vigilant attention over time (Rueda, Posner, & Rothbart, 2011). This self-regulatory power is a limited resource (much like attention itself) that prolonged use will deplete (Hagger, Wood, Stiff, & Chatzisarantis, 2010). A driver's self-control strength should decline over time while attempting to maintain vigilant attention. This decline results in a 1) diminished intensity of attention allocated to the task, leading to weaker attentional modulation of task-relevant information processing (mental fatigue), and 2) diminished goal maintenance, leading to task-irrelevant processing and task-unrelated thoughts (mind-wandering).

Both arousal theory and effort-compensation theory are based on a prolonged activity – CMV driving in this context – resulting in fatigue. In contrast, the final theory on the underlying mechanisms behind driver fatigue is based on attention as a limited resource.

Resource Theory. Wickens' (1980) resource theory noted that attention required for information processing is limited and the requirements to remain vigilant result in a depletion of the attention resources, producing adverse effects on task performance. When the resources for deliberate attentional selection are focused on a task, prolonged inattentional blindness for things in plain view (i.e., the forward roadway) is produced. In driving, perception is an active process guided by other cognitive processes (memory, motivation, interests, and expectations, etc.) that the driver applies to the context and is directed by the driver's attention through top-down processing (Most, Scholl, Clifford, & Simons, 2005). Lapses in selective attention occur through either inattention or distraction and may lead to MVCs (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). Deliberate attentional selection in driving involves the conscious execution of a chosen attention-demanding process at the expense of other cognitive processes. Fatigue affects deliberate selection as drivers begin to withdraw cognitive resources necessary for deliberate, effortful attention selection (Trick & Enns, 2009).

These three theories of driver fatigue all note that fatigue will increase the likelihood of an allocation of attention away from the task of driving. The inattention resulting from fatigued driving is unintentional (Williamson, 2009). Most definitions of distraction identify that distraction is a form of inattention that directs attention away from the primary task at hand – driving. Thus, inattention due to fatigue and mind-wandering may be considered a distraction.

Driver Inattention

In the proposed study, inattention is operationalized as the misallocation of attention away from driving and towards a secondary task unrelated to driving (e.g., cell phone conversation, text messaging conversation, and emailing conversation) resulting in a degradation of driving performance (Hedlund, Simpson, & Mayhew, 2006). NHTSA (2014b) categorized driver distraction in three ways: Visual, physical, and cognitive (see Table 1). Trick and Enns (2009) have categorized distraction into visual, cognitive, activation, and anticipation (See Table 1).

Fatigued driving is considered a cognitive distraction (Williamson, 2009), and as seen in Table 1, is an internal form of distraction. The two other forms of driver distraction (visual and physical) identified by NHTSA are external distractions, meaning they involve the misallocation of visual, auditory, or physical resources away from the task of driving and result from stimuli occurring external to the driver (Williamson, 2009). Fatigued driving, on the other hand, involves the misallocation of cognitive resources away from the task of driving. The result is suboptimal information processing, and possibly CMV driving performance degradation.

Distraction has an effect on the processing of information through the various stages, including top-down and bottom-up cognitive processes. Both NHTSA's (2014) and Trick and Enns' (2009) categories of distractions can be classified as external driver distractions or internal driver distractions.

External Driver Distraction

External driver distractions are distractions external to the driver (not the vehicle) and involve the misallocation of visual, auditory, or physical resources away from the task of driving (e.g., text messaging on a cell phone while driving, talking on a cell phone while driving)(Ranney, Mazzae, Garrott, & Goodman, 2000). A naturalistic study by Virginia Tech Transportation Institute tracked the driving performance of 203 commercial vehicle drivers while driving on a real road. Olson, Hanowski, Hickman, and Bocanegra (2009) captured 4,452 critical safety events (crashes, near-crashes, or crash-relevant conflicts [events requiring a crash-avoidance maneuver]); 81.5% of which involved some sort of driver distraction. While crashes were a rare critical safety event in the study (<0.5%), driver inattention (defined in the study as engagement in any non-driving related task or task that was driving-related, yet not required for vehicle control (Ablassmeier, Poitschke, Wallhoff, Bengler, & Rigoll, 2007)) was observed in 100% of those crashes, a higher frequency than that resulting from an earlier light vehicle study by the same group (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Olson et al. (2009) found that commercial drivers were about 23 times more likely to be involved in a critical safety event while text messaging as compared to periods of time when they were not engaged in a secondary task. A critical safety event was almost 6 times more likely while dialing a cell phone, and nearly 10 times more likely while interacting with the vehicle's dispatching device.

Additionally, naturalistic studies have shown that CMV drivers engage in unique tasks not frequently observed in other populations (i.e., adolescents and light-vehicle adults), deemed "mobile office" tasks such as writing and interacting with dispatch devices, and frequent eating, drinking, and using tobacco products (Dingus, 2014). In a study examining the safety climate and distracted driving experiences of CMV drivers, Swedler, Pollack, and Agnew (2015) found that time pressures often lead drivers to choose to multitask while driving (i.e., drive distracted) with the goal of increasing travel efficiency.

While all tasks secondary to the primary task of driving impact driving performance, not all secondary tasks equally degrade CMV driving performance. Olson and colleagues (2009) suggested that compared to other secondary tasks, handheld cell phone usage had the least deleterious effect with any driving performance outcome. More visually-demanding secondary tasks (text messaging and emailing) degraded driving performance to a greater extent, as evidenced by increased driving violations, collisions, and lane deviations (Olson et al., 2009). Furthermore, as the demands of the driving task increase (e.g., increased traffic), CMV drivers converse on a cell phone less frequently when compared to their light vehicle driving counterparts, indicating mobile device use varies depending on the driving context (Fitch, Hanowski, & Guo, 2015a). Mazzae, Goodmanm, and Garrott (2004) found an association between cell phone conversation and the frequency of long-eye fixations on the forward roadway. Considering that visual attention to the roadway decreases crash risk (Hanowski, Olson, Hickman, & Bocanegra, 2009; Olson et al., 2009), talking on the cell phone may act as a protective measure in CMV driving. However, it is unknown what the underlying mechanism is in the association between increased visual attention to the forward roadway and talking on the cell phone.

The risk of a critical safety event in CMVs may increase even when engaged in tasks that are not commonly considered distractions (e.g., text messaging, dispatching device interaction). Checking the speedometer increases the risk of a critical safety event by 32%, and looking outside of the vehicle at the side mirror increases risk by 10%

(Olson et al., 2009). While these external distractions increase crash risk in CMV driving, the role of internal driver distractions in CMV driving must also be examined.

Internal Driver Distraction

Internal driver distractions involve the misallocation of cognitive resources away from the task of driving. As previously mentioned, fatigue and mind-wandering are considered internal driver distractions (Williamson, 2009), and they may negatively affect driving performance (Connor, Whitlock, Norton, & Jackson, 2001). Self-report assessments of proneness towards boredom have a significant relationship with self-reported moving violations (Kass, Beede, & Vodanovich, 2010). Older drivers and less experienced drivers may be especially prone to narrowing attention, even when not fatigued (Crundall, Underwood, & Chapman, 1999; Mills, Spruill, Kanne, Parkman, & Zhang, 2001).

There is evidence that drivers who are tired or bored utilize external factors in an attempt to overcome the effects of fatigue, hoping to increase arousal and alertness levels (Williamson, 2009). Williamson, Feyer, Friswell, and Finlay-Brown 2001) found that CMV drivers employ various strategies to help them overcome the effects of fatigue, which include talking on a cell phone or CB radio, eating, drinking, and smoking cigarettes. Interestingly, most of these strategies have been implicated as potential external driver distractions (Williamson, 2009). In an attempt to lower internal distraction (fatigue) with external distraction, a balance between internal distraction and external distraction may need to be met. It is possible that the strategies which fatigued drivers use in an attempt to overcome fatigue increase the amount of distraction, and as a result, further increase the misallocation of attention to the task of driving (Williamson, 2009).

CMV drivers may engage in external driver distractions and be vulnerable to internal driver distractions as a result of the long distances and durations that the job of CMV driving requires.

Recent research on inattention suggests that neither task monotony (i.e., mind wandering) nor task demands' depletion of attention (i.e., resource theory as examined above) fully explain the inattention that occurs in sustained-attention circumstances (e.g., long distance CMV driving) (Thomson, Besner, & Smilek, 2015). Studies on CMV driver fatigue have shown that factors related to the time of day have greater effects on the driver's alertness than the time-on-task (FMCSA, 1996), highlighting that inattention is influenced beyond attentional resources alone. Rather, attentional lapses are a combination of attentional recourses (Smallwood & Schooler, 2006b) and control failure (McVay & Kane, 2010).

While all of the above factors affect vigilance, the proposed study will focus on inattention at bottom-up stages of information processes as it relates to the effect of vigilance on CMV driving (see Figure 2). The role of vigilant attention on CMV driving performance warrants further investigation given that vigilance may predict driving performance and impact safety. A reliable method of measuring vigilance has been identified and used in previous CMV driving studies. However, the method used to measure vigilance has typically been limited in the outcomes used and in the status of the samples measured (e.g., sleep deprived or not) (Howard, Jackson, Berlowitz, et al., 2014; Howard, Jackson, Swann, et al., 2014; Jackson, Croft, Kennedy, Owens, & Howard, 2013).

Measuring Vigilant Attention

Given the significant role of vigilant attention depletion in increasing risk for long-haul CMV driving, it is important to identify reliable methods of measuring vigilant attention in CMV drivers. Previous research has primarily used the Psychomotor Vigilance Test (PVT) to measure vigilant attention in this population (Pascal, 2010). The PVT is a 10-minute test of attention, vigilance, and reaction time and measures vigilant attention by measuring sample reaction times to stimuli which occur at random intervals (Dinges, Pack, & Williams, 1997; Drummond et al., 2005; Lim & Dinges, 2008). The PVT has validly assessed behavioral alertness and vigilant attention performance in many studies involving CMV drivers (Howard, Jackson, Berlowitz, et al., 2014; Howard, Jackson, Swann, et al., 2014; Jackson et al., 2013), but the PVT outcomes typically used have been limited. Mean reaction time ([MeanRT] the average correct reaction time) and lapses (reaction times greater than the lapse criterion) (Howard, Jackson, Berlowitz, et al., 2014; Howard, Jackson, Swann, et al., 2014; Jackson et al., 2013) have been historically used. While reaction time decrements and lapses are associated with poorer vigilance (Dinges et al., 1997), these outcomes are measured as an average or sum for the 10-minute PVT task and do not indicate how vigilance changes over time.

The effect of PVT slope on driving performance has not been examined in previous studies on vigilance and professional driving, but it would be worthy of study because PVT slope measures reaction time across time (Dinges et al., 1997). PVT slope is the linear regression slope of the reaction time on trial minute. PVT slope measures the reaction time over the course of the 10-minute PVT task. A positive slope would indicate that reaction time is increasing over time (i.e., vigilance decreases over the duration of the 10-minute PVT task), and a negative slope would indicate that reaction time is decreasing over time (i.e., vigilance remains intact or improves over the duration of the 10-minute PVT task). The purpose of this study is to determine the effect that vigilance (as measured by PVT slope) has on driving performance in CMV drivers while controlling for varying levels of self-reported sleepiness.

Among all of the measures of cognition available, the PVT has been most often applied to the study of cognition in truck drivers (Van Dongen & Dinges, 2003; Van Dongen, Maislin, Mullington, & Dinges, 2003). While the PVT has been most often applied in the study of cognition in CMV drivers, the previous studies involving PVT and CMV drivers have had a narrow focus. The PVT has measured vigilant attention specifically in CMV drivers but primarily in the context of examining the effect of sleep-deprivation and fatigue on CMV driving performance. Jackson and colleagues 2013) found that in sleep-deprived participants, PVT performance significantly predicted specific aspects of simulated driving performance such as increased lane departure and speed variability. Howard, Jackson, Berlowitz, et al. 2014), Howard, Jackson, Swann, et al. 2014), and Jackson and colleagues 2013), specifically used sleep-deprived drivers in both studies. It remains unknown how vigilant attention measured by the PVT affects CMV driving across varying levels of sleepiness – that is, when controlling for sleepiness. The current study did not have sleep-deprivation as inclusion criterion for participants, and thus varying levels of sleepiness in participants may be expected. Because vigilance and its effects on CMV driving performance are measured across varying levels of sleepiness, the results of the study may be translatable to CMV drivers at all sleepiness levels.

This study had the overarching objective of examining the role of vigilance in information processing in the context of CMV driving performance. To address this objective, two experiments were conducted. The purpose of the first experiment was to examine the usefulness of PVT slope as a predictive measure of CMV driving performance. The purpose of the second experiment was to investigate the differing impact that different secondary tasks have on visual attention, and how vigilance moderates this impact.

Experiment 1

The overall objective of this study was to determine the relationship between vigilance and driving performance in licensed long-haul commercial truck drivers. The purpose of this study was to examine the usefulness of PVT slope as a measurement of vigilance, and determine the association of PVT slope and CMV driving performance.

Specific Aims

The current study had two primary specific aims.

Aim 1: To examine the association between vigilance as measured by reaction time over a sustained period and driving performance in 50 licensed commercial truck drivers across 4 simulated drives while controlling for self-reported sleepiness.

Vigilance plays a role in the ability to sustain the limited attentional resources (Wickens et al., 2013c) needed for safe CMV driving over long distances. Whether decrements in vigilant attention occur due to driver fatigue, mind-wandering, or the limited nature of attentional resources, the resulting inattention leads to poor driving performance (Hedlund et al., 2006). Age and experience also affect vigilance. Even when not fatigued, older drivers and less experienced drivers may be especially prone to narrowing attention (Crundall et al., 1999; Mills et al., 2001).

The PVT has been accepted and validated as a measure of vigilant attention (Lim & Dinges, 2006) and has significantly predicted simulated driving performance in CMV drivers (Jackson et al., 2013). The average reaction time and number of lapses recorded by the PVT have been previously used to predict driving performance. However, the association specifically between the reaction time over time (PVT slope) and driving performance is unknown, but is worthy of further study, because previous research has found that PVT performance significantly predicted specific aspects of simulated driving in light vehicles (Van Dongen & Dinges, 2003; Van Dongen et al., 2003).

This study was among the first to investigate the association between the PVT slope variable of vigilance and driving performance in licensed CMV drivers. Generalized estimating equations (GEE) and mixed linear models were used to analyze the association of the independent variable (PVT slope) with each count dependent variable (number of MVCs) and continuous dependent variable (total violations, average speed, number of speed violations, number of hard braking violations, number of tailgating violations, and miles per gallon) respectively across the within-subjects variable of 4 simulated drives. Self-reported sleepiness, age, and CMV driving experience were included as covariates in the models.

Hypothesis 1: Slower reaction time over a sustained period, as indicated by higher values in PVT slope, will be significantly associated with poor driving performance (i.e., increased incidences of MVCs, violations, speed

exceedances, hard-braking violations, tailgating violations, and fewer miles per gallon) over 4 simulated drives in CMV drivers.

Hypothesis 2: CMV driving experience (as measured by self-reported years of CMV driving while controlling for age) will be significantly and negatively associated with poorer vigilance (high PVT slope) and poorer driving performance.

Aim 2: To examine the association between vigilance and driving performance in 50 licensed commercial truck drivers during a single simulated drive under the following conditions: 1) emailing using an on-board emailing device, 2) engaging in a cell phone text messaging interaction, 3) conversing on a hands-held cell phone, or 4) when presented with no secondary task.

Naturalistic studies have previously shown that CMV drivers were much more likely to be involved in a critical safety event when engaged in a secondary task (Olson et al., 2009). Albeit, not all secondary tasks are equally deleterious. Previous research in CMV driving has suggested that handheld cell phones had the least deleterious effect with any driving performance outcome (Olson et al., 2009). Many common tasks engaged in by CMV drivers are not often considered distractions, yet still increase the risk of a critical safety event. The secondary tasks that have been shown to increase critical safety event risk the most for CMV drivers are text messaging, dialing a cell phone, and interacting with the vehicle's dispatching device (Olson et al., 2009).

The current study was among the first to consider the relationship between vigilant attention and secondary task engagement while driving. Mixed linear models were utilized to analyze the effect that the independent variable (PVT slope) has with each within-subjects' secondary task condition presented to CMV drivers (on-board emailing device, text messaging conversation, cell phone conversation, and no secondary task) had on the continuous dependent variables of driving performance (total violations, average speed, number of speed violations, number of hard braking violations, number of tailgating violations, and miles per gallon). GEE were used to analyze the effect that the independent variable PVT slope had on the count dependent variable, MVCs. Fatigue, age, and CMV driving experience were included as covariates in the models.

Hypothesis 1: PVT slope will significantly interact with secondary task condition to predict simulated driving performance in CMV drivers

Hypothesis 2: Contrasts will reveal that the interaction of PVT slope with on-board emailing device will significantly predict CMV driving performance to a greater extent than all other secondary tasks (text messaging interaction, cell phone conversation, and no secondary task presented).

Hypothesis 3: Contrasts will reveal that the interaction of PVT slope with cell phone interaction will have the least deleterious effect on driving performance in CMV drivers.

Hypothesis 4: Older CMV drivers will have poorer driving performance compared to younger CMV drivers in the text messaging interaction and on-board emailing device interaction secondary tasks.

Method

Participants

This study employed analyses of data previously collected from a study investigating health, cognition, and distraction on driving performance in CMV drivers.

The study was conducted at a commercial vehicle driving company located in the Southeast U.S. and was approved by the University of Alabama at Birmingham's Institutional Review Board for Human Use. Fifty-five CMV drivers were recruited from the region through flyers displayed in areas prominently visible to CMV drivers. Flyers were used to encourage interested individuals to contact the program administrator who engaged the potential participant in a detailed discussion of the study to determine eligibility.

Eligibility criteria included: (1) age 21 – 65; (2) possession of a valid, state-issued Commercial Driver's License; (3) long-haul drivers who slept at least three nights per week in the sleeper berths of their commercial vehicles; (4) having been deemed medically fit per USDOT standards; (5) ownership of a cell phone; and (6) being able to read, write, and speak English. Exclusion criteria included: (1) a diagnosis of sleep apnea, and (2) self-reported routine and habitual use of sedating or hypnotic medications, illicit drugs, or alcohol.

Five participants who originally met inclusion criteria were later excluded from the study: (two were run as pilot participants, two due to simulator sickness and one due to missing simulator data), resulting in a total of 50 participants' data that were used in the analyses.

Measures

Psychomotor Vigilance Task (PVT; (Dinges & Powell, 1985)) The PVT is a 10-minute test of attention, vigilance, and reaction time and measures vigilant attention by measuring sample reaction time to stimuli which occur at random intervals (Dinges et al., 1997; Drummond et al., 2005; Lim & Dinges, 2008). The PVT device used in the procedure is pictured in Figure 3. On the front face and at the top of the device was a small screen where red numbers appeared. In the screen below, the question “sleepy?” with a 10-unit scale of sleepiness was displayed, where 1 was not sleepy at all, and 10 was extremely sleepy. The “sleepy?” question was automatically presented to participants immediately before the beginning of the 10-minute PVT task and immediately after the 10-minute PVT task. Finally, two square buttons were located side-by-side and about 1 inch above the bottom of the hand-held device. Depending on the dominant hand of the participant, one of these buttons was pressed in reaction to the red numbers presented in the small screen at the top of the device. A right-handed participant would press the small button on the right, while a left-handed participant would press the small button on the left.

The small red numbers indicated the participants’ reaction time in milliseconds. Participants were instructed to press the appropriate button as soon as he or she saw red numbers appear in the small screen at the top of the device. Pressing a button before the stimulus (i.e., the red numbers) appeared would result in an “offsides,” (i.e., a commission error) and not pressing the button within 3,000 milliseconds (3 seconds) of the presentation of the stimulus would result in a “lapse” (i.e., an omission error). Along with offsides and lapses, the PVT device recorded variables including sleepiness before the PVT task, sleepiness after the PVT task, mean reaction time (MeanRT), the fastest 10% reaction times, the slowest 10% reaction times, and the variable of primary interest in the proposed study, reaction time slope (PVT slope).

The 10-minute PVT trial calculated PVT slope (an indication of vigilance, which determines how reaction time increases, decreases, or remains the same over the 10-

minute task). A positive PVT slope indicates that reaction times increase over the 10-minute task, meaning that reaction time worsens over the duration of the task. A negative PVT slope indicates that reaction times decrease over the 10-minute task, meaning that reaction time improves over the duration of the task. A PVT slope of 0 indicates no change in reaction time over the duration of the task, meaning reaction time neither improves nor worsens, but remains the same over the 10-minute task.

Driving Simulator. Participants engaged in a computerized driving simulation task in an L-3 Communications TranSim™ (D.P. Associates, Inc., Alexandria, Virginia) commercial vehicle driving simulator to provide a measure of driving performance under specified conditions of interest (Figure 4). The simulation was displayed on three plasma screens, providing a 180° field of view. Participants sat within the passenger compartment which provided a view of the roadway and dashboard instruments, including a speedometer, tachometer, trailer and brake release buttons, and a brake pressure gauge. The vehicle was controlled by moving a force-loaded steering wheel in a typical driving manner, changing gears (10-speed), and depressing accelerator, clutch, and brake pedals accordingly. The commercial vehicle was programmed to carry an 80,000 pound high-tarped load. An on-board stereo sound system provided naturalistic engine sounds, external road noise, and sounds of passing traffic.

Driving Scenarios. The simulated daytime environment was a four-lane interstate segment, with traffic moving in a bidirectional manner, mimicking roadway conditions typically encountered on the interstate, including varying levels of traffic and road level grade (i.e., steepness of roadway). Speed limit signs appeared throughout the scenarios and ranged from 55 mph to 60 mph. Drivers were encouraged to "drive as they normally would" and were not restricted to maintain a particular speed. The other simulated vehicles were programmed to interact with the participant driver, based on pre-set parameters. Several vehicles were programmed to appear behind the participant driver, while others were programmed to appear in front. Four driving scenarios were created which all utilized the same length of interstate and same environmental variables (e.g., number of vehicles on road, weather conditions, hill grade). Each scenario had a different starting location, and traffic occurred at different locations to minimize practice effects of the driving simulator. The order of the presentation of the four driving scenarios was counter-balanced across participants.

Outcome Variables. Seven indicators of driving performance were electronically recorded by the simulator

1. The total number of **MVCs** was calculated for each simulated drive. A MVC was reported as an instance when the participant-driver collided with either another vehicle or object (Hanowski, Perez, & Dingus, 2005; Olson et al., 2009).
2. The total number of **violations** committed in each simulated drive. The violations included speed exceedances, hard braking violations, and tailgating (space management) violations (Hanowski et al., 2005; Olson et al., 2009).
3. **Average speed** was calculated as the average speed in miles per hour over the duration of the simulated drive. Average driving speed has been used to measure driving performance and the likelihood of MVCs in various traffic conditions (Li, Wang, Chen, Liu, & Xu, 2013).
4. **Speed exceedances** were calculated as the total number of times a driver went more than 15 mph over the speed limit (Hanowski et al., 2005; Olson et al., 2009).

5. **Hard braking violations** was electronically recorded by the simulator and counted as driver errors. Sudden and improper stopping and excessive braking have been used as measures of driving performance in CMV research (Hanowski et al., 2005; Olson et al., 2009).
6. **Tailgating** was based on the Smith System (Smith System, 2014) and measured by the total number of times the participant driver was less than 10 seconds away from the lead vehicle. Following too closely to lead vehicles has been used in previous research as a measure of CMV driving performance (Hanowski et al., 2005; Olson et al., 2009).
7. **Miles per gallon** was electronically recorded by the simulator and served as an indicator for operational efficiency. The proposed study is among the first to examine operational efficiency in a research setting.

A video camera was strategically mounted on the Operator's Console (OpCon) providing a full, unobstructed view of the driving scene. The OpCon was the simulator's control station, which provided a top-down view of the entire driving scenario centered on the simulated CMV. Videos were manually coded by a trained research assistant for the following additional indicator of driving performance:

1. **Lane deviations per minute** which were defined as center line crossings or road edge excursions, were recorded as indicators of poor driving performance, and has been previously used to measure CMV driving performance (Gillberg, Kecklund, & Akerstedt, 1996; Hanowski et al., 2005; Olson et al., 2009; Ronen, Oron-Gilad, & Gershon, 2014).

Procedure

Participants who met eligibility criteria for the study and gave informed consent arrived for a single session appointment that lasted approximately 4 hours. This study only focused on a subset of the measures and procedures from the larger parent study, and only those relevant parts are discussed herein. Participants completed a lab-created paper and pencil questionnaire that inquired about participant demographic information. Participants were familiarized with the PVT device and were given a 1-minute PVT practice trial. Participants then completed a 10-minute PVT trial which asked participants to self-report his or her "sleepiness" after the 10-minute trial on a scale of 1 to 10, where 1 was "not sleepy at all" and 10 was "extremely sleepy."

All participants were familiarized with the commercial vehicle driving simulator during a brief calibration session to ensure that each driver had an opportunity to perform basic driving tasks in the simulator (e.g., shifting through all ten gears, making a right turn, using the steering wheel, accelerator, clutch, and brakes). The practice driving session began with the truck parked on a straight road with no other vehicles on the simulated roadway. Participants were instructed to start the truck, drive to the end of the simulated road, stop at the stop sign, and make a right turn. The practice simulation ended when the participant had driven for the distance of 1 mile.

Participants' phone numbers were obtained by recording them on a sheet of paper. Participants then engaged in four driving scenarios, each spanning approximately a 22.50-mile distance. The order that the three secondary task conditions were presented to the participants was counter-balanced: (a) no secondary task condition, in which participants anticipated a text, phone call, or email but did not receive any of the three secondary tasks, (b) cell phone conversation, in which participants received a cell phone call after beginning the scenario, quickly answered the phone, and subsequently engaged in a naturalistic phone conversation with an unfamiliar research assistant who had scripted questions for the remainder of the scenario, (c) a text message interaction, in which participants received a text message after beginning the scenario and engaged in reading and responding to text messages from an unfamiliar research assistant who had scripted questions for the remainder of the scenario, or (d) emailing interaction, during which participants were sent an email message after beginning the scenario and engaged in reading and responding to email messages from an unfamiliar research assistant who had scripted questions for the remainder of the scenario. Participants were offered a short (less than 5 minute) break in between each of the four drives.

Cell phone, text messaging, and email tasks were semi-structured to imitate a typical conversation with unfamiliar individuals (i.e., research assistants); these research assistants maintained a natural conversation flow. Each secondary task condition had different scripts but contained similar types of questions. Example conversational questions included, "What is your favorite television show?" and "How many years have you had a commercial driver's license?"

Data Analysis Plan

Preliminary Analyses. Mean and frequency distributions were used for continuous and categorical variables, respectively, to describe demographic characteristics of the participants. Analyses for outlier detection and assumptions of normality were conducted. Data that were three standard deviations away from the mean were considered outliers, and analyses were run both with and without the outliers to determine if the outliers affected outcomes. Dependent variables not normally distributed were analyzed using distribution analyses that could properly handle overdispersion of variance (e.g., Poisson, negative-binomial). Intercorrelations were calculated for all variables used in analyses. All statistical analyses were conducted with $\alpha = .05$, where p values <.05 were considered statistically significant, and p values <.10 were considered to provide marginal evidence suggesting statistical significance. All analyses were conducted using SAS version 9.3 (SAS Institute Inc., 2011).

Aim 1. To examine the association between vigilance as measured by reaction time over a sustained period and driving performance in 50 licensed commercial truck drivers across 4 simulated drives while controlling for self-reported sleepiness.

GEE were utilized for count variables (MVCs) and variables with overdispersed variance (total violations, speed exceedances, hard braking violations, tailgating) and mixed models were used for each normally distributed continuous outcome (average speed, MPG, and lane deviations per minute). The use of GEE modeling methods allowed for the inter-dependence of the observations, as each participant engaged in four drives (Morel & Neerchal, 2012). Thus, these models adjusted for within-person covariance (e.g., driving ability, familiarity with simulator after multiple drives). Age and self-reported CMV driving experience (measured in years) were included in the models. Sleepiness was controlled for by including post-PVT task self-reported sleepiness in these models.

Aim 2. To examine the association between vigilance and driving performance in 50 licensed commercial truck drivers during a single simulated drive while attempting to 1) email using an on-board emailing device, 2) engage in a cell phone text

messaging interaction, 3) converse on a hands-held cell phone, or 4) when presented with no secondary task.

For the estimation of the association between secondary tasks, vigilance and driving performance, GEE Poisson models were utilized for count variables (MVCs) and variables with overdispersed variance (total violations, speed exceedances, hard braking violations, tailgating) and mixed models were used for each normally distributed continuous outcome (average speed, MPG, and lane deviations per minute). Models were created for each driving performance measure (e.g., MVCs and lane deviations per minute). In each model, the no secondary task condition was the referent group. Age and self-reported CMV driving experience (measured in years) were included in the models. Sleepiness was controlled for by including post-PVT task self-reported sleepiness in these models. Orthogonal contrasts were specified to compare secondary tasks to one another.

Results

Demographics

Participants were on average aged 39.8 years (*SD* = 8.36), male (98%), and Caucasian (56%). Participants reported having an average of 8.6 years of CMV driving experience (*SD* = 7.04) with a range of as few as 0 full months of CMV driving experience and as much as 24 full years of CMV driving experience. See Table 2 for descriptive statistics for participant characteristics.

Missing Data

There were no missing data for the independent variables and covariates (PVT slope, age, CMV driving experience, and self-reported sleepiness) or driving performance outcomes (MVCs, total violations, average speed, number of speed exceedances, number of hard braking violations, number of tailgating violations, MPG, and number of lane deviations per minute).

Descriptive Statistics

The outcome variables tailgating, hard braking, speeding, total violations, and MVCs had overdispersed distributions (i.e., the variance was larger than the mean). The outcome variables average speed, lane deviations per minute, and MPG were normally distributed (i.e., the variance was smaller than the mean). The covariates self-reported sleepiness, CMV driving experience, and age were overdispersed. The independent variable PVT slope was normally distributed. All outcome and predictor variables were within acceptable ranges for skewness (±2) and kurtosis (±3), with the exception of MVCs (skewness = 4.28, kurtosis = 21.16). There were 2 outliers (> ±3.0 standard deviations) in the hard braking outcome, 1 outlier in the MPG outcome, and 3 outliers in the lane deviations per minute outcome. One outlier in each of these belonged to 1 single participant. Analyses were run with and without the outliers in order to determine how the data were affected by the presence of outliers. See Table 2 for descriptive statistics for all predictors and CMV driving performance outcomes.

Age and CMV driving experience were significantly correlated ($r = 0.46$, $p < .0001$), but there was no indication of multicollinearity ($r < \pm.8$). Multicollinearity was indicated between speeding and total violations ($r = 0.82$, $p < .001$). Intercorrelations among all predictor variables and CMV driving outcomes are displayed in Table 3.

Aim 1: Examine the association between vigilance as measured by reaction time over a sustained period and driving performance in 50 licensed commercial truck drivers across 4 simulated drives while controlling for self-reported sleepiness.

For the overdispersed driving outcomes (tailgating, hard braking, speeding, total violations, and MVCs), GEE Poisson analyses indicated that PVT slope and the covariates (self-reported sleepiness, CMV driving experience, and age) were not significant predictors of MVCs or the number of total violations in the simulated drive. Initial GEE parameter estimates indicated that CMV driving experience was a significant predictor of the number of tailgating violations ($\chi^2(1) = 4.11$, $p = .04$), but Type III analyses of parameters indicated only marginal evidence that CMV driving experience was a predictor of the number of tailgating violations ($\chi^2(1) = 3.38$, $p = .07$). Type III analysis in GEE Poisson analyses are similar to Type III sums of squares utilized in analysis of variance (ANOVA) framework, with the exception that the likelihood ratios are used rather than sums of squares (SAS, 2015). In Type III analysis, each effect of a predictor variable is adjusted for all other effects (Littell, Stroup, & Freund, 2002) and are generally more appropriate in more complex models (Landsheer & van den Wittenboer, 2015). PVT slope and the covariates were not significant predictors of the number of hard braking violations in both the model which included the 3 outliers and in the model that removed the 3 observations with outliers. PVT slope and the covariates were not significant predictors of the number of speeding violations in the simulated drive, although there was marginal evidence to suggest self-reported sleepiness predicted the number of speeding violations in the simulated drive ($\chi^2(1) = 2.71$, $p = .09$). See Table 4 for RRs and 95% CIs for all predictors.

In the driving outcomes that were normally distributed, PVT slope and the covariates did not significantly predict average driving speed during the simulated drive, although there was marginal evidence suggesting self-reported sleepiness predicted average driving speed ($t(45) = 1.74$, $p = .08$). Removing the 2 outliers from average driving speed did not alter the results. PVT slope and the covariates did not significantly predict the number of lane deviations per minute in the simulated drive for the model including the 3 outliers. In the model with the outliers excluded, age was a statistically significant predictor of the number of lane deviations per minute in the simulated drive ($t(42) = 2.31$, $p = .03$). MPG during the simulated drive was not statistically significantly predicted by PVT slope and the covariates, although there was marginal evidence to suggest self-reported sleepiness predicted MPG ($t(45) = -1.95$, $p = .06$). Removing the MPG outlier indicated marginal evidence to suggest MPG was predicted by CMV driving experience ($t(44) = -2.01$, $p = .05$) and self-reported sleepiness ($t(44) = -1.95$, $p = .06$). See Table 5 for parameter estimates of all predictors.

Aim 2. Examine the association between vigilance and driving performance in 50 licensed commercial truck drivers during a single simulated drive while attempting to 1) email using an on-board emailing device, 2) engage in a cell phone text messaging interaction, 3) converse on a hands-held cell phone, or 4) when presented with no secondary task.

For the driving outcomes with overdispersion, GEE Poisson analyses indicated that PVT slope, secondary task, and the covariates did not significantly predict the number of MVCs in the simulated drive, the number of total violations, or the number of speeding violations during the simulated drive. In the number of tailgating violations in the simulated drive, there was marginal evidence to suggest CMV driving experience predicted tailgating violations ($\chi^2(1) = 3.38$, p = .07). PVT slope, secondary task, and the covariates did not significantly predict the number of hard braking violations. Removing the hard braking violations outlier indicated there was marginal evidence suggesting PVT slope predicted the number of hard braking violations ($\chi^2(1) = 2.82$, $p = .09$). See Table 6 for RRs and 95% CIs for all predictors.

In the normally distributed driving outcomes, secondary task significantly predicted the average driving speed in the simulated drive ($\chi^2(3) = 10.96$, $p = .01$). Compared to engaging in no secondary task, drivers averaged 3.19 miles per hour (MPH) slower while engaged in the cell phone conversation, 2.4 MPH slower while engaged in the text messaging interaction, and 2.66 MPH slower while engaged in the email interaction. There was marginal evidence to suggest self-reported sleepiness predicted average driving speed in the simulated drive ($t(45) = 1.81$, $p = .08$). The PVT slope by secondary task interaction term was added to the model, but there was no evidence to suggest it significantly predicted average driving speed. Removing the two outliers from average driving speed outlier did not alter the results.

Secondary task significantly predicted the number of lane deviations per minute in the simulated drive ($\chi^2(3) = 191.93$, $p < .0001$). Compared to engaging in no secondary task, drivers averaged 0.11 fewer lane deviations per minute while engaged in the cell phone conversation, 0.94 more lane deviations per minute while engaged in the text message interaction, and 1.06 more lane deviations per minute while engaged in the email interaction. The PVT slope by secondary task interaction term was added to the model, but there was no evidence to suggest it significantly predicted lane deviations per minute. Removing the 3 outliers from lane deviations per minute altered the results such that age was now a significant predictor of lane deviations per minute (t(42) = 2.31, p = .03). The PVT slope by secondary task interaction term was included to the model without the outliers, but there was still no evidence to suggest it significantly predicted lane deviations per minute.

PVT slope, secondary task, and the covariates did not significantly predict MPG during the simulation, although there was marginal evidence to suggest self-reported sleepiness predicted MPG (t(45) = -1.95, p = .06). Removing the outlier from MPG altered the results such that there was marginal evidence to suggest self-reported CMV driving experience predicted MPG (t(44) = -2.01, p = .05) along with self-reported sleepiness. See Table 7 for parameter estimates for all predictors.

Secondary Aim 1. Compare the PVT slope variable to the PVT variables most often utilized to measure vigilance, number of lapses and mean reaction time.

PVT slope and mean reaction time (MeanRT) were significantly correlated (r = -.27, p < .0001), but there was no evidence of multicollinearity. Because of the count nature of number of lapses (instances when participants failed to respond to PVT stimulus within 3,000 ms), this variable was treated as a categorical variable with 5 levels (0 lapses – 5 lapses), and a one-way ANOVA was run to examine the relationship between PVT slope and number of lapses. There was a significant difference among the number of lapses on PVT slope (F(5, 48) = 4.04, p = .002). Compared to those with 0 lapses, those with 2 lapses had 0.03 lower PVT slope values (i.e., reaction time improving over time)(t(49) = -2.85, p = .005), and those with 4 lapses had 0.05 lower PVT slope values (t(49) = -2.44, p = .015).

Number of lapses and MeanRT were added to the GEE Poisson along with PVT slope and the covariates as predictors of overdispersed driving outcomes. Initial analyses suggested MeanRT significantly predicted MVCs ($\chi^2(1) = 6.79$, $p = .009$), but Type III analyses indicated MeanRT was not a significant predictor ($\chi^2(1) = 1.94$, $p = .164$). The predictor variables were not significant predictors of total violations or tailgating. MeanRT and the covariate age were initially shown to be significant predictors of hard braking ($\chi^2(1) = 7.00$, $p = .008$ and $\chi^2(1) = 4.76$, $p = .029$, respectively), but Type III analyses only indicated age to be a significant predictor of hard braking ($\chi^2(1) = 3.97$, $p =$ .046. Removal of the 3 hard braking outliers did not alter results. The PVT variables and covariates were not significant predictors of speeding violations. See Table 8 for RRs and 95% CIs for all predictors.

Number of lapses and MeanRT were included in the linear models predicting the normally distributed driving outcomes along with PVT slope and the covariates as predictors. There was marginal evidence to suggest self-reported sleepiness predicted average driving speed ($t(43) = 1.73$, $p = .091$). The removal of the 2 average driving speed outliers did not affect the results. The PVT variables and covariates were not significant predictors of the number of lane deviations per minute with and without the 3 outliers. There was marginal evidence to suggest self-reported sleepiness predicted MPG ($t(43) = -1.90$, $p = .064$). The removal of the MPG outlier altered the results such that along with the marginal evidence suggesting self-reported sleepiness predicted MPG ($t(42) = -1.85$, $p = .072$), CMV driving experience was shown to be a significant predictor of MPG ($t(42) = -2.06$, $p = .046$). See Table 9 for parameter estimates for all predictors.

Discussion

This study investigated information processing, in the context of CMV driving, where inattention (whether by poor vigilance or secondary task engagement) was proposed to disrupt sensory processing and perception by diverting the limited attentional resourses from these steps in information processing (See Figure 2). Both external distractions (e.g., text messaging, emailing) and internal distractions (e.g., sleepiness, mind wandering) disrupt information processing through bottom-up cognitive processes as indicated in Wickens' (1980) model of information processing. This study was among the first to examine vigilance as measured by PVT slope, a measure of reaction time over a sustained period (Dinges et al., 1997; Drummond et al., 2005; Lim & Dinges, 2008).

Vigilance as Measured by PVT Slope

Aim 1, Hypothesis 1 (Slower reaction time over a sustained period, as indicated by higher values in PVT slope, will be significantly associated with poor driving performance over 4 simulated drives in CMV drivers.) was not supported by the findings of this study.

The results of this study suggest that PVT slope by itself may not be a useful measure of vigilance in the CMV driving outcomes measured in this study. Despite the lack of statistical evidence suggesting PVT slope directly predicts CMV driving performance, it is worth noting that PVT slope appears to be an entirely different measure of vigilance from the commonly used PVT variables of MeanRT and number of lapses. The low correlation between PVT Slope and MeanRT while significant, gave no indication of collinearity to the extent of measuring the same aspect of vigilance.

The relationship between the number lapses and PVT slope is particularly of interest. One would expect that more negative PVT slopes (improving reaction time) would be associated with fewer lapses, but the findings of this study indicated the opposite, such that those CMV drivers with more lapses actually had more negative PVT slopes. While participants were in a private room and potential distractions were attempted to be kept to a minimum, it is possible participants were momentarily distracted by something in the room (e.g., poster on the wall), a consideration previous studies utilizing PVT have noted (Geiger-Brown et al., 2012). However, lapses were rare as participants averaged fewer than 1 lapse and no participant had more than 5 Lapses. Thus, a lack of variability in this small sample might explain the inverse relationship between lapses and PVT slope.

When compared to the PVT variables previously used in the scientific literature (i.e., Mean RT, Lapses (Howard, Jackson, Berlowitz, et al., 2014; Howard, Jackson, Swann, et al., 2014; Jackson et al., 2013)), PVT slope is less predictive of CMV driving performance. While the evidence was only marginal, MeanRT was predictive of MVCs and hard braking instances. These data suggest that the PVT variables most commonly used in measuring vigilance are indeed among the most effective at predicting CMV driving performance, and thus strengthen the findings of previous literature in the field of vigilance and CMV driving.

Aim 1, Hypothesis 2 (Less experienced CMV drivers as measured by self-reported years of CMV driving will be significantly associated with poorer vigilance (high PVT slope) and poorer driving performance compared to more experienced CMV drivers) was not supported by the findings of this study as indicated by the significant positive correlation between PVT slope and CMV driving experience ($r = 0.20$, $p = .004$). The significant positive correlation indicates that PVT slope becomes more positive (worsens) with increasing experience. However, increased CMV driving experience was associated with decreased instances of tailgating in the simulated drive. While MPG is more of an indication of operational efficiency rather than CMV driving safety, compared to those with less CMV driving experience, more experienced CMV drivers were associated with poorer MPG. While it is unknown how driving experience may affect vigilance, CMV driving experience positively impacts CMV driving performance (Markkula, Benderius, Wolff, & Wahde, 2013). The inverse relationship between CMV driving experience and vigilance warrants further investigation in future research.

Secondary Tasks and CMV Driving Performance

Aim 2, Hypothesis 1 (PVT Slope will significantly interact with secondary task condition to predict simulated driving performance in CMV drivers) was not supported by the results of the study. The PVT slope and secondary task condition interaction was not a significant predictor of any CMV driving performance outcome.

The findings of the study highlight the detrimental impact that engaging in secondary tasks has on CMV driving performance. The results of this study further support the findings of previous research on secondary task engagement and CMV driving (Fine et al., 2012; Hanowski et al., 2009; Olson et al., 2009). While vigilance plays a role in CMV driving performance (Jackson et al., 2013) and is worth further examination in the CMV driving population, the results of this study suggest secondary task engagement may have a greater impact upon CMV driving performance than the measures of vigilance indicated by the PVT. That is, the disruption of information through the stages of cognitive processing may be more affected by secondary tasks than by vigilance.

Aim 2, Hypothesis 2 (Contrasts will reveal that the interaction of PVT slope with on-board emailing device will significantly predict CMV driving performance to a greater extent than all other secondary tasks (text messaging interaction, cell phone conversation, and no secondary task presented)) was not supported as no interactions between PVT slope and secondary task condition were indicated. Thus, Hypothesis 3 (Contrasts will reveal that the interaction of PVT slope with cell phone interaction will have the least deleterious effect on driving performance in CMV drivers), and Hypothesis 4 (Older CMV drivers will have poorer driving performance compared to younger CMV drivers in the text messaging interaction and on-board emailing device interaction secondary tasks) were also not supported.

While the interaction of PVT slope and secondary tasks was not significant, the impact of secondary tasks on CMV driving performance reflected findings in previous studies. Previous research has suggested a “protective” nature of talking on a cell phone in CMV driving (Olson et al., 2009) and similar findings were indicated in this study. Drivers had fewer lane deviations when talking on the cell phone than while not engaged in any secondary task, text messaging, or emailing from the on-board device. Considering the size and speed of CMVs while travelling, lane deviations are a serious concern and good indicators of CMV driving performance (Hanowski et al., 2009; Olson et al., 2009).

Due to the time demands of CMV driving (i.e., on-time deliveries), operational efficiency is valuable to CMV drivers and dispatchers (Swedler et al., 2015). Secondary task engagement was associated with slower average speed during the simulated drive, with the cell phone conversation being associated with the slowest average driving speed. However, while slower average driving speed may negatively affect operational efficiency via longer travel times, it may be a conscious attempt to compensate for the diversion of attentional resources towards the secondary task in an attempt to maintain CMV driving safety.

CMV Driving Experience

In examining both the effect of vigilance and the effect of secondary task engagement on driving performance, there was marginal evidence or significant evidence suggesting CMV driving experience was a significant predictor of several CMV driving performance. The results of this study underscore the importance that driving experience has on driving performance. As research in inexperienced light-vehicle drivers (i.e., adolescents) has shown the role that driving experience has in driving performance (Jonah & Dawson, 1987), CMV driving experience has a similar role in CMV driving performance (Markkula et al., 2013).

Experience impacts top-down cognitive processing of information as indicated in Wickens' information processing model (1980), and is affected by improvements in selective attention (McManus, Cox, Vance, & Stavrinos, 2015). Selective attention is necessary for optimal and safe driving performance (Castro, 2009), and has shown to be the best predictor of crash risk in other populations, namely older drivers (Ball & Owsley, 1991). The role of driving experience on driving performance is also present in CMV drivers (Markkula et al., 2013).

Experiment 2

CMV Driver Distraction

Fifteen percent of CMV MVCs in 2013 involved driver distraction (National Highway Traffic Safety Administration [NHTSA], 2015a). While all tasks secondary to the primary task of driving impact driving performance, not all secondary tasks equally degrade CMV driving performance. Olson and colleagues (2009) suggested that compared to other secondary tasks, handheld cell phone usage had the least deleterious effect with any driving performance outcome. More visually-demanding secondary tasks (text messaging and emailing) degrade driving performance to a greater extent, as evidenced by increased driving violations, collisions, and lane deviations (Olson et al., 2009). Furthermore, as the demands of the driving task increase (e.g., increased traffic), CMV drivers converse on a cell phone less frequently when compared to their light vehicle driving counterparts, indicating mobile device use varies depending on the driving context (Fitch et al., 2015a). Mazzae, Goodmanm, and Garrott 2004) found an association between cell phone conversation and the frequency of long-eye fixations on the forward roadway. Considering that visual attention to the roadway decreases crash risk (Hanowski et al., 2009; Olson et al., 2009), talking on the cell phone may act as a protective measure in CMV driving. However, it is unknown what the underlying mechanism is in the association between increased visual attention to the forward roadway and talking on the cell phone.

Previous research has suggested simple cognitive secondary tasks may mitigate vigilance decrements in sustained attention tasks (St John & Risser, 2009), and a cell phone conversation may act in this manner in a CMV driving context. Different secondary tasks affect CMV driving performance in varying ways, with more visually demanding tasks (text messaging and emailing) degrading CMV driving performance to a greater extent (Hanowski et al., 2009; Olson et al., 2009). These secondary tasks may impact CMV driving performance by differentially impacting attention's role in information processing. Text message and email interactions are higher in salience, meaning they stand out from the environment more (Wickens, Hollands, Banbury, & Parasuraman, 2013a). Salience influences attention's impact on information processing from a bottom-up direction (Wickens et al., 2013a). High salience of an interrupting task (i.e., secondary task) reliably and rapidly causes attention to switch away from an ongoing task (i.e., driving) (Trafton, Altmann, Brock, & Mintz, 2003). When salience is low, an interrupting task may not trigger attention away from an ongoing task (i.e., driving), and the result is cognitive tunneling (Wickens et al., 2013d). This tunneling of cognitive resources has been defined as the allocation of attention to a particular channel of information or task goal, for a duration longer than optional, due to the cost of neglecting events on other channels of information or goals (Wickens & Alexander, 2009).Visual tasks interfere with driving to a greater extent than auditory tasks do (Dingus, Hanowski, & Klauer, 2011; Horrey & Wickens, 2004). Because talking on a cell phone has shown associations with maintaining vision towards the roadway (Mazzae et al., 2004), it is possible that cell phone conversations are of a lower salience compared to the more visually demanding tasks of text message and email interactions, and the visual attention towards the roadway is due to the cognitive tunneling seen in low salience tasks.

Specific Aims

The purpose of experiment 2 was to examine the differential visual attention effects that secondary tasks have on CMV driving performance, and how these effects are impacted by vigilance in CMV drivers. Experiment 2 had 2 aims:

Aim 1. To examine the effect that secondary tasks have on CMV driving performance through visual attention in 50 licensed CMV drivers across 4 drives in a CMV driving simulator while controlling for self-reported sleepiness.

Previous research has indicated more visually-demanding secondary tasks (text messaging and emailing) degrade CMV driving performance to a greater extent, as evidenced by increased driving violations, collisions, and lane deviations (Olson et al., 2009). Cell phone conversations offer a unique effect on CMV driving performance when compared to other secondary tasks (i.e., text messaging and emailing), in that talking on a cell phone degrades driving performance and visual attention to a much lesser extent (Olson et al., 2009). Visual attention appears to be directed more towards the roadway when talking on a cell phone (Mazzae et al., 2004), which in turn decreases crash risk (Hanowski et al., 2009; Olson et al., 2009). To date, there is no previous research causally linking secondary task engagement to visual attention and in turn, CMV driving performance.

Mediation analyses were conducted to determine the indirect effect of secondary task engagement through visual attention on CMV driving performance. To identify the causal effect of visual attention on the relationship between secondary tasks and CMV driving performance, total driving violations, MVCs, and lane deviations were analyzed as outcomes to compare results to findings in naturalistic research that have shown associations between secondary tasks and CMV driving performance (Olson et al., 2009), but did not empirically causally link secondary tasks to visual attention and in turn, CMV driving performance.

Hypothesis 1: Visual attention as measured by glances of the simulated roadway will significantly mediate the effect of secondary tasks (no task, cell phone conversation, text messaging interaction, and on-board emailing interaction) on CMV driving performance in a CMV driving simulator.

Aim 2. To determine how vigilance as measured by PVT slope moderates the indirect effect of secondary task through visual attention on CMV driving performance in 50 licensed CMV drivers across 4 drives in a CMV driving simulator while controlling for self-reported sleepiness.

Recent research suggests vigilance decrements are not best explained by any single theory of inattention (Thomson et al., 2015), but rather lapses in attention are a combination of attentional recourses (Smallwood & Schooler, 2006b) and control failure (McVay & Kane, 2010). Attention is a limited resource that acts as a filter of information, selecting certain pieces of information to be processed (Wickens et al., 2013c). Sustained attention is necessary for vigilant tasks, such as long distance CMV driving (Wickens et al., 2013a).

Previous research has suggested simple cognitive secondary tasks may mitigate vigilance decrements in sustained attention tasks (St John & Risser, 2009), and a cell phone conversation may act in this manner in a CMV driving application. Because the maintenance of vigilance over time is a self-regulated limited resource (Rueda et al., 2011), it is possible that individual differences in vigilance differentially impact the effect of secondary tasks on visual attention and in turn, CMV driving performance. To date, the conditional effect that vigilance has on differing visual effects of secondary tasks on CMV driving performance is unknown. This study was among the first to determine if vigilance moderates the mediating effect of visual attention between secondary task engagement and CMV driving performance.

Hypothesis 1: Vigilance as measured by PVT slope will significantly moderate the indirect effect that visual attention as measured by Eye Glances Off Road per minute has on secondary tasks (no secondary task, cell phone conversation, text messaging interaction, and emailing interaction) and simulated CMV driving performance in 50 licensed CMV drivers.

Method

The methodology used in the present study utilized the same participants, materials, and procedure as the above Experiment 1 with the inclusion of the number of eye glances off the simulated roadway per minute.

Measures

Eye glances off road per minute. A video camera was strategically mounted above the simulator providing a full image of the participant. Eye glances off road were recorded as instances during which participants' eyes were off of the simulator screen and fixated elsewhere. Videos were manually coded by two-trained research assistants. Each assistant was blinded to the coding of the other assistant. The two assistants obtained an interrater reliability of $r = .99$. Visual attention towards the roadway has been associated with decreased crash risk in CMV drivers (Hanowski et al., 2009; Olson et al., 2009).

Data Analysis Plan

Aim 1. To examine the effect that secondary tasks have on CMV driving performance through visual attention in 50 licensed CMV drivers across 4 drives in a CMV driving simulator while controlling for self-reported sleepiness.

To compare the results to the findings of Olson and colleagues (Olson et al., 2009), lane deviations per minute, MVCs, and number of total violations were analyzed as the dependent variables in mediation analyses. Mediation analyses were conducted as outlined by Preacher and Hayes (2004) and Hayes (2009), where the recommended 10,000 bootstrapped samples (Hayes, 2013, 2015) were utilized to obtain the 95% CIs of the indirect effect (mediating effect) of the independent variable secondary task on each dependent variable. Additionally, interpretations of mediating effects as “full” or “partial” were absent, as these labels are based on faulty assumptions, not recommended, and considered obsolete in modern mediation analyses (Hayes, 2009, 2013; Rucker, Preacher, Tormala, & Petty, 2011). Because there are 4 levels of the independent variable, dummy coding as recommended by Hayes and Preacher (2014) was used such that the no secondary task condition was the referent, and each relative indirect effect was computed and inference conducted with bootstrapped 95% CIs. The number of glances off road per minute were included as the mediator in examining lane deviations per minute, MVCs, and total violations.

Hayes’ (Hayes, 2012) Process macro was utilized to calculate each indirect effect and direct effect for each secondary task compared to the referent, no secondary task. Continuous dependent variables (lane deviations per minute and total number of violations) were analyzed with ordinary least squares path framework to estimate the indirect effects and direct effects. Because mediation analyses with count outcomes (MVCs) result in negatively biased indirect effects (Coxe & MacKinnon, 2010), MVCs were dichotomized and maximum likelihood estimation methods estimated the effect of the mediator on having an MVC or not, where exponentiation of the indirect effect's coefficient and bootstrapped 95% CIs yield odds ratios (Vanderweele & Vansteelandt, 2010). See Figures 5, 6, and 7 for conceptual diagrams of the mediation models.

Aim 2. To determine if the indirect effect of secondary task through visual attention on CMV driving performance is conditional on vigilance as measured by PVT slope in 50 licensed CMV drivers across 4 drives in a CMV driving simulator while controlling for self-reported sleepiness.

Moderated mediation analyses were conducted using Hayes' (Hayes, 2012) Process macro. PVT slope was included as a moderator between secondary task condition and eye glances off road per minute. The no secondary task condition was set as the referent to all other secondary tasks. Inference for the conditional indirect effect was determined by the index of moderated mediation, an interval estimate of the parameter of a function linking the indirect effect to chosen values of the moderator (Hayes, 2015), where 10,000 bootstrapped samples provide the 95% CI for the index of moderated mediation. The index of moderated mediation is an inference test to determine if indirect effects are significantly different from 0 at any two values of the moderator (Hayes, 2015). See Figures 8, 9, and 10 for conceptual diagrams of the moderated mediation models.

Results

All participant characteristics and descriptive statistics were identical to those in the above Experiment 1 with the addition of eye glances off road per minute (*M* = 5.22, *SD* = 5.42, range: 0.04 - 18.53). There were significant differences among the secondary tasks on eye glances off road per minute ($F(3, 46) = 356.01$, $p < .0001$). The cell phone conversation condition had the fewest eye glances off road per minute (*M* = 0.34, *SD* = 0.22), and the text messaging interaction condition had the most eye glances off road per minute (*M* = 12.05, *SD* = 3.56). There were statistically significant differences between each pairwise comparison of secondary tasks with a Tukey-Kramer method correction, with the exception of the comparison of eye glances off road per minute in the no secondary task condition (*M* = 0.62) and the cell phone conversation condition (*M* = 0.34).

Aim 1. To examine the effect that secondary tasks have on CMV driving performance through visual attention in 50 licensed CMV drivers across 4 drives in a CMV driving simulator while controlling for self-reported sleepiness.

Relative to the no secondary task condition, the effect of cell phone conversation, text messaging interaction, and emailing interaction on lane deviations per minute was significantly mediated by eye glances off road per minute. That is, the indirect effect was statistically significantly different from 0. Compared to the no secondary task condition, talking on the cell phone resulted in significantly fewer lane deviations per minute, because there were fewer eye glances off road per minute (indirect effect = -0.03, 95% CI: -0.06 to -0.01). Compared to the no secondary task condition, the text message interaction resulted in significantly more lane deviations per minute, because there were more eye glances off road per minute (indirect effect = 1.05, 95% CI: 0.06 to 1.85). Compared to the no secondary task condition, the on-board email interaction resulted in significantly more lane deviations per minute, because there was more eye glances off road per minute (indirect effect = 0.67, 95% CI: 0.14 to 1.21). See Figure 11 for the coefficients for each path in the mediation analysis on lane deviations per minute.

Eye glances off road per minute significantly mediated the effect of the cell phone conversation on total violations in the simulated drive. Compared to the no secondary task condition, the cell phone conversation resulted in significantly fewer total violations, due to fewer eye glances off road per minute (indirect effect = -0.21, 95% CI: -0.55 to -0.004). Relative to the no secondary task condition, neither the text messaging interaction nor on-board emailing interaction had a significant indirect effect on total violations through eye glances off road per minute. See Figure 12 for the coefficients of each path in the mediation analysis.

Eye glances off road per minute did not significantly mediate the effect of any secondary task (compared to the no task condition) on having a MVC during the simulated drive. See Figure 13 for the coefficients of each path in the mediation analysis.

Aim 2. To determine if the indirect effect of secondary task through visual attention on CMV driving performance is conditional on vigilance as measured by PVT slope in 50 licensed CMV drivers across 4 drives in a CMV driving simulator while controlling for self-reported sleepiness.

Relative to the no secondary task condition, there was significant moderated mediation of the text messaging interaction (index of moderated mediation = 2.18, 95% CI: 0.48 to 4.86). The relative conditional indirect effect of the text messaging interaction on lane deviations per minute through eye glances off road per minute increased with worsening PVT slopes (more positive slopes). Better PVT slopes (more negative slopes) were associated with lower indirect effects of the text messaging interaction on lane deviations per minute through eye glances off road per minute (point estimate: 1.01, 95% CI: 0.28 to 1.83), while poorer PVT slopes (more positive slopes) were associated with larger indirect effects (point estimate: 1.23, 95% CI: 0.37 to 2.12).

Relative to the no secondary task condition, there was significant moderated mediation of the on-board emailing interaction (index of moderated mediation = 1.61, 95% CI: 0.43 to 3.91). The relative conditional indirect effect of the on-board emailing interaction on lane deviations per minute through eye glances off road per minute increased with worsening PVT slopes. Better PVT slopes (more negative slopes) were associated with lower indirect effects of the text messaging interaction on lane deviations through glances (point estimate: 0.66, 95% CI: 0.22 to 1.16), while poorer PVT slopes (more positive slopes) were associated with larger indirect effects (point estimate: 0.81, 95% CI: 0.26 to 1.14). Relative to the no secondary task condition, there was no moderated mediation of the cell phone conversation on lane deviations per minute. See Figure 14 for the coefficients of each path in the moderated mediation analysis and Table 10 for the indirect effects at differing values of PVT slope.

Compared to the no secondary task condition, there was significant moderated mediation of the text messaging interaction on total violations in the simulated drive (index of moderated mediation = 18.97, 95% CI: 2.20 to 49.92). The relative conditional indirect effect of the text message interaction on total violations through eye glances off road per minute was smaller at better PVT slopes (point estimate: 8.83, 95% CI: 0.09 to 16.80), and larger at poorer PVT slopes (point estimate: 10.67, 95% CI: 0.36 to 20.12).

Moderated mediation was also indicated in the on-board emailing interaction on total violations, relative to the no secondary task condition (index of moderated mediation = 13.52, 95% CI 2.05 to 33.01). The relative indirect effect of the on-board emailing interaction on total violations through eye glances off road per minute was smaller at better PVT slopes (point estimate: 5.53, 95% CI: 0.43 to 10.50) and larger at poorer PVT slopes (point estimate: 6.84, 95% CI: 0.46 to 12.51). There was no evidence of moderated mediation in the cell phone conversation task. See Figure 15 for the coefficients of each path in the moderated mediation analysis and Table 11 for the indirect effects at differing values of PVT slope.

There was no statistically significant evidence of moderated mediation among any of the secondary tasks (relative to the no secondary task condition) on simulated MVCs. See Figure 16 for the coefficients of each path in the moderated mediation analysis and Table 12 for the indirect effects at differing values of PVT slope.

Discussion

This study was among the first to causally link secondary tasks to visual attention, and in turn, CMV driving performance. Previous findings from naturalistic research have associated visually demanding tasks with poor CMV driving performance (Hanowski et al., 2009; Olson et al., 2009), and visual attention toward the roadway has been found to decrease crash risk in all drivers (Mazzae et al., 2004). However, to date, this is the first study to empirically identify visual attention as one of the underlying mechanisms in how and to what extent secondary tasks affect CMV driving performance.

Aim 1, Hypothesis 1 (Visual attention as measured by glances of the simulated roadway will significantly mediate the effect of secondary tasks (no task, cell phone conversation, text messaging interaction, and on-board emailing interaction) on CMV driving performance in a CMV driving simulator) was supported. The results of this study indicate that the posited protective measure potentially offered by cell phone conversations (Olson et al., 2009) is due in part to visual attention mediating the effect of secondary tasks on CMV driving performance. Olson and colleagues' naturalistic findings (2009) were experimentally replicated in that the text messaging interaction and on-board emailing interaction resulted in greater visual attention away from the roadway, which in turn resulted in more lane deviations. The opposite effect was displayed during the cell phone conversation, in which visual attention remained on the roadway and resulted in fewer lane deviations and total violations. Because this effect of the cell phone conversation was relative to the no secondary task condition, these results indicate that CMV driving performance as measured by lane deviations and total violations may be *better* when talking on the cell phone due to fewer glances away from the road.

However, it is unknown if the mediating effect of visual attention on secondary tasks and CMV driving performance varies with different driving conditions. Because CMV drivers converse on a cell phone less when in demanding driving conditions (Fitch, Hanowski, & Guo, 2015b), future research should consider investigating the mediating effect of vision on secondary tasks and CMV driving performance in a variety of CMV driving environments.

Aim 2, Hypothesis 1 (Visual attention as measured by glances of the simulated roadway will significantly mediate the effect of secondary tasks (no task, cell phone conversation, text messaging interaction, and on-board emailing interaction) on CMV driving performance in a CMV driving simulator) was supported. The association of vigilance as measured by traditionally used measures of PVT (MeanRT and lapses) and CMV driving has been established (Howard, Jackson, Berlowitz, et al., 2014; Howard, Jackson, Swann, et al., 2014; Jackson et al., 2013), and the findings of this study have added PVT slope as a viable predictor of CMV driving performance. Unlike MeanRT which only supplies an average reaction time across 10 minutes, PVT slope indicates how psychomotor abilities change over time (Dinges et al., 1997). Because attention is a limited resource necessary for driving the stages of information processing (Smallwood & Schooler, 2006a; Wickens et al., 2013c), PVT slope may be a potential indicator of how quickly one's attentional resources deplete. Thus, the finding that the mediating effect of visual attention between secondary tasks and CMV driving performance was found to be conditional on the PVT slope of the CMV driver, may indicate that those with more quickly depleting attentional resources were more affected by the secondary tasks' degradation of visual attention to the roadway.

Regardless of a driver's vigilance as measured by PVT slope, the significant indirect effect linking cell phone conversation to reduced glances off road and in turn reduced lane deviations and violations was constant. That is, regardless of a CMV driver's vigilance, cell phone conversations may benefit CMV driving performance. The mediating effect of visual attention in the text messaging and on-board emailing interactions differed depending on the vigilance of the driver. The results of this study indicate that compared to CMV drivers with better PVT slopes (more negative values), CMV drivers with poorer vigilance are more negatively affected by the eye glances off the roadway that result from texting and on-board emailing, displaying a greater degradation of CMV driving performance.

These findings suggest PVT slope may potentially be utilized as a method of identifying CMV drivers who may be more susceptible to the negative effects of engaging in secondary tasks. While visually demanding secondary tasks should be avoided (Hanowski et al., 2009; Olson et al., 2009), CMV drivers with poor vigilance as indicated by PVT slope may require further education on distracted driving to encourage them to avoid engaging in secondary tasks while driving. CMV drivers may engage in secondary tasks to help them overcome the effects of fatigue (Williamson et al., 2001), and the findings of this study indicate that talking on the cell phone may be the optimal choice. However, dialing on a cell phone should be avoided (Olson et al., 2009), and thus, hands-free cell phone conversations may be the best option, regardless of a CMV driver's vigilance level. The results of this study also support the FMCSA regulations and policy which ban hand-held cell phone use while in motion (United States Department of Transportation, 2011).

Conclusion

The findings of these two experiments highlight the role of vigilance in information processing in the context of CMV driving. Furthermore, the results of these studies identify underlying mechanisms by which secondary tasks impact CMV driving performance, and how these mechanisms are dependent upon vigilance.

Impact on Information Processing

As attention is a limited resource (Wickens & McCarley, 2008) and has an important role in the processing of information (Wickens, 1980), allocating the attention away from the primary task's environment may result in a disruption of sensory processes and perception of environmental stimuli. Secondary task engagement can negatively impact the ability to sense and perceive information from environmental stimuli, known as bottom-up processing (Theeuwes, 1993). While secondary tasks may temporarily disrupt information processing from the bottom-up direction, CMV driving experience affects information processing from top-down cognitive processes, processes driven by experience and knowledge (Wickens & Hollands, 2000).

Because vigilance is defined as the sustained attention to monotonous tasks (Robertson & Garavan, 2004), vigilance may affect both bottom-up processes and top-down processes, and may act as a monitor of attention allocation. Due to long travel distances and delivery time demands imparted on CMV drivers, and the multitasking activities CMV drivers may do in response (Swedler et al., 2015), the self-regulation of maintaining vigilance is an important consideration. The role of vigilance in information processing still has yet to be fully examined, particularly in a CMV driving context.

To better understand how vigilance affects information processing in CMV driving performance across the lifespan, a larger sample of older adults (65 years and older) is necessary. The age range in this sample (24-54 years) limited the generalizability of the findings to older CMV drivers (aged 65 and older). While there were participants with less than a full year of CMV driving experience, the average CMV driving experience was over 8 years. A larger sample of drivers with very little CMV driving experience is also necessary to examine vigilance and CMV driving experience, as CMV carriers consider CMV experience as important criteria for hiring (Corsi & Barnard, 2003) and prior experience as an effective safety management technique

(Knipling, Hickman, & Bergoffen, 2003). Because older drivers and less experienced drivers may be especially prone to narrowing attention (Crundall et al., 1999; Mills et al., 2001), the impact of vigilance on CMV driving in these populations should be examined in future research.

Limitations

No study is without limitations, and several are noted here. The small sample size of 50 made it difficult to thoroughly analyze the association of the PVT slope, secondary task engagement, and the covariates while preserving adequate power. Several analyses indicated marginal evidence to suggest the predictive ability of the independent variables and covariates on CMV driving performance, and a larger sample size would likely indicate sufficient statistical evidence of predicting CMV driving performance.

A few of the covariates were provided by self-report, and as such, there may be a certain degree of error in self-reported data, especially in regards to driving experience (Langford, Koppel, McCarthy, & Srinivasan, 2008; Langford, Methorst, & Hakamies-Blomqvist, 2006). Self-reported sleepiness was used as a covariate in all analyses, as was self-reported CMV driving experience. It may have been difficult for several CMV drivers to accurately recall how long they had been a CMV driver.

Several predictor variables and covariates (self-reported Sleepiness, CMV driving experience, and age) were not normally distributed. While normality is not a requirement of continuous predictors in regression, the solutions are generally improved when the predictor variables are normally distributed (Tabachnick & Fidell, 2007). While transformations to these variables were considered, the results of analyses were not affected by the transformations, and the raw variables were used for interpretability. A larger sample size would potentially improve the distribution of these variables.

Access to the driving simulator was only available following typical office hours (i.e., 5:00 PM), and thus, participation occurred at night. Previous research has found that nighttime driving is slower, with a greater speed variability and increased lane deviations in CMV drivers (Gillberg et al., 1996). It is possible that these effects were present in the simulated drive, although the simulated driving environment was a daytime scenario.

As participants were offered short breaks between driving scenarios, many participants consumed caffeine or tobacco products. Caffeine has been shown to offer a protective effect on CMV driving performance (Heaton & Griffin, 2015). The stimulating effect of nicotine in tobacco may present similar effects to caffeine and may have affected results of the simulated drive. While a potential limitation, it is likely a reality that due to the nature of the CMV driving occupation, CMV drivers frequently drive at night and consume caffeine (Pylkkonen et al., 2015), thereby increasing the external validity of the results of this study.

Driving simulators provided necessary experimental control to test hypotheses with regards to driving performance, especially when investigating secondary tasks that may be detrimental to driving safety. While the driving simulator and scenario were designed to mimic the real-world conditions of CMV driving, it is difficult to truly ascertain the degree to which simulated CMV driving performance maps on to real world CMV driving behavior. In real-world CMV driving, drivers have strong incentives to avoid MVCs for multiple reasons, notably because CMV MVCs may result in serious injury. Such an incentive is likely absent when driving in a CMV driving simulator and could have potentially influenced the findings of this study.

PVT was administered only once before the participants drove in the CMV driving simulator. It is unknown how PVT may have changed over the duration of the simulated drive. A study examining the effects of extended wakefulness and alcohol administered the PVT at two time points along with a simulated drive (Howard et al., 2007). Previous research has indicated the PVT is reliable with no evidence of practice effects over multiple administrations (Balkin et al., 2004).

The findings of this study support the previous research on vigilance and secondary task engagement in CMV driving performance. Because CMV driving is a complex task with a large amount of information to process, the attention which fuels these processes must be managed by vigilance. Thus, vigilance plays an important role in CMV driving performance and safety. Secondary task engagement is detrimental to CMV driving performance, and certainly should be avoided due to safety reasons. However, this study empirically replicated findings of previous naturalistic research and suggested talking on the cell phone may be a protective secondary task in part to the underlying mechanism by reducing eye glances away from the roadway. While reduced CMV average driving speed may be exchanged for fewer lane deviations, talking on the cell phone, particularly hands-free, may be a mechanism to maintain vigilance through a medium that disrupts bottom-up processing to a lesser extent than other forms of distraction which are more visually demanding (e.g., text messaging).

The results of this study investigated a component of vigilance that has previously been unexamined. While PVT slope was not shown to significantly predict CMV driving performance in Experiment 1, its use and other measures of vigilance continue to warrant further investigation in information processing in the context of CMV driving. Because the mediating effect of visual attention between secondary tasks and CMV driving performance was significantly moderated by PVT slope in Experiment 2, PVT slope may provide a measure to identify individuals whose CMV driving performance may be particularly impacted by the visual demands of secondary tasks. PVT slope may also identify times when a driver’s vigilance is poor or decreasing.

By examining factors that affect CMV driving performance, this study has the overarching goal of reducing injury and fatalities in transportation. The results of the study support current FMCSA regulation and policy restricting hand-held cell phone use for CMV drivers, and may inform future policies and procedures related to CMV licensure and driving by identifying the underlying mechanisms affecting long-haul CMV driving performance. Better understanding the role of vigilance in CMV driving may allow for CMV drivers, companies, and training facilities to determine their abilities in a long-haul driving capacity. These findings may assist in the development and implementation of methods to improve vigilance in CMV driving. The results of the study may also further the development of information processing models. Vigilance may be included as a separate or mediating stage in the processing of information, especially in the context of driving.

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Table 1

NHTSA and Trick and Enns' Distraction Categories and Definitions

Categories	Definition	Internal/External
Visual	Tasks that require the driver to look away from the roadway to visually obtain information (National Highway Traffic Safety Administration [NHTSA], 2014b)	External
Manual	Tasks that require the driver to take a hand off the steering wheel and manipulate a device (National Highway Traffic Safety Administration [NHTSA], 2014b)	External
Cognitive	Any thoughts that absorb the driver's attention to the point where they are unable to navigate through the road network safely and their reaction time is reduced (Young, Regan, & Hammer, 2003)	Internal
Visual	Tasks requiring visual and can directly conflict at the visual input of cognition (Trick & Enns, 2009)	External
Cognitive	Tasks requiring cognitive processing that do not directly require looking, or caused by the cognitive effort derived from a visual input (Trick & Enns, 2009)	Internal
Activation	Arousal or energy aspects of attention, altered states, affecting the availability of attentional resources (Trick & Enns, 2009)	Internal
Anticipation	Related to the learning and expertise and are closely linked to inexperience (Trick & Enns, 2009)	Internal

Table 2

Demographic, PVT, and Driving Performance Descriptive Statistics for 50 Commercial Motor Vehicle Drivers

Variables	*M (SD)*	*n* (%)	Range
Demographic variables			
Age (Years)	39.8 (8.36)		24-54
Gender (number of men)		49 (98%)	
Ethnicity (Caucasian)		28 (56%)	
Years since receiving full driver's license	8.02 (6.96)		0-24
PVT variables			
PVT Slope (milliseconds per minute)	-0.03 (0.05)		-0.13-0.12
Self-reported Sleepiness (1 = not at all, 10 = extremely sleepy)	4.12 (2.75)		1-10
Mean Reaction Time (milliseconds)	252.74 (26.03)		202.07-326.16
Number of Lapses	0.84 (1.16)		0-5
Driving Performance variables			
Total Violations	28.89 (10.73)		0-49
Average Speed (miles per hour)	54.86 (6.72)		25.56-72.90
Speeding violations	13.44 (9.33)		0-26
Hard Braking violations	0.67 (0.92)		0-5
Tailgating violations	14.87 (6.02)		0-24
Miles per Gallon	5.48 (0.67)		3.23-7.10
Lane deviations per minute	1.10 (0.99)		0.04-5.61
MVCs (Had at least 1 MVC)		12 (24%)	
MVCs	0.17 (0.55)		0-4

Note: M = mean, SD = Standard Deviation, PVT = Psychomotor Vigilance Task, MVC = Motor Vehicle Collision

Table 3

Intercorrelations Among Variables Used in Analyses

	PVT Slope	Sleepiness	Age	Experience	Total Violations	Average Speed	Speeding	Hard Braking	Tailgating	Miles per Gallon	Lane Deviations per Minute	MVCs
PVT Slope	1	0.14*	0.11	0.20**	-0.14*	0.09	-0.12	-0.07	-0.03	0.05	-0.05	0.03
Sleepiness		1	-0.07	-0.18*	0.12	0.19**	0.16*	0.01	-0.02	-0.20**	0.14	-0.02
Age			1	0.46***	-0.02	-0.09	-0.03	0.10	0.01	0.02	0.12	0.01
Experience				1	0.02	0.01	0.11	0.04	-0.10	-0.12	0.03	0.09
Total Violations					1	0.50***	0.82***	0.02	0.46***	-0.58***	0.34***	0.14*
Average Speed						1	0.59***	-0.06	-0.05	-0.55***	0.38***	0.20**
Speeding							1	0.05	-0.11	-0.67***	0.38***	0.21**
Hard Braking								1	-0.06	-0.30***	0.22**	0.20**
Tailgating									1	0.03	0.004	-0.06
Miles per Gallon										1	-0.50***	-0.26***
Lane Deviations per Minute											1	0.38***
MVCs												1

Note: PVT = Psychomotor Vigilance Task, MVC = Motor vehicle Collision
* *p*<.05
** *p*<.01
*** *p*<.001

Table 4

Rate Ratios (RR) and 95% Confidence Intervals (CI) of Predictors in General Estimating Equation (GEE) Predicting Driving Outcomes

	MVC		Total Violations		Tailgating		Hard Braking		Speeding	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
PVT Slope	1.32	0.0004-4900.36	0.30	0.06-1.59	1.21	0.34-4.36	0.09	0.003-3.17	0.07	0.003-1.62
Age	0.96	0.87-1.05	1.00	0.99-1.01	1.01	1.00-1.01	1.02	0.99-1.05	0.99	0.97-1.01
CMV Driving Experience	1.07	0.96-1.20	1.00	0.99-1.01	0.99*	0.97-0.99	1.00	0.97-1.03	1.02	0.99-1.05
Sleepiness	0.99	0.85-1.16	1.02	0.99-1.05	0.99	0.97-1.02	1.02	0.95-1.09	1.06*	1.00-1.12.

Note: MVC = Motor Vehicle Collision, PVT = Psychomotor Vigilance Task, CMV = Commercial Motor Vehicle
* indicates marginal evidence that RR is not 1.

Table 5

Coefficients (b), Standard Error (SE), and p values (p) for Predictors in Linear Models Predicting Driving Outcomes

	Average Speed				Lane Deviations per Minute				MPG			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
PVT Slope	-0.27	13.68	-0.02	0.98	-1.95	2.08	-0.94	0.35	1.71	1.78	0.96	0.34
Age	-0.07	0.09	-0.82	0.41	0.02***	0.01	2.31	0.03	0.01	0.01	0.69	0.49
CMV Driving Experience	0.10	0.11	0.93	0.36	0.002	0.02	0.14	0.89	-0.03**	0.01	-2.01	0.05
Sleepiness	0.42*	0.24	1.74	0.09	0.06	0.04	1.59	0.12	-0.06*	0.03	-1.95	0.06

Note. PVT = Psychomotor Vigilance Task, CMV = Commercial Motor Vehicle, MPG = Miles per Gallon
* Marginal evidence that coefficient is different from 0
** Marginal evidence coefficient is different from 0 with outlier removed
*** $p < .05$ with outliers removed

Table 6

Rate Ratios (RR) and 95% Confidence Intervals (CI) of Predictors in General Estimating Equations (GEE) Predicting Driving Outcomes

	MVC		Total Violations		Tailgating		Hard Braking		Speeding	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
PVT Slope	1.11	0.00-38883.90	0.30	0.06-1.59	1.20	0.33-4.31	0.08*	0.002-2.82	0.08	0.003-1.69
Age	0.95	0.86-1.06	1.00	0.99-1.01	1.01	1.00-1.01	1.02	0.99-1.05	0.99	0.97-1.01
CMV Driving Experience	1.08	0.95-1.23	1.00	0.98-1.01	0.99*	0.97-1.00	1.00	0.98-1.03	1.02	0.99-1.05
Sleepiness	0.99	0.84-1.18	1.02	0.99-1.05	0.99	0.97-1.02	1.02	0.95-1.09	1.06	1.00-1.12
Cell Phone Conversation	0.46	0.08-2.58	1.03	0.88-1.19	1.06	0.89-1.25	1.45	0.86-2.44	0.86	0.72-1.03
Text Messaging Interaction	2.55	0.68-9.53	1.08	0.92-1.28	1.15	0.95-1.39	1.79	0.92-3.47	0.92	0.74-1.16
Emailing Interaction	30.1	0.89-10.16	1.12	0.96-1.30	1.11	0.94-1.31	1.21	0.69-2.12	1.05	0.90-1.23

Note: PVT = Psychomotor Vigilance Task, MVC = Motor Vehicle Collision, No task was referent group for cell phone conversation, text messaging interaction, and emailing interaction
* Marginal evidence suggesting RR is not 1

Table 7

Coefficients (b), Standard Error (SE), and p values (p) for Predictors in Linear Models Predicting Driving Outcomes

	Average Speed				Lane Deviations per Minute				MPG			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
PVT Slope	8.21	14.67	0.56	0.58	-1.95	2.08	-0.94	0.35	1.71	1.78	0.96	0.64
Age	-0.10	0.09	-1.06	0.30	0.02	0.01	1.20	0.23	0.01	0.01	0.69	0.49
CMV Driving Experience	0.08	0.11	0.71	0.48	0.002	0.02	0.14	0.89	-0.02	0.01	-1.63	0.11
Sleepiness	0.47*	0.26	1.81	0.08	0.06	0.04	1.59	0.12	-0.06*	0.03	-1.95	0.06
Cell Phone Conversation	-3.19**	1.04	-3.06	0.003	-0.11	0.11	-1.04	0.30	0.07	0.07	0.96	0.34
Text Messaging Interaction	-2.36**	1.04	-2.26	0.03	0.94**	0.11	8.67	<.001	0.13*	0.07	1.83	0.07
Emailing Interaction	-2.67**	1.04	-2.55	0.01	1.06**	0.11	9.76	<.001	0.10	0.07	1.40	0.16

Note. PVT = Psychomotor Vigilance Task, MPG = Miles per Gallon, No task was referent group for cell phone conversation, text messaging interaction, and emailing interaction

* Indicates marginal evidence that b is statistically different from 0

** $p < .05$

Table 8

Rate Ratios (RR) and 95% Confidence Interval (CI) of Predictors in General Estimating Equations (GEE) Prediction Driving Outcomes

	MVC		Total Violations		Tailgating		Hard Braking		Speeding	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
PVT Slope	9.77	0.01-14475.75	0.44	0.06-3.38	1.05	0.26-4.29	0.93	0.01-86.75	0.14	0.004-4.84
Lapses	0.70	0.40-1.20	1.03	0.97-1.09	1.01	0.94-1.08	0.85	0.65-1.12	1.06	0.95-1.19
Mean RT	1.02*	1.01-1.04	1.00	1.00-1.01	1.00	1.00-1.00	1.02	1.00-1.03	1.01	1.00-1.01
Age	1.00	0.93-1.08	1.00	0.99-1.01	1.00	1.00-1.01	1.04**	1.00-1.08	1.00	0.98-1.03
CMV Driving Experience	1.03	0.94-1.12	1.00	0.99-1.01	0.99	0.97-1.00	0.99	0.95-1.03	1.02	0.99-1.05
Sleepiness	1.05	0.89-1.22	1.02	0.98-1.05	0.99	0.97-1.02	1.03	0.95-1.11	1.03	0.96-1.10

Note: PVT = Psychomotor Vigilance Task, MVC = Motor Vehicle Collision, RT = Reaction Time, CMV = Commercial Motor Vehicle
** $p < .05$

Table 9

Coefficients (b), Standard Error (SE), and p values (p) for Predictors in Linear Models Predicting Driving Outcomes

	Average Speed				Lane Deviations per Minute				MPG			
	b	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*	*b*	*SE*	*t*	*p*
PVT Slope	3.78	14.28	0.26	0.79	-0.96	2.10	-0.45	0.65	1.23	1.85	0.67	0.51
Lapses	-0.02	0.97	-0.02	0.98	0.04	0.10	0.36	0.72	-0.02	0.09	-0.22	0.83
Mean RT	0.03	0.03	0.94	0.35	0.01	0.004	1.56	0.13	-0.003	0.004	-0.83	0.41
Age	-0.06	0.09	-0.63	0.53	0.02	0.01	1.48	0.15	0.01	0.01	0.53	0.60
CMV Driving Experience	0.10	0.11	0.91	0.37	0.004	0.02	0.24	0.81	-0.02**	0.01	-2.06	0.04
Sleepiness	0.42*	0.24	1.73	0.09	0.06	0.04	1.59	0.12	-0.06*	0.03	-1.90	0.06

Note. PVT = Psychomotor Vigilance Task, MVC = Motor Vehicle Collision, No task was referent group for cell phone conversation, text messaging interaction, and emailing interaction

* Indicates marginal evidence that b is not 0

** $p < .05$ with the removal of outliers

Table 10

Relative Indirect Effects of Eye Glances Off Road Per Minute at One Standard Deviation Below Mean PVT Slope, Mean PVT Slope, and One Standard Deviation Above Mean PVT Slope on Simulated Lane Deviations

	Cell Phone Conversation			Text Message Interaction**			On-board Email Interaction**		
PVT Slope	Effect	Lower 95% CI	Upper 95% CI	Effect	Lower 95% CI	Upper 95% CI	Effect	Lower 95% CI	Upper 95% CI
- 1 SD	-0.027*	-0.07	-0.002	1.01*	0.28	1.83	0.66*	0.22	1.16
Mean	-0.031*	-0.07	-0.01	1.12*	0.33	1.96	0.73*	0.23	1.27
+ 1 SD	-0.034*	-0.08	-0.01	1.23*	0.37	2.12	0.81*	0.26	1.14

Note. PVT = Psychomotor Vigilance Task, CI = Confidence Interval, SD = Standard Deviation

* Effect significantly different from 0

** Significant Index of Moderated Mediation

Table 11

Relative Indirect Effects of Eye Glances Off Road Per Minute at One Standard Deviation Below Mean PVT Slope, Mean PVT Slope, and One Standard Deviation Above Mean PVT Slope on Simulated Total Violations

	Cell Phone Conversation			Text Message Interaction**			On-board Email Interaction**		
PVT Slope	Effect	Lower 95% CI	Upper 95% CI	Effect	Lower 95% CI	Upper 95% CI	Effect	Lower 95% CI	Upper 95% CI
- 1 SD	-0.24*	-0.71	-0.01	8.83*	0.09	16.80	5.53*	0.43	10.50
Mean	-0.28*	-0.62	-0.06	9.75*	0.17	18.36	6.18*	0.45	11.48
+ 1 SD	-0.31*	-0.72	-0.07	10.67*	0.36	20.12	6.84*	0.46	12.51

Note. PVT = Psychomotor Vigilance Task, CI = Confidence Interval, SD = Standard Deviation

* Effect significantly different from 0

** Significant Index of Moderated Mediation

Table 12

Relative Indirect Effects of Eye Glances Off Road Per Minute at One Standard Deviation Below Mean PVT Slope, Mean PVT Slope, and One Standard Deviation Above Mean PVT Slope on Simulated MVCs

	Cell Phone Conversation			Text Message Interaction			On-board Email Interaction		
PVT Slope	Effect	Lower 95% CI	Upper 95% CI	Effect	Lower 95% CI	Upper 95% CI	Effect	Lower 95% CI	Upper 95% CI
- 1 SD	-0.01	-0.10	0.06	0.03	-2.46	2.51	0.19	-1.54	1.95
Mean	-0.01	-0.10	0.07	0.03	-2.68	2.80	0.21	-1.71	2.19
+ 1 SD	-0.01	-0.11	0.09	0.03	-2.87	3.09	0.24	-1.90	2.44

Note. MVC = Motor Vehicle Collision, PVT = Psychomotor Vigilance Task, CI = Confidence Interval, SD = Standard Deviation

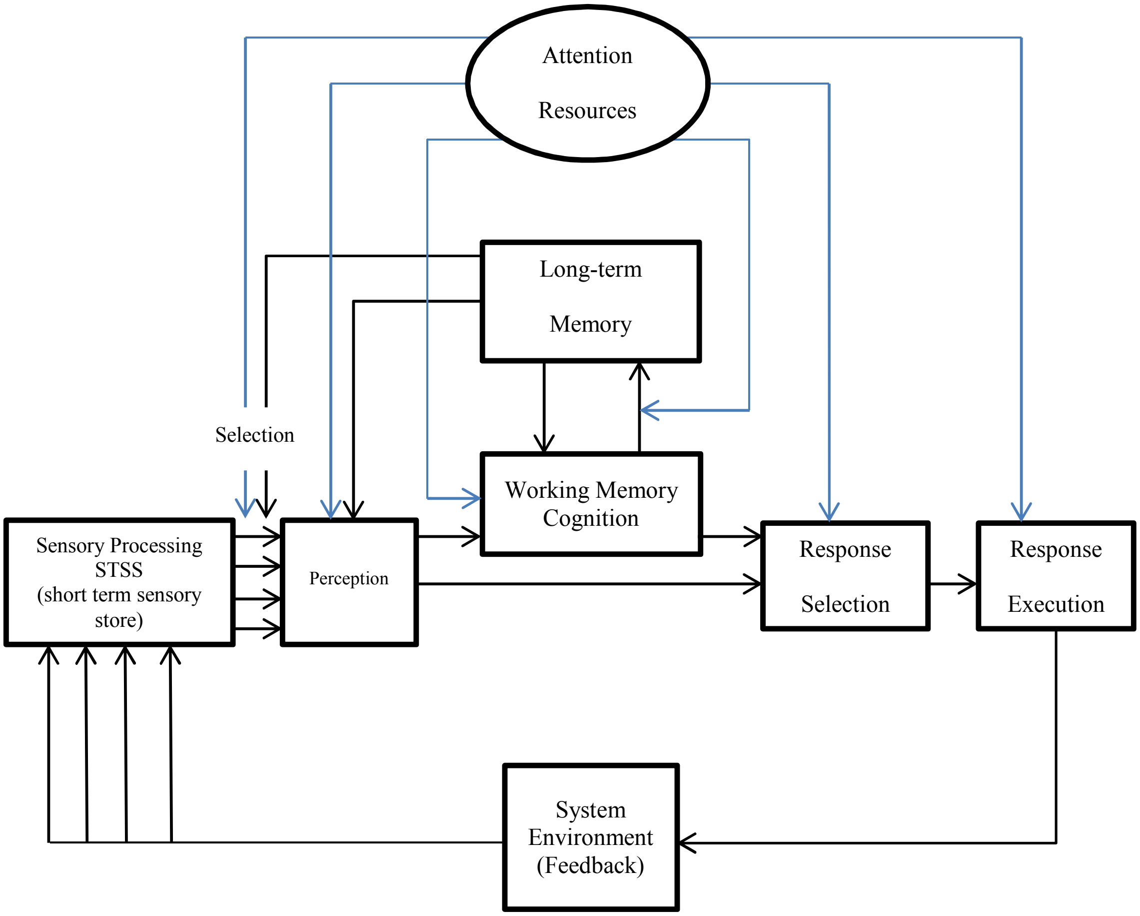


Figure 1. Wickens' model of human information processing (Wickens, Hollands, Banbury, & Parasuraman, 2013c)

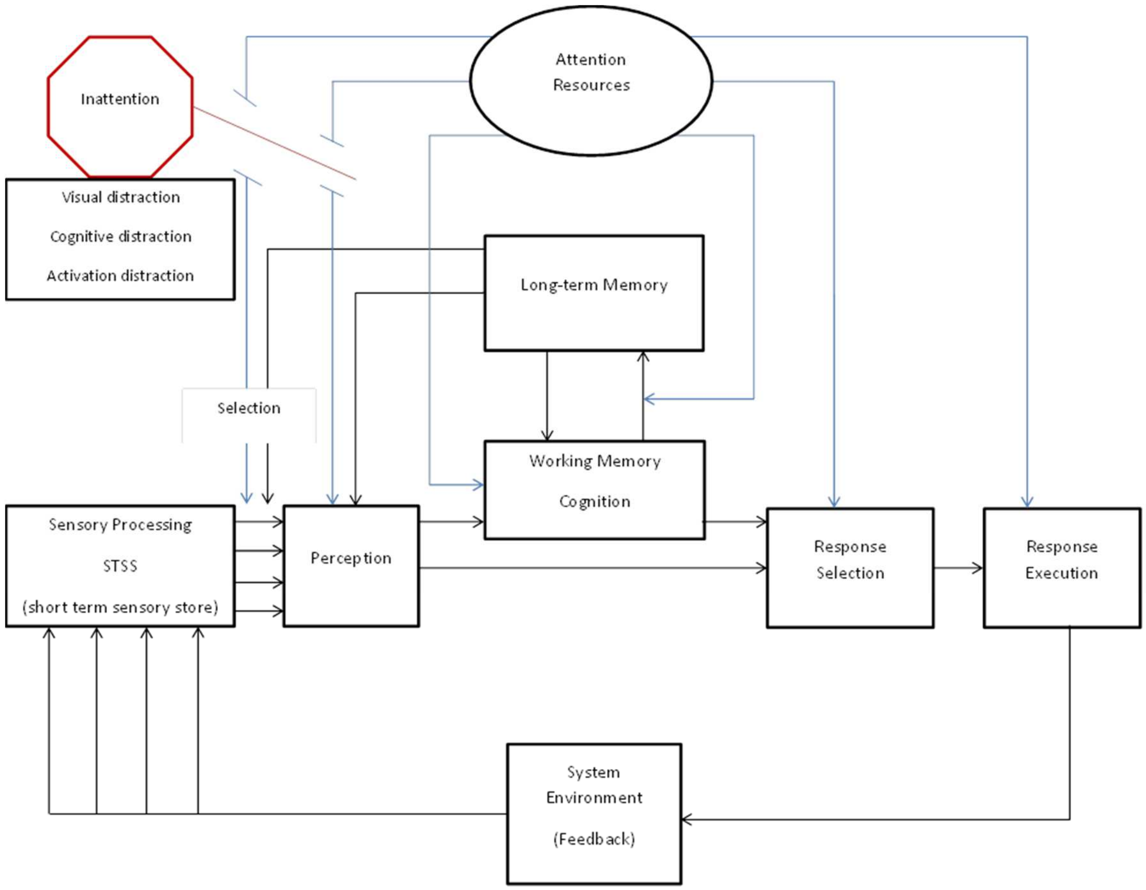


Figure 2: Testing information processing where inattention disrupts sensory processing and perception

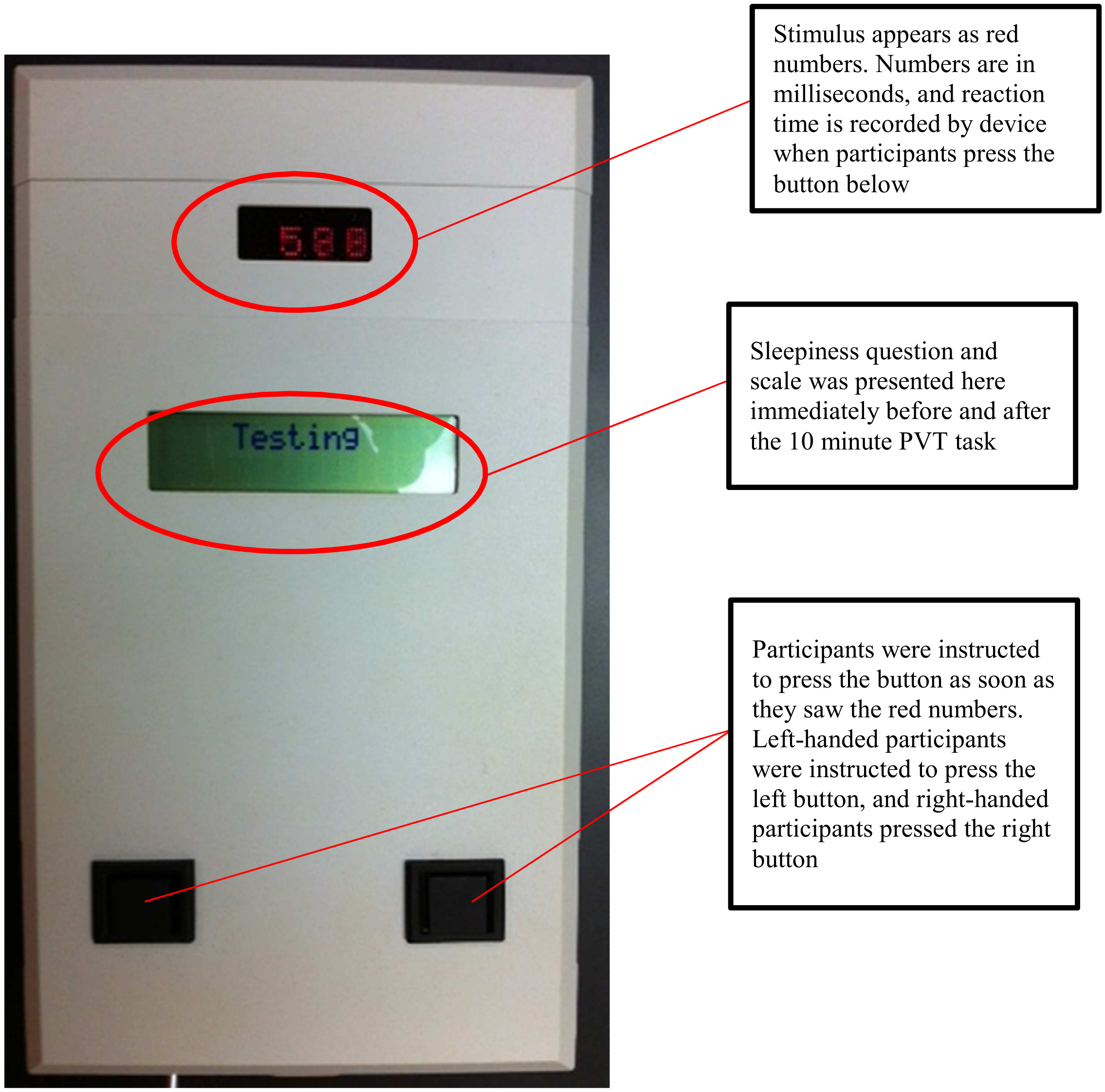


Figure 3. The Psychomotor Vigilance Task (PVT) device

Figure 4. L-3 Communications Truck Driving Simulator

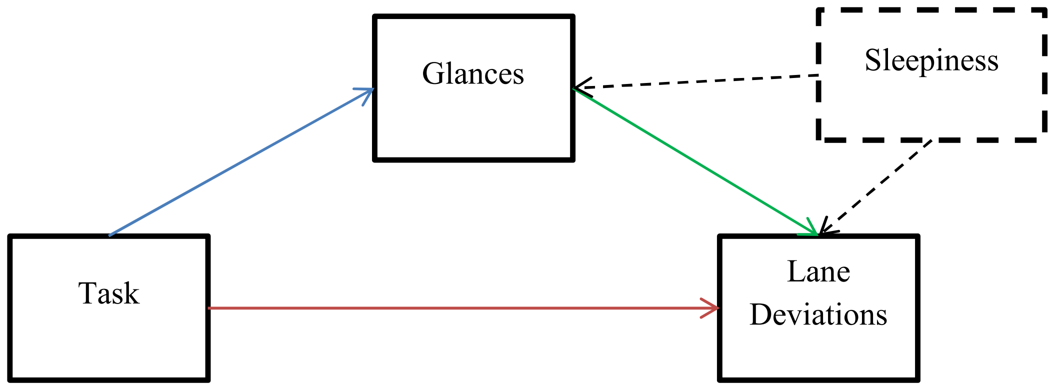


Figure 5. Conceptual model of eye glances off road per minute mediating the effect of secondary task on simulated lane deviations per minute while controlling for sleepiness

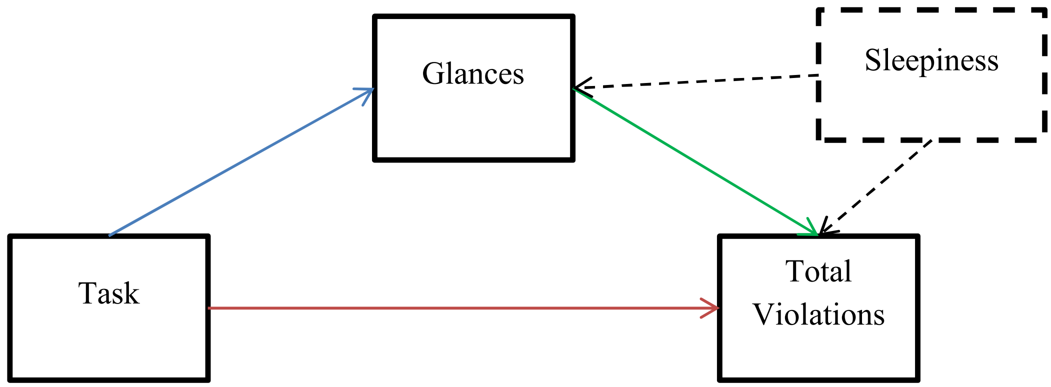


Figure 6. Conceptual model of eye glances off road per minute mediating the effect of secondary task on total violations in the simulated drive while controlling for sleepiness

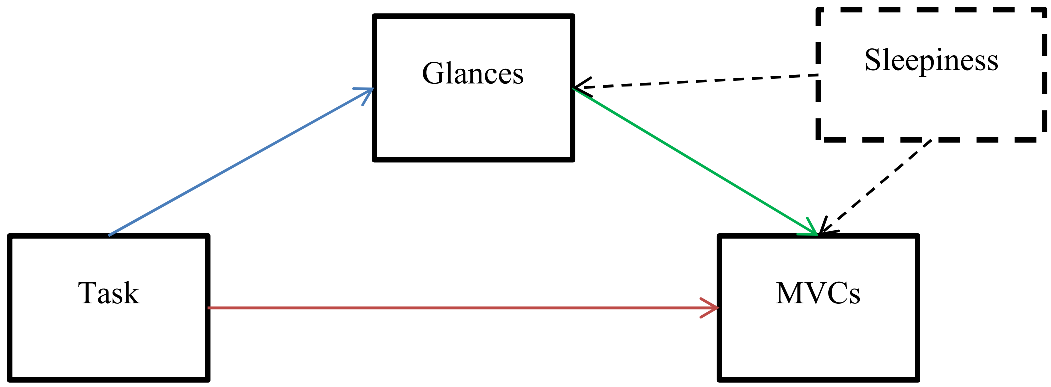


Figure 7. Conceptual model of eye glances off road per minute mediating the effect of secondary task on simulated MVCs while controlling for sleepiness

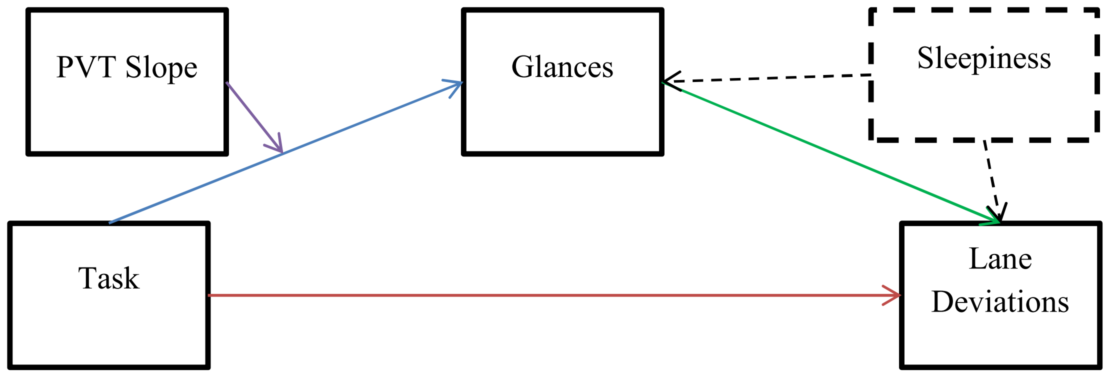


Figure 8. Conceptual model of eye glances off road per minute mediating the conditional effect of PVT slope on secondary task and simulated lane deviations per minute while controlling for sleepiness

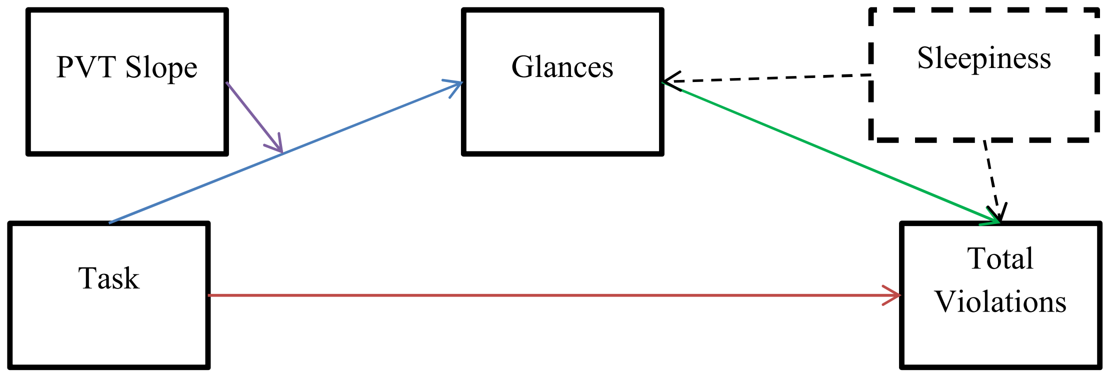


Figure 9. Conceptual model of eye glances off road per minute mediating the conditional effect of PVT slope on secondary task and total violations in the simulated drive while controlling for sleepiness

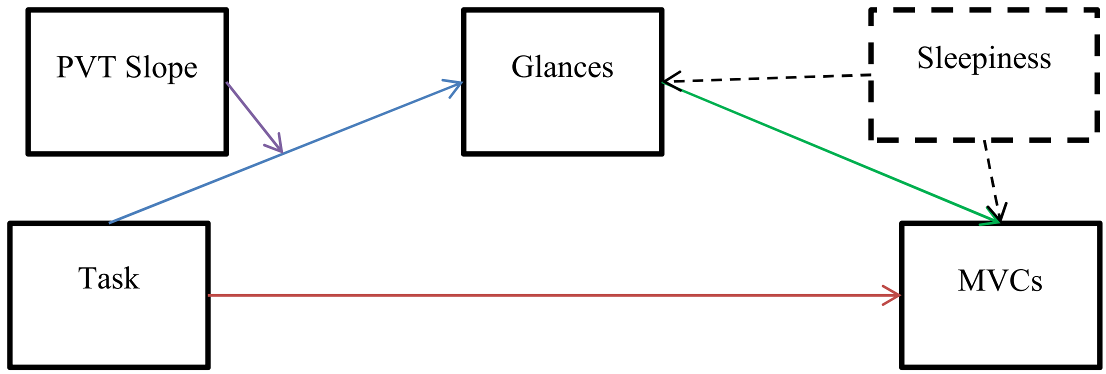
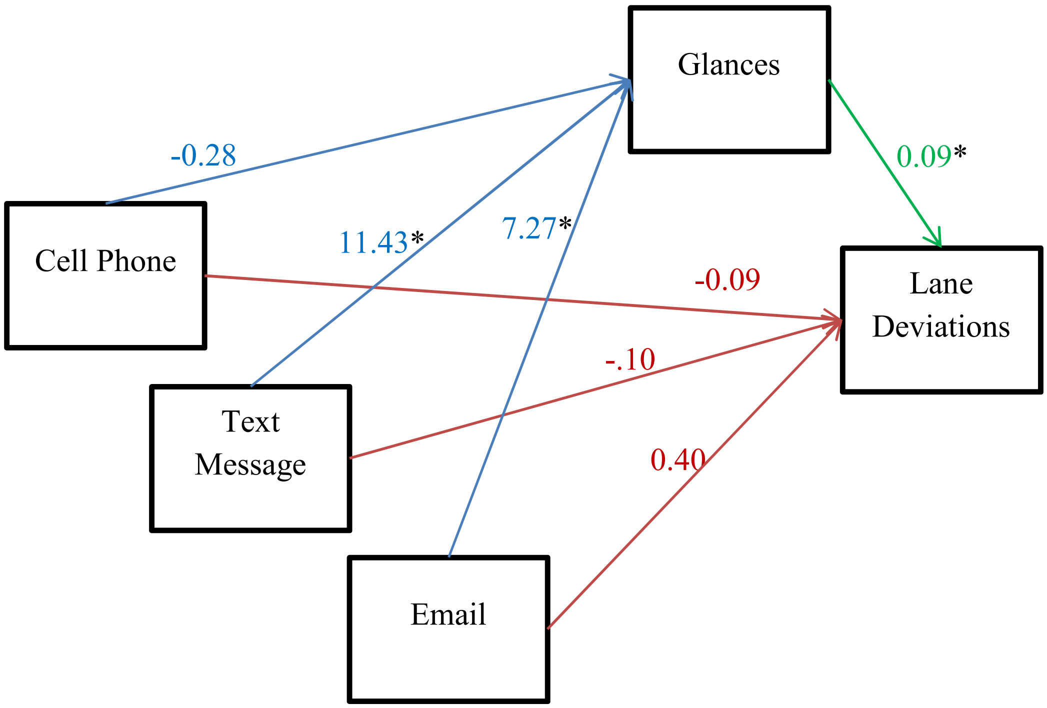


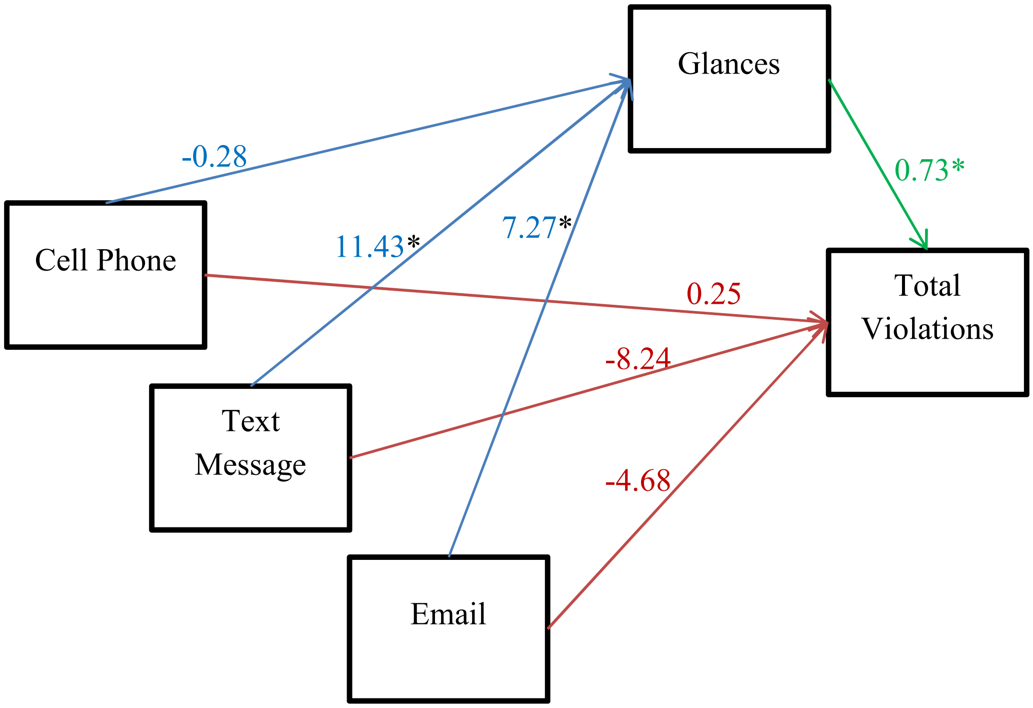
Figure 10. Conceptual model of eye glances off road per minute mediating the conditional effect of PVT slope on secondary task and simulated MVCs while controlling for sleepiness



Relative to no secondary task

Indirect effect of cell phone conversation through eye glances off road per minute: -0.03, bootstrapped 95% CI: -0.06, -0.01
Indirect effect of text messaging interaction through eye glances off road per minute: 1.05, bootstrapped 95% CI: 0.25, 1.85
Indirect effect of on-board emailing interaction through eye glances off road per minute: 0.67, bootstrapped 95% CI: 0.14, 1.21
Note: * indicates coefficient is statistically significantly different from 0.

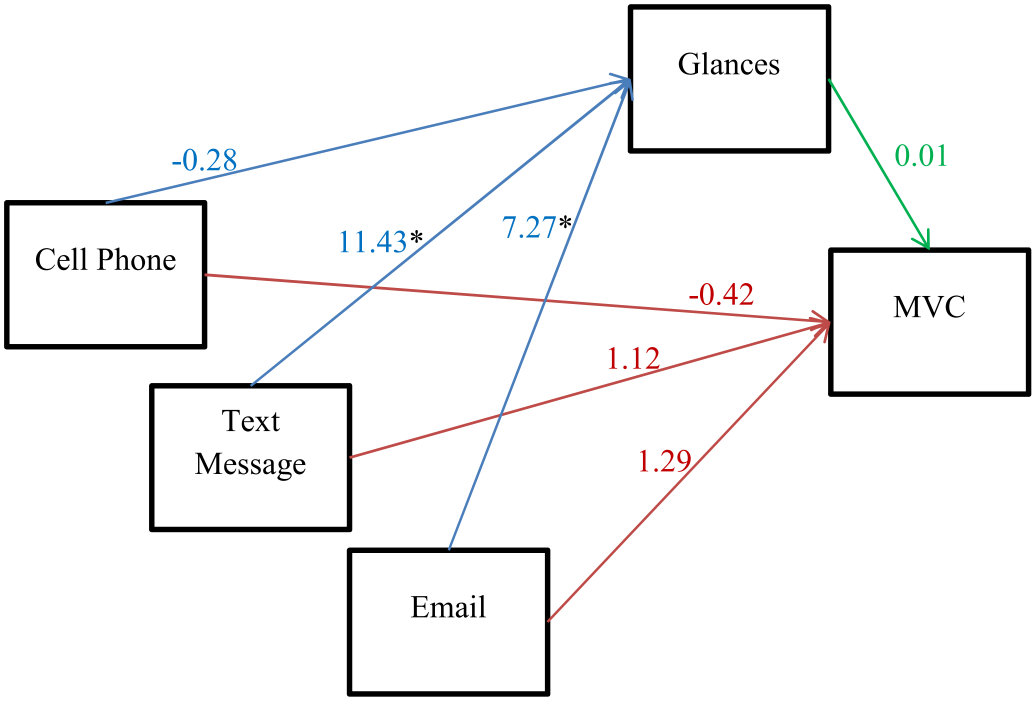
Figure 11. Statistical model of eye glances off road per minute mediating the effect of secondary task on simulated lane deviations per minute



Relative to no secondary task

Indirect effect of cell phone conversation through eye glances off road per minute:
-0.21, bootstrapped 95% CI: -0.55, -0.004
Indirect effect of text messaging interaction through eye glances off road per minute:
8.34, bootstrapped 95% CI: -0.78, 17.01
Indirect effect of on-board emailing interaction through eye glances off road per minute: 5.30,
bootstrapped 95% CI: -0.50, 10.96
Note: * indicates coefficient is statistically significantly different from 0.

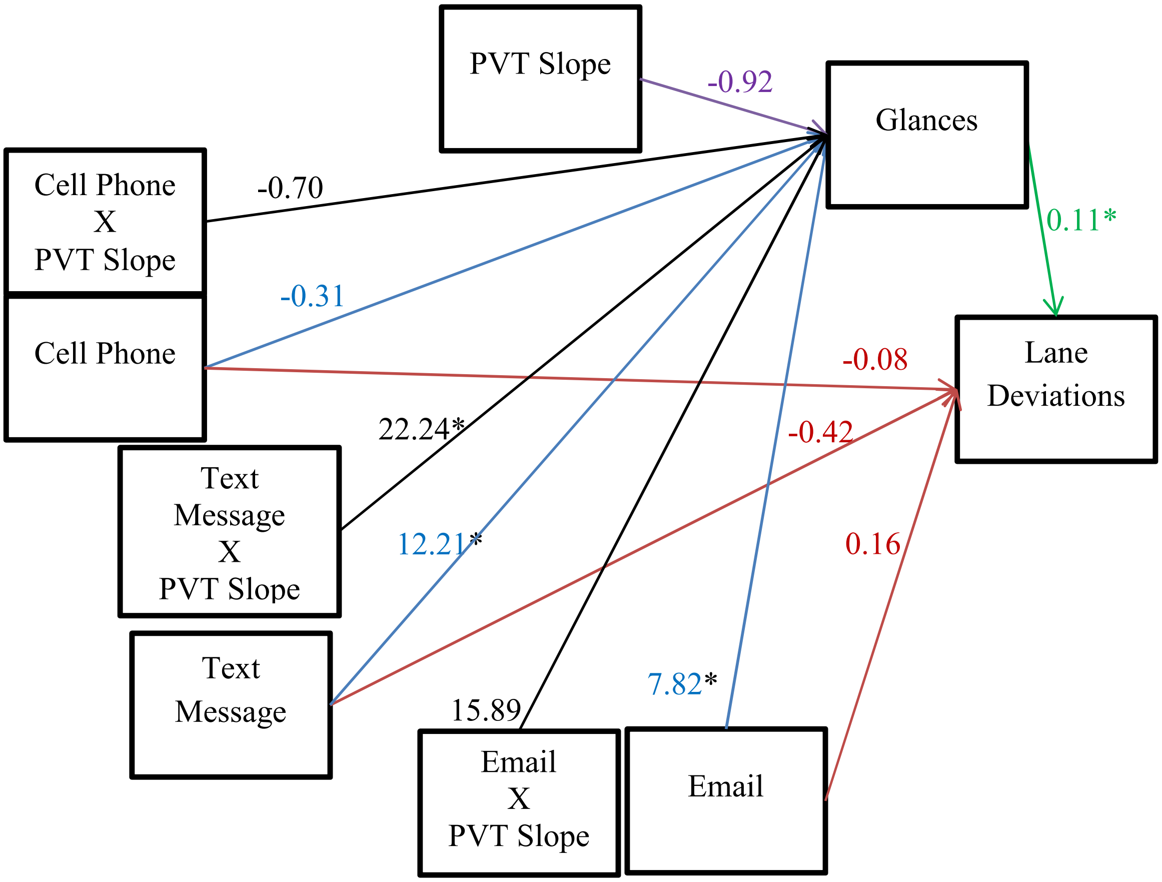
Figure 12. Statistical model of eye glances off road per minute mediating the effect of secondary task on total violations in the simulated drive



Relative to no secondary task

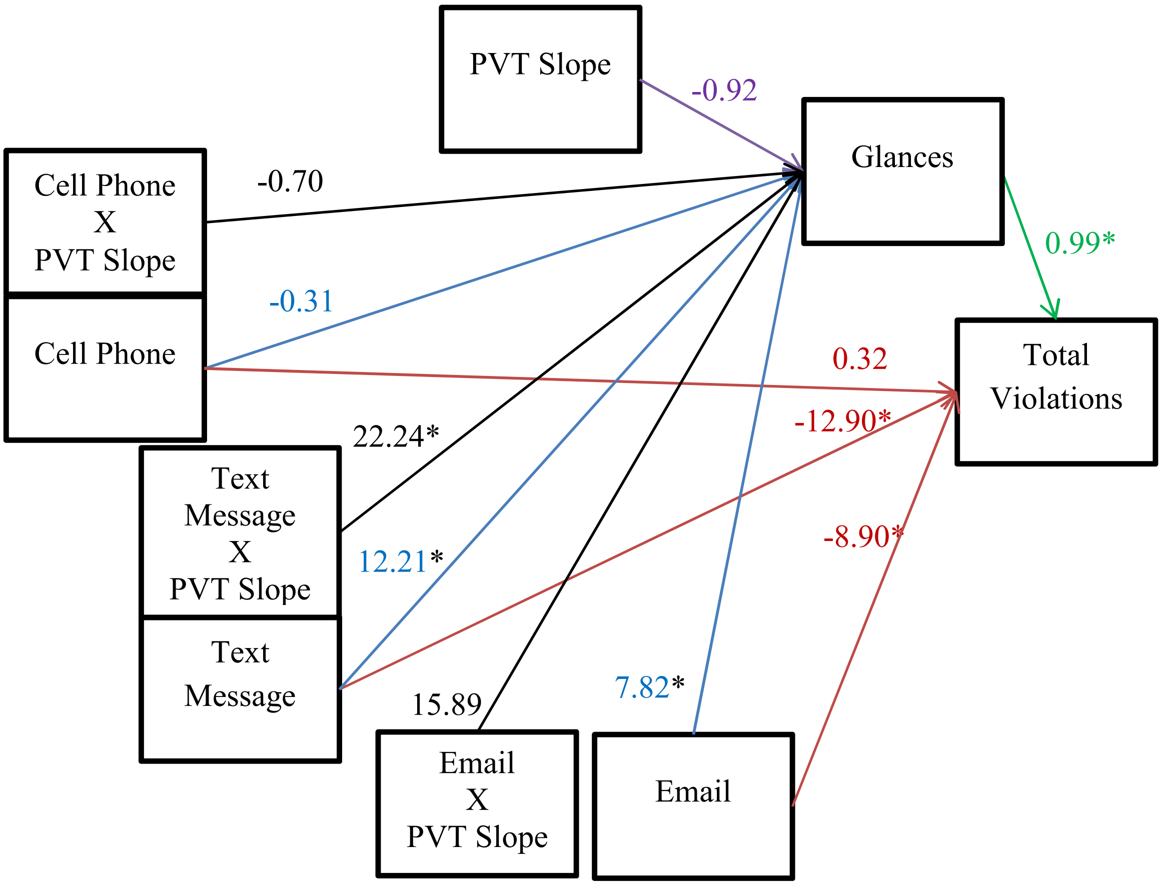
Indirect effect of cell phone conversation through eye glances off road per minute:
Odds Ratio: 0.99, bootstrapped 95% CI: 0.92, 1.07
Indirect effect of text messaging interaction through eye glances off road per minute:
Odds Ratio: 1.13, bootstrapped 95% CI: 0.08, 16.6
Indirect effect of on-board emailing interaction through eye glances off road per minute: Odds Ratio: 1.08, bootstrapped 95% CI: 0.196, 5.81
Note: * indicates coefficient is statistically significantly different from 0.

Figure 13. Statistical model of eye glances off road per minute mediating the effect of secondary task on simulated MVCs



Relative to no secondary task
Conditional indirect effect of cell phone conversation through eye glances off road per minute:
-0.08, bootstrapped 95% CI: -0.54, 0.28
Conditional indirect effect of text message interaction through eye glances off road per minute:
2.18, bootstrapped 95% CI: 0.48, 4.86
Conditional indirect effect of on-board emailing interaction through eye glances off road per minute:
1.61, bootstrapped 95% CI: 0.43, 3.91
Note: * indicates coefficient is statistically significantly different from 0.

Figure 14. Statistical model of eye glances off road per minute mediating the conditional effect of PVT slope on secondary task and simulated lane deviations per minute



Relative to no secondary task

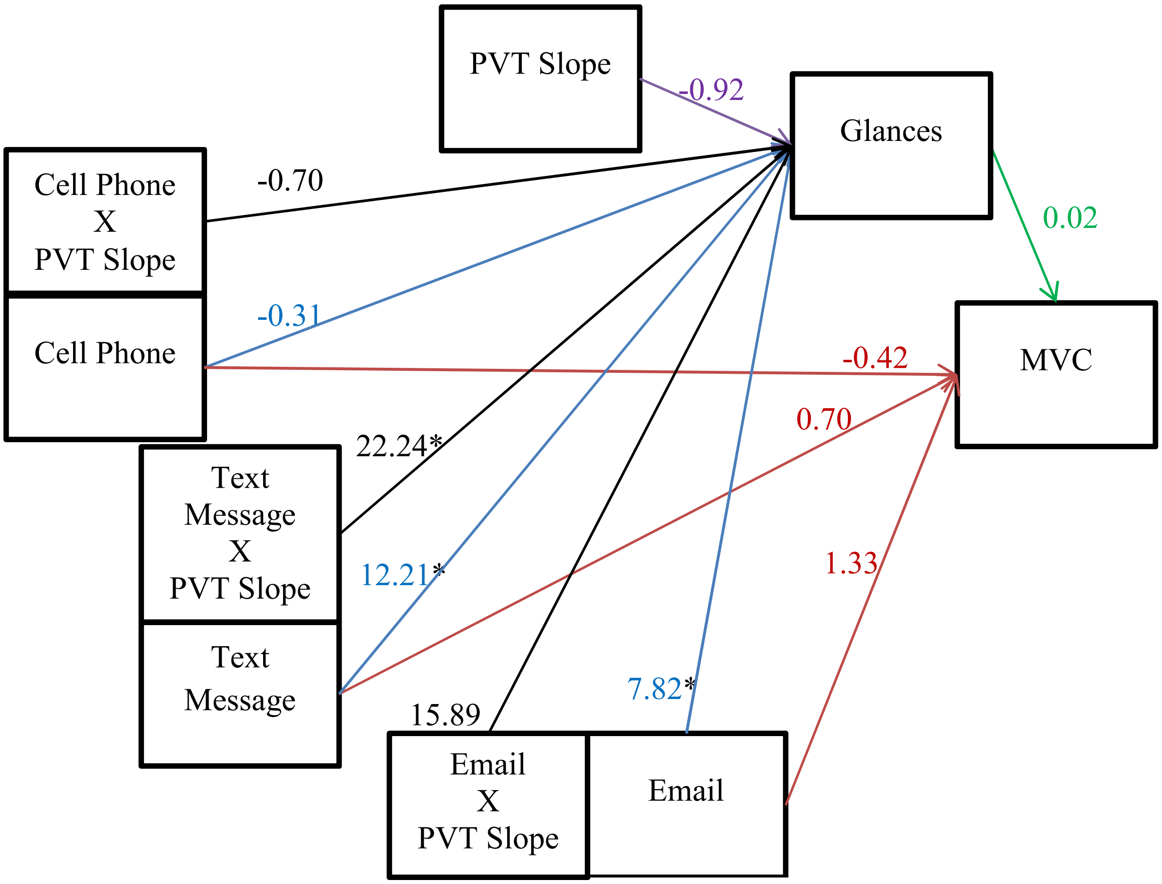
Conditional indirect effect of cell phone conversation through eye glances of road per minute: -0.70, bootstrapped 95% CI: -5.03, 2.57

Conditional indirect effect of text message interaction through eye glances off road per minute: 18.97, bootstrapped 95% CI: 2.20, 49.92

Conditional indirect effect of on-board emailing interaction through eye glances off road per minute: 13.52, bootstrapped 95% CI: 2.05, 33.91

Note: * indicates coefficient is statistically significantly different from 0.

Figure 15. Statistical model of eye glances off road per minute mediating the conditional effect of PVT slope on secondary task and total violations in the simulated drive



Relative to no secondary task
Conditional indirect effect of cell phone conversation through eye glances off road per minute:
-0.01, bootstrapped 95% CI: -0.78, 0.38
Conditional indirect effect of text message interaction through eye glances off road per minute:
0.06, bootstrapped 95% CI: -5.04, 6.36
Conditional indirect effect of on-board emailing interaction through eye glances off road per minute:
0.67, bootstrapped 95% CI: -3.70, 5.62
Note: * indicates coefficient is statistically significantly different from 0.

Figure 16. Statistical model of eye glances off road per minute mediating the conditional effect of PVT slope on secondary tasks and simulated MVCs