

USING FUZZY SIGNAL DETECTION THEORY TO ASSESS THE IMPACT OF TEXT  
MESSAGING ON DRIVERS' HAZARD PERCEPTION ABILITY

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## DEDICATION

To my three kids, who can always make me smile no matter the circumstances, and to my wife, who proved much more resilient than I through this process, helping me to hold it together until the end- we made it

## ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Alex Chaparro, for the many years of guidance, support, understanding, and humor- without which, none of this would have been possible. I would also like to thank my committee members, Dr. Barbara Chaparro, Dr. Joe Keebler, Dr. Jibo He, and Dr. Anthony Dilollo, for their helpful and constructive suggestions along the way.

## ABSTRACT

Hazard perception is a multi-faceted process that requires drivers to maintain an ongoing awareness of a complex driving environment. The majority of research studies, however, utilize behavioral responses to a limited number of discrete hazardous events (e.g., response to a braking lead vehicle, vehicle lane deviations, or pedestrians) to assess a driver's hazard perception ability. The current study uses a modification of SDT to expand these events, called fuzzy signal detection (*fSDT*) to account for the fuzzy nature of real-world driving hazards. Unlike traditional SDT, which requires a classification of any given scenario, as either containing a hazard or no hazard, *fSDT* allows for each scenario to be classified by its potential to develop into a situation where a driver response is necessary to avoid a collision or near collision

The purpose of this study was to explore how performing a texting task impacts a driver's hazard perception ability while viewing real-world driving scenes using SDT metrics. The results showed that texting while driving increased perceived mental workload, reduced a driver's ability to discriminate hazards, and reduced a driver's likelihood to respond to a hazard, compared to driving only. What was found highlights the variability of the hazard perception process, suggesting that both sensitivity and response bias shifts occur when distracted. Additionally, the results indicate that these shifts are at least in part, moderated by the cognitive load the secondary task commands and by the current driving environment. These results also highlight the complexity in which distraction can impact both the allocation of cognitive resources as well as attentional selection.

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## LIST OF ABBREVIATIONS

MRT	Multiple Resource Theory
SDT	Signal Detection Theory
<i>tSDT</i>	Traditional Signal Detection Theory
<i>fSDT</i>	Fuzzy Signal Detection Theory

## **CHAPTER 1**

### **INTRODUCTION**

The National Highway Traffic Safety Association (NHTSA) has identified distracted driving as the most dangerous epidemic on the nation's roadways today (NHTSA, 2014). In fact, distraction has joined driving under the influence and speeding as a leading factor in fatal crashes (NSC, 2010). Since 2009, the U.S. Department of Transportation has made preventing driving distractions a priority; banning texting and cell phone use for commercial drivers, while encouraging states to do the same for civilian drivers, and launching numerous campaigns combating distracted driving (NHTSA, 2014)

The use of cell phones while driving has received the majority of the attention in these efforts, with 14 states prohibiting the use of handheld cell phones and 44 states banning text messaging while driving (IIHS, 2014). This focus is justified, with cell phone use being reported in 10% of all distraction-related fatalities in 2012 (NHTSA, 2014). Additionally, it has been reported that the risk of a crash or near-crash increases anywhere from approximately 2.5% to 8% while performing a cell phone related task (Klauer et al., 2014). While it is difficult to estimate the exact percentage of crashes attributable explicitly to cell phone use due to multiple contributing factors, it is widely accepted by public officials and researchers alike, that the distraction caused by cell phone use impairs driving performance and thus, increases crash risk (Caird, Johnston, Willness, & Asbridge, 2013; Klauer et al., 2014; Strayer et al., 2013).

In terms of driving performance, there are numerous laboratory studies that show talking and texting on a cell phone impairs vehicular control, hazard detection, and the ability to successfully navigate the roadway (Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009; Hosking, Young, & Regan, 2009; Park, Salsbury, Corbett, & Aiello, 2013). Inferring crash risk from such studies, however, can be challenging. For example, some researchers have argued that crash risk associated with cell phone use may be overestimated in the laboratory due to the tendency of drivers to make strategic and tactical decisions to mediate potential risk that are largely unaccounted for in driving research (Poysti, Rajalin, & Summala, 2005). A few studies have also shown that drivers have an increased number of false alarms (i.e., responses when no hazard is present) when completing hazard detection tasks when engaged in a secondary task, resulting in fewer missed hazards (Burge & Chaparro, 2012; Savage, Potter, & Tatler, 2013). This may be a strategy employed by the driver to compensate for the interference of the secondary task on the primary hazard detection task. However, while it is likely that drivers are able to compensate for some of the negative affects of cell phone use while driving, all risk cannot be eliminated.

Additionally, it isn't always clear whether the performance measures typically collected are directly related to driving safety. For example, many studies suggest that greater deviations in lane keeping, headway distance, and braking response demonstrate the negative impacts of distraction on driving performance (Caird, Johnston, Willness, & Asbridge, 2014). It is uncertain, however, whether these behaviors will increase risk or whether they are compensatory strategies adopted

by drivers when distracted (e.g., headway variation may indicate a driver attempting to keep a safer distance from other vehicles). This illustrates the difficulty researchers have in connecting such results to real-world crash risk.

Moreover, there is disagreement among researchers as to whether variations in vehicle control behaviors (e.g., lane keeping and speed control) that are common measurements of distracted driving are direct indicators of crash risk. Indeed, increases in lateral deviation may increase, decrease, or have no impact on crash risk depending on the concurrent driving conditions (Lee, Young, & Regan, 2009b). Some researchers suggest that factors associated with driver characteristics (i.e., propensity to speed or tendency to take risks such as engaging in a secondary task) may be a better gauge of accident involvement than driver skill per se (Horswill & McKenna, 1999; Wasielewski, 1984). For example, there is some evidence that has shown highly skilled race-car drivers in the US have a higher number of accidents than ordinary drivers, partly due to their propensity to take high risks while driving (Williams & O'Neill, 1974). This is not to say that driver skill is irrelevant to driving, just that basic driving skills (e.g., controlling a vehicle) may not be strongly associated with crash risk. On the other hand, Horswill and McKenna (2004) argue that the more advanced skill of hazard perception is the only driving skill that has been found to correlate with an increase in accidents. For example, driver's that performed poorer at a video-based hazard detection test also had a greater number of reported traffic accidents the two years leading up to the test, compared to those that performed well (Horswill & McKenna, 1999; McKenna & Crick, 1991). In addition, prospective studies have shown that poor hazard perception ability

assessed via a hazard detection test was associated with increased fatal accidents the following year (Drummond, 2000).

The relationship between hazard perception skill and crash involvement highlights the importance for future research to focus on exploring the components and processes involved in achieving and maintaining high levels of hazard perception while driving, and how distraction may impact this process. To date, very little research has focused on how distraction impacts hazard response in terms of complete response behavior, especially with consideration for the diverse nature of real-world hazards (Caird et al., 2014). In order to fill this gap in the literature, the current research addresses the skill of hazard perception by utilizing a new information acquisition model adapted from traditional Signal Detection Theory (*tSDT*), called Fuzzy Signal Detection Theory (*fSDT*) to explore how distraction impacts hazard detection. This effort will begin with a review of the effects of driver distraction, with emphasis given to the use of cell phones while driving. This is followed by a proposed framework for understanding the role of attention in driving and how the introduction of a secondary task interferes with attention allocation. Next, hazard perception will be explained as a task that can be better understood through *fSDT* calculations as compared to *tSDT*.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Review of Driver Distraction**

Research efforts have generated numerous definitions of driver distraction over the past decade. Some have focused on defining distraction in terms of

operational outcomes (e.g., delayed response, impaired vehicle control, etc.), while others have focused on the individual sources of distraction (e.g., internal or external factors) (Lee, Young, & Regan, 2009a). For this work, the definition put forth by Lee et al. (2009a) as being a “diversion of attention away from activities critical for safe driving toward a competing activity” (pg. 34) is used. Thus, there are many sources of distraction while driving, including those that are internal (e.g., mind-wandering) and external to the driver (e.g., cell phones), and those that are inside (e.g., navigation system) and outside of the vehicle (e.g., billboards) (Bayly, Young, & Regan, 2009; Horberry & Edquist, 2009; Lee et al., 2009a). Indeed, studies have shown that behaviors that seem to be innocuous while driving can be detrimental to performance, including eating and drinking (Alosco et al., 2012; Jenness, Lattanzi, O'Toole, & Taylor, 2002), reaching for objects (Stutts et al., 2005), and daydreaming (He, Becic, Lee, & McCarley, 2011). Although there are many sources of distraction, this review will focus on distractions external to the driver and located inside the vehicle. Specifically, the use of cell phones and in-vehicle information systems (IVIS), as these are argued to cause the most interference with driving (Bayly et al., 2009).

Early studies of the interaction between drivers and cellular phones found that talking on a phone impairs driver performance (Briem & Hedman, 1995; Brookhuis, Vries, & Waard, 1991; Brown, Tickner, & Simmonds, 1969; Strayer, Drews, & Crouch, 2006; Strayer, Drews, & Johnston, 2003; Strayer & Johnston, 2001), with some finding that this form of distraction was comparable in its effects to drunk driving (Strayer, Drews, & Crouch, 2006; Leung, Croft, Jackson, Howard, &



McKenzie, 2012). More specifically, talking on a cell phone appears to impact a wide range of driving skills, including impaired navigation of traffic (Brookhuis, Vries, & Waard, 1991), slower reaction times to events such as forward vehicle braking (Lamble, Kauranen, Laakso, & Summala, 1999), impaired vehicle control (i.e., speed and lane maintenance) (Horberry, Anderson, Regan, Triggs, & Brown, 2006; Rakauskas, Gugerty, & Ward, 2004), and impaired hazard detection (Strayer & Drews, 2004). Additionally, talking on a cell phone has also been found to degrade driver's situation awareness (SA), while also increasing perceived mental workload (Ma & Kaber, 2005). Nonetheless, there has been no successful legislation against all forms of talking on a cell phone while driving, despite the impact on driving performance.

### **2.1.1. Texting and Driving**

In the last decade texting while driving has received a great deal of attention in both public policy, and research regarding distracted driving, mainly due to the combination of visual, manual, and cognitive resources it demands. A recent meta-analysis has outlined the significant impact texting has on driving performance, including increased reaction time to events, a greater number of crashes, impaired longitudinal and lateral control, impaired hazard detection, increased perceived workload, and more restrictive eye movements, across a diverse set of studies (Caird et al., 2013). Of these studies, Hosking et al. (2009) explored the effects on young drivers, asking participants to send and receive text messages while driving in a simulator. They found that the text messaging drivers showed increases in lateral lane control and following distance variability, and an increase in missed lane

change prompts. In a related study, Drews et al. (2009) found drivers that engaged in text messaging while in a driving simulator, had slower reaction times in response to the onset of brake lights, showed impairments in forward and lateral control, and were involved in more crashes compared to those that only engaged in the driving task. More recent studies have confirmed these results finding that overall, drivers exhibited impaired vehicle control and hazard detection when texting (Alosco et al., 2012; Burge & Chaparro, 2012; Crandall & Chaparro, 2012; Rudin-Brown, Young, Patten, Lenne, & Ceci, 2012). Additional evidence for the impact of texting on attention has also been found in functional studies, finding that physiological responses (i.e., increased heart and respiratory rate) and modulation of brain activity in response to texting and performing a driving related reaction time test are indicative of decreases in attention and the ability to perceive stimuli (Park et al., 2013; Savage et al., 2013).

When compared to alternative forms of distraction (e.g., radio tuning), texting while driving has been shown to be significantly worse in terms of lane and speed management, and lane deviation (McKeever, Schultheis, Padmanaban, & Blasco, 2013; Strayer et al., 2013). One interesting aspect of the study conducted by McKeever et al. (2013) is that differences between texting and comparative secondary tasks were observed even under easy driving conditions while participants used their own phones to complete a relatively simple naturalistic texting task. One theory as to why texting while driving is so disruptive, even under relatively easy conditions, is that it presents the “perfect storm” of distraction, requiring visual, manual and cognitive attention (Lee et al., 2009a). As a result, there

has been some debate as to whether a hands-free and/or eyes-free texting system will benefit driving performance by reducing manual and visual interference.

A recent naturalistic driving study completed by NHTSA, found that drivers who talked on a hand-held cell phone had an increased crash risk due to visual-manual interference compared to drivers that used hands-free systems (Fitch et al., 2013). Indeed, some studies have shown advantages, albeit limited, of hands-free over handheld systems while driving (Ferlazzo, Fagioli, Nocera, & Sdoia, 2008; McCallum, Campbell, Richman, & Brown, 2004; Owens, McLaughlin, & Sudweeks, 2011). For example, Ferlazzo et al. (2008) found that drivers were faster at responding to various visual stimuli when talking on a hands-free cell phone compared to a handheld phone. Additionally, compared to handheld text messaging, an in-vehicle hands-free system has been found to require less mental demand when receiving text messages, required less time to complete texting tasks, and resulted in less interior glances (Owens et al., 2011). Despite these advantages over the handheld system, however, hands-free texting was still worse than driving-only baseline conditions in terms of mental demand, number of interior glances, and glance duration.

Alternatively, many studies have found few benefits of using a hands-free system in reducing the distraction that accompanies cellular phone tasks (Haigney, Taylor, & Westerman, 2000; McEvoy et al., 2005; Strayer & Johnston, 2001). For instance, Haigney et al. (2000) found operators drove slower regardless of whether they were using hands-free or handheld phones compared to those that were not talking on a cell phone. Similar studies have found that drivers have more variation

in speed regulation, increased lane deviation, and lower levels of situational awareness while using both hands-free and handheld systems (Gugerty, 1997; Horberry et al., 2006; Rakauskas et al., 2004).

The recent advances of the digital personal assistant (DPA) has added more complexity to exploring whether a hands-free texting system can potentially be beneficial while driving. DPAs such as Apple's Siri, are distinctive from traditional hands-free texting systems, in that these systems attempt to mimic natural speech interaction more closely, rather than depending solely on a relatively rigid template matching architecture that creates a more artificial interaction between user and device. Studies specifically associated with the use of DPAs to complete secondary tasks while driving are limited. One study mimicked a DPA by using text-to-speech software to present e-mail and text messages to the participants aurally while driving in a simulator (Strayer et al., 2013). Since researchers manually entered each message into the speech-to-text software, they were able to maintain perfect fidelity when reacting to the participant's verbal commands, which were limited to a short list given before the sessions. This study found that texting using the speech-to-text software caused an increase in following distance and an increase in brake reaction time to a lead vehicle, compared to driving only and to other common forms of distraction (e.g., radio dialing, listening to an audiobook, talking on a cell phone, and talking to a passenger). Furthermore, a follow up experiment found that participants were less likely to glance at critical hazard locations while driving an instrumented vehicle while utilizing the speech-to-text system. Yager (2013) utilized DPAs that are currently on the market, including Siri and Vlingo, to explore

what impact voice-to-text programs have on driving. Participants were required to drive at 30 mph, stay in a marked lane and respond to a peripheral light detection task, while also completing text message tasks that included sending, reading and replying. They found that response times were higher and the time spent looking at the forward roadway was significantly less for both manual texting and texting using the DPAs compared to the driving only condition, but did not differ from each other. When they analyzed the standard deviations in speed maintenance, however, there were more speed fluctuations when using the DPA systems than all other driving conditions.

### **2.1.2 Hazard Perception and Distraction**

As mentioned before, hazard perception and the ability to successfully detect road hazards, is the only driving skill researchers have correlated with accident involvement (Horswill & McKenna, 2004). Despite this, hazard perception has received limited explicit attention in the literature on distracted driving. Hazard perception is considered to be a component of the larger cognitive construct known as Situation Awareness (SA), being defined as the SA for dangerous situations within a traffic environment (Gugerty, 1997, 2012; Horswill & McKenna, 2004). SA is a type of knowledge (i.e., dynamic mental model) that driver's have of the immediate environment. This knowledge is continually being updated as the operator moves through the environment both spatially and temporally, and thus, can differ from moment to moment and from situation to situation. There is disagreement as to whether SA is solely a conscious process (Endsley, 1995a), or whether there are also unconscious components (Gugerty, 1997, 2012). Despite this dispute, most theorists

agree that the sub-component of hazard perception in particular, is a effortful process that requires conscious processes (Gugerty, 2012; Horswill & McKenna, 2004).

One argument for hazard perception being a conscious, controlled process is that real-world hazards are simply too complex, and in some cases too infrequent for hazard perception to have developed into an automatic process (Groeger, 2000; Shiffrin & Schneider, 1997). Even in experienced drivers, where the skill of hazard perception is well practiced, it seems automaticity is never fully achieved. In fact, one study found that completing a random letter generation task caused expert drivers' hazard perception performance to drop to novice levels. (McKenna & Farrand, 2004). Thus, experienced drivers' high level of hazard perception skill comes at a cost, requiring more attentional resources to carry out. This suggests that hazard perception is unlikely to become automatic, even after years of practice and supports the argument that the more sophisticated mental model that an experienced driver develops probably requires even more cognitive resources to carry out effectively and may be more susceptible to interference from a dual-task.

The majority of research that explores hazard perception explicitly focuses on the differences between novices and experts, and how training can improve hazard detection skill. Numerous studies have shown that experienced drivers are better at detecting hazards and that this skill can be improved with training (Crundall et al., 2012; Horswill & McKenna, 1999, 2004; Jackson, Chapman, & Crundall, 2009). For instance, experienced drivers were more likely to recognize obscured stop signs and pedestrians as potential hazards than teen drivers when

performing a driving task on a test track (Lee et al., 2008). In an interesting study exploring responses to hazards with either direct or indirect relationships with their precursors, researchers found that drivers with varying degrees of experience responded differently based on this relationship (Crundall et al., 2012). The authors suggest this can be explained by an a priori categorization of the hazards based on structural differences. This work is important, not only because it adds to the evidence that experienced drivers are better at detecting hazards than inexperienced drivers, but also because it highlights the need to consider driving hazards as complex events that can fluctuate structurally from one situation to the other and one person to another, impacting performance differentially.

A large portion of the hazard perception literature exploring the differences between novices and experts has focused on eye movements as an indicator of performance. Drivers seem to have visual fixation patterns that are systematic and predictable (Shinar, 2008). Experienced drivers in particular, tend to increase their fixation durations and decrease variability in search when engaged with a potential hazard (Chapman & Underwood, 1998). Novice drivers, however, do not show this same pattern of eye movements with less exclusive attention being given to hazard locations in the periphery (Crundall, Underwood, & Chapman, 2002) and to areas where potential risks may be found (Borowsky, Shinar, & Oron-Gilad, 2010).

As mentioned before, less attention has been given to the impact of distraction on hazard perception performance explicitly. There have been, however, studies showing that using a phone to complete various tasks increases a driver's reaction time to certain road events (Brookhuis, Vries, & Waard, 1991; Strayer &

Johnston, 2001). In their exploration of various secondary tasks on the detection of lane violations from surrounding cars, Greenberg et al. (2007) found that using a cell phone impaired detection of events ahead of front of the driver, while cell use and some climate control tasks impaired detection of rear events. One study looked at the impact of using a cell phone while experiencing three different types of hazards (lead vehicle braking, pedestrians, and vehicle pull out events) on both novice and experienced drivers (Chisholm, Caird, Lockhart, Teteris, & Smiley, 2006), finding that novices in particular, displayed delayed braking in response to the events when engaged in a phone talking task. Interestingly, the number of collisions (with pedestrians and pull out vehicles) actually decreased when the drivers were engaged in the cell phone tasks, and may be a result of participant's heightened awareness of collision events while engaged in a secondary task.

Additionally, increases in mental workload (e.g., introduction of a secondary task) has been shown to be associated with engaging in various secondary tasks while driving, including cellular phone tasks (Strayer et al., 2013). This is relevant to hazard perception in that, as the level of workload increases, less attentional resources are available to keep up-to-date with hazardous situations (Vidulich & Tsang, 2012). Indeed, it has been shown that increases in perceived mental workload load (i.e., as measured by the NASA TLX) caused by such tasks as talking on a cellular phone (handheld and hands-free) and interacting with a speech-to-text system, has resulted in impaired driving performance (Strayer et al., 2013).

Although these studies explore the effects of distraction on hazard perception, there needs to be more explicit focus on utilizing diverse and realistic

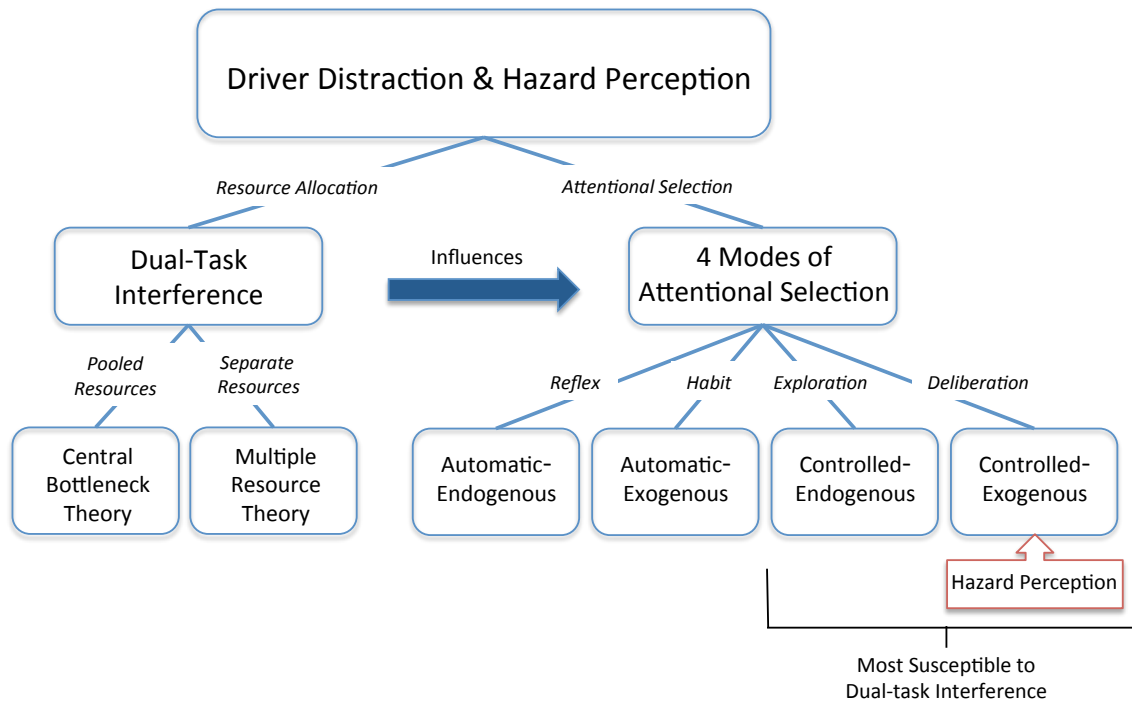


hazard scenarios. As Crundall et al. (2012) noted, studies that utilize hazard detection measures to infer hazard perception skill without deliberative *a priori* consideration for the diverse and complex nature of real-world hazard perception, risk an overgeneralization of their results. To date, there have been a limited number of studies that have approached exploring how distraction impacts hazard perception in such a deliberative manner.

## **2.2 Attention and Driving**

### **2.2.1 Mechanisms of dual-task interference**

The specific impact of texting on driving performance, such as hazard perception, can be explained via models of dual-task interference in information processing (see Figure 1). Research has established that persons are limited in their ability to perform two tasks at once (e.g., texting and driving) that results in deficits on one or both of the tasks being performed (Allen, McGeorge, Pearson, & Milne, 2006; Allport, Antonis, & Reynolds, 1972). This dual-task interference is often attributed to a “central bottleneck” (i.e., interference occurring at a central stage of processing) (Welford, 1952) and has been shown to be true in the majority of dual-task research studies with few exceptions (Lien, Ruthruff, & Johnston, 2006; Pashler, 1994).



*Figure 1.* Conceptual mapping of the impact of distraction on a driver's hazard perception ability.

For example, one study showed that simply talking on a telephone disrupted performance on a multiple object-tracking (MOT) task when in the act of generating the message, which suggests attention was disrupted at a central (i.e., verbal message generation) as opposed to a peripheral (i.e., listening or speaking) stage of processing (Kunar, Carter, Cohen, & Horowitz, 2008). In a related study, drivers were slower at responding to lead vehicle brake lights when asked to perform a secondary auditory processing task, compared to driving-only conditions, even when instructed to give the driving task priority (Levy & Pashler, 2008). Despite the findings supporting dual-task interference, there is some evidence that this interference can be reduced under certain circumstances.

An alternative theory of dual-task processing suggests that some of the interference can be circumvented if the competing task taps separate resources from those of the primary task (Horrey, Wickens, & Consalus, 2006). This approach, referred to as the Multiple Resource Theory (MRT), argues that there are distinct and separate attentional resources depending on the nature of the tasks being performed (Wickens, 1980), rather than a single, more general pool of resources (Kahneman, 1972). More precisely, dual-task performance should be improved to the extent that the two tasks differ along each of four dichotomous dimensions. These include stages of processing (perception/cognition vs. response), codes of processing (spatial vs. verbal), modality (visual vs. auditory), and visual channels (ambient vs. focal vision) (Wickens, 1980, 2002). According to this theory, dual-task performance should be improved if the interference between distinct resources (e.g., visual and manual) is reduced. For example, this model would predict that a hands and eyes-free system will reduce the effects of texting while driving, depending on the prioritization of the tasks.

Models on how information from competing tasks is processed are important in understanding and predicting how using a cell phone will impact driving performance. Evidence supporting MRT include better driving performance when navigation instructions are presented aurally vs. visually (Parkes & Coleman, 1990), advantages of cross-modal displays over intra-modal displays in information processing (Wickens, et al. 1983), and some support for distinctions between tasks that require focal visual processing (e.g., hazard perception) and those that require ambient visual processing (e.g., vehicle control). However, there is compelling

evidence that in the majority of dual-task situations, interference occurs at a central stage of resource processing. This may be especially true in cases where linguistic processes (especially message generation) are involved, such as talking or texting on a cell phone (Almor, 2008; Roelofs & Piai, 2011). For example, Roelofs and Piai (2011) showed that the planning of words required a large portion (but not all) of central attention devoted to the task. Dual-task driving studies have found similar results, often finding that the greatest interference of cell phone tasks occur during message planning and generation (requiring central executive processes) (Almor, 2008; Kunar et al., 2008). Another study that compared the effects of a working memory task (i.e., rehearsal) to those of a central executive task (i.e., manipulation) found that the latter caused significantly more impairment on a driving task (Morris, Phillips, Thibault, & Chaparro, 2008). In addition to these tasks requiring large portions of central attention, studies show that linguistic processes involve peripheral spatial attention resources, as evidenced by reducing interference by collocating a secondary auditory task with a primary visual driving task (Almor, 2008; Spence & Read, 2003). However, although certain aspects of texting impact peripheral stages of processing, there is also interference in central stages of processing that cannot be eliminated by employing communication systems attempting to eliminate the visual and manual sources of interference with driving. Furthermore, although these information process models help to explain why and how a secondary task might interfere with driving, a framework for understanding attentional allocation as a whole is still necessary.

### 2.2.2 Distraction and Attentional Selection

From the time of the very first automobiles, attempts have been made to provide a theoretical framework for understanding driving, with emphasis on explaining driving errors. For example, Gibson and Crooks (1938) suggested that driving is based on a *field of safe travel* that extends along the road radiating from the driver. This field is dependent upon incoming information about the driving environment that provides affordances that allow the driver to navigate safely. The *field of safe travel* dynamically changes as a car moves through the environment and as the driver reacts to objects in order to keep the vehicle within the boundaries of this field. This theory, however, like many focused on information acquisition (e.g., MRT & Central Bottleneck) does not involve a driver's subjective experience, such as the allocation of attention while driving. In particular, errors in selective attention are a major contributing factor to automobile crashes (Klauer et al., 2014). Thus, to understand how distraction impacts a driver's hazard perception, one must first gain an understanding of attention as it applies to driving. Research on attention as it relates to driving, however, is fragmented, which has led some researchers to attempt to outline a more overarching theory of attention that can be applied to driving research (Trick & Enns, 2009).

One of the most recent theories is the Four Modes of Attentional Selection, put forth by Trick and Enns (2009). They propose a two-dimensional framework of attentional selection while driving based on automatic vs. controlled processes and exogenous vs. endogenous processes. This results in four modes of selection including, reflexive, habitual, exploratory, and deliberative (See Figure 2). This

theory provides a framework for understanding how attention supports hazard perception and a means for predicting how a secondary task will impact the detection of hazardous events in terms of disrupting attention allocation.

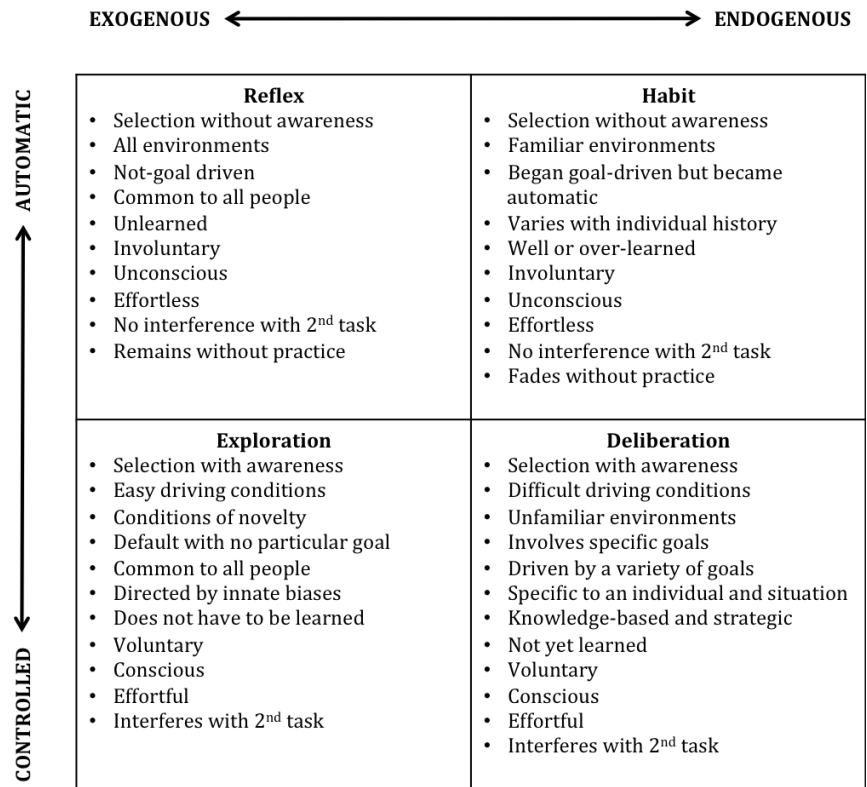


Figure 2. Four modes of attentional selection (adapted from (Trick, Enns, Mills, & Vavrik, 2004).

Reflexive selection (automatic-exogenous process) is processed automatically, without awareness, and requires very little (if any) mental effort to guide attentional selection. As a result, completing a secondary task will have little to no impact on this form of selection. Furthermore, reflexive attentional selection is innate and is common to all people, and thus, driving experience will have no impact. Reflex may play only a limited role in hazard perception, since the task of

selecting a potentially hazardous object from the environment and responding to it is thought to be a goal-directed, deliberate process which requires higher levels of cognition (Endsley, 1995a; Gugerty, 2012; Horswill & McKenna, 2004). Instead of playing a productive role in hazard perception in most driving situations, reflexive selection may actually play a more disruptive role by pulling driver's attention away from tasks that are associated with successfully detecting hazardous events.

Additionally, since it is involuntary, this selection would require deliberate control to overcome. For example, a flashing business sign may pull a driver's attention away from the forward roadway, resulting in a delayed reaction to a road hazard. In order for the driver to overcome this reflexive attention allocation, the individual must engage in a controlled cognitive process to overcome this tendency.

The second mode is referred to as habitual selection (automatic-endogenous process). This form of attentional selection is similar to reflexive in that it is unconscious and relatively effortless, developed by repeatedly completing a task until it becomes habit (i.e., through experience). In terms of a driver's hazard perception ability, habitual selection may play a role in adopting search strategies based on experience. Indeed, it has been shown that inexperienced drivers are less efficient in their visual search, fixating in areas unlikely to offer information about a potential hazard, while more experienced drivers tend to fixate in areas where the likelihood of hazards are the greatest (i.e., intersections) (Crundall et al., 2002). Habitual selection will also play a role in response selection when encountering a hazard. For example, a driver's most likely response to a lead vehicle braking is to slam on their brakes, a reaction that has developed into habit through multiple

exposures of this event. As with reflexive selection, however, it takes deliberate attention to overcome this response when it is counterproductive (e.g., in the presence of a tailgating rear vehicle) and it is necessary to select another response (e.g., to change lanes). Furthermore, as with reflexive attentional selection, introduction of a secondary task should cause little interference with habitual selection. Although behaviors such as visual scan patterns most likely have a habitual component, the identification of hazards most likely requires a more deliberate form of attention.

A third mode of attentional selection that is voluntary, conscious, and effortful is exploratory selection (controlled-exogenous process). Since this form requires cognitive effort, a secondary task will interfere with the allocation of exploratory attentional resources. Additionally, in the case of exploratory selection, there is no explicit goal the driver is working toward. Instead, drivers are motivated by the innate goal to simply explore their surroundings. This form of selection occurs in situations of novelty or in relatively easy driving conditions. Since hazard perception is largely a goal-directed behavior, exploratory selection may only play a role in triggering goal-directed attention, once a hazard has been encountered through exploration.

Deliberative selection (controlled-endogenous process) is the fourth mode of attentional selection and involves very specific goals that are unique to a given operator and the current situation. Deliberation is primarily a controlled, top-down process, requiring the most effort and is especially sensitive to secondary tasks. As mentioned before, hazard perception is the awareness of hazardous situations, and



is primarily driven by the goal of avoiding hazards and ensuring driving safety. Thus, deliberation is the primary driving force behind attention allocation in hazard perception tasks.

Trick and Enns (2009) two-dimensional framework of attention selection provides a useful model in outlining the allocation of attention in hazard perception and in predicting the effects that distraction may have on detection processes. Within this framework, each mode of selection would likely play a role in hazard detection in certain situations. For example, a driver may suddenly brake in reaction to a car changing into their lane due to a looming effect (reflexive selection), or suddenly braking when approaching a green light (habitual selection). In both of these situations a driver may successfully avoid a hazard through primarily bottom-up, automatic processing. In these situations, however, the automatic modes of selection may lead to delayed or even dangerous responses (e.g., slamming on the brakes when a car is tailgating). Thus, for a driver to gain a more complete awareness of hazardous environments a deliberative, controlled mode of selection must be adopted to provide the highest level of hazard perception performance. Deliberation allows the driver to go beyond simply instinctively reacting to immediate hazardous events by strategically interpreting environmental information, predicting whether an event will become hazardous in the near future, and making decisions on when and how to respond. The deliberative nature of attentional allocation in hazard perception, however, makes this skill susceptible to interference from secondary tasks.

One way to predict how a secondary task will interfere with the processes involved in hazard perception is to explore how well the driver is able to filter out interfering distractors found in the environment. Research on selective attention has shown that increasing the amount of perceptual load (i.e., increasing the number of elements within a visual scene) an operator experiences, actually reduces the processing of distractors, allowing more focus to be put on goal-relevant stimuli (Lavie, 2005). Under conditions of low perceptual load, however, a greater number of distractors are processed, reducing the ability to maintain focus on goal-relevant stimuli. Conversely, when drivers engage in a secondary task the concern is the load that is placed on cognitive rather than only perceptual resources. Additional research has found that when individuals perform tasks that require high cognitive load, fewer distractors are filtered out, reducing the attentional focus on relevant elements within the environment (Lavie, 2004). Taken together, these findings indicate that perceptually, all stimuli is automatically processed until a limited capacity is reached and that cognitive control is necessary for distinguishing between distractors and targets (Lavie, 2005). This line of research, referred to collectively as Load Theory, highlights the importance of not only the level, but also the type of load (i.e., perceptual vs. cognitive) in predicting the interference of irrelevant distractors on selective attention in tasks such as hazard detection.

The implication for hazard perception is that detection performance may actually be improved when placed in a more complex driving environment that requires a relatively large portion of perceptual resources. Improved hazard perception (in terms of reducing the interference of distractors) under conditions of

high perceptual load, however, may only occur if the act of driving does not also become more difficult resulting in a higher cognitive load. The same would also be true for instances in which the driver is engaged in a secondary task. Distractor interference may be reduced to the degree to which a secondary task engages perceptual resources independent of cognitive-control resources resulting in better hazard perception performance. Research on distracted driving, however, suggests there may be few secondary tasks that would require increased perceptual resources without also requiring additional cognitive resources.

### **2.3 Measuring Driver Distraction**

As stressed in the review above, there are a variety of measures that can be used to assess the impact of distraction on driving performance. Driver distraction is a multidimensional construct, making it necessary to employ a number of different driving performance measures across numerous studies to assess the full effects of interference. For example, there is evidence that the source of the distraction differentially affects driver performance measures (Lee et al., 2009b). This illustrates the need for careful consideration in both, choosing appropriate measures and interpreting how those measures relate to real world driving and safety.

Driving performance measures can be divided into two broad categories including those that measure aspects of vehicular control (e.g., lane keeping, speed maintenance, and steering wheel movement) and those that measure object or event identification and detection (e.g., hazard perception). These categorical designations are supported by research that suggests that many components of

vehicular guidance require separate visual processes than those of object recognition (Leibowitz & Owens, 1977; Schieber, Schlorholtz, & McCall, 2009). This theoretical framework is referred to as the Ambient-Focal dichotomy, and contends that peripheral vision (i.e., ambient processing) is primarily used in basic vehicle control tasks while foveal or central vision (i.e., focal processing) is primarily used in object recognition and identification tasks (Schieber et al., 2009). Although this framework has its exceptions (e.g., the longitudinal control measure of vehicle following most likely utilizes focal resources), it highlights the need to acknowledge that different driving components can require distinctive processing resources. In turn, this may impact the results of a research study, depending on the nature of primary and secondary tasks and how performance is being measured.

### **2.3.1 Vehicle Control Metrics**

Vehicle control metrics include both longitudinal control (e.g., speed and vehicle following) and lateral control (e.g., lane maintenance and steering wheel movement) measures (Lee et al., 2009b). A large portion of studies exploring the effects of text messaging on driving rely on these metrics in order to quantify the effects of distraction on performance (Caird et al., 2014; McKeever et al., 2013; Strayer et al., 2013). This line of research has identified that texting while driving impacts both longitudinal control (i.e., lower speeds, increased speed variability, and increased headway) and lateral control (i.e., impaired lane keeping and increased steering wheel reversal rate) behavior (Caird et al., 2013). However, as mentioned before, relying solely on measures of vehicle control can lead to an incomplete understanding of how distraction impacts driving safety. Depending on

the current driving situation, the same performance outcome (e.g., increased speed variation) may either be beneficial or detrimental to maintaining driving safety. For instance, a few studies have found that speed was lower and headways longer while drivers text message (Drews et al., 2009; Hosking et al., 2009; Owens et al., 2011). Typically these findings would be reported as impairment in driving performance, however it is difficult to determine whether this behavior is a direct result of attention being directed away from the driving task, or whether it is a compensatory strategy deliberately adopted by the driver.

### **2.3.2 Object Identification and Event Detection Metrics**

Object identification and event detection driving performance measures (e.g., reaction time, number of missed or detected events, and incorrect responses) are considered a more direct measure of driving safety (Horswill & McKenna, 2004; Victor, Engstrom, & Harbluk, 2009) and should be used in coordination with vehicle control measures to understand the full impact of distraction on driving safety. Event detection metrics are often used to assess a driver's hazard perception skill (i.e., ability to identify and detect hazards), which has been correlated with increased crash rates (Drummond, 2000; Horswill & McKenna, 1999; McKenna & Crick, 1991). As with vehicle control skill, hazard perception has been shown to be sensitive to distraction (Burge & Chaparro, 2012), however, most studies that focus on hazard perception explicitly, are predominantly interested in outlining how experience moderates the process (Borowsky et al., 2010; Crundall et al., 2012; Kaber, Zhang, Jin, Mosaly, & Garner, 2012). For example, research suggests that more experienced drivers are better at detecting hazards, especially in cases where

hazards have an indirect relationship to their precursors, and that this skill can be improved through training (Kaber et al., 2012). Less work has focused on how engagement in a secondary task, especially text messaging, impacts the hazard perception process.

Object identification and detection methods that focus on driving hazards, also provide researchers insight into a driver's mental model of the environment around them. As mentioned above, hazard perception is the SA (i.e., mental model) for dangerous situations while driving, and includes the perception, comprehension, and projection of hazardous events (Endsley, 1995a; Horswill & McKenna, 1999). Gugerty (2012) argues that event detection measures, such as those that can be used to measure hazard perception, are especially useful when measuring how a driver's current SA is affected by environmental factors (e.g., different types of hazards) and internal driver factors (e.g., distraction), and doesn't suffer from confounding affects that may be caused by memory limitations of other SA measurement methods (e.g., query techniques).

As mentioned earlier, the level of mental workload increases as more tasks are taken on by a driver resulting in impaired hazard detection (Recarte & Nunes, 2003). For this reason, the measurement of mental workload in detection studies can be useful in interpreting the effects of distraction on hazard perception. Mental workload can be measured a variety of ways, including performance measurement (i.e., primary and secondary-task performance), physiological measurement (e.g., cardiovascular, ocular, and brain activity), and subjective workload ratings (e.g., NASA-TLX) (Vidulich & Tsang, 2012). In particular, combining a driver's hazard

detection performance with subjective mental workload ratings can provide a better understanding of how texting impacts driving performance. For example, studies have shown incremental rises in perceived mental workload induced by completing various cellular phone tasks while driving, led to poorer performance on a peripheral detection task, increases in reaction time to a lead vehicle braking, higher ratings of perceived mental workload, and impaired physiological indices (Strayer et al., 2013). The combination of these mental workload indices provides a more comprehensive assessment of distracted driving.

### **2.3.3 Measuring Hazard Perception using Signal Detection Theory**

Along with reaction time, event detection paradigms provide measures of performance that typically involve missed and detected events. One model that has often been used for measuring performance in traditional psychophysics research, but rarely used in analyzing such response behavior within the hazard perception literature, is Signal Detection Theory (SDT). SDT can be used when there are two states of the world (i.e., noise and signal+noise) in which an operator makes a response decision as to whether they detect a signal amongst all the noise (Green & Swets, 1966). Thus, SDT attempts to model how operators behave when faced with a detection scenario. In terms of hazard perception, the signal would be a hazardous event, with the noise encompassing all the other incoming information about the driving scene. The task of the driver is to determine the presence of a hazardous event and then respond to avoid a collision. For example, a driver may need to decide whether a car parked along the side of the road will pull out in front of them. One factor that will impact the difficulty of this task is the degree to which the

information indicating a signal (hazard) overlaps with information unrelated to the signal (i.e., noise). In the scenario above, a car with a blinker indicating they are going to pull out into traffic may constitute a stronger “signal” than one that simply has their brake lights on, making a hazard classification easier. Thus, in this case, the car with a blinker provides for a signal with less overlap with the noise.

In terms of describing response behavior in detection scenarios, there are four categories of outcomes that characterize an operator’s response pattern. These include hits (responds to a signal that is present), misses (does not respond to a signal that is present), false alarms (responds to an absent signal) and correct rejections (does not respond to an absent signal). The most common method of analyzing event detection in driving research primarily focus on whether the operator detected or missed an event, but largely ignore false alarms and correct rejections. This exclusion however, provides an incomplete picture of operator response performance. For example, interpretation of near perfect performance at detecting events in hazard trials should also consider response behavior on non-hazard trials as well. This will determine whether heightened performance is due to an exceptional ability to discriminate hazards from non-hazards, or a result of an operator simply responding to both events and non-events in order to ensure successful hazard detection. Thus, SDT allows researchers to explore whether impairments found in hazard detection performance (e.g., resulting from differences in experience or engagement in a secondary task) are due to deficiencies in hazard discrimination or in changes in thresholds for classifying an event as hazardous (Wallis & Horswill, 2007).



According to the traditional SDT ( $t$ SDT) model, there are two stages of information processing that are involved in the detection of a signal, including the aggregation of sensory evidence concerning the presence or absence of the signal and the decision as to whether this evidence reaches an operators threshold warranting a response that the signal is present (Green & Sweets, 1966). This translates into two independent influences on a driver's ability to detect a hazard, referred to as sensitivity (bottom-up influence) and response criterion (top-down influence), respectively (Wickens, Lee, Liu, & Becker, 2004).

Sensitivity describes how good a driver is at discriminating a signal from the noise, and depends on factors such as the strength of the signal stimulus and experience. For instance, detecting braking lights in degraded visual environments (e.g., fog) will result in reduced sensitivity for detection, compared to those in normal conditions (e.g., clear summer night). Response criterion describes the bias a driver may have in responding yes to a signal. For example, a driver may adopt a more liberal response bias (i.e., tendency to respond yes to hazards being present) in a school zone during school hours, in order to ensure they detect a child if one entered the roadway. In turn, this criterion may return to relatively normal levels when outside of school hours. This scenario is an example of an operator's modification of assigned values for each type of response. In this scenario, the operator knows that the costs of missing a hazard could be disastrous, i.e., striking a child, and thus, accepts more false alarms in order to increase the amount of hits. Another influence on response bias is the expectancy that a signal will be present. Operators often adopt a more liberal response bias when they know the probability

of a signal is high. This is an important influence with regard to hazard perception research as the hazards used in driving scenarios are usually limited to only a few types of events, occurring relatively often, that may introduce artificial participant expectancy for such events.

An operator's ability to adjust their response bias, based on factors such as cost/benefit tradeoffs, is an important factor in understanding how drivers interact with their environments to ensure driving safety. As mentioned previously, some researchers believe that crash risk attributed to using a cell phone while driving may be inflated due to the lack of consideration for strategies employed by the driver to circumvent the performance impairments (Poysti et al., 2005). Indeed, there is some evidence within event detection research that show drivers increase the number of false alarms they commit when engaged in a secondary task (Chisholm et al., 2006; Savage et al., 2013). Although only one study utilized SDT calculations to determine that this resulted in a more liberal response bias (Burge & Chaparro, 2012), researchers suggest that this response pattern might indicate strategies that were employed to avoid the negative impact of distraction on hazard perception. Due to the limited nature of these results, however, more research is needed to understand these outcomes more clearly.

SDT is considered one of the most robust theoretical models of human performance (Hancock, Masalonis, & Parasuraman, 2000). One of the basic tenets of *t*SDT, however, is the notion that the presence of a signal is discrete and binary (i.e., it's either present or absent). Thus, its efficacy for use in certain applications in which the presence of a signal may lie on a continuous scale is questionable. It has

been argued that in most complex real-world settings the definition of what constitutes a signal is situational and depends on a variety of factors (Parasuraman, Masalonis, & Hancock, 2000). That is, the signal (in terms of its state in the world) is “fuzzy”. For example, the classification of an object as being a driving hazard is not necessarily binary by nature, especially when the driver is making a decision based on “potentially” dangerous events. Rather, any given event can be defined as being somewhere on a continuous scale based on its potential for causing an accident (Wallis & Horswill, 2007). In this case two events may be deemed hazardous, but one may have a higher potential for causing an accident than the other. Thus, some states of the world point stronger to their being a signal (e.g., an event that has a 90% probability of resulting in a collision vs. a 20% probability of resulting in a collision). In real-world driving scenarios, it is often inappropriate to apply *tSDT*, because not all hazards are equal in their indication of a signal.

Furthermore, as with the relationship between the state of the world and a signal, the operator’s response value can also be “fuzzy”. For instance, an operator may have varying levels of confidence in their response that a signal was present. Confidence ratings in SDT calculations have been used in previous research (Gescheider, 1997; Green & Swets, 1966), however they are often forced into crisp categorical designations rather than continuous functions for later calculation.

Traditional measures of SDT do not account for the “fuzzy” nature of state of the world and response variables. As such, theorists have modified *tSDT* to account for these real-world scenarios, developing the model of Fuzzy Signal Detection Theory (*fSDT*). This model builds upon the foundations of *tSDT* (Green & Swets,

1966) and fuzzy logic (Zadeh, 1965) to develop the theory and basic postulates. As in *tSDT*, *fSDT* has four categories of outcomes (i.e., hits, misses, false alarms, and correct rejections) that are then used to calculate measures of sensitivity and response bias. Where *fSDT* is unique, however, is that instead of an outcome being mapped exclusively to one of the categories, an outcome can claim a proportion of membership in multiple categories (Parasuraman et al., 2000). Table 1 shows examples of signals and responses with their respective outcomes for both models. As can be seen in *tSDT*, each outcome is exclusive to a particular category, but in *fSDT*, outcomes can overlap amongst multiple categories. Thus, for a certain response trial, a large proportion of membership can be in the hit category (e.g., 0.8) with a small proportion being in the false alarm (FA) category (e.g., 0.1). In this case, there is a strong indication that the response was a hit, however it also indicates that the response was somewhat stronger than the signal called for, resulting in some membership in the FA category.

Table 1. *Response outcomes for both tSDT and fSDT (Adapted from Parasuraman et al., 2000).*

	<i>Signal</i>	<i>Response</i>	<i>Hit</i>	<i>FA</i>	<i>Miss</i>	<i>CR</i>
<b>Standard SDT</b>	0	0	0	0	0	1
	0	1	0	1	0	0
	1	0	0	0	1	0
	1	1	1	0	0	0
<b>Fuzzy SDT</b>	0.8	0.9	0.8	0.1	0	0.1
	0.1	0.2	0.1	0.1	0	0.8
	0.1	0.1	0.1	0	0	0.9
	0.2	0.2	0.2	0	0	0.8

Although *f*SDT is a fairly recent adaptation, a few studies have used the model to analyze operator response behavior in situations where *t*SDT was found to be inappropriate. In on such application, *f*SDT was used to analyze the detection of aircraft conflicts in air traffic control (ATC) scenarios (Masalonis & Parasuraman, 2003). In this case, the signal (i.e., aircraft conflict) was mapped to the distance between aircraft (between range 0, 1) and the response mapped to alert severity (range 0, 1), defining the fuzzy designations. When compared to *t*SDT, the utilization of *f*SDT generally produced fewer hits and false alarms in the ATC scenarios. In turn, the researchers argue that this provided for a more complete picture of the controllers detection performance. In a study comparing hazard perception ability of novice with experienced drivers, *f*SDT was used to determine whether differences were attributable to the expert's ability to better discriminate more hazardous from less hazardous situations or having lower thresholds for designating a particular event as being hazardous compared with novices (Wallis & Horswill, 2007). By using hazard potentiality ratings (based on expert driver's ratings for collision potential) for each scenario as a fuzzy definition of the signal, they found that poor performance by novice drivers was actually due to novices having a higher threshold for designating an event as being dangerous enough to warrant a response. Finally, research has shown that *f*SDT meets the assumptions of *t*SDT, adding to the validity of using such measures to model human performance in real-world settings where fuzzy designations of the states of the world and response sets are necessary (Bohil, Szalma, & Hancock, 2014 (In-press); Murphy, Szalma, & Hancock, 2004).

## 2.4 Current Study

The current research utilized event detection methods in order to assess the impact of text messaging on a driver's hazard perception ability. More specifically, the purpose of this research was to determine whether the impairments in hazard perception due to distraction observed in past driving studies (Caird et al., 2014), are due to differences in hazard discrimination (i.e., sensitivity) or changes in drivers' response thresholds (i.e., response criterion). Additionally, building upon a previous study conducted in our lab, this research explored whether measures of sensitivity and response bias are differentially affected by two types of texting tasks in real world hazard driving clips (Burge & Chaparro, 2012). In this previous study, it was found that while completing an artificial texting task that required the repeating of a random letter string (primarily information rehearsal), drivers adopted a more liberal response bias (ensuring hazard detection) compared to a task requiring alphabetization of a random letter string (manipulation of information). These results were similar to a study completed by Morris et al. (2008), which found that a manipulation task was significantly worse in terms of driving performance than a rehearsal task. In our previous study, however, a low fidelity simulator with only one type of hazard (e.g., cars moving into your lane on a three lane highway) was used. As mentioned before, response bias can be influenced by events that are highly probable and predictable, thus more complex and variable real world driving video clips will be used in the current research. Furthermore, naturalistic cellphone tasks, requiring both rehearsal and manipulation of information to provide different types of tasks, will be used in a second study to

improve the ecological validity of the work. Another unique contribution of this work to the broader field of driving research was the use of SDT to provide a complete description of driver detection behavior. In order to account for the fuzzy nature of real-world hazards, *f*SDT was used to calculate measures of sensitivity and response criterion in addition to *t*SDT calculations.

#### **2.4.1 Hypotheses**

*Hypothesis 1:* It was hypothesized that, similar to the previous study completed by Burge and Chaparro (2012), drivers will adopt a more liberal response criterion ( $\beta''$ ) in each of the drive + information rehearsal texting conditions (i.e., repeating a 7-letter string and repeating a telephone number) relative to each of the drive + information manipulation phone task conditions (i.e., alphabetizing 7-letter string and generating a text message response) and driving-only baseline condition. This response behavior will be a result of driver's attempting to compensate for distraction by adopting a more liberal response bias. Accordingly, in the drive + information manipulation task conditions participants will demonstrate a more conservative response bias (i.e., higher number of missed hazards and low FA rate), as a result of having fewer cognitive resources to devote to applying the more liberal response criterion. Furthermore, in the driving-only baseline condition, drivers will adopt a more neutral response bias. Additionally, it was hypothesized that no differences in sensitivity ( $A'$ ) measures will be found when comparing the various driving conditions.

*Hypothesis 2:* In terms of driving environment, it was hypothesized that drivers will show a more liberal response criterion in the in-city driving scenarios

compared to the highway scenarios due to the increase in the number of potential hazards (i.e., more complex driving environment). The increase number of potential hazards will result in drivers' responding to more events in anticipation of a hazard than highway scenarios. No differences in sensitivity are predicted, as all participants will be similar in terms of driving experience with the two driving environments.

*Hypothesis 3:* It was hypothesized that the time to react to hazards will be the fastest in the baseline condition, followed by each of the driving + information rehearsal tasks, and the slowest in each of the driving + information manipulation tasks.

*Hypothesis 4:* Additionally, reaction time will be faster in the highway conditions compared to the in-city conditions, due to the more complex nature of in-city driving that will require the processing and filtering of more information before reacting.

*Hypothesis 5:* It was hypothesized that perceived mental workload will be the lowest in the baseline condition, higher in each of the driving + information rehearsal tasks, and the highest in each of the driving + information manipulation tasks.

*Hypothesis 6:* Lastly, it is hypothesized that similar results will be found for both the artificial (i.e., repeat and alphabetize 5-letter strings) and naturalistic (i.e., dialing a phone number and responding to questions via text message) cellular phone tasks.



## **CHAPTER 3**

### **METHODS**

Hazard perception is a multi-faceted process that requires drivers to maintain an ongoing awareness of a complex driving environment, composed of an assorted set of potential hazards (Horswill & McKenna, 2004). A degraded awareness for such hazardous conditions (e.g., caused by distraction) leads to errors in the detection of events that could result in collisions, having a direct impact on driving safety (Victor, Engström, & Harbluk, 2009; Horswill & McKenna, 2004). The majority of research studies utilize behavioral responses to a limited number of discrete hazardous events (e.g., response to a braking lead vehicle, vehicle lane deviations, or pedestrians) to assess a driver's hazard perception ability (Greenberg, et al., 2003; Summala, Lamble, & Laakso, 1998; Strayer & Johnston, 2001). Simply recording the number of missed events, however, does not provide all the information required to describe hazard response. Thus, measures of SDT need to be used in order to provide a complete understanding of drivers' hazard detection behavior.

#### **3.1 Current Study**

The current study is a continuation of a previous experiment completed in our lab that utilized SDT measures to assess the effects of distraction on a driver's ability to detect immediate hazards. We found that drivers adopted a more liberal response bias when faced with a secondary texting task that primarily involves rehearsal of information, however, this response pattern diminished when

completing a task that required to manipulate information, resulting in a greater number of missed hazards (Burge & Chaparro, 2012).

Similar to the previous experiment, the purpose of this study was to explore how performing a texting task will impact a driver's hazard perception in terms of the SDT calculations of sensitivity and response bias. However, the utilization of real-world driving scenes introduced less predictable hazards than those found in the simulator used in the preceding study. In addition to the previous artificial tasks, two naturalistic tasks were added to improve external validity. A second limitation of the previous work is that in order to apply calculations based on *tSDT*, a binary designation must be made for each scenario as having a signal (i.e., hazard) present or absent. The classification of hazardous situations, however, is not binary in the real world but lie on a continuum, with each hazardous situation containing a different level of potentiality in terms of developing into a hazard that requires a response.

The current study accounted for this limitation by utilizing *fSDT* to account for the fuzzy nature of real-world driving hazards. Unlike *tSDT*, which requires a classification of any given scenario as either containing a hazard or no hazard (a binary designation), *fSDT* allows for each scenario to be classified by its potential to develop into a situation where a driver response is necessary to avoid a collision or near collision. This is akin to realistic driving environments in which a hazardous situation will vary within different contexts and over time, thus making it necessary to utilize non-binary definitions of signal and response (Parasuraman et al., 2000).

### **3.1.1 Design**

The study was completed as a 2x5 within subject's design. The first factor presented two different driving environments, i.e., highway and in-city driving scenes. The second factor presented five conditions that included a combination of artificial and naturalistic texting tasks, each of which included one task that primarily required rehearsal and one task that also required information manipulation and generation. The fifth condition served as a no-texting, drive-only baseline condition. The two artificial texting tasks required the participants to either repeat (rehearsal) or alphabetizing (manipulation) 7-letter strings that were sent to them via text message. The two naturalistic texting tasks required participants to either repeat a phone number (rehearsal) or answer an open-ended question (manipulation).

Hazards within each traffic scene were determined using a continuous rating scale and included an equal number of scenarios with large, moderate and little potential for traffic conflict (e.g., situations that would require a driver to respond). The hazard potential was determined through a method adapted from Wallis and Horswill (2007), in which experts rated the potential for an accident to occur for each scenario (see section 3.1.4 for a full description). These hazard potential ratings were utilized in the  $fSDT$  calculations.

### **3.1.2 Participants**

Thirty participants (evenly split between male and female;  $M=23.1$  years old) from the Wichita State University student body and from the surrounding community were recruited to participate in the driving session. All participants

were active drivers, with at least 2 years of driving experience ( $M=6.73$  years), and at least 20/20 visual acuity. All participants owned a touch screen phone to ensure familiarity with the cell phone used in the experiment and on average, report sending at least 10 text messages a day ( $M=66.83$  texts/day). The nature and purpose of the experiment was explained to all participants who give their informed consent to participate.

### **3.1.3 Materials**

Before beginning the session, participants completed a background survey concerning driving behavior and history, texting habits and frequency, and basic demographic information (see Appendix A). Snellen visual acuity was measured with participants wearing their normal optical corrections during the session. After each condition, an online version of the NASA TLX was given to the participants to assess perceived mental workload (Hart & Staveland, 1988). Furthermore, multiple GoPro cameras (Whit Edition) were used to record the session. In order to record eye glances to the cell phone, the internal camera of the experimental cell phone (iPhone 4) was used to capture when the participant was looking at the screen during the session.

#### *3.1.3.1 Driving Hazard Scenarios*

Hazard detection was assessed using hazard perception videos that were filmed from the driver's perspective, including a rear-view and side mirrors, providing a view of cars in the front, rear, and to the sides of the drivers car. Participants viewed these videos on a 60" Sharp Aquos LC-HD television (model LC-70LE845U). These scenarios were collected from a range of genuine, unstaged

hazardous traffic scenes, including both highway and in-city environments. A sample screen shot of the videos can be seen in Figure 3. The scenarios included situations that had high, moderate, or low potential for a collision based on ratings from experienced drivers. The main purpose for choosing equal scenarios for each of the categories is to ensure that a full spectrum of hazardous situations is presented. There were a total of 12 city and 12 highway scenarios (each including 4-high, 4-moderate, & 4-low hazard potential scenarios) of 30-90 seconds in length, for each block of trials. Baseline (non-texting) and texting trials were presented randomly within each block to ensure the participants could not predict when they would receive a text message.



*Figure 3.* Sample screenshot of hazard perception video with a pedestrian.

In each hazard scenario, a response interval was defined for an observable threat that would require the driver to take some sort of evasive action to avoid a collision or near collision (Wallis & Horswill, 2007). The interval begins when an

object that represents a potential hazard enters the visual field (e.g., pedestrian on a crosswalk) and ends when a driver response would have been too late to avoid a collision (0.7 seconds before a possible collision impact). The media player iTunes (V. 12.1) was used to control the presentation of the driving scenarios, with a keylogger being used to collect the driver's behavioral responses to potential hazards.

#### *3.1.3.1.1 Hazard Scenario Potentiality Ratings*

The final driving scenarios were chosen to represent an equal number of scenes with low, moderate and high potential for a collision based on expert ratings. Scenarios included non-staged driving scenes that were recorded from the driver's perspective, including rear and side-mirror views. Scenes included in-city and highway-driving environments to provide two types of scenarios in the assessment. A total of 120 traffic scenarios ( $M=30.66$  sec;  $range=$  15 to 50 sec) that fit the requirements for the study (i.e., represented a wide range of hazard scenarios, included only one hazard, and fit the time parameters for the study) were chosen to be rated by the experts. The scenarios were occluded 3 s before the driver reaches the hazard event, after which the experts were asked to estimate the potential for a traffic conflict (e.g., collision with an object in the scene) within 3-5 s of the occlusion if no evasive action is taken by the driver. After ratings were attained, an equal number of scenarios from each category for hazard potential were selected (0-6 rating = low potential, 7-13 = moderate potential, 14-20 = high potential), choosing scenarios with the lowest standard deviations across experts to ensure the highest agreement possible. To determine the potentiality of a collision for each

scene, three expert drivers rated each scenario on a 20-point scale as to its potential to result in a traffic conflict (0-no potential to 20-unavoidable) (Wallis & Horswill, 2007) (see Appendix B). As outlined by Wallis and Horswill (2007), these expert drivers included trained driver education instructors (at least 20 years of driving experience and 10 years of experience teaching driver's education courses).

Additionally, there is evidence that hazard perception skill can improve greatly through targeted training and education (Beanland, Goode, Salmon, & Lenne, 2012), suggesting that driving instructors that have experience teaching such skills are ideal candidates for rating the hazard scenarios. The definition of a traffic conflict was taken from Wallis and Horswill (2007) as being

*“ a situation in which a collision or near collision with another road user (including stationary vehicles, cyclists, or pedestrians) would occur unless you take some type of evasive action (slowing, steering, etc.)” (pg. 1181).*

Intraclass Correlations (ICC) were used to calculate inter- and intra-rater reliabilities (Bravo & Potvin, 1991; Shrout & Fleiss, 1979). Inter-rater reliability between the three experts was high, ICC = 0.79, 95% CI (0.73, 0.84). For the intra-rater reliability calculations, the experts rated a subset of the scenarios (20) for a second time at the end of the session. The intra-rater reliability within the three experts was high (ICC = 0.97, .71, and .77), indicating they were consistent with their ratings.

#### *3.1.3.2 Text Input Device*

An iPhone 4 (iOS version 7.1; Apple, California) equipped with iMessage was used to complete the texting task. The keyboard was a touch screen with a QWERTY

arrangement. Participants were allowed to use either the vertical or horizontal keyboard layout, however all chose to keep one hand on the steering wheel while texting with one hand in the vertical layout. The text messages were sent using iMessage on a MacBook laptop.

#### **3.1.4. Procedure**

Participants first gave their consent to participate in the study, after which they completed a demographics survey. Participants were then given an explanation of the study with a brief driving scenario to help guide the session. Once the participants received the initial briefing, they began with the practice phase of the experiment that included a practice of the texting task alone, practice of the driving task alone, and practice of the driving task with each texting task. Once the participants were performing the tasks well and felt comfortable, they were reminded of the driving scenario, and moved to completing the experimental phase of the session.

The experimental phase included four counterbalanced blocks of 24 trials for each of the four-texting tasks (96 trials total). The texting tasks were selected to include both artificial and naturalistic tasks, which require either, primarily working memory (i.e., rehearsal) or central executive (i.e., manipulation/generation) processes. Previous studies have shown that tasks that require manipulation/generation of information result in poorer driving performance than those that require rehearsal (Burge & Chaparro, 2012; Morris et al., 2008) that the generation of messages requires central executive processes (Almor, 2008). The artificial tasks required the participants to copy a 7-letter string (rehearsal) or



alphabetize the 7-letter string before sending it back to the experimenter (manipulation). The naturalistic texting tasks will require the participants to copy a 7-digit phone number (rehearsal) or answer an open-ended question (generation). Half of the trials for block were no-text conditions to serve as a baseline. No corrections of the text messages were permitted.

Within each block, a randomized block design was used to ensure that each driving environment (i.e., in-city vs. highway) and hazard potentiality (i.e., low, moderate and high) included an equal number of both texting and no-texting conditions.

For each trial, participants were asked to view the driving scenario as if they were driving in the real world and to respond to any event that would require evasive action in order to avoid a collision or near collision event by pressing a button positioned on a steering wheel. Each scenario was ended either after a participant response or at the point a response would have been too late to avoid a collision event. In half the scenarios, participants were sent a text at random intervals. The task continued until the end of each driving scenario. A 5-second no-texting buffer was included at the beginning of each scenario so that the participant has time to acclimate to the scene. Following each trial, participants were asked to rate their confidence (0-100%) in whether their response was necessary to avoid a collision event, or if they did not respond, their confidence that the lack of response was accurate (Parasuraman et al., 2000). Participants were also asked to identify the hazard if a response was made (see Appendix C). Once this was completed, they were presented the next traffic scene. Additionally, they were administered the

NASA-rTLX after each texting block. Lastly, glance-based metrics (e.g., number and duration of glances away from the roadway) were calculated using the ISO standards for visual demand metrics (Victor et al., 2009) to account for differences between texting conditions. This included analyzing the iPhone video frame by frame (per ISO 15007-2) transcribing the time stamp interval of the first frame once the driver's eyes glanced to the phone to the last frame when the driver glanced back up to the driving scene. This allowed for the calculation of the duration of each glance, as well as the number of glances per texting task. The experiment took 1.75-2 hours to complete.

## **CHAPTER 4**

### **RESULTS**

#### **4.1 fSDT Calculations**

As mentioned, fSDT was used to evaluate hazard response behavior, with expert ratings for the potentiality of a collision occurring and participant response confidence ratings serving as the fuzzy mapping functions (i.e., state of the world ( $s$ ) and response values ( $r$ ), respectively). To assign degrees of membership in the four outcome categories of fSDT (i.e., Hit, Miss, FA, CR), a mixed set of implication functions were used based on previous work applying fSDT, allowing for membership in multiple categories (Parasuraman et al., 2000; Wallis and Horswill, 2007) (See Appendix F for calculations). Once membership values were assigned, they were summed over the total number of available trials to return the standard SDT measures of Hit and FA rates (Table 2).

In addition, mean sensitivity and response criterion values were calculated, shown as a function of texting condition in Table 2. Parametric SDT calculations were inappropriate for this analysis given the relatively low number of trials and occasions when no false alarm memberships were assigned. Alternative, non-parametric SDT indices, specifically  $A'$  and  $B''$ , are well established and are especially advantageous for paradigms in which traditional SDT assumptions are not met, especially within vigilance paradigms (Pollack & Norman, 1964; Donaldson, 1992; See et al., 1997). Therefore,  $A'$  was used to calculate sensitivity and  $B''$  was used to calculate response criterion.

Table 2. Correct detection and false alarm rates (i.e., weighted average across trials) and means of  $A'$  (sensitivity) and  $B''$  (response criterion) for driver hazard detection as a function of texting condition

Texting Condition	Correct Detection Rate $M (SD)$	False Alarm Rate $M (SD)$	$A'$ $M (SD)$	$B''$ $M (SD)$
Baseline (No-Text)	0.65 (0.14)	0.31 (0.16)	0.76 (0.09)	0.07 (0.35)
Repeat 6-Letter String	0.52 (0.17)	0.25 (0.15)	0.70 (0.15)	0.37 (0.43)
Alphabetize 6-Letter String	0.40 (0.14)	0.16 (0.12)	0.73 (0.11)	0.74 (0.37)
Repeat Phone #	0.51 (0.19)	0.24 (0.16)	0.72 (0.11)	0.43 (0.48)
Answer Question	0.42 (0.15)	0.15 (0.10)	0.73 (0.10)	0.74 (0.44)

#### 4.1.1 Sensitivity ( $A'$ )

Overall, the texting conditions had significantly lower sensitivity measures compared to the driving-only, baseline condition,  $t(29) = -2.21, p < .05$ , Cohen's  $d_z =$

0.45. Additionally, a 2x5 repeated-measures ANOVA was used to examine the effects of the five different texting conditions and driving environment (i.e, city vs. highway) on the measure of sensitivity ( $A'$ ). A main effect for sensitivity was found for texting condition,  $F(2.53, 73.50) = 19.40, p < .001, \eta^2_p = .68$ , and for driving environment (i.e, city & highway),  $F(1,29) = 10.13, p < .01, \eta^2_p = .26$  (see Appendix G for means). Additionally, a significant interaction was found for texting condition x driving environment,  $F(2.73, 79.29) = 4.24, p < .05, \eta^2_p = .25$  (See Figure 5). More specifically, the alphabetization task had significantly lower sensitivity than all other texting conditions, in both city & highway driving ( $p < .05$ ). On the other hand, the baseline (no-texting) condition resulted in an increase in sensitivity across all conditions ( $p < .05$ ). The alphabetization and baseline trials are the only conditions to differ significantly in sensitivity between city and highway driving scenarios, with the alphabetization task resulting in increase in sensitivity in the highway condition compared to the city condition ( $t(29) = -3.16, p < .01, \text{Cohen's } d_z = 0.58$ ). The baseline condition, however, showed the opposite pattern, with sensitivity being higher in the city condition compared to the highway ( $t(29) = 6.36, p < .001, \text{Cohen's } d_z = 1.16$ ).

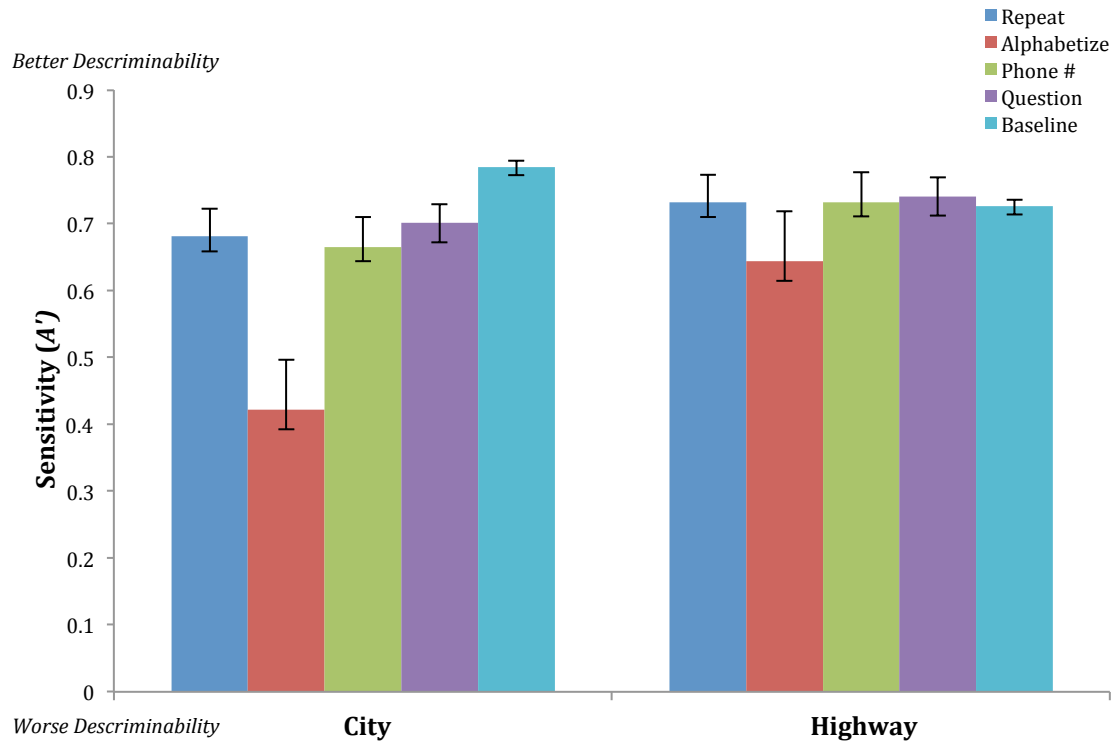


Figure 4. Mean sensitivity ( $A'$ ) calculations for the different texting conditions. (Bars represent  $\pm$  1 standard error.)

#### 4.1.2 Response Criterion ( $B''$ )

Overall, the texting conditions had more conservative response bias measures compared to the driving-only, baseline condition,  $t(20) = 10.91, p < .001$ . Additionally, a repeated-measures ANOVA found significant main effects across texting condition and driving environment for response bias ( $F(2.66, 77.16) = 25.10, p < .001, \eta^2_p = .904$  and  $F(1, 29) = 32.64, p < .001, \eta^2_p = .209$ , respectively) (see Appendix G for means). Correspondingly, a significant interaction effect was found for texting condition  $\times$  driving environment,  $F(4, 116) = 7.65, p < .001, \eta^2_p = .356$  (See Figure 6). Post hoc tests showed that the baseline condition resulted in a more liberal response bias compared to that of the other conditions across both city and highway environments ( $p < .05$ ), except for the repeat a 6-letter string texting task,

which was only more conservative than baseline in the highway driving ( $p < .05$ ). The alphabetization texting condition resulted in a significantly more conservative response bias than those of the repeating a 6-letter string task, repeating a phone number task, and the baseline condition ( $p < .05$ ), but not the question texting task. As mentioned above, participants completing the repeating a phone-number task showed a more liberal response bias than the alphabetization and question tasks ( $p < .05$ ), but a more conservative bias compared to the baseline condition ( $p < .05$ ). Lastly, when participants completed the question texting task, they showed a more conservative bias compared to completing all other tasks ( $p < .05$ ), except for the alphabetization texting task. Interestingly, no differences were found for tasks that were found to be similar in MWL ratings (i.e., repeat 6-letter string vs. repeat phone number and alphabetize 6-letter string vs. question). Another finding was that only the two artificial texting tasks (i.e., repeat and alphabetize 6-letter string) along with the baseline condition were significantly different between the two driving environments, with each showing a more liberal bias while completing the hazard detection task in the city condition ( $p < .001$ ).

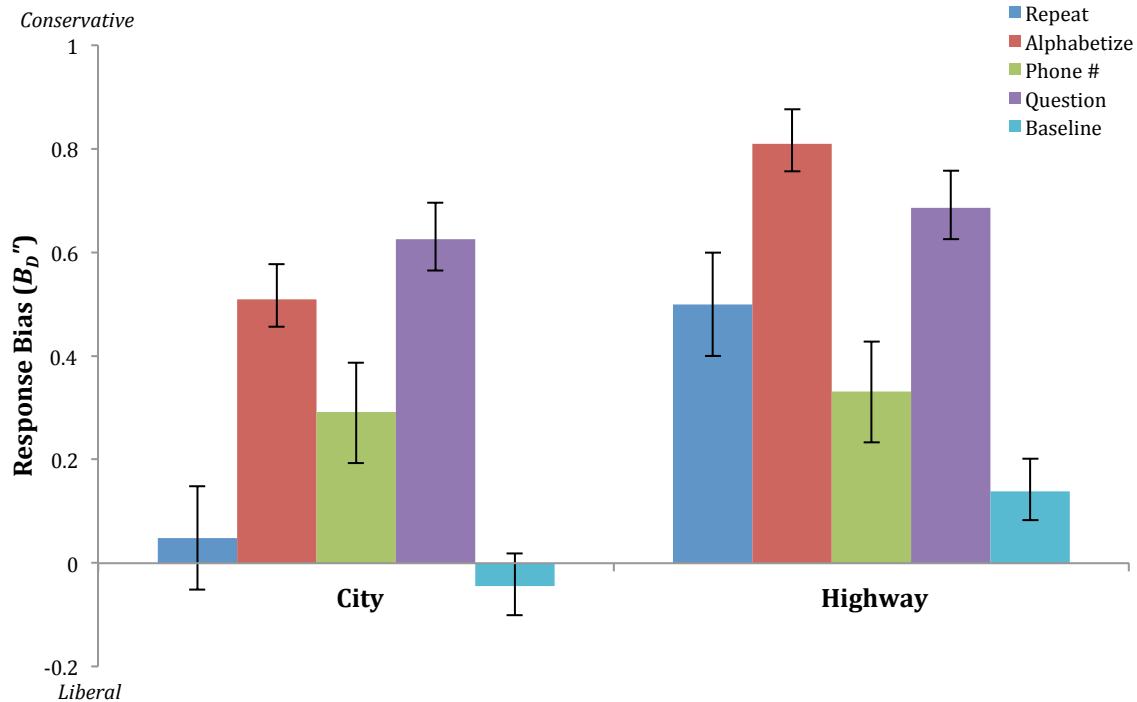


Figure 5. Mean response bias ( $B_D''$ ) calculations for the different texting conditions. (Bars represent +/- 1 standard error.)

No comparisons between  $f$ SDT and  $t$ SDT calculations of the data were made due to the nature of the potentiality ratings of the hazard scenarios. Dividing the scenes into dichotomous hazard/no-hazard categories was inappropriate because the scenarios were chosen specifically to vary systematically along a continuum. The moderate rated scenes would be especially problematic, since these scenarios are somewhat ambiguous and designating these scenes as either hazard or no-hazard would be arbitrary.

#### 4.2 Time to respond to hazards

Reaction time (RT) was calculated from the end of the scenario back to the time of response, indicating the “buffer” a participant allowed between the response and the point in time that a collision could no longer be avoided if no response was

made. This was done because the end of each scenario provided the only standard point in time across all scenarios (i.e., 1.7 sec before a collision would occur). RT measures were transformed using a  $\text{Log}_{10}$  function in order to meet normality requirements.

Overall, there was a longer buffer between response and the end of the scenario for the no-texting condition compared to the texting conditions, ( $t(29) = -5.33, p < .001$ ). That is, participants allowed more time between their response and the collision event, increasing the likelihood they would respond with enough time to avoid a collision. A repeated-measures ANOVA indicated a significant main effect of RTs across the texting conditions,  $F(4,72) = 4.88, p < .01, \eta^2_p = .633$ , but not driving environment,  $F(1,18) = 0.615, p = .44$  (see Appendix G for means). Post-hoc paired comparisons show that the baseline condition had a significantly longer reaction buffer than all tasks ( $p < .01$ ), except for the repeat a phone number task (see Figure 7). This indicates that the participants responded sooner to hazards in the no-texting condition, except for the repeat a phone number task, in which there was no difference. The interaction effect between texting conditions and driving environment only approached significance, so no further analyses were completed ( $F(2.18, 39.19) = 2.95, p = .069$ ).



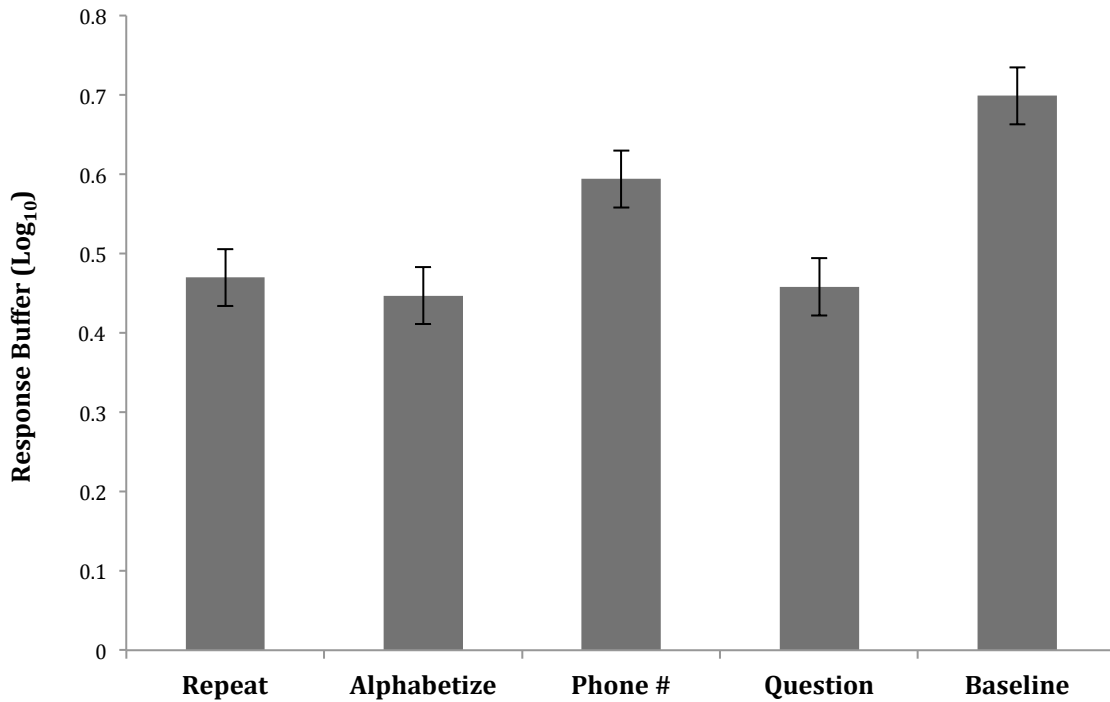


Figure 6. Length of time between response and a potential collision for the different texting conditions (i.e., response buffer). (Bars represent +/- 1 standard error.)

The number of glances the participant made to the cellular phone per texting task was not informative, because participants were continuously engaged in the tasks until the end of the scenario. Thus, the total number of glances per scenario were similar. A more meaningful glance metric is the duration of each glance, with sustained glances causing more disruption with the driving task. No significant differences were found between texting tasks ( $F(3, 81) = 1.672, p = .180$ ) for glance duration (See Figure 8). This suggests that differences in performance between texting tasks was not due to drivers taking their eyes off the road per se, but rather from the cognitive load that the tasks induced.

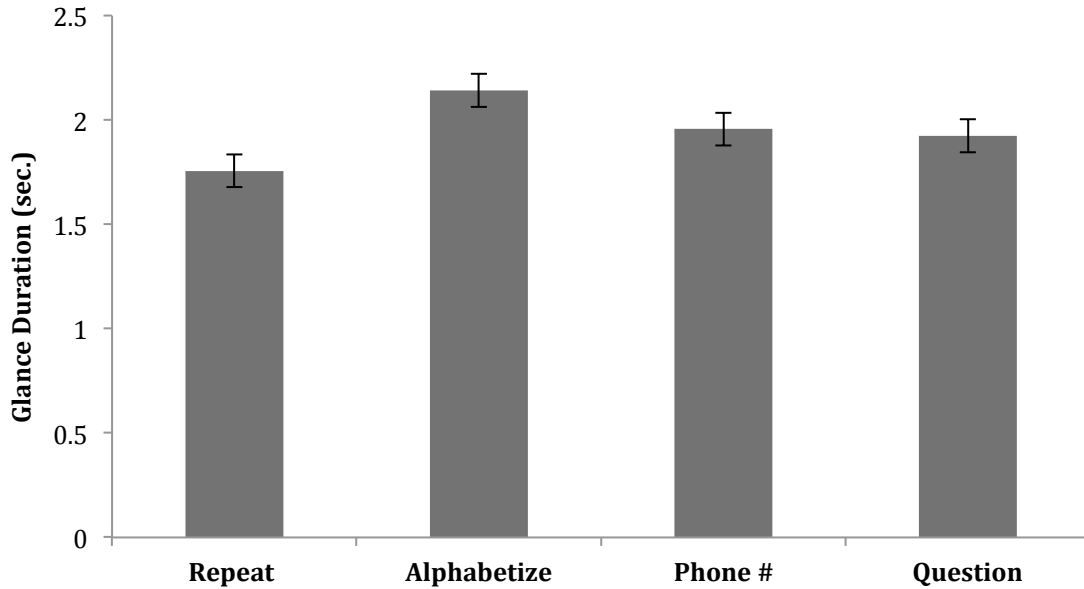


Figure 7. Average glance duration (sec.) across texting conditions. (Bars represent +/- 1 standard error.)

#### 4.3 NASA TLX: Perceived Mental Workload Ratings

The NASA TLX was used to assess perceived mental workload after each texting block to identify which texting tasks caused the highest workload (see Figure 4). It has been shown that an increase in mental workload on a secondary task impairs performance on the primary task (Recarte & Nunes, 2003). A one-way repeated measures ANOVA was used for each dimension of the NASA TLX to assess the demands that the texting tasks placed on the participant while completing the hazard detection tasks (see Appendix for a table of means). All dimensions were found to be significant across texting conditions including, mental demand ( $F(2.25, 65.26) = 9.89, p < .001, \eta^2_p = .254$ ), physical demand ( $F(2.72, 65) = 3.49, p < .05, \eta^2_p = .257$ ), temporal demand ( $F(2.58, 74.94) = 4.53, p < .01, \eta^2_p = .34$ ), performance ( $F(3, 87) = 5.54, p < .01, \eta^2_p = .329$ ), effort ( $F(2.65, 76.78) = 9.12, p <$

.001,  $\eta^2_p = .559$ ), and frustration ( $F(2.62, 75.98) = 10.68, p < .001, \eta^2_p = .42$ ) (see Appendix G for a table of means).

Further analysis showed that participants rated the alphabetization texting task as requiring higher mental, physical, and temporal demand, requiring more effort, causing more frustration, and resulting in poorer performance, than the repeating a phone number task ( $p < .001$ ). This task was also rated as having a higher mental demand, requiring more effort, causing more frustrations, and resulting in poorer performance than the repeating a 6-letter string task ( $p < .05$ ). An additional finding was that participants rated the answer a question task as requiring higher mental demand, and increased effort and frustration than the repeating a phone number task ( $p < .05$ ). It also caused increased frustration compared to the repeating a 6-letter string task ( $p < .001$ ).

In summary, participants rated the naturalistic tasks (i.e., repeating a phone number and answering questions) similarly on mental demand as their “equivalent” artificial tasks (i.e., repeating and alphabetizing a 6-letter string, respectively). Additionally, participants perceived the alphabetization task and, to a lesser extent, the question texting tasks as having a higher MWL than the repeat a 6-letter string task and the repeating a phone number task. Lastly, repeating a phone number resulted in the lowest MWL ratings compared to the other three texting conditions in the mental demand, effort and frustration dimensions.

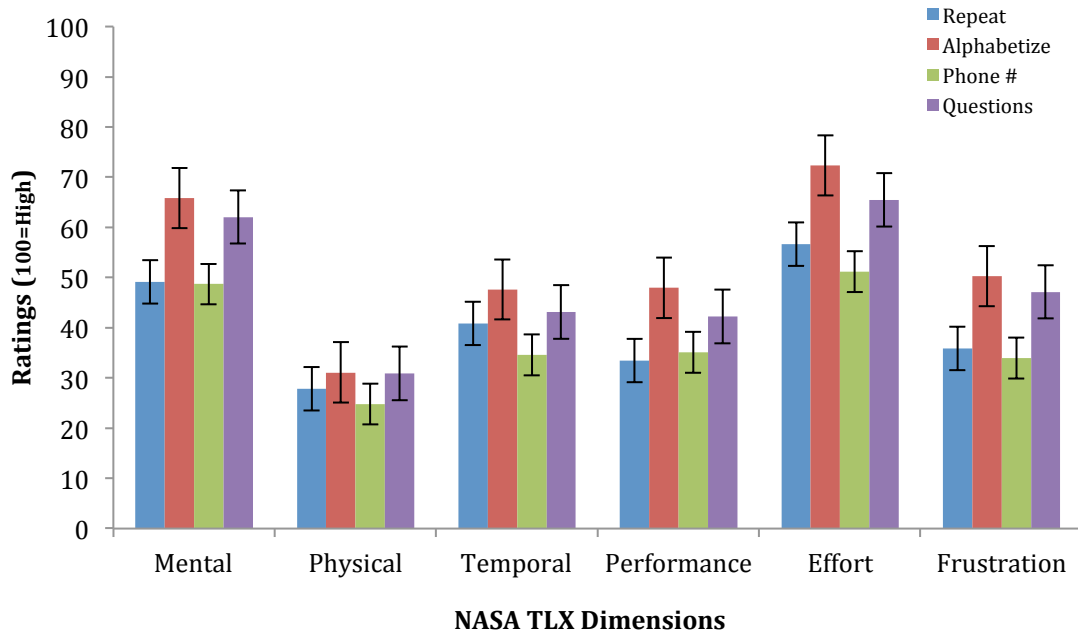


Figure 8. NASA TLX ratings across workload dimensions as a function of texting task

## CHAPTER 5

### DISCUSSION

#### 5.1 Summary of Results

The findings of this study supplement the growing evidence that texting negatively impacts driving performance, while also highlighting the complexity of the hazard perception process. Specifically, texting while driving resulted in increased perceived MWL, decreases in sensitivity, a more conservative response bias, and caused drivers to react later to hazards compared to driving only conditions. Notably, these effects were also influenced by the type of texting tasks and by the driving environment.

The MWL ratings suggest that texting tasks requiring information manipulation are more cognitively taxing than those that require primarily information rehearsal. This is consistent with previous work that has found tasks

involving information manipulation causes more interference than those that involve simple information maintenance (Burge & Chaparro, 2012). One explanation for this may be that the tasks requiring information manipulation are taxing central executive resources, while the rehearsal tasks requiring mainly working memory resources. Central executive secondary- tasks have been shown to cause more interference than tasks that require a lower level of cognitive resources (Kunar, et. al., 2002). One interesting finding was that the naturalistic, answer a question task was rated similar to the alphabetization task in perceived frustration. One could argue that this task shouldn't cause this level of frustration because of it is similar to real-world texting tasks. This may be due to requiring participants to answer questions they are not necessarily interested in answering, causing some annoyance. Having a self-selected conversation with each participant may reduce frustration. In addition to providing a more complete understanding of how different texting tasks may impact cognitive load while driving, this provides a first step in identifying tasks that may be the most distracting and thus, those that should be avoided while driving. Furthermore, in general, the naturalistic tasks were rated as requiring less MWL than the artificial tasks, with the alphabetization task being the highest on almost all dimensions. Consequently, the use of difficult and artificial secondary tasks that require the manipulation of information (i.e., mathematical calculations, arrangement of letters, etc.) may lead researchers to overestimate the negative effects of texting while driving and emphasizes the need to focus on improving the external validity of driver distraction research by utilizing naturalistic tasks.

The effects of texting on sensitivity measures complement the MWL ratings, with an overall decrease in sensitivity while texting and driving. Furthermore, sensitivity for the alphabetization texting task was lower than all other conditions, both in city and highway environments, with no other texting conditions being different from one another. This pattern of results were curious, as our previous research found no sensitivity changes as a result of the introduction texting tasks, whether they required information manipulation or rehearsal (Burge & Chaparro, 2012). This finding, however, was likely due to the previous study using relatively easy and predictable hazard scenarios. This may have resulted in a ceiling effect, allowing the driver to overcome even the most difficult secondary task to maintain hazard detection performance. In contrast, the use of real-world hazard scenes in the present study introduced more complex and less predictable hazards. As a result, sensitivity was impaired while engaged in texting tasks that are more cognitively demanding.

As expected, the highest sensitivity levels were found in the driving-only condition. More interestingly, the alphabetization condition showed a significantly lower sensitivity level in the city compared to the highway, with the baseline condition showing the opposite pattern. This is contrary to our expectation that across all conditions, sensitivity would be lower in the city environment considering the increased environmental complexity. It may be that drivers are better at discriminating hazards from non-hazards in the city due to a perceived increase in risk, at least when demand for processing is low. Research has shown that when individuals encounter high perceptual load within basic visual search tasks, they are

better able to filter out distractors (Lavie, 2004, 2005). What occurs while driving in the city may be similar in that, when a driver encounters an environment that involves high perceptual load, they may be better able to filter out unrelated information improving the detection of hazards. When the driver is experiencing high cognitive demand, such as the case in the alphabetization condition, however, driver's seem unable to use this enhanced focus to filter out distractors, causing a decrease in their ability to perceive hazards in such a multifarious environment.

Consistent with initial hypotheses, participants demonstrated a more conservative response bias (i.e., less likely to respond to a hazard) in the texting conditions compared to the driving only condition across both driving environments (except for the repeat the 7-letter string, which was only more conservative in the highway environment). Furthermore, the alphabetization and question task resulted in a more conservative response bias compared to both of the repeat tasks (7-letter string and phone number). Thus, it seems drivers are less likely to classify an event as warranting a response when they are texting, especially when the texting task requires central executive resources. This may be the result of driver's not fully processing and connecting cues that normally lead to a hazard classification (especially indirect cues that present a more difficult classification task). Based on the consistent eye glance durations to the phone across texting conditions, it isn't necessarily that the drivers didn't look at the cues, but that they failed to process them at a deep enough level in order to make a projection of a hazard. Additionally, no differences were found between the two central executive

tasks or the two working memory tasks, providing further evidence for the distinction between these processes.

Lastly, only the two artificial tasks and the baseline task differed between the two driving environments, with city driving resulting in more liberal response biases, possibly due to the complexity of city environments. This may have influenced the more liberal response bias compared to the more predictable highway environments, in which drivers believe they are less likely to encounter a collision. The finding that the two artificial tasks differed between driving environments, but the two naturalistic tasks did not is something of an anomaly. It could be that drivers were better able or simply more focused to compensate while performing the naturalistic tasks (i.e., adopting a more liberal response bias in both city and highway environments) than the artificial tasks, however this needs to be explored further.

Analysis of the reaction time data revealed that the time between hazard response and time-to-potential collision was greatest for the baseline condition compared to all other texting conditions except for the repeat a phone number task. It is notable that the central executive tasks were not different than the working memory tasks. This may be explained in part, by the similar eye glance durations (per glance) found between the four texting conditions and implies that when drivers were able to identify a situation as being hazardous, they had the visual resources to respond equally as fast in all texting conditions. This also indicates that the impaired hazard response behavior resulting from the more difficult texting tasks was due more to limitations in cognitive processing (e.g., inattentional



blindness) and not to an increase in glances away from the roadway. Even more surprising perhaps, was that no difference was found between the driving-only and repeat phone number conditions. This suggests that in terms of reaction time, a relatively low cognitive demanding naturalistic task causes similar interference as that of completing a driving task alone.

## **5.2 Real-world Implications and Design Recommendations**

The current study highlights the importance of considering multiple factors when attempting to understand the effects of texting on driving behavior and offers some opportunities for circumventing impairment. The findings suggest that studies that use artificial tasks, especially those that are increasingly difficult, may cause researchers to overestimate the effects of texting on driving safety. With this said, texting did impact the driving task, especially in terms of the adoption of a more conservative response bias, which may lead to more missed hazards in driving environments.

The current focus of the auto industry on the inclusion of advanced warning systems and augmented reality in future model years may be beneficial in circumventing some of the negative effects of driver distraction. In terms of filtering out distractors and attending to important information, this may help a cognitively loaded driver identify relevant situational information that may impact driver safety. With this said, more research is needed to explore how the false alarm rate of the system, as well as driver reliance may impact driver performance. Additionally, our results suggest that drivers adopt a more conservative approach to hazard detection while driving on the highway as opposed to city environments. Although

this may be advantageous in terms of city driving, drivers should be alerted to this tendency via public awareness programs highlighting the dangers of texting in what seems to be innocuous driving environments.

### **5.3 Limitations**

The current study was unable to make straightforward comparison between *f*SDT and *t*SDT methods, due to the approach with which hazards were classified in terms of their potential to cause a collision. As a result, we were unable to clearly indicate a cut-off with which to assign a dichotomous value of hazard/no-hazard to each scenario in order to apply the traditional calculations. Although this would have been ideal, this demonstrates the difficulty researchers have in determining a hazard from a non-hazard and highlights the flexibility of the *f*SDT method.

Another limitation of the study is that no other driving tasks other than the hazard perception task was performed while texting. Adding other driving tasks (e.g., steering, speed manipulation, etc.) most certainly will impact the results, most likely causing even more interference with the hazard perception process.

### **5.4 Future directions**

Future research should continue to utilize methods that allow for the use of a diverse set of hazards when exploring driver distraction. In order to do so, *f*SDT and traditional methods of SDT should be explicitly compared to highlight the advantages and disadvantages to using SDT in hazard detection research. This could be done by a more deliberative approach to designing certain hazard scenarios that are easier to classify. Although, this would impact the ecological validity of the study by ignoring many situations that drivers face on a day-to-day basis, it would be a

nice supplement to the current work. Additionally, another direction would be to take the recommendations and explore whether advanced warning systems and augmented reality could improve hazard perception performance in the face of distraction of varying cognitive loads.

## **5.5 Conclusion**

Few studies have explored the impact of distraction on the complex process of hazard perception while driving, perhaps due to the difficulty of quantifying real-world driving hazards. By utilizing *f*SDT, the current study explored hazard perception more explicitly, focusing on outlining the driver's complete response behavior while using a wide spectrum of real-world hazards differing in their potential to cause a collision. What was found highlights the variability of the hazard perception process, suggesting that both sensitivity and response bias shifts occur when distracted, and that these shifts are at least in part, moderated by the type of secondary task and by the current driving environment. These results also highlight the complexity in which distraction can impact both the allocation of cognitive resources as well as attentional selection (Pashler, 1994; Trick & Enns, 2009).

In general, the information manipulation tasks impacted the drivers' hazard perception to a greater degree than information rehearsal tasks. These findings are consistent with multiple studies that have shown secondary tasks will cause more interference with primary tasks when they tax executive resources (Fougnie & Marois, 2007, Recart & Nunes, 2005). The important implication here is that not all tasks drivers engage in while driving are equal, and to the extent that they require

the use of higher order cognitive resources, more interference will occur with hazard perception processes.

In terms of resource availability, taxing the driving with a high demanding secondary task negatively impacted the hazard perception process. In particular, the amplified interference between hazard detection and tasks that require central executive processing is consistent with past research (Morris, Phillips, Thibault, & Chaparro, 2008). This suggests the total amount of available resources for information processing are limited, causing a central bottleneck for incoming information (Pashler, 1994 ; Fougne & Marios, 2007). Thus, dual-task interference caused by texting will continue to cause competition for resources necessary to driving, especially hazard perception. Previous work has shown that secondary tasks that require linguistic processes are especially challenging (Almoor, 2008; Roelofs & Piai, 2011), however the current study highlights that difficult artificial secondary tasks may be even more problematic. Thus, task selection while driving can differentially impact performance.

The competition for resources observed when texting and driving makes it even more important for the driver to be able to selectively attend to certain pieces of environmental information. As mentioned, hazard perception is argued to be a deliberate and effortful process, making it more susceptible to interference when a driver is in a dual-task situation (Trick & Enns, 2009). Thus, when distracted, drivers may be more likely to be diverted by irrelevant information and less likely to be able to focus on information related to hazard perception. This may be especially true for information that may be indirectly related to the hazards themselves

(Crundall, 2013). According to Lavie (2005), under conditions of high cognitive load, individuals have difficulty filtering out distractors and focusing on relevant information. Alternatively, under conditions of low cognitive load and high perceptual load, individuals are better able to filter out distractors than low perceptual load conditions. This may explain in part, why participants exhibited higher sensitivity in the city environments (high perceptual load) than highway (low perceptual load), with this advantage diminishing when engaged in a texting task. Thus, it could be that texting is not only competing for a limited amount of pooled resources, but it is also making it more difficult for drivers to filter out irrelevant information when completing hazard detection tasks. In terms of response bias, the more conservative measures while texting, especially when engaged in the more difficult tasks, suggests that drivers are failing to project events as being hazardous in the near future. This may be due to missed cues or because there are not enough cognitive resources to take the step from processing incoming information to the distinction of that information indicating a danger situation. Researchers argue that this classification requires higher-level cognitive processes and due to the diverse and ever-evolving driving environment, will never become automatic.

The purpose of the present study was to assess how text messaging impacts a driver's real-world hazard perception ability. The use of *f*SDT methods allowed for a more complete analysis of driver response behavior and accounted for the "fuzzy" nature of real world driving hazards, thus permitting the use of naturalistic, unstaged hazard scenarios to increase the ecological validity of the study. This fills a need in driving research, which has traditionally struggled to operationally define

driving hazards, often using a limited set of hazards that could be clearly defended. And although this earlier research has provided the foundation for understanding hazard perception while driving, it overlooks the majority of hazardous events a driver may encounter on any given day. Additionally, the use of text messaging that required different cognitive resources, indicates that performance is largely dependent on whether the tasks require manipulation or simple maintenance of information, with the latter having relatively little impact on hazard perception. As mentioned, hazard perception is argued to have the most direct relationship with driving safety. Consequently, this opens the discussion as to whether all secondary tasks completed while driving are deleterious and helps to focus intervention attempts at curbing distracted driving accidents.

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## APPENDICES

## A. Demographic Survey

### Survey

#### 1. Demographic Information

Age \_\_\_\_\_ Gender: Male / Female Handedness: Right / Left

If you are a student:

Year (Circle one): Fresh. Soph. Junior Senior Graduate Student

Major: \_\_\_\_\_

Occupation (if applicable): \_\_\_\_\_

Which hand is your dominant hand? \_\_\_ left hand, \_\_\_\_\_ right hand, \_\_\_\_\_ both hands.

#### 2. Driving Experience

Valid Drivers License: Yes / No How long have you been driving (years): \_\_\_\_\_

Your car is: Standard transmission / Manual transmission / I do not have a car

How many hours do you drive per week: \_\_\_\_\_

How many miles do you drive per week: \_\_\_\_\_ miles.

Where do you do the majority of your driving (i.e. rural, urban, highway): \_\_\_\_\_

In the past 12 months how many car accidents have you been involved in? \_\_\_\_\_

Please specify below (e.g. description of accident, when, where, fault?)

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_

In the past 12 months how traffic violations have you committed? \_\_\_\_\_

Please specify below (e.g. description of violation, when?)

1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_

How often do you go over the speed limit:

*Never*

*Always*

1

2

3

4

5

How far over on average: 0-5 mph 6-10 mph 11-15 mph 16+ mph

3. Cell Use

Do you use a cell phone: Yes / No

How many hours talk per day: \_\_\_\_\_ hours

How many minutes per month do you have on your phone plan: \_\_\_\_\_ minutes

What percent of the time do you answer your cell phone while driving? \_\_\_\_\_

What percent of the time do you make phone calls while driving? \_\_\_\_\_

How many text messages do you send per day: \_\_\_\_\_

How many text messages per month do you have on your phone plan: \_\_\_\_\_

What percent of time do you send text messages while driving? \_\_\_\_\_

What percent of time do you spend reading text messages while driving? \_\_\_\_\_

What method of texting do you prefer? \_(1) touch screen\_(2) physical keyboard\_(3) voice input\_\_\_\_(4) others, please specify \_\_\_\_\_

4. Cell Type

What type of cell phone do you have (Brand/Model):  
\_\_\_\_\_

Is it touch screen: Yes / No Other: e.g., both touch screen and physical keyboard

What type of text entry: Normal / T-9 / QWERTY / other (specify):\_\_\_\_\_

How would you rate the risk associated with texting while driving?

<i>Not at all Dangerous</i>					<i>Very Dangerous</i>
1	2	3	4	5	

How would you rate the risk associated with talking on a cell phone while driving?

<i>Not at all Dangerous</i>					<i>Very Dangerous</i>
1	2	3	4	5	

5. Gaming Experience

Do you have video game experience: Yes / No How many hours per week: \_\_\_\_\_ hours

What type of video games do you play (please list):  
\_\_\_\_\_

## B. Traffic Potentiality Rating Scale & Survey Questions

Please rate the potential for this traffic scene to develop into a situation in which a driver would be required to respond in order to avoid a collision:

No potential

Unavoidable

1

5

10

15

20

--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

What is the hazard in this scenario?

Are there multiple hazards in this scenario? If so, provide a rating for all of them.

### C. Post-trial Confidence Questionnaire

Please give a percentage of confidence as to whether a response would have been required to avoid a collision in this scenario: (e.g., 0% = Not confident at all; 100% Fully confident)

\_\_\_\_\_ %

What were you responding to?

Why were you responding to it?

What was your comfort level completing this task in this driving environment?

Very comfortable  
1

5

Not at all comfortable  
10

--	--	--	--	--	--	--	--	--	--

## D. Sample naturalistic text messages

1. How's the weather today?
2. What's your major?
3. How do you like Wichita?
4. How often do you go to the theater?
5. What's your favorite food?
6. What kind of music do you listen to?
7. What car do you drive?
8. What phone do you have?
9. What weather do you prefer?
10. What did you eat today?
11. What's your favorite movie?
12. Where would you like to travel?
13. How long does it take you to get to school?
14. What kind of books do you like?
15. What TV show do you really like?
16. What TV show do you really dislike?
17. What's your favorite color?
18. Where is your hometown?
19. What's the color of your hair?
20. What's the color of your eyes?
21. Who's the current president?
22. Can you give an example of good leadership?
23. What do you do for fun?
24. What's your favorite board game?
25. What's your favorite animal?
26. What's one of the classes you have now?
27. Where did you go to high school?
28. Where did you go to elementary school?
29. What do you like to eat on campus?
30. What do you do during the weekends?
31. Can you recommend a burger place?
32. Do you like dogs or cats better?
33. What was your high school mascot?
34. What sports do you like to play?
35. Do you prefer white, dark, or milk chocolate?
36. Do you prefer burgers or hot dogs?
37. What kind of computer do you have?
38. What's your favorite song?
39. What is a popular game that students play on their phone?
40. What is a popular video game?
41. What kind of video games do you like?
42. What's the best class you've had at WSU?
43. What's your favorite video game?
44. What language would you like to learn?
45. What do you like most about Wichita?
46. What kind of car do you like?
47. What was the worst movie you ever saw?
48. Name a U.S. President.
49. Who's your role model?
50. What's your favorite fruit?
51. What's your favorite vegetable?
52. Where do you go for fun?
53. How long have you attended WSU?
54. Do you prefer action or comedy?
55. What's your favorite card game?
56. How often do you eat breakfast?
57. How long do you usually sleep?
58. How do you deal with cold weather?
59. What country are you from?
60. How many classes are you taking this semester?
61. What is your favorite branch of science?
62. What size are your feet?
63. What is your favorite extracurricular activity?
64. What website do you visit most?

65. How often do you go on Facebook?
66. What was your favorite childhood game?
67. What is your favorite breed of dog?
68. What's your favorite candy?
69. What style of decoration do you like best for your home?
70. Who is your favorite celebrity?
71. Do you prefer to be outdoors or indoors?
72. What do you do when you're tired?
73. When do you like to have your classes during the day?
74. Who is your favorite superhero?
75. Who is your favorite villain?
76. What is your least favorite household chore?
77. Do you prefer Mac or PC?
78. How often do you exercise?
79. What's your favorite dessert?
80. What language(s) are you fluent in?
81. What kind of food do you dislike?
82. How good is your eyesight?
83. How much time do you spend on homework?
84. Who's a musical artist that you like?
85. How often do you check your email?
86. What do you like to drink?
87. Do you usually arrive early, late, or on time to class?
88. How often do you cook?
89. What do you like to do at home?
90. What do you like to do outside?
91. How often do you watch TV?
92. How often are you on the Internet?
93. How tall are you?
94. What's your favorite day of the week?
95. How often do you clean your room?
96. What month were you born in?
97. What's today's date?
98. How do you usually like to dress?
99. What's your favorite fast food place?
100. What's your favorite holiday?

## E. Texting Errors

A total error per character for each texting condition was calculated. Errors consisted of omission (e.g., leaving out a letter), substitution (e.g., substituting j for i), and addition errors (e.g., adding an additional letter). A breakdown of these text error types as a function of text condition can be seen in Table 1.

Table 1. *Percentage of text error types as a function of text condition and total errors per character.*

Texting Condition	Omissions (%)	Substitutions (%)	Additions (%)	Errors/Character
Repeat 7-letter String	10.53	63.16	31.58	0.013
Alph. 7-letter String	26.67	70.00	26.67	0.020
Repeat Phone #	27.17	36.26	45.46	0.007



## F. fSDT Equations

### A. Continuous values based on mapping functions

$$\begin{aligned}\text{Hits:} & H = \min (s, r) \\ \text{Miss:} & M = \max (s - r, 0) \\ \text{False Alarm:} & FA = \max (r - s, 0) \\ \text{Correct Rejection:} & CR = \min (1 - s, 1 - r)\end{aligned}$$

Where  $s$  is the continuous signal value and  $r$  is the continuous response value.

### B. Equations for fuzzy hit and false alarm rates

$$\begin{aligned}\text{Hit Rate} &= \Sigma(\min(s_i, r_i)) / \Sigma(s_i) \text{ for } i = 1 \text{ to } N \\ \text{Miss Rate} &= \Sigma(\max(s_i - r_i, 0)) / \Sigma(s_i) \text{ for } i = 1 \text{ to } N \\ \text{False Alarm Rate} &= \Sigma(\max(s_i - r_i, 0)) / \Sigma(1 - s_i) \text{ for } i = 1 \text{ to } N \\ \text{Correct Rejection Rate} &= \Sigma(\min(1 - s_i, 1 - r_i)) / \Sigma(1 - s_i) \text{ for } i = 1 \text{ to } N\end{aligned}$$

### C. Equations for sensitivity ( $A'$ ) and response criterion ( $\beta''$ )

Sensitivity

$$A' = \frac{1}{2} + \frac{(PHIT - PFA) \times (1 + PHIT - PFA)}{4 \times PHIT \times (1 - PFA)}$$

Response Bias

$$B'' = \frac{PHIT \times (1 - PHIT) - PFA \times (1 - PFA)}{PHIT \times (1 - PHIT) + PFA \times (1 - PFA)}$$

G. Tables of Means

Table 1. *Table of means for the measure of Sensitivity (A')*

Texting Condition		<i>M</i>	<i>SD</i>
Repeat 7-Letter String	City	0.68	0.23
	HW	0.73	0.14
Alph. 7-Letter String	City	0.42	0.41
	HW	0.64	0.16
Repeat Phone #	City	0.67	0.25
	HW	0.73	0.12
Answer Question	City	0.70	0.15
	HW	0.74	0.16
Baseline (No-text)	City	0.79	0.05
	HW	0.73	0.07

Table 2. *Table of means for the measure of Response Bias ( $\beta''$ )*

Texting Condition		<i>M</i>	<i>SD</i>
Repeat 7-Letter String	City	0.05	0.54
	HW	0.52	0.29
Alph. 7-Letter String	City	0.51	0.37
	HW	0.81	0.19
Repeat Phone #	City	0.29	0.52
	HW	0.33	0.54
Answer Question	City	0.29	0.52
	HW	0.69	0.33
Baseline (No-text)	City	-0.04	0.34
	HW	0.14	0.31

G. Table of Means (Cont.)

Table 3. *Table of means for Reaction Time (Log<sub>10</sub>)*

Texting Condition		<i>M</i>	<i>SD</i>
Repeat 7-Letter String	City	0.45	0.20
	HW	0.49	0.24
Alph. 7-Letter String	City	0.47	0.25
	HW	0.42	0.46
Repeat Phone #	City	0.64	0.26
	HW	0.55	0.39
Answer Question	City	0.35	0.37
	HW	0.57	0.28
Baseline (No-text)	City	0.70	0.14
	HW	0.70	0.13

G. Table of Means (Cont.)

Table 4. *Table of means for the NASA TLX mental workload ratings.*

NASA TLX Dimension	Texting Condition	<i>M</i>	<i>SD</i>
Mental	Repeat 7-Letter String	49.17	25.70
	Alph. 7-Letter String	65.80	20.64
	Repeat Phone #	48.70	22.67
	Answer Question	62.07	26.15
Physical	Repeat 7-Letter String	27.87	20.70
	Alph. 7-Letter String	31.10	23.22
	Repeat Phone #	24.83	19.16
	Answer Question	30.90	24.85
Temporal	Repeat 7-Letter String	40.90	22.10
	Alph. 7-Letter String	47.67	27.24
	Repeat Phone #	34.57	22.33
	Answer Question	43.13	28.77
Performance	Repeat 7-Letter String	33.50	21.54
	Alph. 7-Letter String	47.93	21.87
	Repeat Phone #	35.10	20.05
	Answer Question	42.23	25.69
Effort	Repeat 7-Letter String	56.63	24.36
	Alph. 7-Letter String	72.37	19.07
	Repeat Phone #	51.20	24.21
	Answer Question	65.50	25.08
Frustration	Repeat 7-Letter String	35.90	23.19
	Alph. 7-Letter String	50.23	28.38
	Repeat Phone #	33.93	22.41
	Answer Question	47.17	30.35