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ARE DISTRACTED DRIVERS AWARE THAT THEY ARE DISTRACTED?: EXPLORING AWARENESS, SELF-REGULATION, AND PERFORMANCE IN DRIVERS PERFORMING SECONDARY TASKS

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ARE DISTRACTED DRIVERS AWARE THAT THEY ARE DISTRACTED?: EXPLORING AWARENESS, SELF-REGULATION, AND PERFORMANCE IN DRIVERS PERFORMING SECONDARY TASKS

A Dissertation
Presented to
The Graduate School of
Clemson University

In Partial Fulfillment
Of the requirements for the Degree
Doctor of Philosophy
Human Factors Psychology

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by
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August 2010

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ABSTRACT

Research suggests that driving while talking on a mobile telephone causes drivers not to respond to important events but has a smaller effect on their lane-keeping ability. This pattern is similar to research on night driving and suggests that problems associated with distraction may parallel those of night driving. Here, participants evaluated their driving performance before and after driving a simulated curvy road under different distraction conditions. In Experiment 1 drivers failed to appreciate their distraction-induced performance decrements and did not recognize the dissociation between lane-keeping and identification. In Experiment 2 drivers did not adjust their speed to offset being distracted. Continuous feedback that steering skills are robust to distraction may prevent drivers from being aware that they are distracted.

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INTRODUCTION

Research efforts in the area of distracted driving have identified many risks associated with driving while communicating on a telephone or engaging in other non-driving activities. The bulk of this literature has identified when distraction causes diminished driving performance, and how that diminished performance is manifested. Horrey and Wickens (2006) and Caird et al. (2008) used meta-analytic techniques to combine the results of many of the studies completed in the area of driving with telephones. Their analysis identified a pattern of results that suggests that distracted driving does not have a large effect on drivers' ability to maintain position within their lane; however, when drivers are tasked with identifying elements and changes within the driving environment, their performance is diminished by distraction. This suggests that the primary danger of distracted driving may not come from an inability to control the vehicle, but rather from an increased likelihood of failing to respond to important events within the roadway environment.

With this pattern identified, further distraction research should address what is necessary to limit the problems caused by distracted driving. It would be ideal, for example, if drivers could realize when they are distracted enough for safety to be compromised and make appropriate behavioral adjustments such as removing the distraction or safely stopping the vehicle until the distraction is no longer present. However, research on vision and driving at night has revealed a similar pattern of results to that seen when driving distracted. The similarity of the two patterns of performance decrements suggests that drivers may be unlikely to recognize and respond to distraction similarly to their lack of recognition of the dangers of night driving (Leibowitz & Owens, 1977; Leibowitz & Owens, 1986; Owens & Tyrrell, 1999; Brooks J. O., 2005; Brooks, Tyrrell, & Frank, 2005). This line of research presenting and evaluating the selective degradation hypothesis has shown that as illumination decreases, driving performance as measured by lane-keeping performance is robust; however, when performance is measured by an acuity or identification task (e.g., noting pedestrians on the side of the roadway, etc.) performance decreases rapidly even with relatively small decreases in luminance. It has also been shown that using lenses to blur participants' vision results in a similar pattern of robust steering performance in the face of marked decreases in visual recognition abilities (Brooks et al., 2005; Klein, 2008; Owens & Tyrrell, 1999).

Brooks (2005) further suggests that this pattern of robust performance in lane-keeping with diminished performance on identification tasks may result in overconfidence in "recognition" visual abilities while driving. Prior to driving in this study, drivers overestimated the detrimental effect of luminance reduction on their ability to maintain lane position, but were more accurate in predicting reduced performance on a pedestrian identification task. Although this suggests that they may realize that their visual recognition is degraded, Brooks suggests that in real life, drivers may feel that their headlights compensate for this degradation. In addition, the experimental task of predicting one's recognition task performance may have highlighted the fact that recognition would be degraded. The difference in predicted and actual performance in lane-keeping suggests that drivers get consistent feedback that the lane-keeping portion of the driving task is simple and easy (even easier than they would expect). This may cause drivers to believe that other aspects of the driving task are equally as easy.

Although this phenomenon has not been tested directly in the case of distracted driving and the current effort is not attempting to equate the neural underpinnings of the two phenomena, the pattern of performance in the two tasks (lane-keeping and identification) has been shown to be similar between distracted driving and driving in conditions with reduced illumination. Therefore, it is possible that the end results of the two situations are similar – drivers not realizing the extent to which their ability to drive safely is being compromised. If this is the case then it is likely that some of the methods used to counteract issues of reduced luminance could guide mitigation strategies for distracted driving.

The purpose of this research effort is to test the application of the selective degradation hypothesis as a useful metaphor from which to better understand distracted driving. This research effort confirms the pattern of results seen in past research on distracted driving and further shows how the selective degradation pattern results in drivers that are unlikely or unable to self-regulate distracted driving behaviors just as they are unlikely to self-regulate speed when driving under low luminance conditions. This lack of self-regulation is potentially explained by a confirmation bias (Wason, 1960) in which drivers assume they are driving perfectly well at a given speed due to constant feedback that they are able to maintain lane position nearly effortlessly; however, the limited feedback about identification performance is less salient and ignored. This is supported by distraction research such as Tornros and Bolling (2006) that showed that drivers barely slow down (less than 1.9 mph on average) when they are sufficiently distracted to show diminished performance on peripheral detection tasks.

Background – Distracted Driving

The use of wireless communication devices has been on the rise since the introduction of the cellular telephone in the 1980's. Although in many cases this technology has allowed significant advancements in safety and convenience for users, it has also created situations where wireless customers may reduce their safety due to the distracting influence of the devices. Even prior to the introduction of mobile telephones, researchers had been attempting to quantify the effect of this distraction on users that are operating a motor vehicle while simultaneously communicating on a phone (Brown, Tickner, and Simmonds, 1969). Although the convenience of the mobile phone is hard to deny, it is important that we address the safety issues associated with its use.

Decrements in Performance

Horrey and Wickens (2006) conducted a meta-analysis of much of the research on distracted driving that had been published prior to 2004. Their analysis suggests that there is a decrement in performance on driving tasks that can be attributed to the use of mobile phones; however, this decrement is more pronounced or potentially only exists for tasks that measure reaction time to events or objects in the environment. The meta-analysis showed an increase in reaction time of on average 0.13 seconds. However, they note that the largest safety issues occur not with average scenarios, but rather when the worst case scenario for reaction time aligns with the worst-case driving scenario. They showed that there seems to be either no effect or a relatively small effect of mobile phone use on performance of lane-keeping and tracking tasks. Weighted effect size estimates (r) were 0.23 for lane-keeping/tracking and 0.5 for response time in the Horrey and Wickens (2006) analysis. Another more recent meta-analysis showed similar results for response time tasks compared to lane-keeping and other vehicle control measures. This analysis suggests that there is an effect of distraction on lateral control measures (r_c = 0.152), but that it is much smaller than that observed for response time and identification tasks (r_c = 0.546 for handheld and r_c = 0.460 for hands-free phones) (Caird, Willness, Steel, & Scialfa, 2008). One major difference observed between the Horrey and Wickens (2006) and Caird et al. (2008) meta-analyses is that the Caird et al. analysis suggests that cognitive tasks designed to simulate the effects of distraction from cellular phone use have resulted in a larger effect on response time measures as compared to more naturalistic conversation methods; however, this larger effect was not significant in the Caird et al. analysis (Caird et al. 2008; Horrey & Wickens, 2006).

In addition to presenting this pattern of performance decrements, both meta-analyses (Horrey & Wickens, 2006; Caird et al., 2008) investigated whether there is a difference between using handheld phones and hands free phones. Both analyses concluded that no difference has been observed; however, Horrey and Wickens' qualification that danger is manifested when worst case distraction intersects worst case driving performance suggests that the use of handheld phone devices is likely more dangerous during dialing and other manual phone manipulation tasks. This is supported by studies showing large performance decrements, even for vehicle control measures, when drivers engage in text messaging while driving (Crisler, Brooks, Ogle, Guirl, Alluri, & Dixon, 2008). Overall, these analyses and the studies that they are based on support the conclusion that response time increases caused by phone use while driving result from attentional issues caused by the conversation itself rather than the act of holding the device.

In addition to these patterns of performance decrements, there is little or no evidence that suggests drivers modify their driving behavior while distracted in ways that would meaningfully enhance safety. Tornros and Bolling (2006) showed minimal reductions in speed while distracted in simulated driving. Tornros and Bolling also present data suggesting that the driving environment may moderate distraction effects for peripheral detection tasks. In their task, complex urban environments resulted in larger performance decrements than the rural environments with 70 and 90 km/hr speed limits as well as urban environments of lower complexity. Additionally, subjective measures of driving skill and style show that drivers that use mobile phones while driving tend to have more aggressive driving tendencies such as disregarding speed limits, driving close to a leading car to signal the driver to get out of the way, and crossing intersections knowing that the traffic lights have turned red (Bener, Lajunen, Ozkan, & Haigney, 2006). This lack of self-regulation of distraction and safe driving behavior may be caused by drivers who do not realize that they are distracted to an extent that their driving performance is affected. It has also been shown that cell phone owners agree more than non-owners with the statement “The use of cellular phones by other drivers is more dangerous than if I use a cellular phone while driving” (Wogalter & Mayhorn, 2005, p. 458); however, it must be noted that the mean score for cell phone owners was only 3.6 where 3 represents somewhat disagree and 4 is neutral.

Simulator and Field Methodologies

Both the Horrey and Wickens (2006) and Caird et al. (2008) meta-analyses suggests that although there are small differences between simulator and field methodologies, both methods have identified similar changes in driving performance. Horrey and Wickens suggest that simulator based studies produce smaller effects of distraction than field studies; however, they explicitly note that they make no claims as to the validity of simulator based research in this field due to the large variability in simulator fidelity found in the studies that they are analyzing. Caird et al. (2008) identified a marginally significant increase in effect size for on-road assessments compared to simulator assessments and suggest that simulator studies may result in greater speed reductions than on-road studies. In addition, it has been suggested that performance decrements identified during observed driving likely underestimate the decrements that would be expected ”when not being observed and free to adopt typical habits of their own vehicles” (Caird, Lees, & Edwards, 2005, p. 41).

Modality of Distraction

Different distracting tasks involving mobile phones and simulations of mobile phone use have been used to test the effects of distracted driving with varying results. Horrey and Wickens (2006) noted that there is a difference in the size of the effect of distraction based on what type of task was used by experimenters. Their analysis suggests that information processing tasks have resulted in smaller performance decrements as compared to conversation tasks. This suggests that it may be possible to moderate the difficulty of a distraction task by adjusting the form of the task being completed, not just its difficulty. However, due to the fact that the overall effect of distraction on lane-keeping measures was identified as non-significant, this change was not investigated for lane-keeping measures.

The studies analyzed by Horrey and Wickens (2006) utilized distraction tasks ranging from natural conversation (Strayer & Johnston, 2001; Strayer, Drews, & Johnston, 2003) to scripted conversation with predetermined questions (Consiglio, Driscoll, Witte, & Berg, 2003; Hanowski, Kantowitz, & Tigerina, 1995; Rakauskas, Gugerty, & Ward, 2004) to information processing tasks such as math problems and choosing words that fit within categories (Hanowski et al., 1995; Green, Hoekstra, & Williams, 1993) to simple word shadowing (Strayer & Johnston, 2001). These results and the Horrey and Wickens analysis suggest that the largest decrements in driving performance tend to be observed when using more natural conversation tasks as compared to information processing tasks. Strayer and Johnston (2001) present data that suggest that simple shadowing of a message does not result in decrements in performance; however, when that shadowing task included a word generation task where participants had to generate a word beginning with the last letter of the word they were presented over the phone, performance decrements were observed. These results suggest that the "normal" use of a mobile telephone (i.e., natural conversation) is more distracting than many of the various experimental tasks that have been used thus far to simulate cell phone use. However, a more recent meta-analysis (Caird et al., 2008) suggests that the cognitive tasks used to simulate distraction from mobile phones actually result in larger decrements in performance than mobile phone conversations. Although this result is contrary to those previously obtained by Horrey and Wickens, this may be due to the fact that the difficulty of the cognitive tasks has not been analyzed. It is therefore likely that some of the cognitive tasks used result in a larger distraction effect than conversation while others result in a smaller effect. This also suggests that it is possible to experimentally manipulate the amount of distraction both by changing the distracting task and the intensity of those tasks. Data from Nakayama et al. (1999) support this conclusion by showing that response times as well as steering entropy, a measure of the predictability of steering inputs, vary significantly when completing different tasks (of different difficulties) while driving.

Background – Selective Degradation

Origin and Theory

The neurological underpinnings of the selective degradation hypothesis were stimulated by early work done by Gerald Schneider (1969). In his dissertation, Schneider described a process by which he identified that there are two visual systems in the golden hamster that can be dissociated with brain lesions in the visual cortex and the superior colliculus. Schneider showed that the hamster was capable of discriminating patterns even with lesions to the superior colliculus; however, the hamster was incapable of orienting itself within an environment with these lesions. The opposite pattern was observed with lesions of the visual cortex. In this case, the hamster could orient itself and locate an object in space, but failed to discriminate between patterns.

Leibowitz and Owens later proposed the selective degradation hypothesis based on Schneider’s work, on similar work in other species (Held, 1968; Ingle, 1967; Trevarthen, 1968), and on psychophysical observations of visual performance in decreased luminance (Leibowitz & Owens, 1977). They suggested that when luminance is reduced the visual performance of drivers is degraded mainly in the area of visual recognition; whereas, the ability to locomote within an environment is not affected at relevant luminances. This presents interesting problems to drivers who must continuously make decisions regarding driving safety and appropriate speeds to travel at night. Unfortunately, Leibowitz and Owens note that “most of us drive as if we can safely go as fast at night as during the day” (Leibowitz & Owens, 1986, p. 56). As Owens (2003) explains, in the case of reduced luminance, “thanks to good engineering, these focal abilities are partially enhanced by lighting and reflectorization. Consequently, drivers are not likely to recognize that their ability to see dim, low-contrast objects is drastically degraded in the night road environment” (Owens, 2003, p. 167).

Leibowitz and Owens elaborate to explain that drivers choose speeds that are unsafe as a result of the selective degradation of vision and the design of vehicles and roadways. Due to the robustness of visual guidance skills (such as steering) to decreased illumination, drivers receive constant feedback that the driving task is just as easy as it was during the day. In addition, the majority of objects that need to be seen by night drivers (e.g., road signs, vehicle lights, lane markings, etc) have been engineered to be conspicuous even when ambient illumination is near zero. The combination of these factors is believed to leave drivers feeling overconfident and driving faster than appropriate at night relative to their ability to identify and avoid collision with low contrast objects (such as pedestrians, animals, objects, or stopped vehicles; (Leibowitz & Owens, 1986).

Empirical Evaluations of Selective Degradation

More recently, the theory of selective degradation has been tested empirically (Brooks J. O., 2005; Brooks et al., 2005; Owens & Tyrrell, 1999). These researchers have used a paradigm in which an experimental manipulation disrupts one class of visual functions (i.e., either recognition or guidance) while maintaining the other visual system and testing visual acuity and the ability of simulated drivers to maintain lane position. Owens & Tyrrell (1999) used a low-fidelity driving simulator to test lane-keeping ability under severe blur and reduced luminance as well as with reductions in visual field size. They showed that lane-keeping performance was robust to blur and luminance manipulations that drastically degraded visual acuity. They also showed that visual acuity was robust to restrictions of the visual field whereas lane-keeping performance was diminished with similar reductions in visual field. Brooks et al. (2005) utilized a similar procedure and produced similar results in a medium fidelity fixed-base driving simulator with wrap-around visual display and automotive controls.

Brooks (2005) presents evidence to support the other portion of the selective degradation hypothesis – that drivers fail to recognize their visual limitations at night due to the fact that only the less salient visual recognition system is significantly degraded. Although Brooks' participants were reasonably accurate at predicting their reductions in visual acuity and ability to identify roadside pedestrians, they failed to predict that their lane-keeping performance would not be degraded by reductions in luminance. Brooks interpreted this to suggest that drivers are likely to be encouraged by how easily they are able to maintain position within a lane, and therefore may overestimate the function of other aspects of vision such as acuity and recognition ability.

Theories Relevant to the Application of Selective Degradation to Distracted Driving

SEEV Model of Visual Scanning

Although it does not directly address the issues of inattentional blindness presented by Strayer, Drews, and Johnston (2003), Wickens and Horrey (2008) suggest that the SEEV (Salience, Effort, Expectancy, Value) model of visual scanning can be used to understand portions of inattentional blindness and to design mitigations to enhance drivers' ability to avoid it. Unfortunately these mitigations do not address the issue of true "looked but didn't see" errors identified by Strayer, Drews, and Johnston. However, the concepts of the model are important to distracted driving research and the mitigation methods that are suggested may be useful.

The SEEV model consists of 4 additive factors that model the likelihood that an observer will allocate visual attention to a certain portion of the visual environment. Salience suggests that objects or areas that "stand out" from the rest of the environment are more likely to be attended. Effort suggests that areas that are further away from the current focus of attention are less likely to be attended. Expectancy suggests that observers will dedicate more attention to areas where bandwidth, or information rate, is higher. Value suggests that observers are more likely to look at an area or an object that is more relevant to the task currently at hand. The model adds each of these values together to create a probabilistic view of how often different areas of a scene will be attended (Wickens & Horrey, 2008). More recently, an advanced version of the computational model was presented at the 2009 Annual Meeting of the Human Factors and Ergonomics society. This model, N-SEEV, accurately predicts the time it will take to notice an alert (tested in the context of an airplane cockpit) by utilizing a SEEV model to determine a probabilistic view of where observers are likely to be looking and extending it to include the effects of dynamic changes in the visual environment. Theoretically, this model can also account for cognitive load by reducing the modeled functional field of view, which would in turn increase the time required to notice the alert (Steelman-Allen, McCarley, and Wickens, 2009; Recarte & Nunes, 2000; Wickens et al., 2009).

There are a number of implications for visual scanning as modeled by the SEEV model if drivers suffer from a pattern similar to selective degradation while driving distracted. First, salience of all stimuli would be modeled as lower due to distraction; however, the more important issue with salience occurs when dealing with mitigating distraction. In this instance, the salience of relevant stimuli within the environment is of paramount importance when trying to avoid crashes, and anything that can be done to enhance the salience of safety critical stimuli while reducing salience of non-safety critical stimuli would enhance safety whether or not a driver is distracted. Unfortunately, although mitigation strategies involving enhancing the salience of roadway objects or events (e.g., enhanced brake lights, automated pedestrian warning systems, headway distance alarms) may enhance safety, they do not address the issue of distraction specifically.

Second, the issues associated with effort are somewhat more relevant to distraction as it has been shown that verbal and spatial imagery tasks reduce the size of the functional visual field and increase fixation duration (for visual imagery) while driving (Recarte & Nunes, 2000). This suggests that distracting tasks increase the overall effort associated with redirecting visual attention from one location to another (Wickens & Horrey, 2008). If drivers are unable to perceive their decrements in driving and scanning performance, they are unlikely to be able to self-regulate the priority of visual scanning relative to their distracting activities.

Third, the overall expectancy of safety-relevant events in the environment is likely to be incorrectly assumed to be smaller than it actually is if drivers base their safety decisions on the more salient (and higher bandwidth) feedback of lane-keeping and other vehicular control measures. According to the SEEV model, this reduction in expectancy would result in decreased scanning of the environment, and more attention focused on maintaining lane position rather than identifying suddenly decelerating vehicles, pedestrians, or other important objects in the environment.

The most relevant component of the SEEV model to the current experiment may be the fourth component, value. If drivers fail to recognize the dissociation between the effects of distraction on lane-keeping and identification performance, it is possible that they would assign similar values to dedicating attentional resources to each. Since it would appear to the driver that the value of devoting attention to lane-keeping is minimal (since they can devote attention to other tasks and receive feedback suggesting that this has no effect on their performance) they may infer (incorrectly) a relatively small value in dedicating attention to identification of roadway hazards. Wickens and Horrey even suggest that due to the separation of focal and ambient vision, drivers are likely to divert focal vision for in-vehicle tasks (tasks requiring visual attention away from the roadway which would be a more demanding task than a phone conversation which does not require visual attention) with the incorrect assumption that the remaining ambient vision can identify hazards (Wickens & Horrey, 2008).

Control Theory

Regan, Lee, and Young discuss control theory and its applicability to distracted driving (Regan, Lee, & Young, 2009). This application of control theory to driving was proposed by Sheridan (2004) and suggests that driving a vehicle requires constant interaction of driver intention, sensing, deciding, and the vehicle system itself. Breakdowns or disturbances at any of these levels can cause the system to be incorrectly controlled or out of control altogether.

As might be expected, the outputs of this model are focused more on the vehicular control metrics identified above as being less affected by distraction; however, this may be due to the fact that many of these vehicle control measures are fairly gross in nature (lane-keeping violations only occur with a fairly large steering error). In studies where more sensitive measures of vehicular control such as speed variability have been used, breakdowns in control have been observed during distracted driving (Crisler et al., 2008).

Sheridan would refer to attending to tasks outside the driving task as a control disturbance to one of the above mentioned control levels (e.g., looking away from the roadway would be viewed as a disturbance to the sensing level). Sheridan suggests that there may be a form of control switching between the driving task and the distracting task. Data showing increased speed variability while distracted supports this conclusion. In this instance, the driver would shift feedback control away from the driving task and allow it to operate in an open loop manner (without feedback) while the distracting task is completed. In most instances this is reasonably safe, and causes no problems that would be noticeable to the driver. Small changes in lane tracking, speed control, etc. would be expected while control remained open loop, but these would likely be easily rectified when the feedback loop is restored and the system re-enters closed loop control. In addition, Horrey, Wickens, and Consalsus (2006) suggest that ambient vision may be capable of serving the lane-keeping task even when gaze is directed away from the roadway altogether suggesting that only some portion (visual search, hazard awareness, etc) of the driving task is actually operating in an open-loop fashion. The problems associated with distracted driving occur when an unexpected event occurs during this open loop period. This suggests that whether a distraction results in a reduction in safety is related to the criteria used to decide whether to switch control and the potential resulting occurrence of external unpredicted events (Sheridan, 2004). Therefore, any misunderstanding of the effects of distraction on the ability to identify driving relevant events could result in unsafe control switching at inappropriate times.

It is possible that this control switching behavior could be modeled using a similar approach to the SEEV model of visual scanning discussed above (e.g. the pitfalls associated with decreased salience of all stimuli, increased effort in visual scanning due to reduced functional visual field, low bandwidth associated with hazard identification, and skewed value assigned to the identification of roadway hazards) would be expected to result in less than ideal control switching behavior. In addition, if the SEEV model were extended beyond guidance of visual attention and used to predict control-switching behavior, it would be implied that the bandwidth (or intensity) of the distracting conversation would be a determinant of control-switching behavior. From a safety perspective, this would be inappropriate. The only way to mitigate this would be for the value assigned to attending to the driving task to strongly outweigh that of the conversation; however, as discussed in the section on SEEV, an unrecognized dissociation between lane-keeping and identification performance is likely to reduce the perceived value associated with attending to the hazard identification portion of the driving task.

Lee, Regan, and Young present an extended version of this basic theory that includes three distinct control mechanisms whose inputs and outputs are connected. These make up “operational control”, “tactical control”, and “strategic control” (Regan et al., 2009, p. 43) levels that operate similarly to the control model presented by Sheridan (2004). Each of these levels represents a different time-scale of control from milliseconds to seconds at the operational level where drivers actually control the vehicle to seconds to minutes at the tactical level where decisions are made as to tasks such as lane changes and gap judgments to minutes to weeks for strategic control of routes chosen etc. Unfortunately, distraction can cause cascading failures across all of these levels (Regan et al., 2009).

The occurrence of these failures may be increased by drivers' inability to judge the effects of their distraction due to the pattern of distraction effects described above. A system involving feedback inherently relies on the feedback signal to be accurate in order to control the output of the system to ensure that goals (in this case including safety) are fulfilled. Incomplete or misleading feedback allows the system to be outside of the established control parameters without the knowledge of the driver. This results in unsafe driving due to distraction. Regan et al. (2009) would likely refer to this as a failure of adaptive control at the tactical and/or strategic level where drivers adjust their safety goal outside of safe parameters based on the incorrect feedback signal that their driving performance is acceptable. This might occur because it seems easy to maintain lane position even though identification performance is degraded.

Inattentional Blindness and Change Blindness

Inattentional blindness and change blindness are related phenomena in which an observer fails to notice an object or a change in the visual environment that is clearly visible due to not attending to that portion of the visual stimulus (Mack, 2003). There is significant controversy concerning whether the observer fails to notice altogether or just fails to remember noticing (Wickens & Horrey, 2008). Although this controversy exists, its relevance to distracted driving and regulation of driving and distraction behaviors is minimal as regardless of whether drivers' fail to notice or fail to remember, it would be impossible to use the information to properly regulate driving behaviors.

In the context of driving, it has been shown that drivers suffer from inattentional blindness when driving and talking on a cellular phone. Strayer, Drews, and Johnston used eye tracking to show that participants had “impaired implicit perceptual memory for items presented at fixation” (2003, p. 23). However, Wickens and Horrey point out that the procedure used here is only partially relevant due to the controversy mentioned above. They suggest that crashes result from a failure to notice rather than a failure of memory and therefore it is possible that the failure to remember does not actually cause problems for driver safety (Wickens & Horrey, 2008).

However, if one is willing to assume that driving while conversing on a phone can cause safety problems based on the body of evidence presented above, then inattentional blindness as identified by Strayer, Drews, and Johnston (2003) is likely to affect driver’s decision making as to whether to engage in distracting activities and whether or how to moderate these effects by changing driving habits. In other words, if drivers fail to recall that they are not identifying objects and events in the environment, they are unlikely to avoid distracting behavior due to their inability to recognize those objects and events.

Unlike driving in low illumination, in the case of distraction there is currently no engineering solution to enhance recognition abilities. However, the pattern is similar in that objects that drivers’ fail to attend to are likely to remain unnoticed and thus are unlikely to affect decisions related to engaging in or moderating distraction or driving behavior. For example, a distracted driver who fails to notice a pedestrian entering the roadway ahead, will be unable to adjust either his or her engagement in distraction or his or her driving style to compensate for their distraction . It is possible that drivers will recognize their impairment only when they are involved in a collision.

Wickens and Horrey also note that inattentional and change blindness generally occurs more often for unexpected events (Wickens & Horrey, 2008). Therefore, methods of assessing the effects of distracted driving in the context of inattentional blindness should include unpredictable events.

Situation Awareness

Situation awareness (SA) is a concept that is not specific to distracted driving; however, maintaining SA is critical for drivers. In addition, researchers can use concepts associated with SA in order to explain and understand distracted driving. Endsley defines SA as "knowing what is going on around you" (Endsley, 2000, p. 5). Endsley further expands on this concept by defining three levels of SA: Perception, Comprehension, and Projection. In driving, as in all other arenas, these levels are dependent upon each other as accurate comprehension depends on perception and accurate projection requires comprehension of the driving environment (Endsley, 2000). Gugerty (1997) addresses the issue of whether SA is determined by explicit or implicit knowledge (specifically in a driving context). Though the results from Gugerty (1997) suggest that, in the context of driving, explicit and implicit measures of SA are reasonably well correlated, it is likely that explicit knowledge of SA would be required in order for that knowledge to be applied to strategic decisions such as whether to engage in distracting behaviors as well as tactical decisions such as how to adjust one's driving to compensate for distraction. Therefore, issues such as inattention blindness, which would limit SA (at least explicit, conscious SA if not implicit SA), could result in situations where drivers fail to notice that they are failing to notice relevant events.

The pattern of driving performance decrements previously discussed is likely to result in distracted drivers suffering from poor situation awareness. In addition to the obvious problems associated with inattentional blindness and "missing" important objects or events in the driving scenario that would fall within level 1 SA (perception), perhaps the more important issue related to SA and distracted driving occurs at levels 2 (comprehension) and 3 (projection). The lack of salience of missed objects and impaired reaction time as compared to the feedback received about maintaining control of the vehicle is likely to bias drivers' comprehension of the driving scene and encourage them to believe that their distraction is not causing safety issues (they are falsely led to believe that the driving situation while distracted is safe based on lane-keeping feedback and fail to account for the limited identification feedback). Drivers are also unlikely to be able to project the future of the driving scenario accurately without appropriate perception and comprehension of the risks. This lack of appropriate SA is likely to encourage drivers to engage in distracted driving behaviors that they might not engage in if SA were improved or if they understood how their situation awareness were degraded.

From the perspective of mitigation strategies for distraction and the inability to recognize identification performance decrements in the face of a lack of lane-keeping decrements, a discussion of meta-comprehension and situation awareness may be relevant. Meta-comprehension is defined by Dunlosky and Lipko (2007) as a person's ability to judge his or her own learning and/or comprehension of text materials. Though the topic of meta-comprehension has been studied mostly in the realm of text comprehension and learning (Dunlosky and Lipko, 2007), some of the methods used to understand and enhance meta-comprehension of text may be relevant to enhancing meta-comprehension of Situation Awareness in the context of distracted driving as well.

Research suggests that the accuracy of judgments of meta-comprehension of text materials can be enhanced by encouraging deeper processing of the materials such as re-reading material or generating keywords from material that has been read. In the context of distracted driving, this may imply that if drivers can be convinced to reflect upon their distracted driving behaviors this may enhance their understanding of their performance. Unfortunately, this strategy is not perfect, and only offers a modest increase in meta-comprehension ability (measured in the context of text comprehension). Further study has revealed that other methods can be used to enhance meta-comprehension of text material. Specifically, utilizing term-specific measures of perceived comprehension may enhance meta-comprehension ability relative to an overall judgment. Finally, encouraging learners to assess their learning on their own via a form of informal testing with rigorous checking against appropriate feedback has also been shown to be a very successful method (Dunlosky and Lipko, 2007). Unfortunately, this type of checking against performance feedback would be difficult in the context of driving as objective identification performance feedback is rare.

Distracted Driving and the Problems Associated with Selective Degradation

The similar pattern of performance decrements observed between driving while distracted and driving with low levels of illumination suggests that the methods that have proven useful for understanding night driving may also be useful for understanding distracted driving. As with self-regulation of driving speed at night, self-regulation of distracted driving behaviors is impossible if drivers are not aware of their own distraction or the potential consequences of being distracted. Unfortunately, in both instances (driving while distracted or in low illumination) the patterns of performance changes lend themselves to a lack of driver awareness of his or her own limitations. This may be the reason why subjective measures assessing perceptions of cellular phone use have shown that many drivers feel that it is dangerous when other drivers use a phone while driving; however, they themselves feel that they are capable of driving safely while talking on their phone (Wogalter & Mayhorn, 2005). Drivers may occasionally notice the more severe effects of distraction on others, while not having the capacity to sense their own distraction.

In the case of selective degradation due to blur or reduced luminance, a variety of methods have been investigated as potential ways to enhance drivers' ability to identify roadside objects or pedestrians at night. The use of retroreflective "conspicuity tape" on tractor trailer trucks has dramatically reduced under-ride collisions and saved many lives (Morgan, 2001). In addition, researchers have shown that pedestrians can significantly enhance their visibility to night-time drivers using retroreflective materials in bio-motion configurations (Owens, Antonoff, & Francis, 1994; Wood, Tyrrell, & Carberry, 2005; Balk, Tyrrell, Brooks, & Carpenter, 2008). However, because pedestrians typically fail to appreciate the extent to which they are difficult for drivers to see, a large-scale educational effort would likely be required to convince pedestrians that this type of intervention is necessary. This is due to the fact that it is easy for pedestrians to see the headlights of an approaching vehicle, and therefore most assume that they are also visible to the driver of oncoming vehicles (Tyrrell, Wood, & Carberry, 2004). In this instance, an educational intervention is necessary so that pedestrians are more likely to recognize that they cannot be seen by oncoming drivers and will avoid collisions rather than assuming that drivers will avoid them (Tyrrell, Patton, & Brooks, 2004). Similarly, educational interventions may be necessary in the case of distraction in order to convince drivers that there is a reason to limit distraction while driving.

Given the similar patterns of degradation observed between distracted drivers and nighttime drivers, it is possible that the issue of distracted driving can be further understood using parallel approaches. Although the current study does not suggest or test specific mitigation strategies, the results may suggest that regulation of distracting behaviors through laws and threats of legal penalties or following a path similar to that which has been successful in mitigating selective degradation due to luminance and blur could be effective. This might include enhancing the salience of important driving events or in some instances recognizing that the driver is incapable of regulating behavior safely and therefore implementing solutions such as adaptive cruise control that are intended to help avoid collisions while bypassing the distracted driver altogether. Unfortunately, although systems like adaptive cruise control (ACC) have been shown to be effective at maintaining proper following distances, a number of negative behavioral adaptations also can occur when drivers utilize ACC. Unintended consequences may include increased distraction behavior or other increases in risk-taking (Rudin-Brown & Parker, 2004). These types of issues must be addressed in any mitigation strategy focusing on increasing safety through automation; however, the current investigation seeks to guide the design and show the importance of new technological or legal approaches to distraction that will either lessen the demands on the driver, provide them with enhanced feedback about their ability to respond to sudden unexpected events, or implement legislation that will eliminate the problem.

It is important to note that the current investigation is not attempting to investigate whether the neurological underpinnings associated with the selective degradation of vision during night driving are equivalent to those of distracted driving. However, research supporting the theory of selective degradation during night driving suggests that the two visual systems associated with selective degradation of vision derive from two distinct neural pathways, and specifically that visual guidance can occur even without conscious awareness of vision (Weiskrantz, 1986). This may imply that visual guidance can occur pre-attentively and therefore, lane-keeping (a guidance task) would be expected to be unaffected by distraction (when addressing only the issues of visual guidance). However, the current investigation does not require and will not present evidence that selective degradation is equivalent to distracted driving. Rather, the similar pattern of performance results makes the parallels associated with selective degradation relevant to distraction regardless of the theoretical underpinnings due to the fact that the end result of both situations is that drivers have much more information suggesting that the lane-keeping task associated with driving is easy compared to relatively little information available suggesting that their identification performance may be degraded.

Importance of Driver Awareness

Horrey and Wickens (2006) suggest that further research in the field of distracted driving is necessary to examine considerations of vehicle speed and hazard exposure in order to establish procedures to address the distracting effect of mobile telephones. Along these lines, Lesch and Hancock (2004) have identified patterns that suggest that drivers vary in their ability to identify their distraction-induced decrements in driving performance. In their study, drivers rated their confidence in dealing with distractions while driving on a 4 point scale (very uncomfortable, uncomfortable, comfortable, and very comfortable) and then drove a test-track course while distracted and undistracted. Their results showed that in male drivers increased confidence ratings were predictive of better driving performance. This relationship was not observed for female drivers, for whom individual differences in confidence were uncorrelated with individual differences in driving performance. Driving performance was measured by braking response time, stopping time and distance, and stopping accuracy. Although this suggests that there is some hope for drivers recognizing their driving decrements, it shows that a large portion of the driving population is unable to appreciate when their ability to drive safely is compromised due to distraction.

Horrey, Lesch, and Garabet (2009) also showed dissociation between actual driving performance measures and subjective ratings of driving performance in an on-road driving task while completing two secondary tasks. The two tasks consisted of mental arithmetic (a paced serial addition task) and a guessing game similar to 20 questions. Drivers rated their performance during the mental arithmetic task as worse than during the guessing game task. In reality, driving performance as measured by braking response time, accuracy in a pace clock task, and variability in lane-keeping was better in the arithmetic task than in the guessing game task. Both distracted tasks resulted in decrements in performance in all measures compared to the baseline undistracted condition. This result suggests that drivers may be basing their assumptions about distracted driving performance decrements on their feelings about the tasks themselves rather than actual driving related feedback. This is potentially due to their inability to accurately perceive the small magnitude of decrements in lane-keeping and the relatively uncommon problems associated with decrements in identification of roadway hazards.

Although it is a controversial area of research with conflicting results, there is some empirical evidence that supports the hypothesis that passengers and drivers modulate their conversations based on real-time roadway conditions. Recently, Charlton (2008) suggests that passengers are capable of modulating conversation to enhance safety and may even help to notify drivers of impending hazards. This ability is also supported by previous research on team performance that suggests that members of flight teams monitor the activities of other team members visually, and use this knowledge to coordinate team-based actions and communication (Segal, 1994). Given this ability and the long term ineffectiveness of handheld cell phone use bans (Rajalin, Summala, Poysti, Anteroinen, & Porter, 2005; McCartt & Geary, 2004) in combination with data suggesting that the use of hands-free kits do not solve the distraction problem caused by verbal communications (Horrey & Wickens, 2006; Amado & Ulupinar, 2005), deeper understanding of driver awareness of distraction may lead to an understanding of why these measures are ineffective, and will be important moving forward with attempts to encourage more responsible use of mobile devices and compliance with regulations.

This research effort will attempt to quantify drivers' awareness of their own phone-induced distraction as well as their ability to regulate driving style (defined as speed for this experiment) to offset their performance decrements. The research will enhance our understanding of the ability of drivers to perceive, comprehend, and respond to decrements in driving performance caused by telephone-induced distraction.

It is important to understand whether drivers are capable of self-regulating driving behavior based on the feedback that they normally receive while driving or if consistent positive lane-keeping feedback encourages over-confidence and engagement in inappropriate distracting behaviors without moderation of driving style. This knowledge may guide or encourage distracted driving legislation and potential distraction mitigation strategies. For example, vehicle safety systems that alert drivers to potential hazards and make them more salient may be required in order to enhance safety if drivers are incapable of moderating their own behavior while distracted (e.g., lane departure warnings, headway warnings, and other hazard detection and warning systems). These types of systems would be important if it is shown that drivers cannot self-regulate distracting behaviors due to their being misled by consistent positive lane-keeping feedback. In addition to guiding mitigation strategies, the current research may also be useful in educating drivers as to their driving abilities while distracted. It is possible that an understanding of the performance decrements associated with mobile phone use may encourage drivers to minimize distracted driving behavior, and the current research may be one step towards helping to convince drivers that even though they feel as if they are capable of driving distracted, they are potentially putting themselves and others at risk.

Current Investigation

In order to test this application of selective degradation to distracted driving, I propose 2 experiments. The first experiment will mirror procedures used to test selective degradation of vision by luminance and blur (Brooks J. O., 2005; Brooks et al., 2005; Klein, 2008; Owens & Tyrrell, 1999) and will involve having participants drive on a curvy roadway in a simulated environment while identifying roadside objects. The severity of distraction will be manipulated. Before and after experiencing the various distractions during driving, participants will predict their performance on the lane-keeping and identification tasks. These ratings will be used to assess whether drivers' can accurately perceive and understand the magnitude of their own distraction as well as to assess their ability to predict which tasks will be particularly distracting.

The second experiment will quantify drivers' ability to adjust their driving to compensate for distraction. Drivers will be asked to complete a driving and pedestrian identification task while distracted and undistracted. During the distracted phase, drivers will be instructed to maintain a speed at which they can maintain the same level of safety that they exhibited when they were not distracted. While distracted, it is expected that participants will maintain a speed at which they can maintain lane position; however, they are not expected to reduce speed to the point where undistracted performance levels are achieved on the identification task.

EXPERIMENT 1

Methods:

Participants:

Participants were 15 students (10 male) enrolled in an introductory psychology course recruited from the Psychology Department subject pool. All participants were licensed drivers with corrected binocular visual acuity of 20/40 or better, log contrast sensitivity of 1.5 or higher, and no reported visual pathologies other than corrected refractive error. Participant age ranged from 18 to 23 years, M = 19.1 years, SD = 1.41 years. Driving experience ranged from 2 to 7 years, M = 3.7 years, SD = 1.3 years. All participants reported having talked on cell phones while driving. 14 of 15 participants reported having used media devices such as iPods while driving, 10 of 15 reported having sent text messages while driving, 14 of 15 reported having read text messages while driving, and 13 of 15 reported that they were average or better at text messaging (not texting while driving). In addition, 14 of 15 reported having set guidelines for themselves about whether and when they should use cell phones while driving.

Apparatus:

Simulator:

A DriveSafety DS-608C driving simulator with 360° field of view provided by five 60° projector screens (each with 1024 by 768 resolution) and 3 LCD rear view mirror displays was used for this experiment. Participants sat within the front half of a Ford Focus cab and interacted with the brake, gas, and steering wheel as they would in a normal vehicle. The vehicle cab sits on a partial motion base that rocks backward and forward simulating accelerations. The simulator was programmed such that drivers steered the vehicle along a continuously curvy two-lane roadway with no traffic in either direction. Cruise control maintained a constant speed of 55 mph throughout the driving scenarios.

The virtual roadway was lined with 210 randomly placed pedestrians, and 10 (4.7%) of the pedestrians began walking across the roadway when the participant drove to within 75 meters (straight line distance) of the pedestrian. An equal number of moving pedestrians were encountered in each of the distracting conditions, and the number of pedestrians moving from the left of the road to the right was equal to the number moving from the right to the left. Participants responded to a moving pedestrian by pressing one of two buttons on the back of the steering wheel (see Figure 1) corresponding to the side of the road from which the pedestrian began walking. To avoid collisions, the pedestrians disappeared when the correct button was pressed. In addition to the pedestrians that began moving at 75 meters from the participant, each course had 2 sham pedestrians that began moving at 35 and 50 meters from the participant's vehicle. Response time data from these pedestrians was collected, but no analysis was conducted for these pedestrian reactions as they were included only to avoid having participants assume that the pedestrians would never enter the roadway a short distance from the participant's vehicle.

Figure 2 and Figure 3 show driver views of the simulated roadway scene with pedestrians along the roadway and crossing the roadway, respectively. After the participant drove a distraction condition for 4 minutes, the cruise control gradually stopped the driver in the roadway allowing the experimenter to collect the subjective measures for that distraction condition. Once these measures were collected, the participant pressed both steering wheel buttons at once and the cruise control re-engaged allowing the driver to continue down the roadway and begin the next distraction condition as specified by the experimenter.

Figure 1: Button (red) located on the rear of the right side of the steering wheel. Participants will use this button to indicate when they detect pedestrian movement from right to left.

Figure 2: Driver view of roadway scene with pedestrians.

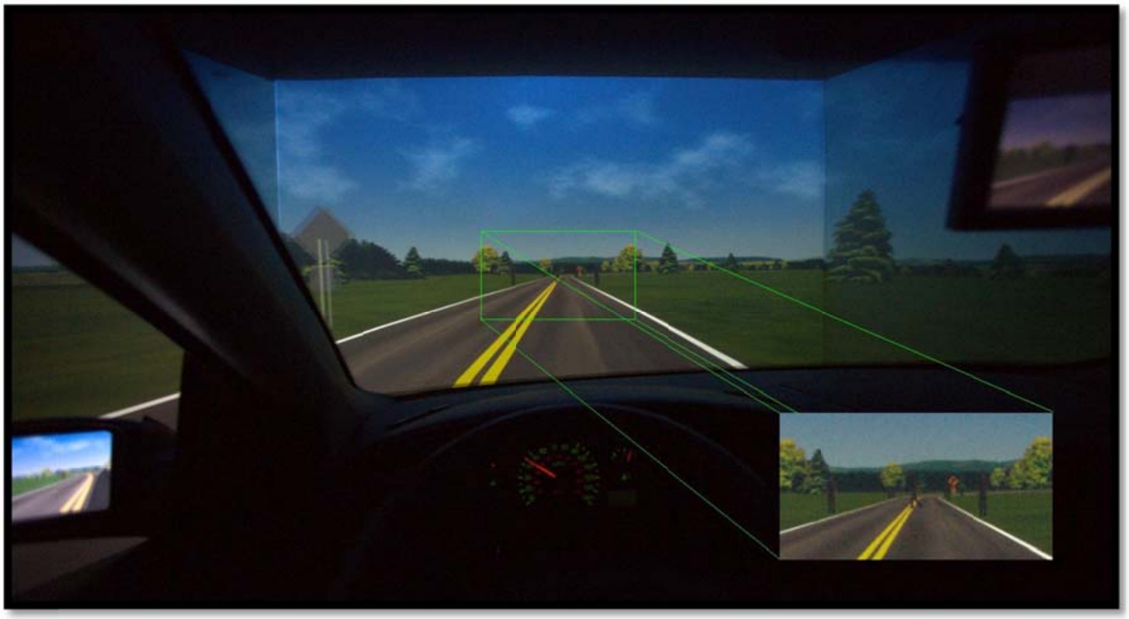

Figure 3: Driver view of roadway scene with pedestrian crossing roadway. The central roadway is magnified here for emphasis.

Distractions:

Participants drove through the scenario under different distraction conditions ranging from light distraction (repeating words) to strong distraction (text messaging). All distraction conditions except text-messaging were conducted over a commercially available cellular telephone using a wired hands-free kit. All interaction with the device (e.g., dialing or answering phone) other than talking and listening was conducted prior to the onset of data collection, and the experimenter was facing away from the driver and simulator while conducting the distracting tasks to prevent the experimenter's conversation from being affected by knowledge of pedestrian movement. The distraction conditions included:

1. No distraction
2. Repeating Spoken Words

Participants were asked to repeat a list of words spoken over the phone by the experimenter. After the participant successfully repeated the word, another word was presented (approximately 3 second inter-word interval). The total number of words repeated was recorded.

3. Mental Arithmetic

   A modification of the Paced Auditory Serial Addition Task (PASAT) was used (Gronwall, 1977). This task was recently used by Horrey, Lesch, and Garabet (2009) to study driver performance estimates while distracted. The task consists of presentation of a new digit every 7 seconds, and requires the participant to add the most recent two numbers presented together and report the answer. The original task included numbers presented every 2.4, 2.0, 1.6, and 1.2 seconds; however, it was designed for testing recovery from concussion. Horrey et al., (2009) as well as Brookhuis, de Vries, and de Waard (1991) have used the task in distraction studies with a 7 second interval as was used here.

4. Twenty Questions Test

   Participants played a game similar to twenty questions where they asked yes or no questions of the experimenter via the hands free telephone in order to identify an object chosen by the experimenter (an Animal, Fruit, or Vegetable). This task has been used recently by Horrey et al. (2009) to simulate naturalistic conversation using a method with a quantitative task performance measure. It was shown to adversely affect driving performance more than the Paced Auditory Serial Addition Task.

5. Text Message Word Game

   Participants were sent a text message with a single letter and responded via text message with a word that begins with that letter. This task should was included because it results in a significant reduction in lane-keeping abilities in addition to increases in response time. Note: During the text messaging task, the pedestrian identification task was simplified such that drivers responded by hitting either button when a pedestrian moves rather than identifying which side the pedestrian moved from. For this task, participants were allowed to use their own cell phones if it would not cost them money to do so.

These conditions were adapted from Nakayama et al. (1999), Horrey et al. (2009), and Crisler et al. (2008) and are listed in order of increasing magnitude of their expected degrading effect on driving performance. The twenty questions task is expected to correspond most closely with naturalistic conversation. This task and the PASAT task were not tested by Nakayama et al.; however, *a priori* knowledge of the distraction effects of each task was not necessary for this investigation. Rather, the experiment was designed to ensure a range of different distractions that would produce a range of performance decrements.

Prior to beginning the simulated driving task, participants completed a minimum of 20 practice responses for each task so that they were familiar with the tasks and what to expect while driving. This also allowed them to understand the tasks so that they could make predictions about their driving performance while completing the tasks. Participants were instructed that they could complete more practice trials if they felt it was necessary in order to make their performance predictions; however, none of the participants chose to complete additional practice.

Measures:

Prior to the experimental scenarios, but after training in the simulator and each distraction task, participants predicted their driving performance under each of the different distraction conditions. Participants predicted the percentage of time that they would remain entirely within their lane in a manner similar to that used by Brooks (2005). They also predicted their average response time to pedestrian movement onset. To assist them in making these estimates, participants were told their response time (expressed in seconds) after each pedestrian identified during the training scenarios. This feedback was not provided during the experimental scenarios. Participants were also asked to predict their expected performance for lane-keeping and for pedestrian identification using continuous visual analog scales with anchors "Extremely Dangerous" and "Perfectly Safe". Finally, participants rated their mental effort for each distracting task alone using the rating scale for mental effort (RSME).

The performance predictions for distraction tasks were completed in a counterbalanced random order to avoid having participants assume that their performance predictions should decrease as they go through a list of tasks of increasing difficulty. For example, participant one predicted his performance on task 1, 5, 4, 2, and then 3. Subsequent participants predicted their performance on the tasks in an order determined by a balanced latin square starting with the order shown above. Therefore, no participant predicted performance for the tasks in order of increasing expected difficulty. Example data sheets with rating scales are included as appendix B.

During each driving scenario, performance measures were collected by the simulator or calculated from simulator variables. Simulator data were collected at 60 Hz. The variables collected / calculated included:

1. Lane Position
2. Percentage of Time Spent Entirely in lane
3. Lane Position Variability (Standard Deviation of Lane Position)
4. Steering wheel position
5. Steering Entropy (A measure of steering predictability – see Appendix A for calculations) (Nakayama, Futami, Nakamura, & Boer, 1999)
6. Response time to pedestrian movement
7. Identification rate for pedestrian movement

In addition to these driving performance measures, a number of self-report measures were collected. After each distraction task, participants estimated both the percentage of time they spent entirely within their lane and their average response time for the pedestrian movement identification task. They were also asked to rate their lane-keeping, pedestrian movement identification performance, and overall driving safety on continuous scales with anchors “extremely dangerous” and “perfectly safe”. These continuous measures were coded linearly from 0 to 100 based on where participants marked the scale. In addition, participants also rated their lane-keeping and identification performance relative to how they felt other drivers would perform using a similar continuous scale with anchors “Worse” and “Better”. However, these ratings are treated as exploratory and not thoroughly analyzed in the current investigation since they are not directly relevant to participants’ perceived safety and the hypotheses of this experiment.

The rating scale for mental effort (RSME) was also administered to assess participants’ perceived workload after each distraction condition. Examples of each of these scales are in Appendix B.

Procedure:

After arriving and giving informed consent to participate, participants’ visual acuity and contrast sensitivity were measured using Bailey-Lovey and Pelli-Robson test charts, respectively. After completing the vision testing, simulator training began. Participants drove through the following 3 training scenarios:

1. Straight Road – 2 minutes
2. Curvy Road – 4 minutes (half without, and then half with, 55 MPH cruise control)
3. Curvy Road with Pedestrian ID task – 10 minutes with cruise control

In the final training scenario with the pedestrian identification task, participants received feedback about their average time spent entirely within their lane as well as their response time to each pedestrian and average response time to all pedestrians during the practice trial. After completing each of these training scenarios, participants were given a modified motion sickness assessment questionnaire (MSAQ) to identify any instances of simulator sickness following a protocol presented in Brooks et al. (2010). Participants were also instructed to notify the experimenter immediately if they felt uncomfortable at any time. Although this procedure was implemented to limit the severity of any simulator sickness episodes that may have occurred, the data were also used to identify participants' whose performance may have been affected by simulator sickness. Given the high degree of variability in responses to this questionnaire, no *a-priori* rule was used to screen participants whose data would or would not be used. Rather, patterns of performance and MSAQ responses were analyzed subjectively to identify participants whose results may have been affected by simulator sickness. No issues with simulator sickness were observed during the data collection process, and no data were excluded due to simulator sickness.

After completing the training scenarios, participants were given an opportunity to ask any questions about the task before the experimental driving sessions began. In addition, participants practiced each of the 4 distractions and then predicted their lane-keeping performance (percentage of time in lane) and identification reaction time for each task as described in the measures section above and the datasheets in Appendix B.

After completing the performance predictions, the experimental driving session began. It lasted approximately 30 minutes (approximately 5 minutes for each of 5 distraction conditions plus approximately 5 minutes for performance ratings and transitions). Within this scenario, the distraction conditions were conducted in counterbalanced order using a balanced Latin square design. After approximately 5 minutes of driving in a distracted condition while completing the pedestrian identification and appropriate distracting task, participants reported their overall driving safety, lane-keeping performance, and pedestrian identification performance using the datasheet for that condition included in Appendix B and described in the measures section. They also reported their mental workload using the RSME at this time. After giving these ratings and initiating the phone call for the next distraction condition (except for the control condition with no phone interaction and the text messaging condition), participants pressed both steering wheel buttons simultaneously, and the cruise control re-engaged to begin the next driving condition. Data collection did not begin until the vehicle settled at speed and the distracting task was started. After another 5 minutes of driving, the process was repeated until all distraction conditions had been conducted.

When all conditions were completed, participants were asked if they had been exposed to the topic of selective degradation in any of their classes and about their experience with distracted driving and then allowed to ask any questions that they may have had, and then dismissed. No participants had been exposed to selective degradation.

Hypotheses, Analyses, and Results:

Hypotheses:

Compared to the baseline condition, it was expected that there would be differences in objective driving performance for each of the different distraction conditions other than repeating spoken words. However, the effect sizes were expected to be larger for identification performance as compared to lane-keeping performance. Only the more sensitive lane-keeping performance measures, steering entropy and possibly standard deviation of lane position, were expected to result in statistically significant performance differences. In addition, it was expected that drivers would both fail to predict prior to driving and fail to recognize after driving that their lane-keeping and identification performances were differentially affected by distraction. These hypotheses are specified in greater detail in the following sections. Throughout this document, the term "prediction" refers to participants' subjective predictions of their driving performance <u>prior</u> to completing the simulated driving portions of the experiment (that is, their expectations for their performance while completing that task) and the term "rating" refers to subjective ratings of driving performance reported <u>after</u> completing the simulated driving portions of the experiment (that is, their evaluation of their recently completed task).

Hypothesis 1: Increases in response time to pedestrian movement

Based on previous research and meta-analyses, it was expected that distraction-induced increases in response time would range from statistically non-significant in the repeating words condition to approximately 0.5 seconds in the text messaging condition relative to the undistracted baseline condition (Caird et al., 2008; Reed & Robbins, 2008). The 20 questions test was expected to produce the largest distraction effect other than text messaging; however, the rank order of distraction conditions was not central to the current study.

Hypothesis 2: Only small decreases in lane-keeping performance except for text messaging where a significant decrease in lane-keeping performance is expected

The existing literature on lane-keeping while distracted offers little consistent guidance on expected effects for lane-keeping measures as even meta-analysis “yielded minimal reconciliation of essentially contradictory results” (Caird et al., 2008, p. 1287). It was expected that in the voice-only conditions, the current study would result in small and likely statistically non-significant changes in lane-keeping as measured by percentage of time spent entirely within the lane and standard deviation of lane position. However, the steering entropy measure was expected to show a small increase while distracted. This was expected to be statistically significant for only the PASAT task, the twenty questions task, and the text messaging task. Based on results from Nakayama et al. (1999), it was expected that steering entropy would increase by approximately 0.05 for the twenty questions task. The text messaging condition was expected to result in significant increases in lane position variability and steering entropy as well as a decrease in percentage of time spent entirely within the lane. As in Hypothesis 1, the rank order of distractions is not central to the current study.

Hypothesis 3: Similar reductions in predicted lane-keeping, identification, and overall driving safety performance across tasks.

Participants were expected to predict some level of performance decrement while distracted. It was expected that the lane-keeping, identification, and overall performance decrements would be predicted to be similar. Of the voice-only tasks, the PASAT task was expected to elicit the largest change in predicted driving performance due to its math component and previous research suggesting that this task results in larger reductions in predicted performance as compared to the 20 questions task (Horrey et al., 2009). The text messaging task was expected to elicit the worst performance predictions of all the tasks.

Hypothesis 4: Similar subjective performance ratings for lane-keeping, identification, and overall driving safety.

As with the predicted performance, and in line with tests of selective degradation of vision, it was expected that across distraction conditions, subjective ratings of recent performance would be similar across the lane-keeping, identification, and overall safety measures. Although significant rated performance decrements were not expected, it was expected that amongst the voice-only conditions, the PASAT task would result in the largest rated performance decrements. This is due to its math component and was expected even though previous research suggests that the twenty questions task will result in a larger decrement in objective performance (Horrey et al., 2009).

Hypothesis 5: Rated performance expected to be higher than predicted performance.

Across distraction tasks, it was expected that performance ratings would be higher than performance predictions. This was expected due to the significant media coverage of distracted driving that is likely to result in participants predicting larger-than-accurate performance decrements prior to driving. In contrast, the lack of salient feedback of reduced performance due to robust lane-keeping performance was predicted to result in performance ratings remaining high after driving.

Analyses and Results:

All inferential analyses were conducted using an alpha level of 0.05 and, as appropriate, Greenhouse-Geisser degrees of freedom adjustments for violations of sphericity assumptions. For all ANOVA results, post-hoc paired comparisons were conducted using LSD protected t-tests. All directional hypotheses supported by theory were tested using one-tailed tests and noted by *. Significant interactions were followed up with tests of simple effects within the levels of an interacting variable.

Prior to and as part of conducting analyses, data were examined for statistical outliers. Although there were some observations in the ratings and predictions of performance that did not seem logical, there were no observations outside of 3 standard deviations of the mean for any of the conditions. In addition, Cook's D values were saved for ANOVA analyses, and no values greater than 0.7 were observed. As such, all data were included in the analyses unmodified. However, performance ratings that did not make logical sense are noted in some instances (e.g. lane-keeping safety ratings that do not correspond with % Time in Lane ratings).

Descriptive Statistics

Descriptive statistics including mean, median, and standard deviation are included in Appendix D presented for all dependent variables. Graphs of dependent variable means and standard errors by condition are included below as Figure 4 - Figure 9.

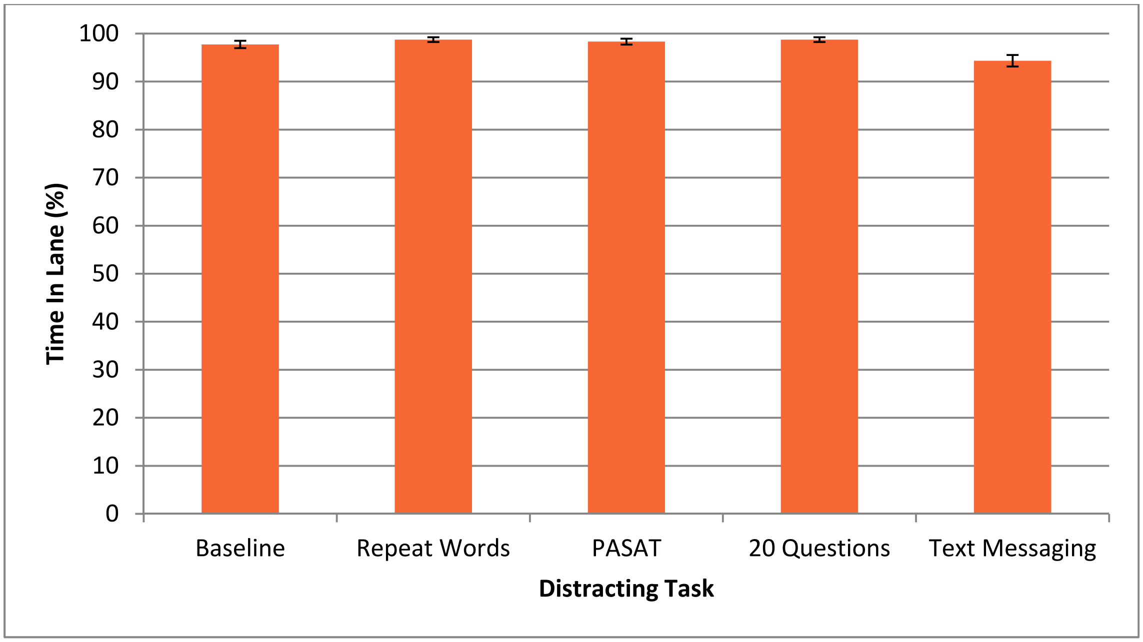

Figure 4: The mean percentage of time (±1 standard error of the mean) spent entirely within the lane for all conditions. No difference in lane-keeping was observed across the voice-only tasks. Text-messaging resulted in a decrease in time in lane.

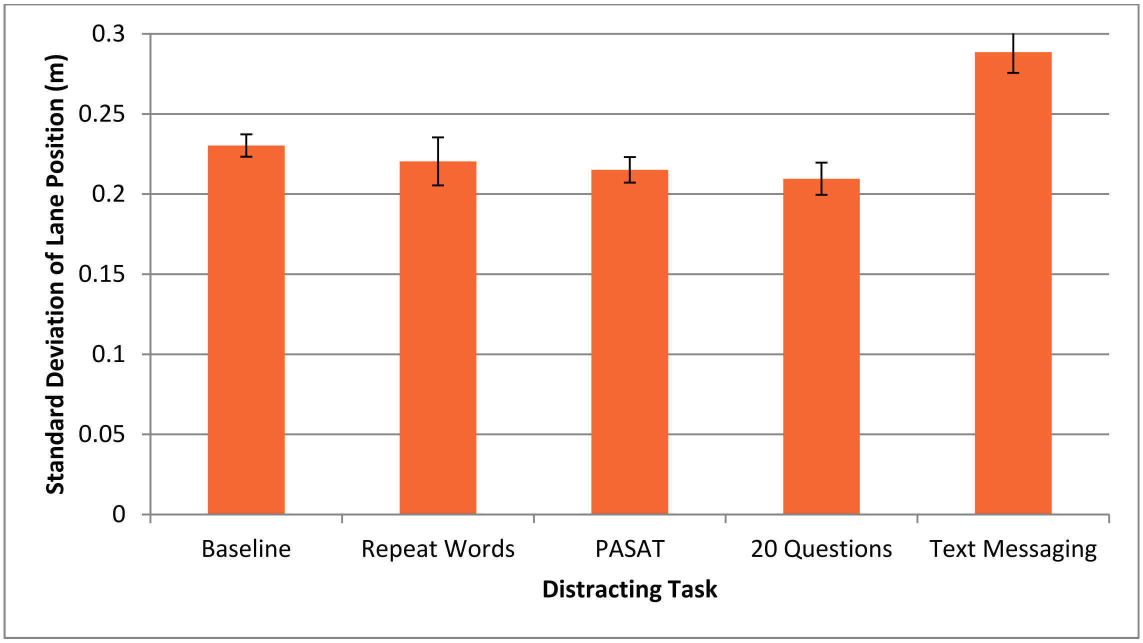

Figure 5: Mean (±1 standard error of the mean) standard deviation of lane position (SDLP, lane position variability) increased significantly in the text messaging condition compared to all other conditions. All other distraction conditions did not differ significantly.

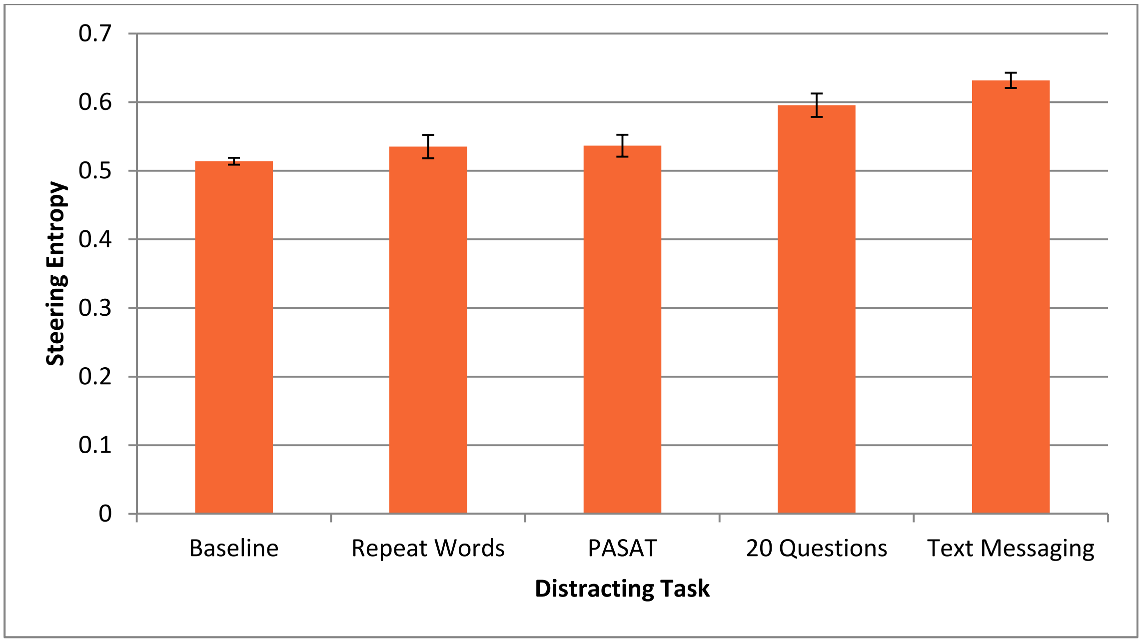

Figure 6: Mean (±1 standard error of the mean) steering entropy increased significantly in the 20 questions and text messaging trials relative to the baseline trial.

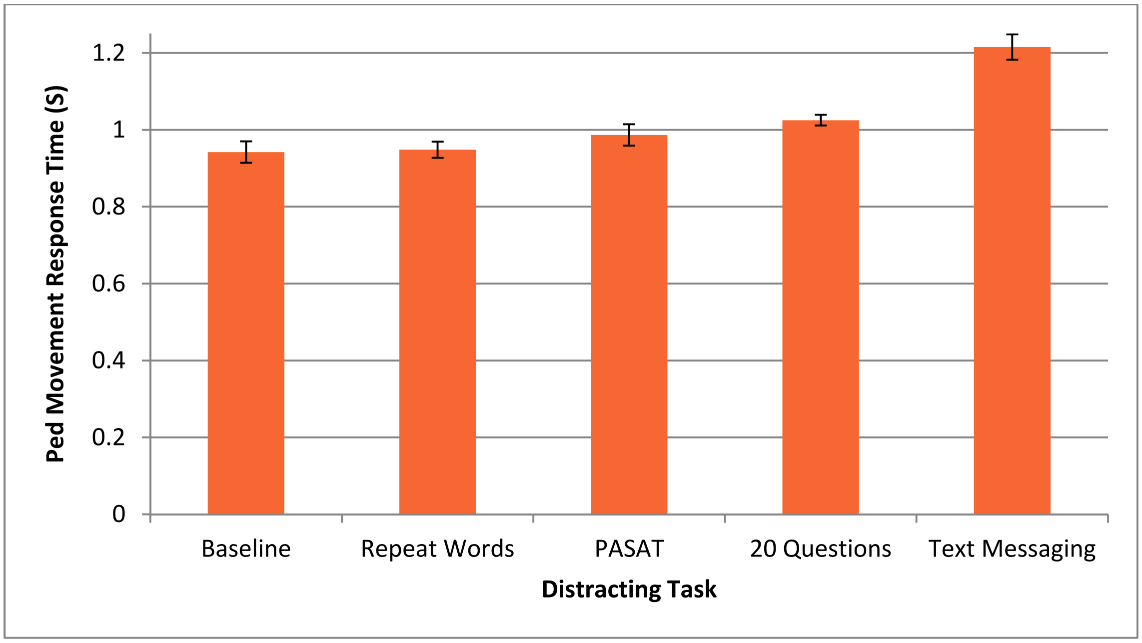

Figure 7: Mean (±1 standard error of the mean) response time increased significantly in the PASAT, 20 Questions, and Text Messaging trials relative to the baseline trial.

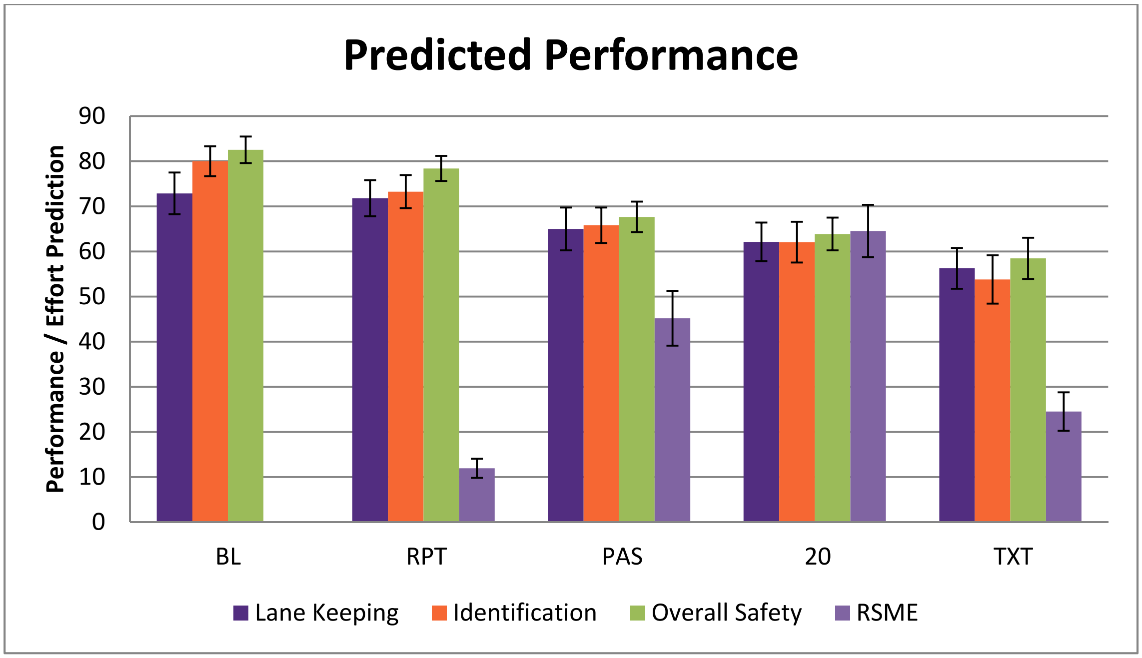

Figure 8: **The participants' mean (±1 standard error of the mean) predictions about their own performance and workload. Participants provided these ratings after they were trained on the distraction tasks but before they experienced the tasks while driving. As hypothesized, the dissociation in actual performance between lane-keeping and identification was not predicted by participants in the experiment. Performance was predicted on a visual analog scale and assigned values from 0 to 100.**

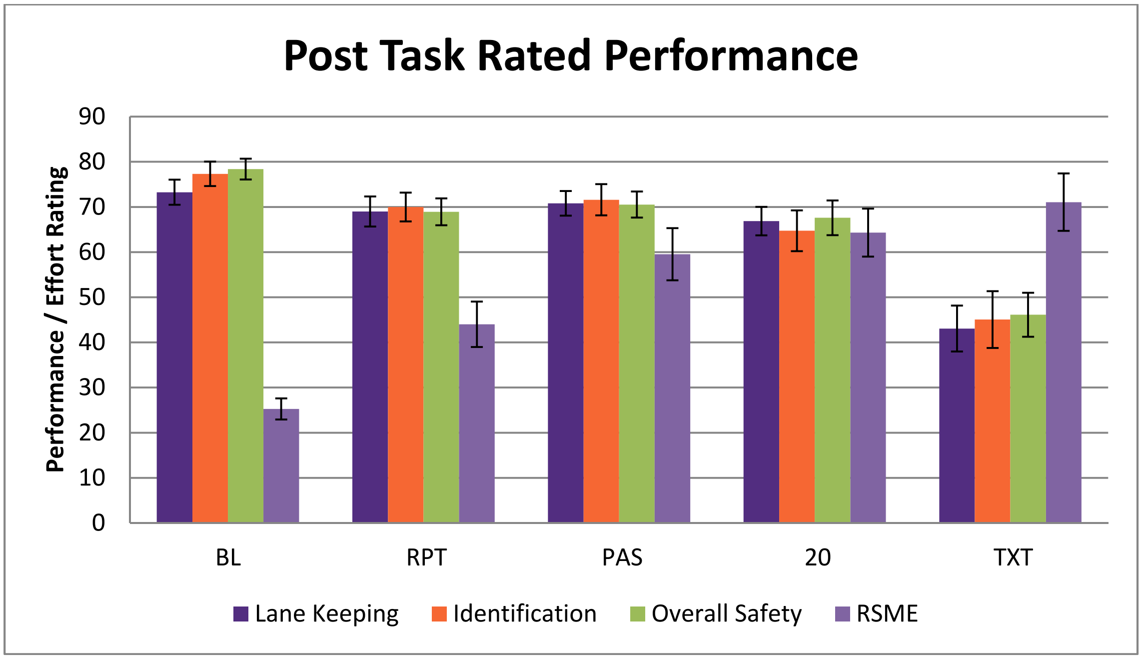

Figure 9: **Mean (±1 standard error of the mean) post driving task ratings of workload and driving performance. As hypothesized, the dissociation between objective lane-keeping and identification performance measures was not reported by participants in the experiment. Performance was rated on a visual analog scale and assigned values from 0 to 100.**

Secondary Task Performance

Performance data were collected for the secondary tasks completed by participants. Table shows the mean and standard deviation of performance for each of the tasks completed. Overall, participants were generally responsive when completing the secondary tasks. Due to variable cell-phone network conditions, it was difficult at times to ensure consistency of the text messaging task; however, there were enough letters sent and words responded to ensure that the task was reasonably difficult as it was designed to be.

Table 1: Secondary Task Performance

	20 Q: Number Asked	20 Q: Number Correct	20Q: Number Passed	PASAT: Number Correct	PASAT: Number Incorrect	Number of Words Repeated	Number of Words Texted
Mean	47.9	2.7	4.5	41.3	2.9	77.5	10.5
SD	12.2	2.1	1.5	2.7	2.3	4.2	3.1

Hypothesis 1 – Increased response time to pedestrian movement (See Figure 7)

A one-way repeated measures ANOVA was conducted on the mean response time to the onset of pedestrian movement with 5 levels of distraction condition as the independent variable. The ANOVA analysis revealed a significant difference among conditions, (2.027,28.374) = 24.034, $p < 0.0005$, $\eta^2 = 0.632$. LSD post-hoc paired comparisons conducted to follow up a significant main effect of distraction on response time revealed increases in response time relative to baseline in the PASAT, 20 Questions, and Text Messaging conditions, p=0.031*, p=0.003*, and p<0.0005* respectively. Response times were expected to be significantly increased for the PASAT, 20 questions, and text messaging tasks relative to the baseline undistracted task. Though the difference was only marginally significant, the 20 questions task resulted in longer response times relative to the PASAT task, p=0.062*. As expected, participants responded to the pedestrian movement slower during the text messaging task compared to all other tasks, all p values < .0005*.

Hypothesis 2 – Small differences in lane tracking ability (See Figures 4-6)

Another one-way repeated measures ANOVA was conducted on each of the lane tracking variables (% Time in Lane (% TIL), Standard Deviation of Lane Position (SDLP), and Steering Entropy) with distraction condition as the independent variable.

The ANOVA on data representing the percentage of time spent entirely within the lane revealed a significant main effect of distraction, $F(1.528, 21.391) = 10.435$, $p = 0.001$, $\eta^2 = 0.427$. However, post-hoc paired comparisons revealed that only the text messaging task (mean % time in lane = 94.3%) resulted in a decrease in time spent entirely within the lane relative to the baseline (97.7%, p = .012), repeating words (98.7%, p < .0005), PASAT (98.3%, p =.002) and 20 questions (98.7%, p < .0005) tasks.

Similarly, an ANOVA on the data representing the standard deviation of lane position (lane position variability) revealed statistically significant differences between the distraction conditions, $F(4, 56) = 20.651$, $p < 0.0005$, $\eta^2 = 0.596$. Interestingly, the PASAT (0.215 meters) and 20 questions (0.210 meters) tasks resulted in slight decreases in lane position variability relative to the baseline (0.230 meters) condition, p = 0.035 (PASAT) and p = 0.014 (20 questions). As expected, the text messaging (0.289 meters) condition resulted in significantly increased lane position variability relative to all other tasks, $p < 0.0005$ (all comparisons).

Finally, the ANOVA on the data representing steering entropy revealed significant differences between the distraction conditions, $F(4, 56) = 19.029$, $p < 0.0005$, $\eta^2 = 0.576$. Again, steering entropy was increased (worse) in the the text messaging (0.632) condition compared to all other conditions, $p < 0.0005$* for baseline (0.514), repeating words (0.535), and PASAT (0.537) and $p = 0.0495$* for 20 questions (0.596). In addition, a significant increase in steering entropy was observed for the 20 questions task relative to the baseline, repeating words, and PASAT tasks, all $p \leq 0.0005$*.

For the purposes of comparing the effect sizes of the distraction effect on lane-keeping with the distraction effect on response time, another series of ANOVA analyses were conducted excluding the text messaging task. This was done due to the fact that the main focus of the current investigation is to determine whether drivers can recognize their distraction when talking on hands-free cell phones (it was hypothesized that they could identify the effects of distraction in the case of text messaging). Therefore, the text messaging condition, though relevant to certain aspects of the experiment would be misleading to include in a comparison of the relative size of effects of distraction on lane-keeping measures compared to response time measures. The effect sizes of the distraction effect for each dependent measure are shown in

Table .

Table 2: Effect sizes (partial eta squared) of distraction on objective lane-keeping and identification performance measures. Effect sizes are presented for analyses with and without the text messaging condition. As predicted, the effect size of distraction was larger for response time than for % TIL and SDLP.

Measure	Effect Size	Effect Size (with text messaging condition)
% TIL	0.128	0.427
Std. Dev. of Lane Position	0.123	0.596
Steering Entropy	0.467	0.576
Response Time to Ped. Movement	0.300	0.632

Hypothesis 3 – Consistent reductions in predicted driving performance across prediction type (lane-keeping, identification, and overall safety)

Figure 8 shows the values for the participants' mean predictions of their own performance. The pattern of decrements is similar across the three measures of performance (Overall, Lane-keeping, and Identification). A 5 X 3 (distraction condition X prediction type) repeated measures ANOVA explored the differences among driving performance predictions across distracting tasks and prediction types. The prediction type variable represents whether participants were predicting their lane-keeping, identification, or overall safety performance. No significant main effect was observed for prediction type, F(1.389, 19.442)=1.533, p=0.238, partial $\eta^2 = 0.099$. However, an interaction between distraction condition and prediction type was observed, F(8, 112)=2.583, p=0.013, partial $\eta^2 = 0.156$ as well as a main effect of distraction, F(4, 56) = 15.919, $p < .0005$, partial $\eta^2 = 0.532$. As seen in figure 8, the general pattern of performance ratings is consistent across distraction conditions except for an unexpectedly low rating for baseline lane-keeping performance. As can be seen in figure 8, participants predicted that their lane-keeping performance in the baseline condition would be somewhat lower than their identification and overall safety performance. This results in smaller decreases in lane-keeping performance predictions (relative to baseline) across distraction conditions. This is partly due to a single participant who reported significantly lower predicted lane-keeping performance in the baseline condition relative to the distracted conditions while reporting that the % time in lane would not change across the same conditions. In addition, the effect size of the interaction (partial $\eta^2 = 0.156$) is smaller than that of the main effect of distraction (partial $\eta^2 = 0.532$). Consequently, even though the interaction suggests that the distraction effect changes in slightly with rating type, the main effect of distraction is presented averaged across rating type.

Averaged across rating type, participants' performance predictions decreased with increasing intensity of distraction. All 4 distracted conditions resulted in significantly lower predicted performance relative to the baseline task, p=0.040* for the repeating words task and p<0.0005* for the PASAT, 20 questions, and texting tasks. Inconsistent with the previous comparison of the PASAT and 20 questions task (Horrey, Lesch, and Garabet, 2009), participants predicted the 20 questions task would result in poorer driving performance than the PASAT task; however, this result was not statistically significant, p=0.145.

Table shows all significant paired comparisons observed.

Table 3: Post-hoc comparisons between participants' mean predictions of their own driving performance under different distraction conditions (averaged across rating type)

Comparison	p-value
Baseline > Repeat Words	p=.040*
Baseline > PASAT	p<.0005*
Baseline > 20 Questions	p<.0005*
Baseline > Text Messaging	p<.0005*
Repeat Words > PASAT	p=.002*
Repeat Words > 20 Questions	p=.002*
Repeat Words > Text Messaging	p=.0005*
PASAT > Text Messaging	p=.006*

Hypothesis 4 – Consistent subjective driving performance ratings across rating type (lane-keeping, identification, and overall safety) (See Figure 9)

The participants' mean ratings of their own driving performance are presented in Figure 9. A 5 X 3 (distraction condition X prediction type) repeated measures ANOVA was conducted on the subjective performance ratings. A main effect of distraction (but no main effect or interaction involving rating type) was expected. This would imply that participants failed to recognize and report the dissociation of lane-keeping and identification performance. No significant main effect of rating type, F(2, 28) = 0.185, p=0.832, partial η^2 = 0.013, or interaction between distraction and rating type, F(3.769, 52.765) = 0.710, p=0.581, partial $\eta^2 = 0.048$, was observed. The main effect of distraction was significant, F(1.876, 26.257) = 26.820, $p < 0.0005$, partial $\eta^2 = 0.657$. Post hoc paired comparisons revealed that participants rated their performance to be significantly lower in all distraction conditions (averaged across rating type) relative to the baseline undistracted condition (see Table). As expected, participants rated the text messaging condition lower than all other conditions; however, there were no significant differences among the ratings for the 3 verbal-only distraction conditions, $p > 0.05$.

Table 4: Post-hoc comparisons between participants' mean ratings of their driving performance under different distraction conditions.

Comparison	p-value
Baseline > Repeat Words	p = .008*
Baseline > PASAT	p = .015*
Baseline > 20 Questions	p = .002*
Baseline > Text Messaging	p < .0005*
Text Messaging < Repeat Words	p < .0005*
Text Messaging < PASAT	p < .0005*
Text Messaging < 20 Questions	p < .0005*

Hypothesis 5 – Actual performance will be rated higher than predicted performance (See Figures 8-9)

A series of three (one each for lane-keeping, pedestrian movement identification, and overall safety) 5 X 2 (Distraction Task X Predicted vs. Rated performance) repeated measures ANOVAs investigated differences in predicted and rated performance across distraction task. A similar pattern of results was observed for each of the three ANOVAs (See Figures 8 and 9). Across all three measures of subjective driving performance (overall safety, lane-keeping performance, and identification performance) a significant main effect of distraction and a significant interaction between distraction and pre- vs. post-task rating was observed. Due to the similarity of these analyses and the fact that it would be expected that the overall safety rating would drive decision making, the analyses of the overall safety measures are emphasized here (the lane-keeping and identification analyses are presented in Appendix F). Here, the interaction between distraction and predicted versus post-task rating was significant, $F(4, 56) = 6.415$, $p<0.0005$, partial $\eta^2 = 0.314$. There was also a main effect of distraction, $F(1.982, 27.748) = 24.411$, $p<0.0005$, $\eta^2 = 0.636$, suggesting that participants did not expect or rate their performance to be equal during the distracted and undistracted conditions. However, the interaction effect is more relevant to the current hypotheses and reduces the relevance of the main effect in isolation. Though the analyses presented for hypotheses 3 and 4 represent tests of the simple effects of this interaction, a more direct look at pre-task predictions compared to post-task ratings of performance is relevant to this hypothesis specifically. For this analysis, 5 paired samples t-tests were conducted comparing the pre-task and post-task predictions and ratings within each distraction condition. Results from these tests revealed a significant reduction in rated performance after the repeating words and text-messaging trials (relative to the corresponding prediction), a non-significant reduction in rated performance was observed after the baseline task, and non-significant increases in rated performance were observed after the PASAT and 20 Questions trials. Detailed results of these comparisons are included in Table .

Table 5: Comparisons of Pre and Post-Drive predictions and ratings of performance

Distraction Condition	**Mean Difference (Post – Pre)**	**t-test**
Baseline	-4.1	t(14)=1.285, p=0.220, d=0.403
Repeat Words	-9.5	t(14)=2.546, p=0.023, d=0.849
PASAT	2.9	t(14)=1.003, p=0.333, d=0.235
20 Questions	3.7	t(14)=1.031, p=0.320, d=0.257
Text Messaging	-12.3	t(14)=3.818, p=0.002, d=0.674

Correlational Analyses

Although the above analyses are the primary outcomes of Experiment 1, correlational analyses were conducted to determine whether individual differences in changes in participants' performance ratings while distracted were correlated with individual differences in changes in objective driving performance. This between subjects analysis is both exploratory and limited in statistical power (N = 15).

To address whether participants' objective performance changes due to distraction were correlated with distraction-related changes in subjective performance ratings and predictions, a dataset was generated by subtracting each participant's objective and subjective performance measures for each of the distracted conditions from that participant's corresponding baseline measure (e.g., a baseline time-in-lane score of 94% paired with a 20 Questions Task time in lane of 92% would result in a score of 2. Similarly, a subjective rating of 80 in the baseline condition and 76 in the 20 questions condition would result in a score of 4 for the 20 questions condition.) This dataset was used to correlate the change in objective performance from baseline with the change in performance predictions and ratings from baseline within each of the four distraction conditions. Since the analyses of objective performance revealed no significant performance changes due to distraction in the repeating words condition, only the correlations within the text-messaging, PASAT, and 20 questions tasks are presented in detail here (see Tables 6-8). Correlations within the repeating words task are presented in Appendix E.

As seen in Table 6, the significant positive correlation between changes from baseline in objective % TIL and changes from baseline in post-task rated lane-keeping safety (= 0.732) and rated % TIL (r = 0.622) suggest that even though there was no overall effect of distraction on lane-keeping performance, there were individual differences in the effect of the 20 questions task on lane-keeping performance, and that drivers were able to recognize and report these differences to some degree. However, as can be seen in Figure 10, the majority of drivers actually maintained the vehicle within the lane during the 20 questions task slightly more than during the baseline task; however, most of these same drivers still rated their performance as diminished suggesting that the knowledge of performance relative to each other does not imply accurate knowledge of actual performance. In addition, the corresponding correlation between change in objective response time performance (where there was a systematic effect of distraction on performance) and corresponding changes in subjective ratings of identification performance was smaller and non-significant (see Figure 11).

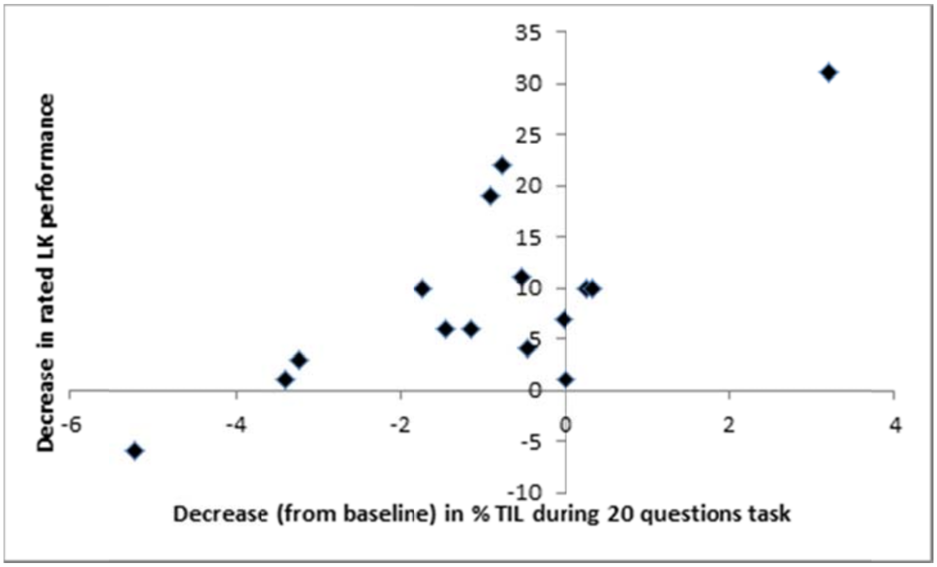

Figure 10: Scatter plot of change in lane-keeping performance versus change in lane-keeping ratings during the 20 questions task. The correlation between objective and subjective changes in lane-keeping performance suggests that drivers may be able to identify whether they are more or less affected by distraction compared to other drivers as measured by % TIL. Note that though there is a significant correlation in the appropriate direction, most drivers performed slightly better on the lane-keeping metric while distracted, but all but one reported poorer performance.

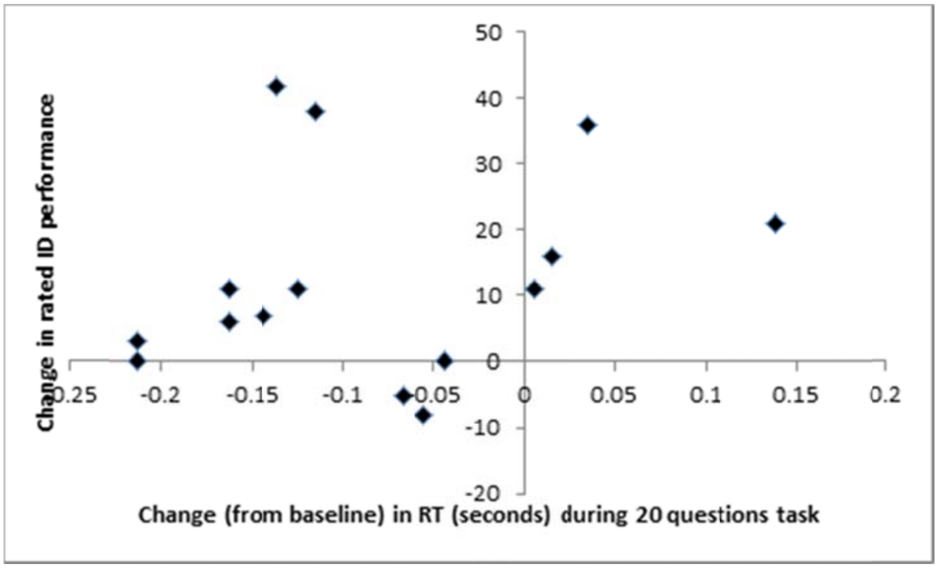

Figure 11: Scatter plot of change in pedestrian response time versus change in identification performance ratings during the 20 questions task. The lack of correlation between objective and subjective changes in response time performance gives no indication that drivers were able to identify whether their response times were more or less affected by distraction compared to other participants.

This suggests that drivers are less able to report their identification performance decrements than they are with their lane-keeping decrements. However, the current experiment was designed mainly to identify whether drivers recognized the dissociation in lane-keeping and identification performance using a repeated measures design. As such, further research will be required to determine the extent to which performance ratings are correlated with objective performance. However, the current analysis gives no indication that objective identification performance (RT) is tightly linked with any of the subjective measures of performance within any of the distracting tasks (see Tables 6-8). This remains true even in the text-messaging condition where a strong correlation between rated %TIL and actual %TIL was observed ($r = 0.838$) along with marginally significant correlations between both predicted and rated identification performance and objective %TIL ($r = 0.503$ and $r = 0.497$ respectively). The largest correlation observed between objective response time performance and subjective identification performance ratings was $r = 0.382$, $p = 0.160$ between change in rated response time and change in objective response time during the PASAT task.

Table 6: Correlations (with p values) between objective and subjective changes in performance (from baseline) within the 20 questions task.

Objective Measure	Predicted LK Safety	Rated LK Safety	Predicted ID Safety	Rated ID Safety	Predicted TIL	Predicted RT	Rated TIL	Rated RT	RSME
TIL	-.157	**.732****	-.338	.389	-.125	.286	**.622***	-.066	-.370
	.576	.002	.217	.152	.656	.302	.013	.815	.175
SDLP	-.314	-.362	.124	-.048	-.271	-.229	**-.511**	-.122	.224
	.254	.185	.659	.864	.329	.412	.051	.665	.422
Entropy	.343	.200	-.248	-.333	-.435	.460	.198	.253	-.281
	.211	.476	.373	.226	.105	.084	.478	.364	.311
ID	-.140	.020	.129	.232	.038	-.047	-.292	.171	.232
	.620	.945	.648	.406	.892	.867	.291	.543	.405
RSME	-.466	-.302	-.119	-.005	-.295	.360	-.048	.439	1.000
	.080	.274	.674	.985	.286	.187	.865	.102	

** p<.01, * p<.05

Table 7: Correlations (with p values) between objective and subjective changes in performance (from baseline) within the PASAT task.

Objective Measure	Predicted LK Safety	Rated LK Safety	Predicted ID Safety	RatedID Safety	Predicted TIL	Predicted RT	Rated TIL	Rated RT	RSME
TIL	-.376	.241	-.142	.192	-.034	.231	.401	-.173	-.178
	.168	.387	.615	.494	.903	.407	.139	.538	.526
SDLP	-.052	-.318	.276	-.080	-.247	-.230	-.205	-.021	.275
	.854	.248	.320	.777	.375	.410	.463	.940	.321
Entropy	.251	.201	.459	-.006	**-.624***	-.138	.450	-.030	-.187
	.367	.472	.085	.984	.013	.623	.092	.916	.505
ID	-.044	.083	-.104	-.100	-.243	.304	.285	.382	.413
	.876	.769	.712	.724	.383	.270	.303	.160	.126
RSME	-.415	-.326	**-.596***	-.257	-.219	**.673****	-.171	.203	1.000
	.124	.236	.019	.355	.433	.006	.543	.468	

** p<.01, * p<.05

Table 8: Correlations (with p values) between objective and subjective changes in performance (from baseline) within the text messaging task.

Objective Measure	Predicted LK Safety	Rated LK Safety	Predicted ID Safety	Rated ID Safety	Predicted TIL	Predicted RT	Rated TIL	Rated RT	RSME
TIL	.408	.354	.503	.497	.050	-.292	**.838****	-.382	**-.834****
	.132	.196	.056	.059	.860	.291	.000	.160	.000
SDLP	-.453	-.448	**-.585***	-.388	.358	**.649****	**-.595***	**.625***	**.530***
	.090	.094	.022	.153	.190	.009	.019	.013	.042
Entropy	-.338	-.269	**-.658****	-.388	.323	.188	-.155	-.110	.410
	.218	.333	.008	.153	.241	.502	.582	.697	.129
ID	-.211	-.213	.011	.077	.191	.335	-.372	.337	.052
	.450	.446	.968	.784	.494	.222	.172	.220	.854
RSME	-.171	-.365	-.444	**-.635***	-.115	-.028	**-.605***	.187	1.000
	0.541406	.181	.097	.011	.684	.921	.017	.506	

** p<.01, * p<.05

Discussion:

Experiment 1 was designed to investigate the effects of distraction on driving performance as well as to identify how well drivers can predict their performance prior to completing a variety of distracting secondary tasks and evaluate their performance afterwards. The experiment focused on the distinction between lane-keeping performance and identification performance in an attempt to show that drivers can fail to recognize that their driving performance and safety is affected by distraction due to the absence of noticeable objective lane-keeping performance decrements that are likely to encourage over-confidence in distracted driving ability.

The results of this study confirm those of previous studies of distracted driving by revealing a slowing of drivers' identifying driving-relevant events. The magnitude of this effect was relatively small (an increase of 0.08 seconds) compared to previous research suggesting that the average increase in response time is approximately 0.13 seconds (Caird et al., 2008; Horrey and Wickens, 2006); however, this small effect was expected as drivers had been alerted to the fact that pedestrians would occasionally enter the roadway from the shoulder and the fact that it was their task to watch for this specific event. Other factors that may have reduced the magnitude of the distraction effect on response time were the fact that the drivers were young, healthy, and aware that their performance was being assessed. In addition, the response stimulus included a motion-onset cue that was designed to capture attention and the response to the event in question had been specified in advance (pressing one of two buttons) so neither deep cognitive assessment nor complex decision-making was required.

Under the same conditions where the slowing of event identification was observed, lane-keeping, measured by %TIL and SDLP, remained robust to distraction except for during the text messaging condition. Also consistent with previous research, an increase in steering entropy was observed as distraction intensity was increased. In contrast to the verbal-only conditions, a more dramatic decrease in performance across all four lane-keeping and identification measures was observed in the text-messaging condition which, in contrast to the other distractions, required drivers to look away from the roadway.

Excluding the text-messaging condition, the effect sizes of the distraction effects on objective driving performance measures suggest that the effect of distraction on response time (partial $\eta^2 = 0.300$) was larger than those for lane-keeping (partial $\eta^2 = 0.128$ and partial $\eta^2 = 0.123$ for %TIL and SDLP). However, consistent with previous research (Nakayama et al., 1999), the steering entropy measure was more sensitive to distraction than % TIL and SDLP and resulted in the largest effect size observed ($\eta^2 = 0.467$). Unfortunately, this measure is likely more difficult for drivers to perceive compared to time spent in the lane. Though this has not been investigated directly, the lack of a correlation between changes in steering entropy and any of the post-task ratings of subjective performance suggests that this may be the case. Further research should investigate whether drivers can perceive differences in steering entropy induced by distraction or other methods.

Though it was important to confirm the pattern of objective results observed in previous research, the main focus of the current investigation was to determine the extent to which drivers recognize the dissociation in performance while distracted as measured by lane-keeping and identification measures. Though there were small differences between predictions of overall, lane-keeping, and identification performance, the pattern of performance predictions (decreasing performance with increasing distraction) was generally stable across the three measures. This suggests that drivers fail to recognize the distinction between lane-keeping and identification related performance. This result is consistent with predicted performance observed in studies of selective degradation of vision during night driving (Brooks, 2005) and suggests that drivers could become over-confident in their driving ability while distracted partly due to continuous feedback that their lane-keeping is robust even though they expect (incorrectly) problems associated with distraction to manifest themselves as reductions in lane-keeping ability as well as identification ability.

It was also important to understand drivers' assessment of their own performance after completing the driving tasks. Similarly to the performance predictions, the pattern of performance ratings supports the hypothesis that drivers fail to recognize the dissociation between objective lane-keeping and identification performance. These data suggest that this lack of recognition remains even after drivers experience a driving-while-distracted task. It must be noted that there was a weak trend towards reporting slightly more decrement in identification performance as compared to lane-keeping performance. However, as was the case for the performance predictions discussed previously, this trend is primarily a result of one participant who reported an abnormally low rating for lane-keeping safety in the baseline condition even though he or she did not report a corresponding reduction in rated %TIL. These data show only a small trend towards reporting slightly more decrement in identification performance relative to lane-keeping performance, but overall these data suggest that people do not recognize and/or report the near-complete dissociation between objective lane-keeping and identification performance while distracted (as measured by % TIL and response time).

Though it is intriguing that drivers reported both their lane-keeping and their identification performance as being diminished by the secondary tasks, it is possible that this represents an expectancy effect or demand characteristic. Correlational analyses revealed that drivers who are more strongly affected by distracted driving only rate themselves as such on lane-keeping measures and not on identification measures. This suggests that drivers were not rating identification performance based on decrements that they actually observed. Rather, their ratings may have been biased by what they felt was expected or correct for that scenario (i.e., demand characteristics). Future research (using between-subjects experimental designs) should determine whether the reductions in rated and predicted driving performance observed here stem from experimental artifacts or real changes in perceived performance as well as exploring individual differences associated with distraction and whether drivers who are more strongly affected by distraction are capable of recognizing these decrements.

Though drivers failed to recognize that different aspects of driving performance can be differentially affected by distraction (lane-keeping vs. response time), drivers correctly rated and predicted the rank-order of the severity of the distracting tasks (e.g. PASAT worse than repeating words, 20 questions worse than PASAT, texting worse than 20 questions, etc). This is in contrast with Horrey et al. (2009), who showed a reversal of objective performance and subjective performance involving the 20 questions and PASAT tasks such that objective performance was worse for 20 questions, but subjective ratings of performance were worse for the PASAT task. Though the tasks were implemented similarly between the two studies, it appears that the 20 questions task was more difficult for participants in the current investigation compared to the Horrey et al. (2009) study. Based on pilot testing results obtained from W. Horrey (personal communication, February 24'th, 2010), it appears that participants were more successful at guessing objects in Horrey's implementation of the task compared to the current investigation. This increase in relative difficulty may have biased participants' ratings towards reporting poorer performance on the driving task during the 20 questions task. Though this is an interesting result, it is not directly relevant to the hypotheses of the current investigation.

The hypotheses of the current investigation suggest that the lack of recognition of the dissociation of performance decrements can lead to over-confidence in driving ability. The results of the analysis for this hypothesis were inconclusive and not statistically significant; however, the trend of the data supports the hypothesis that drivers rated their performance higher than they predicted their performance would be (suggesting confidence beyond what was expected prior to actually driving) during the two most intense verbal distraction conditions. In these conditions that resulted in diminished identification performance without diminished lane-keeping performance (i.e., PASAT and 20 Questions tasks), performance ratings were non-significantly increased relative to performance predictions. Though this difference was non-significant, it was the opposite of the trend in the baseline and repeating words conditions where participants rated their performance as being worse than they predicted their performance would be. Also in contrast to the trend observed for the PASAT and 20 Questions tasks, the text messaging task, where lane-keeping decrements were observed, showed a significant reduction in rated performance relative to predicted performance (across all 3 measures). Consistent with predictions based on the selective degradation pattern, this suggests that the lack of a lane-keeping performance decrement results in over-confidence in driving performance, and the existence of a lane-keeping effect allows drivers to recognize that their performance is reduced.

Though the patterns of subjective performance predictions and ratings suggest that drivers failed to recognize the dissociation of objective driving performance decrements, drivers did predict (pre-task) and rate (post-task) their driving performance to be reduced while distracted. As such, it is important to investigate the extent to which these predictions and ratings correspond with objective measures of driving performance. Significant correlations between changes from baseline objective lane-keeping measures and changes from baseline subjective measures of lane-keeping performance were observed during the 20 Questions task. These suggest that drivers whose lane-keeping performance suffered during the 20 questions trial rated their performance as being more reduced relative to their baseline rating than those drivers who whose performance was more robust. However, the corresponding correlations between changes in objective response time and identification performance ratings were smaller and non-significant. The fact that this analysis revealed that objective identification performance was not significantly correlated with any of the subjective predictions or ratings of performance suggests that the tendency to report poorer performance while distracted was driven by some factor other than drivers' recognizing and reporting their own identification performance. This interpretation admittedly involves accepting a null result from correlations with limited statistical power; however, statistical power was sufficiently high to identify the correlation between objective %TIL and rated lane-keeping safety. Further research in this area using methods designed to assess whether individual differences in the effect of distraction are correlated with individual differences in performance ratings is warranted.

The correlations observed between objective lane-keeping performance (%TIL) and subjective ratings of lane-keeping performance and the lack of a corresponding correlation between objective identification performance (RT) and the subjective safety ratings lends some support to the overall hypothesis that drivers do not account for their identification performance when estimating safety. Rather, the data are consistent with the hypothesis that drivers evaluate their safety on a single continuum and that their lane-keeping performance informs their evaluations while their ability to respond quickly to discrete events may not.

Overall, Experiment 1 measured distraction-induced decrements in the ability to respond quickly to changes in the driving environment; however, lane-keeping performance was more robust to distraction. This confirms the pattern of results seen in previous studies of distraction as well as observed in studies of night driving (Horrey and Wickens, 2006; Caird et al., 2008; Brooks, 2005; Owens and Tyrrell, 1999). In this instance, drivers spent no more time outside their lane when they were distracted despite being slower to respond to events outside the vehicle.

Further, this experiment revealed that drivers fail to recognize the dissociation between their ability to steer and their ability to respond quickly to discrete events. Rather than assessing lane-keeping and event detection separately, drivers appear to view their performance as if they were assessing a single global variable (driving performance). Results are also consistent with the hypothesis that the absence of conspicuous feedback suggesting degraded performance results in performance ratings of event detection that are not tightly correlated with corresponding objective driving performance measures. In the case of this experiment this remains true even in the face of stronger than normal feedback about identification performance. The fact that the current experimental design required a discrete response to each of the pedestrian events presents more feedback about identification performance than is typically available in real-world driving. The failure to recognize the dissociation of lane-keeping and identification performance observed in the current experiment suggests that drivers may be less likely to resist the temptation to engage in distracting behaviors because they remain unaware of the extent to which the distraction interferes with their driving performance.

Recognizing that drivers failed to report the dissociation in driving performance decrements observed while driving distracted in experiment 1, experiment 2 was designed to assess the extent to which drivers can regulate their speed to offset the effects of distraction, and may help to address the potential for drivers to change their behavior to offset distraction even without accurate conscious awareness of their own driving decrements.

EXPERIMENT 2

Experiment two consisted of two distracted and two undistracted driving scenarios. The two distracted conditions were designed to answer two specific questions. The standard distracted condition addressed the primary research question of whether individuals are capable of modifying their speed to match their undistracted performance. This condition addressed the main purpose of Experiment 2 which is to determine whether people are able to self-regulate their driving style in order to compensate for being distracted by a secondary task. The second distraction condition included simulated wind induced steering perturbations. This represented an attempt to further extend this to show that when drivers were asked explicitly to modulate their speed in order to match their driving safety to the baseline condition, the drivers would be more likely to adjust their driving style due to perceived changes in lane-keeping ability (from the simulated crosswinds) which are more salient than distraction-induced changes in their ability to identify and respond to events.

Methods:

Participants:

Participants were another 15 students (11 male) enrolled in an introductory psychology course recruited from the Psychology Department subject pool. All participants were licensed drivers with corrected binocular visual acuity of 20/40 or better, log contrast sensitivity of 1.5 or higher, and no reported visual pathologies other than corrected refractive error. Participant age ranged from 18 to 23 years, M = 19.1 years, SD = 1.08 years. Driving experience ranged from 1.5 to 7 years, M = 3.5 years, SD = 1.5 years. All participants reported having talked on cell phones while driving. None of the participants from Experiment 1 completed Experiment 2.

Apparatus:

Simulator:

The same DriveSafety DS-608C driving simulator used for Experiment 1 was also used for this experiment. The same scenario was utilized for Experiment 2 as was used for Experiment 1; however, some minor changes were implemented. For Experiment 2, the cruise control was only used in the baseline trial. In addition, instead of remaining in the vehicle with the scenario running in between trials, the scenario was stopped and restarted for each of the five scenarios. The speedometer was occluded during all experimental trials in order to force participants to choose the speed at which they felt safe rather than just driving at a certain speed limit or slowing down by some predetermined amount for each condition. As in Experiment 1, participants' task was to drive through the scenario and respond to a moving pedestrian by pressing a button on the back of the steering wheel corresponding to the side of the road from which a pedestrian began walking into the roadway.

The steering perturbations were implemented using simulated crosswind. A wind with a variable and unpredictable magnitude in a direction perpendicular to the driver’s vehicle was simulated. The force of the wind was determined by the following equation and was updated 2 times per second while the participant drove:

$$Wind\ Force = 80 * (\sin(t/5) + 80/3 * \mathrm{expr\ rand}() - 80/6)$$

Where t = time, and expr rand() returns a random value between zero and one.

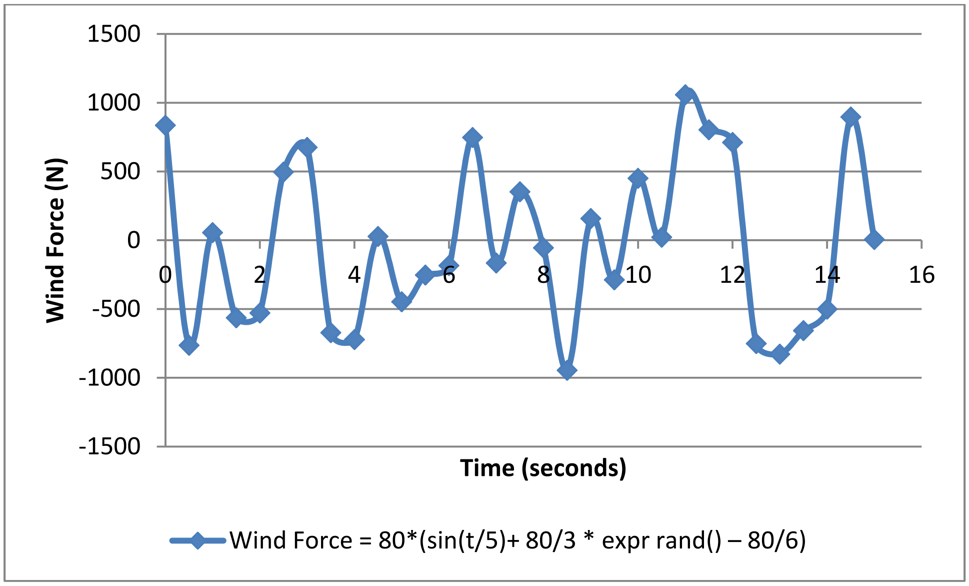

Figure 12: Example of wind force over time. The magnitude of the force was modulated over time by combining a sinusoidal component and a random component. The wind was always in a direction perpendicular to the vehicle.

This resulted in an instantaneous wind force that varied over time and, on average, would result in a wind that would return the vehicle to its starting lateral position but would also be unpredictable to the driver. Figure 12 shows an example of the wind force that could have been produced for a 15 second time period. The driver was not informed of the existence of wind in any specific scenario; however, after the baseline trial they were informed that in the next trials they would drive through similar road courses and would at times be completing the cell phone task and might also experience challenging driving conditions such as driving in a gusty wind.

Distractions:

Participants drove through the scenarios either distracted or undistracted. The distracted conditions consisted of talking on a hands-free cellular phone while completing the same twenty questions task used in Experiment 1 (Horrey et al., 2009). This task was chosen to simulate a natural phone conversation and produce measurable performance decrements. This task also allowed for measurable secondary-task performance metrics to be collected.

Measures:

During the driving scenario a number of driving performance measures were collected by the simulator or calculated from simulator variables. Simulator data were collected at 60 Hz. The variables collected include:

1. Lane Position
2. Percentage of Time in lane
3. Lane Position Variability (Standard Deviation of Lane Position)
4. Steering Wheel Position
5. Response time to onset of pedestrian movement

6. Response distance to onset of pedestrian movement
7. Pedestrian movement identification rate and false alarm rate

In addition to driving performance measures, a number of self-report measures were also collected. After each distraction task, participants rated their overall driving safety on the same continuous scales used in Experiment 1 (extremely dangerous to perfectly safe and much worse to much better than other drivers). The rating scale for mental effort (RSME) was also administered to assess participants' perceived workload.

After all of the driving scenarios were completed, drivers described the methods or cues that they used to determine the speed that they drove in each condition. For the baseline condition, they described the methods or cues that they used to determine how safe they were driving (with cruise control). Drivers were also asked to think back about each individual scenario and then rated their lane-keeping and identification performance separately on the same continuous scales used in Experiment 1. All of the continuous measures were coded linearly from 0 to 100 based on where the participant marked the scale. They also reported the percentage of time that they spent entirely within their lane and the average distance traveled prior to responding to the movement of the pedestrians for each scenario. Finally, a matching technique was used to estimate and report the average distance from the pedestrians where the participants felt they were able to correctly respond to the pedestrian movement. In this technique participants drove the simulated vehicle towards (and away from) a stationary pedestrian and pressed both steering wheel buttons at the point that represents their estimate of the average distance that they were from the pedestrian when they responded to identify that the pedestrian was moving. They drove forward and pressed both steering wheel buttons at the location corresponding to what they felt was the average distance from the stationary pedestrian in the road that they were able to identify the pedestrians during the experimental driving scenario. After pressing both steering wheel buttons simultaneously, the car was placed within 1 meter of the pedestrian, and the participants were asked to drive in reverse and press both buttons at the location corresponding to what they felt was the same average distance from the stationary pedestrian in the road that they were able to identify the pedestrians during the experimental driving scenario. These two values were averaged for analysis. Though these data were collected, detailed analysis was not conducted using these data as it became clear during the data collection process that participants were unable to remember which scenario was which. For example, many participants asked questions such as "This one was with cruise control?" in scenarios including distraction even though they never drove with cruise control and distraction at the same time.

Examples of all of the scales and datasheets used for Experiment 2 can be found in Appendix C.

Procedure:

After arriving and giving informed consent to participate, participants' visual acuity and contrast sensitivity were measured. All participants were tested for the vision vision criteria, and then began simulator training sessions. Participants drove through the following 3 training scenarios:

1. Straight Road – 2 minutes
2. Curvy Road – 4 minutes
3. Curvy Road with Pedestrian ID task – 10 minutes

After completing each of these training scenarios, participants completed a modified motion sickness assessment questionnaire (MSAQ) to identify any instances of simulator sickness. Participants were also instructed to notify the experimenter immediately if they felt uncomfortable at any time. Although this procedure was designed to limit the severity of simulator sickness episodes, the data were also used to identify participants whose performance may have been affected by simulator sickness. However, none of the participants' responses suggested significant problems associated with motion sickness. One participant reported relatively high values for the MSAQ assessment starting from the baseline. This participant reported having arrived at the experiment immediately after a strenuous workout. Throughout the experiment, careful observations were conducted to avoid simulator sickness issues, and the data from this participant were investigated carefully for outliers. No aberrant observations were found for this participant.

After completing the training scenarios, participants were given an opportunity to ask any questions before the experimental driving sessions began. In addition, participants practiced the 20 questions distraction task by completing 1 item of each of the three categories: animals, vegetables, and fruits. In addition to guessing on their own, participants were given some basic feedback and guidance about good questions to ask for each category and how to phrase questions. After practicing until they were comfortable, participants were timed for a 5 minute session of the twenty questions task.

The number of correct answers as well as the number of questions asked by the participant was recorded.

Once the distraction training and non-driving baseline tasks were completed, participants entered the simulator and began driving a course for approximately 5 minutes. This course was completed as a baseline without distraction and using cruise control set to 55 mph to control vehicle speed. Cruise control was used in this condition to avoid the tendency of simulator participants to drive extremely fast when given instructions such as “drive at any speed that allows you to maintain reasonable driving safety”. Pilot testing revealed that it would be more appropriate to use cruise control to set a specific level of safety that drivers would then be asked to match later in the experiment. Drivers were instructed to respond to the pedestrians entering the roadway as they did in their final practice session. After the baseline driving session, participants were instructed to remember how well they drove in that condition as they would be expected to maintain equivalent driving safety throughout the next few scenarios as well as rate their driving performance after the experimental drives were completed. Participants then rated their overall driving safety on a continuous scale and rated their mental effort using the RSME as described in the measures section.

After a short break, the distraction and wind trials were conducted in a counterbalanced order determined by a balanced Latin square. Participants drove a similar path of equal length that was matched for number of turns in each direction and for the severity of turns. In each condition after the baseline, participants were instructed to “drive at a speed that allows you to be equally as safe as you were in the first scenario when you weren't playing the guessing game." This speed based control of safety occurred in a situation where drivers knew that there were no explicit speed limits and did not know their actual speed as the speedometer was occluded. Participants were given no reason to believe that there was any benefit to driving faster such as arriving at a destination sooner. Participants were also instructed to continue to complete the pedestrian identification task in the same manner as before. After completing the drive, participants were asked to rate their overall driving safety on a continuous scale and rate their mental effort using the RSME. Participants took a short break between the three experimental trials.

After the end of the four simulated driving scenarios (baseline, distracted, distracted with wind, and wind only), participants repeated the baseline scenario with cruise control. The purpose of this was to produce data to identify whether any learning or fatigue effects may have affected the results of the experiment.

After completing the second baseline trial, participants were asked to describe their performance in each of the driving trials in more detail. This involved explaining their choice of speed and rating their lane-keeping and identification performance separately as described in the measures section. These ratings were conducted at this time rather than after each of the driving scenarios in order to avoid highlighting the fact that there is a difference between lane-keeping and identification performance throughout the experiment and potentially adding demand characteristics (Orne, 1959) that may have influenced their choice of speeds in the later trials. Unfortunately, this also made it somewhat difficult for participants to keep track of which scenario was which throughout the ratings process, and as such, the data from these ratings (which are of secondary importance to this experiment) may represent what participants think *should* have been their performance rather than how well they actually thought they performed in that specific scenario.

After completing the paper-based performance ratings, participants drove the vehicle to the distance from a stationary pedestrian that they believed corresponded to their average response distance for each scenario as described in the measures section. When this procedure was completed for each of the four scenarios (detailed performance ratings were not collected for the second baseline scenario), participants were given an opportunity to ask any questions about the study and then excused.

Hypotheses, Analyses, and Results:

Hypotheses:

It was expected that participants' speed would not change between the baseline driving task without the guessing game and the driving task with the guessing game due to their failure to perceive lane-keeping only reductions in performance. However, a speed reduction from baseline was expected when the steering perturbations (wind) were added to either the baseline or distracted conditions. At the same time, a decrement in response distance performance was expected for only the distracted trials such that the two distracted trials would have longer response distances than the baseline and the undistracted steering perturbed trial. This hypothesis suggests that even when drivers are explicitly encouraged to adjust speed to maintain an equivalent level of driving safety, they fail to recognize or respond to the decrements in identification performance. In contrast, any crosswind-induced reduction in speed suggests that drivers can and do recognize and respond to lane-keeping challenges appropriately. In general, it was expected that participants would base their speed choice mainly on their ability to maintain proper lane position. That is, I expected the magnitude of the wind effect (on speed) to exceed that of the distraction effect.

Hypothesis 1: Baseline and distracted speeds are similar, but both wind conditions result in speed reductions.

It was expected that drivers would not reduce their speed in the distracted trial relative to the baseline trial. However, it was expected that when driving in the two conditions with wind, drivers would reduce speed to compensate for the steering challenge.

Hypothesis 2: Distraction impairs response to pedestrian events; however, wind does not affect drivers' pedestrian responses.

It was expected that when crosswinds were not present there would be an increase in response distance (poorer performance) to pedestrian movement in the distracted condition relative to the baseline. No hypothesis was proposed for the existence of a distraction effect on response distance during the steering perturbed trial. This was because the expected decrease in speed due to the wind manipulation was expected to offset the expected distraction-induced increase in response time; however, the magnitude of the speed reduction was unknown. However, it was expected that response times would be increased in the two distracted conditions relative to the baseline condition. The two distracted conditions were expected to result in similar response times.

Hypothesis 3: More mention of lane-keeping in explanations of speed choice

It was expected that participants would report more use of lane-keeping cues than identification cues when asked to describe the methods or cues they used to choose their speed.

Hypothesis 4: Subjective performance ratings are approximately equal for lane-keeping, pedestrian movement onset identification, and overall performance and show little or no perceived performance decrements

Participants were expected to rate their lane-keeping, identification, and overall driving performance approximately equally across distracted and undistracted conditions. That is, drivers were not expected to be aware of any distraction-induced performance decrement. However, the wind conditions were expected to result in lower ratings for steering performance relative to the non-wind conditions. This was predicted because unlike the distraction of the secondary task, drivers were aware of the steering challenge that crosswinds induced.

Hypothesis 5: Smaller distraction-induced reduction in secondary task performance while driving in the non-steering perturbed condition than in the steering perturbed condition

Participants were expected to perform similarly on the twenty questions task while driving and while completing the task alone with only minor reductions in question speed and number of correct answers. However, during the wind and distraction condition, it was expected that performance would be reduced more dramatically. Therefore, both crosswinds and distraction were expected to slow performance on the 20 Questions task. Correspondingly, secondary task performance was expected to be worst in the condition when both crosswinds and distraction were present.

Analyses and Results:

All inferential analyses were conducted using an alpha level of 0.05 and, as appropriate, Greenhouse-Geisser degrees of freedom adjustments for violations of sphericity assumptions. For all ANOVA results, post-hoc paired comparisons were conducted using LSD protected t-tests. All directional hypotheses supported by theory were tested using one-tailed tests and (noted by *). Significant interactions were followed up with tests of simple effects within the levels of an interacting variable.

Prior to and as part of conducting analyses, data were tested for statistical outliers. There were no observations outside of 3 standard deviations of the mean for each condition. In addition, Cook's D values were saved for ANOVA analyses, and no values greater than 0.7 were observed. As such, all data were included in the analyses unmodified.

Comparison of Baseline Conditions (Pre and Post Baselines)

Since the goal of the experiment was to encourage participants to adjust their speed to match the driving safety achieved in the baseline scenario without distraction, it was impossible to counterbalance the order of all conditions. Specifically, the baseline condition was completed first by all drivers. A second baseline condition was completed after all experimental conditions were completed so that a comparison could be made to determine whether learning or fatigue effects occurred. The 3 main performance measures from the two baseline conditions (% Time in Lane, Standard Deviation of Lane Position, and Response Time) were compared, and no significant difference was observed for any of the three variables, t(14) = -0.403 (d = 0.04), t(14) = 0.200 (d = 0.02), and t(14) = -0.347 (d = 0.03), all p's >0.05 for %TIL, SDLP, and RT respectively.

Descriptive Statistics

Descriptive statistics including mean, median, and standard deviation for all dependent variables are included in Appendix G. Figure 13 - Figure 18 show dependent variable means (with standard errors) by condition.

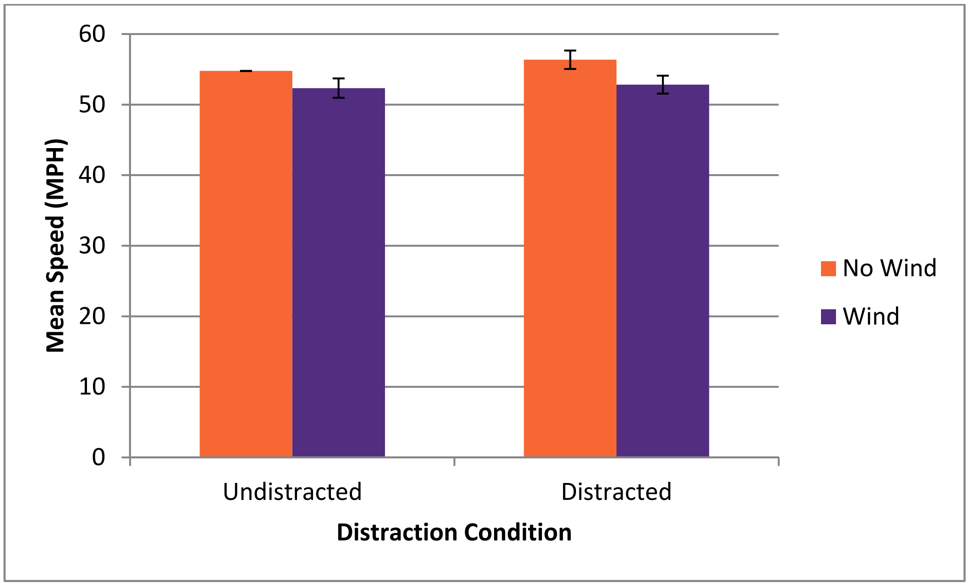

Figure 13: Mean (±1 standard error of the mean) speed driven during each scenario. The speed in the undistracted / no wind condition was fixed at ~55 mph by cruise control.

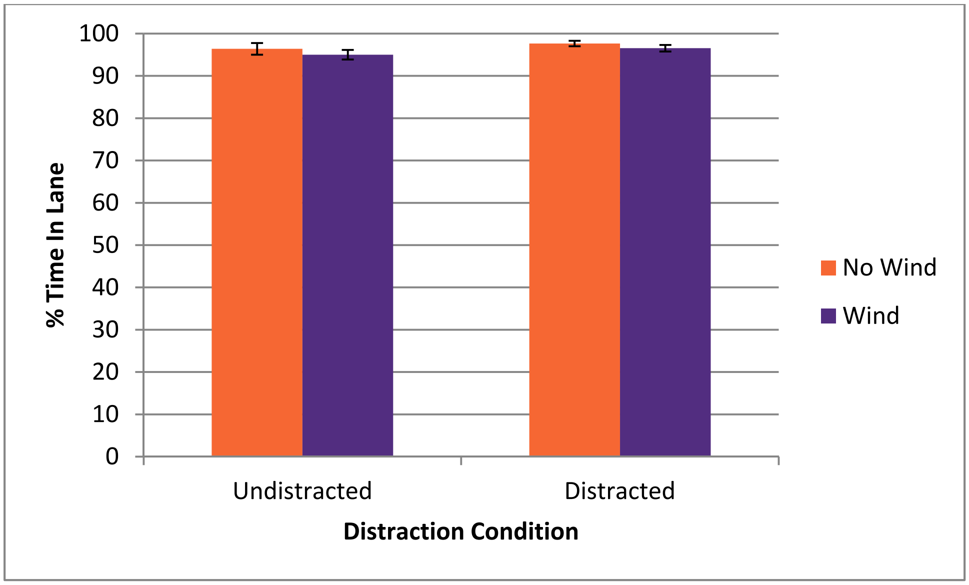

Figure 14: Mean (±1 standard error of the mean) percentage of time spent entirely within the lane during each driving scenario.

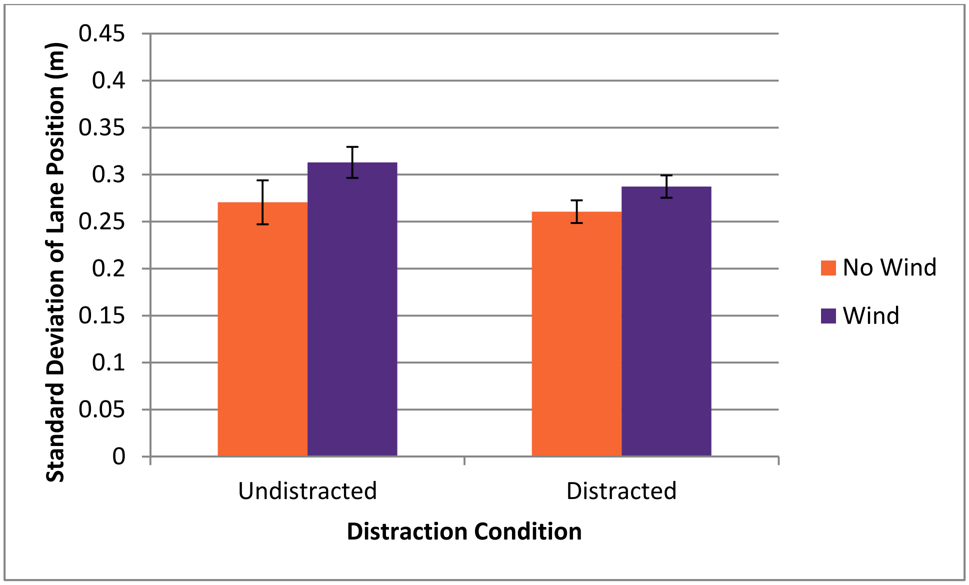

Figure 15: Mean (±1 standard error of the mean) standard deviation of lane position during each driving condition.

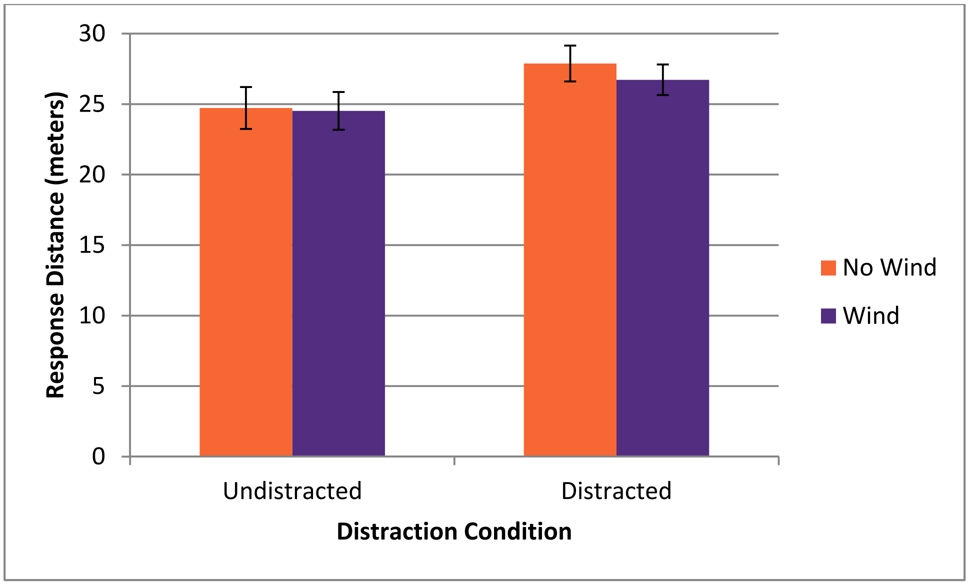

Figure 16: Mean (±1 standard error of the mean) response distance to pedestrian movement onset in each driving condition.

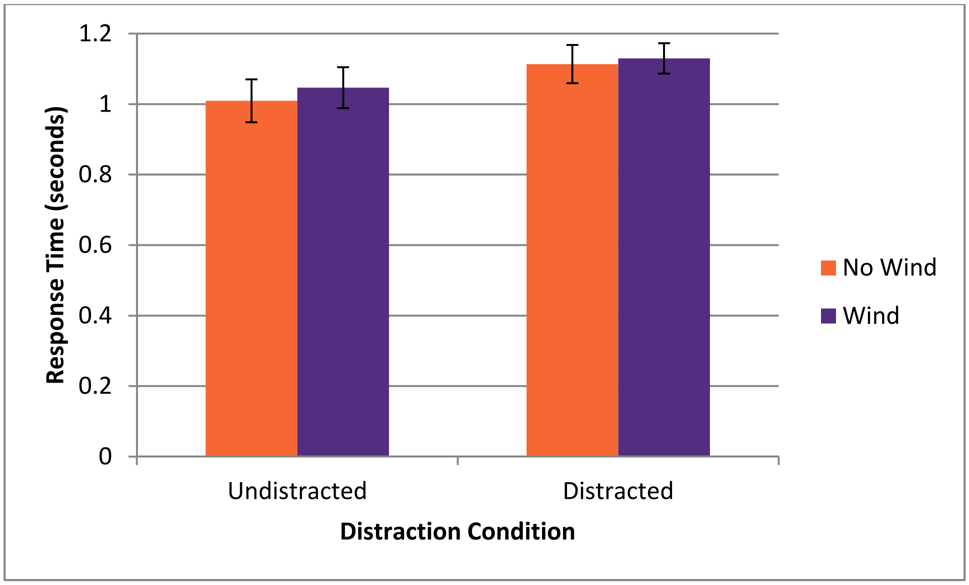

Figure 17: Mean (±1 standard error of the mean) response time to pedestrian movement onset in each driving condition.

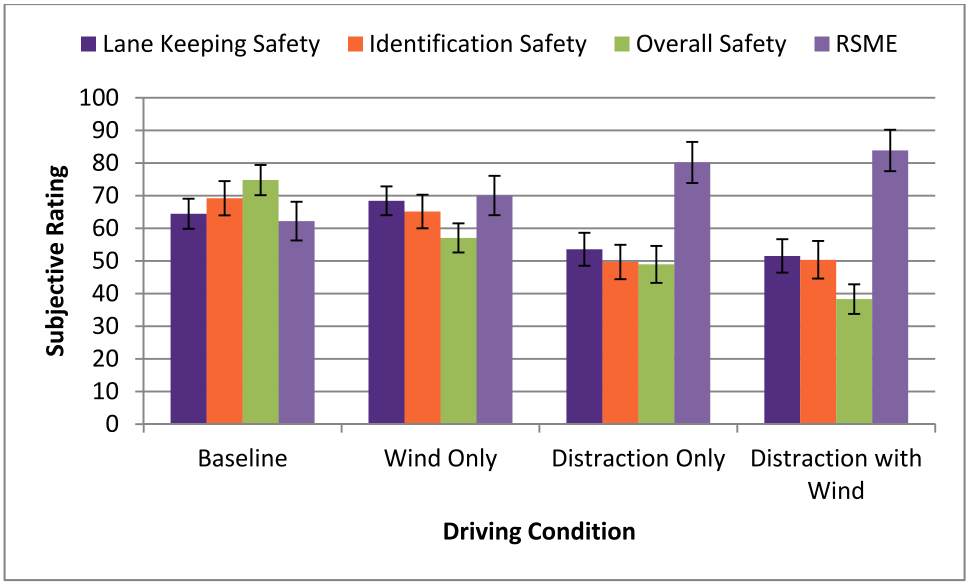

Figure 18: Mean (±1 standard error of the mean) subjective ratings of performance (post-task).

Hypothesis 1: Speed Choice

A 2 X 2 (Distraction X Wind) repeated measures ANOVA revealed the expected effect of wind on vehicle speed, F(1, 14) = 16.244, p=0.001, partial $\eta^2 = 0.537$. Also as expected, no main effect of distraction, F(1, 14) = 1.548, $p > 0.05$, partial $\eta^2 = 0.100$ nor interaction between distraction and wind, F(1, 14) = 0.483, $p > 0.05$, partial $\eta^2 = 0.033$, was observed. Note that this ANOVA clearly violates assumptions of homogeneity of variance as the baseline condition had speed controlled by the simulator for all participants.

Baseline speed was controlled by cruise control at a mean speed of 54.78 mph (cruise control was designed for approximately 55 mph, but the actual mean speed was 54.78) Because of this, one-sample t-tests compared each of the means from the 3 conditions in which drivers selected their own speed to the mean speed value from the baseline trial (54.78 mph). These analyses revealed that mean speed during the wind trial (without distraction), 52.34 mph , was significantly slowed relative to the baseline value of 54.78 mph, t(14) = -1.772, p = 0.049 (*). The mean speed from the distraction + wind trial, 52.84 MPH, was not significantly slower than baseline, t(14) = -1.534, p > 0.05, 95% CI -4.65 to 0.77 MPH. The mean speed in the distracted / no-wind condition , 56.36 MPH, was also not significantly different from the baseline speed, t(14) = 1.209, p > 0.05, 95% CI -1.23 to 4.40 MPH. In addition to the comparisons to the non-wind baseline, a comparison was conducted between the wind only and wind with distraction conditions. This analysis revealed that adding distraction to wind did not result in a speed reduction, t(14) = 0.519, p > 0.05, 95% CI -2.55 to 1.55 MPH.

Hypothesis 2: Increase in response distance when distracted

Drivers failed to respond to a walking pedestrian on only 3 occasions (one each in the wind, distraction with wind, and post-task baseline conditions). Trials with missed pedestrians were treated as anomalies and not included when calculating the mean response distance and mean response time. In addition, only 16 false alarms (either hitting the wrong button, or hitting a button when no pedestrian was moving) were observed. Of these, 8 were in the baseline condition, 1 was in the wind only condition, 2 were in the 20 questions condition, 4 were in the 20 questions with wind condition, and 1 in the post task baseline condition.

A 2 X 2 (distraction X steering perturbation) repeated measures ANOVA with mean pedestrian response distance as the dependent variable revealed the expected main effect of distraction, F(1, 14) = 10.162, p = 0.007, partial $\eta^2 = 0.421$. This effect indicates that when averaged across the two wind conditions response distances increased from the undistracted conditions (M = 24.6 m) to the distracted conditions (M = 27.3 m). Thus, once a pedestrian began walking into the roadway distracted drivers traveled 2.7 m farther before responding than they did when they were undistracted. The increase is slightly larger when comparing only the baseline and distraction only conditions as the reduction in speed observed in the distraction with wind condition decreased the mean response distance when averaged across both distraction conditions. The mean response distance was significantly higher (27.9 m) for the distraction only condition compared with the baseline condition (24.7), $t(14) = 2.874$, $p = 0.012$. No main effect or interaction involving wind was observed, $F(1, 14) = 1.485$, $p > 0.05$, partial $\eta^2 = 0.096$, and $F(1, 14) = 0.590$, $p > 0.05$, partial $\eta^2 = 0.040$ respectively.

A similar 2 X 2 (Distraction X Steering Perturbation) ANOVA with response time as the dependent variable revealed a significant main effect of distraction, $F(1, 14) = 10.497$, $p = 0.006$, partial $\eta^2 = 0.429$, with no main effect or interaction involving wind, $F(1, 14) = 2.622$, $p > 0.05$, partial $\eta^2 = 0.158$ and $F(1, 14) = 0.273$, $p > 0.05$, partial $\eta^2 = 0.019$ respectively. This suggests that the secondary task did slow drivers' responses to the pedestrian movements, but the wind manipulation had little or no effect on participants' speed in responding to pedestrian movement.

Analyses on maximum response distances and maximum response times confirmed the patterns seen in the analyses of the mean response distances and response times (See

Figure 19). Because they are largely redundant with the earlier analyses they are not reported here.

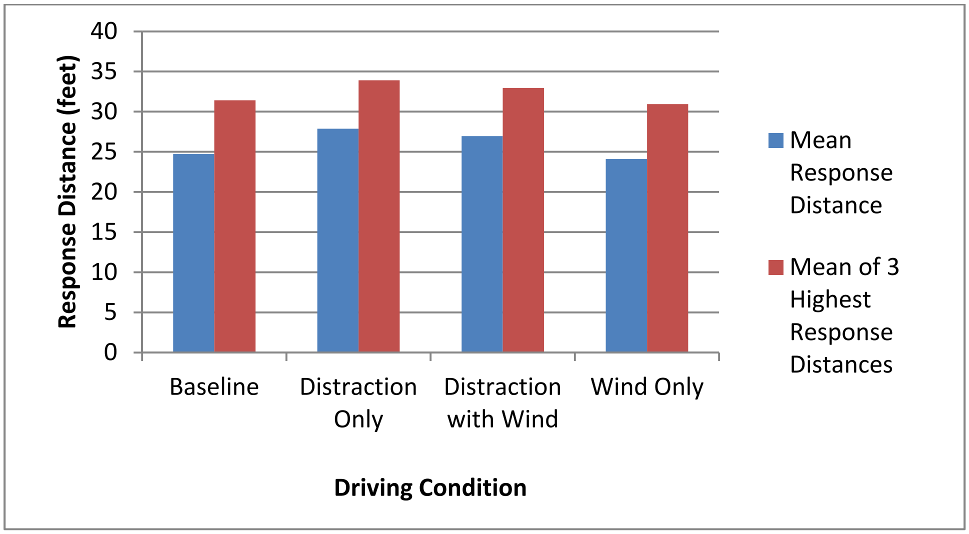

Figure 19: Comparison of mean response distance measure to mean of the 3 longest response distances measure.

Since the focus of this investigation involves the difference between identification performance and lane-keeping performance, another 2 X 2 repeated measures ANOVA was conducted to explore any differences observed in lane-keeping performance as measured by % TIL. This ANOVA revealed no main effect of distraction, F(1, 14) = 3.264, $p > .05$, $\eta^2 = 0.189$, a main effect of wind, F(1, 14) = 0.006, $p = .006$,$\eta^2 = 0.430$, and no interaction between wind and distraction, F(1, 14) = 0.092, $p > .05$, $\eta^2 = 0.006$. As seen in figure 14, though there was a decrease in % TIL during the wind trials relative to the non-wind trials, the % TIL was only 1.2% lower in the wind trials compared to the non-wind trials. This suggests that the wind manipulation, though strong enough to produce changes in driving speed, was not too strong to allow drivers to maintain reasonable control of the vehicle. A similar 2 X 2 repeated measures ANOVA was conducted using the SDLP variable (See Figure 15). This analysis revealed similar results to %TIL with no main effect of distraction, $F(1, 14) = 2.671$, $p > 0.05$, $\eta^2 = 0.160$, a main effect of wind, $F(1, 14) = 20.920$, $p < 0.0005$, $\eta^2 = 0.599$, and no interaction between distraction and wind, $F(1, 14) = 1.671$, $p > 0.05$, $\eta^2 = 0.107$.

Hypothesis 3: Speed choice explanations

Explanations of speed choice in each condition (given by the participants after all driving trials were completed) were coded for the number of references to lane-keeping and the number of references to identification of roadway objects and events. Two independent coders coded the data, and Krippendorf's Alpha (Hayes & Krippendorff, 2007) was calculated to be 0.861 suggesting that rater agreement was acceptable for this analysis. One of the two coders was completely blind to experimental condition while conducting the ratings. The second rater knew whether the participant was distracted, but was blind to the wind manipulation while conducting the ratings.

The coders' ratings for each participant's data were averaged for analysis, and a two sample t-test revealed no difference in the mean number of mentions of lane-keeping ($M = 0.65$) versus identification ($M = 0.59$) as a method or cue used to guide speed choice, $t(59) = 0.444$, $p > 0.05$.

Hypothesis 4: Subjective performance

Analysis for this hypothesis is focused on the subjective measures of lane-keeping, identification, and overall safety that are rated on continuous scales from extremely dangerous to perfectly safe as testing this hypothesis requires comparing values across measures of lane-keeping and identification and therefore all measures must be on the same scale. In addition to the analyses focused on these measures, means and standard deviations for all measures are presented in Appendix G.

To determine whether subjective ratings varied across the three rating types (lane-keeping, identification, and overall safety), a 2 X 2 X 3 (distraction condition X steering perturbation X rating type) repeated measures ANOVA was conducted. The ANOVA revealed a significant main effect of distraction, $F(1, 14) = 40.079$, $p < .0005$, partial $\eta^2 = 0.741$. This effect shows a decrease in rated performance while distracted from a mean rating of 66.5 when undistracted to a mean rating of 48.7 while distracted. In addition, a main effect of wind was observed, $F(1, 14) = 7.295$, $p = .017$, partial $\eta^2 = 0.343$. The reduction in ratings due to the addition of wind was from a rating of 60.1 to 55.1; however, this is qualified by a Wind X Rating Type interaction, $F(2, 28) = 15.521$, $p < .0005$, partial $\eta^2 = 0.526$. Simple effects of the significant Wind X Rating Type interaction were investigated by conducting 3 separate 2 X 2 (Distraction X Wind) ANOVAs, one for each of the 3 rating types (Overall, Lane-keeping, and Identification safety). Each ANOVA revealed a similar effect of distraction, $F(1, 14) = 35.177$, 20.635, and 18.537, $p \leq .001$, partial $\eta^2 = 0.715$, 0.596, and 0.570 for overall safety, lane-keeping safety, and identification safety measures respectively. However, tests of the simple effects of the interaction between Wind and Rating Type revealed that the effect of wind was only significant for the overall safety rating, $F(1, 14) = 30.504$, $p < 0.0005$, partial $\eta^2 = 0.685$. The effect of wind was not significant for either the lane-keeping safety or identification safety measures, $F(1, 14) = 0.131$ and 0.580, partial $\eta^2 = 0.009$ and 0.040

respectively, $p > 0.05$. The effect of wind was strong for the overall safety rating. A reduction from 61.9 in the no wind condition to 47.7 in the wind condition was observed. It should be noted that this interaction is confounded with the time that the rating was completed in addition to the rating type as the overall safety ratings were conducted immediately after driving, and the lane-keeping and identification safety ratings were conducted after all tasks had been completed.

A 2 X 2 (Distraction X Wind) ANOVA was conducted on the RSME score data in order to identify the effects of distraction and wind on participants' perceived mental effort. A main effect of distraction was observed, $F(1, 14) = 16.235$, $p = 0.001$, partial $\eta^2 = 0.537$. The effect of distraction resulted in an increase in RSME score of 15.9 from $M = 66.1$ when undistracted to $M = 82.0$ when distracted. A main effect of wind was also observed, $F(1, 14) = 19.759$, $p = 0.001$, partial $\eta^2 = 0.585$. The effect of wind resulted in a smaller increase in RSME of 5.8 from 71.2 to 77.0. The interaction effect (Distraction X Wind) was not significant, $F(1, 14) = 1.150$, $p > 0.05$, partial $\eta^2 = 0. 076$.

Hypothesis 5: Secondary Task Performance

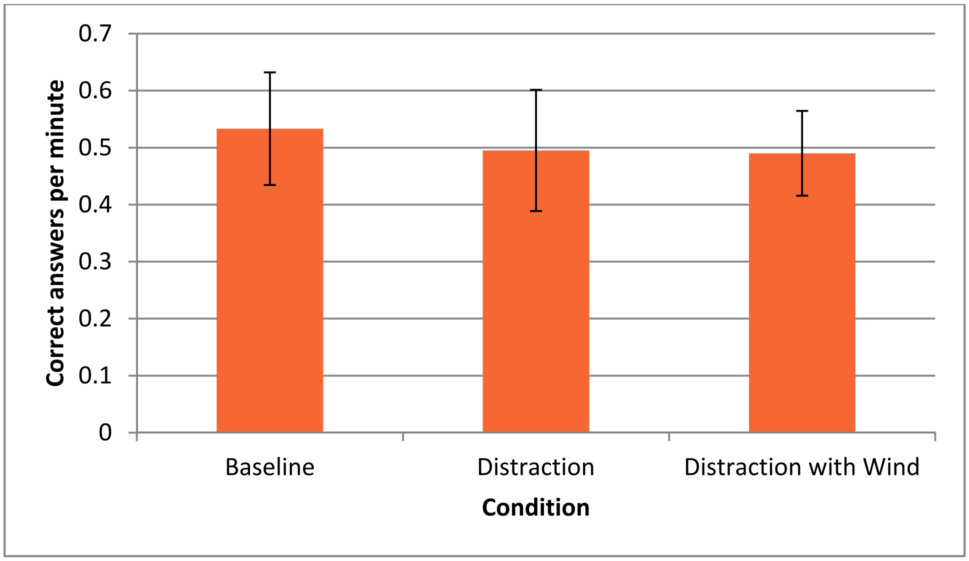

Figure 20: Mean (± 1 SEM) number of correct answers to the 20 Questions task per minute as a function of condition.

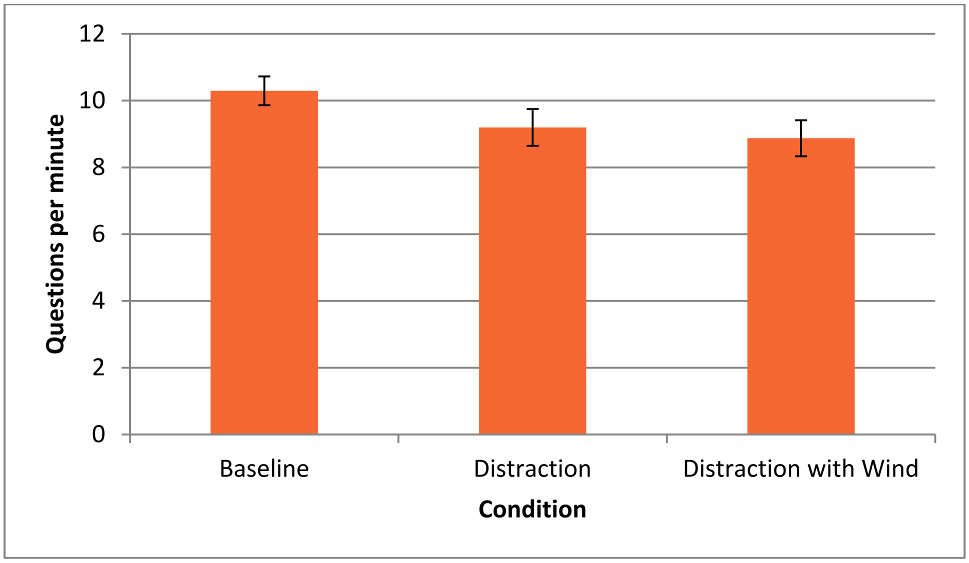

Figure 21: Mean (± 1 SEM) number of questions asked per minute as a function of condition.

Figure 20 and Figure 21 show the number of correct responses per minute and the total number of questions asked per minute for the three secondary task conditions.

Two ANOVAs were conducted with three levels of task condition as the independent variable (single-task baseline, distraction, and distraction with wind) and number of correct responses per minute and total number of questions asked per minute as dependent variables. The first ANOVA on the number of correct responses per minute revealed no significant difference among the three conditions, $F(2, 28) = 0.090$, $p >.05$, $\eta^2 = 0.006$. However, the second ANOVA on the number of questions asked per minute revealed a significant main effect of secondary task condition, $F(1.437, 20.116) = 5.598$, $p =.019$, $\eta^2 =0.286$. LSD post-hoc paired comparisons revealed that significantly more questions were asked in the baseline condition, 10.3 per minute, compared to the distraction condition, 9.2 per minute, ($p =.038$) and the distraction with wind condition, 8.9 per minute, ($p = 0.019$). However, the two distraction conditions, with and without wind, did not differ significantly ($p > 0.05$).

Discussion:

The purpose of Experiment 2 was to determine whether drivers could adjust their driving speed in order to offset the effects of distraction. Experiment 1 showed that drivers do not recognize the dissociation between lane-keeping and identification driving performance reductions caused by distraction. Therefore, it was expected that drivers would not decrease their speed appropriately while distracted due to the consistent positive lane-keeping feedback received. Simulated wind was also included in Experiment 2 to show that drivers are more likely to recognize challenges to steering performance than the challenges to identification performance observed in studies of distracted driving.

Speed choice throughout the experiment was the main focus of the analysis for Experiment 2. Even when explicitly instructed to maintain equivalent safety by adjusting their speed, drivers failed to slow down to offset the effects of engaging in a distracting secondary task. However, they did reduce their speed when they experienced crosswinds that affected their ability to maintain lane position. In addition to suggesting that lane-keeping challenges are salient to drivers and resulted in reductions in speed, the identification of this effect on speed suggests that statistical power should have been sufficient to identify a similar reduction in speed caused by distraction had it existed. This pattern suggests that drivers are more likely to recognize and respond to lane-keeping challenges than challenges that affect their ability to identify potential roadway hazards. This was observed even though the conditions of this experiment represent a "best-case" scenario for drivers being able to recognize identification performance decrements. In real-world driving, most identification tasks require little or no response from the driver (thankfully most roadside pedestrians do not walk into the roadway when drivers approach). Therefore, if a driver is slow to identify (or fails to identify) a critical event, there is much less feedback about the poor performance than there was in the current experiment where every pedestrian walking across the roadway required the driver to respond and presented a reasonable option to measure how well the task was completed (based on how far the pedestrian made it across the roadway). Thus, it appears that in the real world drivers might be less likely to recognize and respond appropriately to the effects of distraction as compared to the current experimental conditions.

In addition to not reducing speed when distracted, it was observed that drivers were slower to respond to dangerous pedestrian movements while distracted. As was observed in Experiment 1, the increase in response time (M = 0.104 seconds between baseline and distracted trials) was on the low end of that observed in most distraction studies (Horrey and Wickens, 2006; Caird et al., 2008). As with Experiment 1, this is likely due to the predictability of the pedestrian response task, the motion onset cue associated with the task, and the fact that participants in the study were young and healthy. This increase in response time resulted in significant increases in response distance while distracted even when instructed explicitly to maintain equivalent driving safety by adjusting speed. If drivers were successful at regulating speed to offset the effects of distraction, speed would have been reduced in proportion to the increase in response time. However, drivers failed to reduce speed, so the increase in response time resulted in poorer performance on the identification task. These data support the thesis that drivers can fail to recognize when distraction from a secondary (i.e., in-vehicle) task affects their driving performance and that they are therefore unable to compensate for being distracted even when they are explicitly requested to do so. Again, this was observed even though the experimental task would be expected to artificially inflate the salience of identification performance relative to real-world driving. Therefore, it would be expected that real-world drivers would be even less likely to adjust their driving speed or driving style to offset the effects of distraction.

Though drivers were instructed to adjust speed to offset distraction, it was also possible for drivers to adjust their engagement in the secondary task to avoid problems caused by distraction. Though not explicitly instructed to adjust secondary task performance to maintain safety, it is possible that participants may have adjusted their performance of the distracting task to mitigate their distraction rather than or in addition to adjusting driving speed. Though there is some evidence to support that they have done so which goes against the original hypotheses of this experiment (a decrease in questions asked per minute), the changes in task performance represent ~1 fewer question asked per minute and may not represent a conscious decision to adjust secondary task performance, but rather are likely attributable to the fact that the guessing game task utilizes resources used by driving and therefore attention cannot be perfectly divided. This would be expected as this task is known to produce (Horrey and Wickens, 2006; Caird et al., 2008) (and did produce) driving performance decrements and therefore it can be assumed that it utilizes some of the same resources required for driving the car. An alternate interpretation of this result would be that the combination of the two tasks results in an unconscious regulation of secondary task performance observed here as a reduction in the number of questions asked per minute while driving distracted.

Even if it was a conscious or unconscious decision to adjust performance on the secondary task to avoid driving performance decrements, the fact that the reduction in secondary task performance failed to offset the effect of the distracting task on driving performance suggests that in this case drivers did not consciously or unconsciously reduce their performance on the secondary task in order to maintain driving performance. This is further supported by the fact that adding the wind manipulation, which did cause a reduction in driving speed, did not significantly affect secondary task performance.

Therefore, though there is some evidence of performance changes on the secondary task, it appears that participants were completing the task mostly as instructed and adjusting speed to offset the effects of distraction (or wind) rather than adjusting their performance of the distracting task.

Though the objective measures of driving performance followed the pattern that was predicted, the subjective descriptions of methods used to choose an appropriate speed revealed no difference in the number of mentions of lane-keeping vs. identification-related methods for choosing speed. However, this may be related to the experimental design which strongly highlights identification performance as compared to normal driving due to the conspicuous presence of a large number of pedestrians and the requirement to respond to each moving pedestrian. It is likely that this emphasis on pedestrian identification contributed to the number of mentions of identification performance. Though it did not reveal any significant difference in this analysis, this method or similar methods may be useful for more naturalistic investigations of distraction and self-regulation of driving performance.

Similar to the results seen in Experiment 1, participants reported performance decrements in the distracted conditions; however, they did not recognize that their lane-keeping performance, but not their identification performance, was robust to the effects of distraction. This suggests that their reports of diminished performance stem from feelings that they should report decrements while distracted rather than an actual objective assessment of how well they performed the task in each condition. There was no evidence that participants rated their steering abilities to follow patterns that were any different from their ability to recognize a hazardous pedestrian movement. Rather, participants appear to evaluate their own driving more globally, as if on a single continuous scale. This result is a similar pattern to that observed by Brooks' (2005) tests of selective degradation of vision during night driving.

It must also be noted that the current experimental design required drivers to "keep track" of how well they performed in each condition and properly rate their steering and identification performance for the individual conditions after all conditions were completed. Unfortunately, these data reveal that this may have been a difficult task as participants' ratings of their overall driving performance immediately after completing each task were responsive to the wind manipulation; however, the ratings of performance completed after all tasks were finished were not responsive to the wind manipulation. Throughout the rating process, participants were not told which tasks had and did not have wind; however, they were reminded which tasks involved the guessing game. This may have induced demand characteristics in which participants reported that they were affected by distraction because they felt that is what was expected. However, given these circumstances and the fact that the ratings do not reflect an understanding of the dissociation between lane-keeping and identification performance, it is unlikely that these post-experiment reports represent an objective assessment of performance on which drivers would be likely to act. This is also supported by the speed choice data showing that drivers did not slow down to offset the effects of distraction.

In addition to the quantitative data suggesting that the post-experiment ratings of performance may not represent an accurate representation of drivers' assessment of their own performance, it was also observed that after the experimental trials were complete participants had difficulty keeping track of which task was which during the rating process. For example, participants often asked whether the distraction trial they were rating had cruise control even though they never drove with cruise control and the distraction task at the same time. However these subjective ratings were not the focus of Experiment 2, and the subjective ratings of Experiment 1 did not suffer from this problem as they were conducted immediately following each trial rather than all together at the end of the experimental session. This phenomenon may also suggest that drivers are unlikely to accurately reflect on their (distracted) driving when making strategic decisions (Regan et al., 2009, Sheridan, 2004) about utilizing cell phones while driving.

As was observed in Experiment 1, the participants' ratings of workload recognized that they had to work harder to complete the distraction task along with driving (and driving in wind) relative to the baseline task. However, the fact that they chose not to slow down in order to offset this increase in workload suggests that they fail to recognize that the extra workload affects their driving performance negatively.

Overall, the results of Experiment 2 suggest that drivers are unable or unwilling to adjust their speed to offset distraction; likely due to the fact that they fail to recognize the selective effect of distraction (as seen from the subjective driving performance results) on identification performance without affecting lane-keeping performance.

Though participants did report diminished driving performance in the distracted trials, it is highly likely that these reports were due to an expectancy effect or demand characteristics rather than participants' recognition of actual driving performance decrements. These data support that participants failed to recognize that their lane-keeping abilities were robust to distraction even though their identification performance was not. In this respect, it appears that the effects of distracted driving mirror the effects of driving in low-light conditions, and the end result of each situation is drivers that are over-confident in their ability to drive "normally" even though their performance is degraded.

The results of Experiment 2 suggest that drivers do not adequately recognize when they experience distraction-related decrements in their ability to respond to events in the roadway, and therefore cannot regulate their driving strategy (in this instance by adjusting speed) in order to account for the decrements in performance and maintain equivalent safety. This experiment has shown that challenges to lane-keeping appear to be more salient (or at least more relevant) to drivers and result in changes in driving strategy to enhance safety (reducing speed in this instance). This experiment further supports the overall hypothesis that the pattern of driving decrements due to distraction is similar to that seen with reduced luminance, and therefore, over-confidence in driving ability similar to that seen while driving at night is also observed while driving distracted.

LIMITATIONS AND FUTURE RESEARCH

As mentioned above, the current set of experiments is limited by the relative predictability of the identification task as well as the fact that drivers are limited in their ability to adjust driving style to offset distraction since the only option they were instructed to use was adjusting speed. Though drivers could also adjust their engagement in the distracting task to avoid performance decrements, the current investigation was unable to quantify these changes in secondary task performance in a way that captures only conscious attempts to control the effect of distraction by adjusting secondary task performance. The fact that there was no other traffic on the roadway and this experiment was conducted in a driving simulator may have also encouraged people to not recognize the effect of distraction on their actual driving safety. Future research should extend this theory utilizing experimental methods involving driving on open- and closed-roads as well as more realistic, complicated, and longer duration scenarios within simulators. Future work should also focus on methods that could be used to enhance the salience of identification performance decrements or to educate drivers and/or policy makers on the effects of distraction on identification versus lane-keeping performance.

CONCLUSION

Together, these two experiments have assessed the ability of drivers to self-regulate driving behavior while distracted. In experiment 1, this was accomplished by exploring whether drivers' could recognize performance decrements and the dissociation of lane-keeping and identification performance decrements caused by distraction. After establishing that drivers fail to recognize this dissociation, Experiment 2 investigated whether drivers could or would adjust their speed in order to offset the effects of distraction. Both experiments involved participants driving down a 2-lane curvy roadway while distracted and undistracted. In order to measure identification performance, participants were asked to identify when any pedestrians located on the side of the roadway began moving into the road, and response time and response distance were collected. During Experiment 2, simulated wind was also used to induce lane-keeping performance challenges in order to compare the effects on driving speed between the distraction and wind manipulations.

The pattern of effects of distraction on lane-keeping and identification performance observed in these two experiments was similar to that observed in previous experiments on distracted driving (Horrey and Wickens, 2006; Caird et al., 2008). This pattern is also similar to the pattern of decrements and driving responses that has been observed in studies of driving in reduced illumination (Brooks, 2005; Brooks et al., 2005; Owens & Tyrrell, 1999). The pattern observed in both cases reveals that lane-keeping performance (% TIL, SDLP) is robust to both distraction and reduced illumination; whereas, identification performance (RT) is significantly reduced by reductions in illumination and added distraction. Thus the results from the present experiments suggest that because drivers do not get salient and distinct feedback about their ability to respond to external events, distracted drivers may not regulate their behavior to compensate for the attentional loads associated with engaging in secondary tasks while driving just as they appear to drive faster than is appropriate at night (Leibowitz & Owens, 1986). This is likely due to the fact that they do not recognize the extent to which the ability to drive safely is degraded during distracting activities. Robust lane-keeping abilities give feedback that the driver can interpret as indicating that he or she is operating the vehicle safely and appropriately even though he or she may fail to respond to roadway events safely. This may be a consequence of lane-keeping feedback being continuously present while feedback on how well drivers respond to external events can be intermittent or even rare.

Though the subjective data from these experiments suggests that drivers recognize that their ability to drive safely can be degraded when they are distracted, the fact that their performance reduction ratings are largely uncorrelated with their identification related driving performance and that they do not report differential changes in lane-keeping performance and identification performance is consistent with the hypothesis that the reductions in performance ratings arise not from a genuine assessment of real-time performance, but rather from prior knowledge that they would be expected to have a performance decrement. It is likely that while driving distracted, the over-confidence induced by positive lane-keeping performance feedback can outweigh these expectations of reduced performance and encourage drivers to engage in distracting activities without a full understanding of the potential consequences.

Taken together, the results of these two experiments have shown that drivers fail to perceive the decrements in the area of identification performance, and instead rely on the positive feedback of lane-keeping performance to guide driving strategy (in this instance limited mainly to speed choice). Based on these data, one could argue that we should not expect drivers to be capable of successfully adjusting their driving behaviors to compensate for distraction. The lack of understanding of the dissociation in driving performance decrements caused by distraction is likely to cause inappropriate driving decisions due to unrecognized reductions in situation awareness (Endsley, 2000). From a control theory perspective (Regan et al., 2009; Sheridan, 2004), this lack of understanding is likely to result in inappropriate control switching to distracting tasks caused by inaccurate or incomplete driving performance feedback.

In addition to suggesting that it will be challenging for drivers to self-regulate their distraction behaviors, these data may also be useful in guiding the design of public educational interventions that would encourage drivers to minimize or eliminate distracted driving. If individual drivers are not capable of evaluating their own ability to safely cope with distractions then decisions must be made at a societal level concerning how best to balance the risk associated with a given activity and its potential benefits to individuals and to society. Though mobile telephones and other wireless communications devices offer many potential advantages, we need to recognize and evaluate the safety implications of these technologies. If we are unwilling to accept the reductions in safety associated with using these devices while driving, we must identify a method that will encourage drivers to operate vehicles safely and avoid or minimize such distracting behaviors. These results suggest that, as with night driving, educating drivers and policy makers about the differential effects of distracted driving on lane-keeping and identification performance may be an important step in this process (Tyrrell et al., 2004).

They also suggest that without advanced understanding of distraction and its effects, drivers are unlikely to modify their behavior on their own.

APPENDIX A: STEERING ENTROPY CALCULATIONS (NAKAYAMA, FUTAMI, NAKAMURA, & BOER, 1999)

Steering entropy is a measure of steering predictability. The measure allows researchers to use a more sensitive measure of lateral control than was previously available that has been shown to identify significant differences in lateral control not identified by other measures such as lateral speed, standard deviation of lane position, and percentage of time in lane. Basically, the measure involves creating a prediction of an upcoming steering input based on very recent previous inputs and then calculating the amount of error that exists in that prediction. This error is then compared to a baseline value for a course with equivalent turns and is reported to represent a highly sensitive measure of workload relative to the baseline condition.

Although a more recent modification of the procedure used to calculate steering entropy has been presented, the simpler first version is used for the purposes of this investigation. Though the newer version is likely to be a more sensitive measure, the newer measure is much harder to understand for the average reader, and I feel that the sensitivity gains are more than offset by the fact that most readers will not understand how the measure was calculated; whereas with the original calculation method, it is a fairly easily understood metric that would easily be understood and replicated. In addition, the measure in the form used here has been shown to be sensitive enough to identify performance differences on tasks used in this investigation.

In order to calculate steering entropy, one has to first create a prediction of future steering inputs based on previous inputs. This is accomplished by sampling the steering input at 50 millisecond intervals (20 Hz) over a 450 millisecond interval and then averaging each of the three available 150 millisecond periods resulting in three samples at 6.66 Hz. The predicted steering input for the next 150 millisecond period is then calculated using a taylor series expansion of the three previous samples using the following formula where $\theta(n-1), \theta(n-2), and\ \theta(n-3)$ represent the three steering input samples calculated previously and $\theta\ p(n)$represents the predicted steering input:

$$\theta\ p(n) = \theta(n-1) + \big(\theta(n-1) - \theta(n-2)\big) + \frac{1}{2}[\big(\theta(n-1) - \theta(n-2)\big) - \big(\theta(n-2) - \theta(n-3)\big)]$$

After the predicted steering angle is calculated, the difference between the actual and the predicted steering angle is recorded. A distribution of steering prediction errors is then generated. Using the baseline condition distribution, the range of values, α, around the mean is calculated such that 90% of samples fall within the range. Then a histogram with 9 bins is created with bins defined from -∞ to -5α, -5α to -2.5α, -2.5α to – α, -α to -0.5α, -0.5α to 0, 0 to 0.5α, 0.5α to α, α to 2.5α, 2.5α to 5α, and 5α to ∞. The proportion of samples in each bin is then used to calculate the steering entropy, H_p using the following formula where P_i represents the proportion of samples in bin i.

$$H_p = \sum_{i}^{1\ldots9} P_i log_9(P_i)$$

Higher entropy values represent increased driver workload and decreased smoothness of control.

APPENDIX B: SAMPLE DATASHEETS FOR EXPERIMENT 1

particpant code: MDISSE2P_____ Motion Sicknes or Migraines?__________

tell me the number that best describes how you feel right now
where 0 is "not at all" and 10 is "severely"

	Pre	**Straight**	**Curvy**	**PedT**	**E1**	**E2**	**E3**	**E4**	**E5**
1. sick to my stomach									
2. faint-like									
3. annoyed/ irritated									
4. sweaty									
5. queasy									
6. lightheaded									
7. drowsy									
8. clammy/ cold sweat									
9. disoriented									
10. tired/fatigued									
11. nauseated									
12. hot/warm									
13. dizzy									
14. like I am spinning									
15. as if I might vomit									
16. uneasy									
17. as if I'm floating									
18. Mental Effort									

Contrast Sensitivity: _________ 1m

Licensed Driver: ___

Age: ____________

Circle one

Gender: __________

Acuity: _________ 6m 3m 1m

Years Driving: _____

Participant:_______________________

Exp1 - baseline

Predicted

1. **Estimate the percentage of time that you will spend entirely within your lane.** __________________%

2. **Estimate your average response time to the pedestrians.** __________________ Seconds

3. **Please rate how well you expect to stay in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |--- Perfectly Safe

4. **Please rate how well you expect to stay in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Worse |--- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |--- Perfectly Safe

6. **Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.**

Worse |--- Better
Much worse than other drivers Much better than other drivers

5. **Please predict your overall driving safety.**

Extremely Dangerous |--- Perfectly Safe

Participant:____________________

Exp 1 - Repeat Words

Predicted

1. Estimate the percentage of time that you will spend entirely within your lane. __________________%

2. Estimate your average response time to the pedestrians. __________________ Seconds

3. Please rate how well you expect to stay in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.

Extremely Dangerous |-- Perfectly Safe

4. Please rate how well you expect to stay in the center of your lane without weaving from side to side by placing a mark on the scale below.

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.

Extremely Dangerous |-- Perfectly Safe

6. Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. Please predict your overall driving safety.

Extremely Dangerous |-- Perfectly Safe

Participant:____________________

Exp 1 - Mental Arithmetic

Predicted

1. **Estimate the percentage of time that you will spend entirely within your lane.** __________________%

2. **Estimate your average response time to the pedestrians.** __________________ Seconds

3. **Please rate how well you expect to stay in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you expect to stay in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please predict your overall driving safety.**

Extremely Dangerous |-- Perfectly Safe

Participant:____________________

Exp 1 - 20Q

Predicted

1. **Estimate the percentage of time that you will spend entirely within your lane.** _________________%

2. **Estimate your average response time to the pedestrians.** _________________ Seconds

3. **Please rate how well you expect to stay in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you expect to stay in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please predict your overall driving safety.**

Extremely Dangerous |-- Perfectly Safe

Participant:______________________

Exp1 - Texting

Predicted

1. Estimate the percentage of time that you will spend entirely within your lane. ____________________%

2. Estimate your average response time to the pedestrians. ____________________ Seconds

3. Please rate how well you expect to stay in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.

Extremely Dangerous |-- Perfectly Safe

4. Please rate how well you expect to stay in the center of your lane without weaving from side to side by placing a mark on the scale below.

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.

Extremely Dangerous |-- Perfectly Safe

6. Please rate how well you will perform the pedestrian identification task by placing a mark on the scale below.

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. Please predict your overall driving safety.

Extremely Dangerous |-- Perfectly Safe

Participant:____________________

Exp 1 - Baseline

Actual Performance

1. **Estimate the percentage of time that you spent entirely within your lane.** ____________________%

2. **Estimate your average response time to noticing the pedestrians' movement.** ____________________ Seconds

3. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate your overall driving safety during the simulation.**

Extremely Dangerous |-- Perfectly Safe

6. **Rating Scale for Mental Effort Score.** ____________________

Participant:____________________

Exp 1 - Repeat Words

Actual Performance

1. **Estimate the percentage of time that you spent entirely within your lane.** __________________%

2. **Estimate your average response time to noticing the pedestrians' movement.** __________________ Seconds

3. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate your overall driving safety during the simulation.**

Extremely Dangerous |-- Perfectly Safe

6. **Rating Scale for Mental Effort Score.** __________________

Participant:____________________

Mental Arithmetic

Actual Performance

1. Estimate the percentage of time that you spent entirely within your lane. __________________%

2. Estimate your average response time to noticing the pedestrians' movement. __________________ Seconds

3. Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.

Extremely Dangerous |-- Perfectly Safe

4. Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.

Extremely Dangerous |-- Perfectly Safe

6. Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. Please rate your overall driving safety during the simulation.

Extremely Dangerous |-- Perfectly Safe

6. Rating Scale for Mental Effort Score. __________________

Participant:____________________

Exp 1 - 20Q

Actual Performance

1. **Estimate the percentage of time that you spent entirely within your lane.** ________________%

2. **Estimate your average response time to noticing the pedestrians' movement.** ________________ Seconds

3. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |--- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Worse |--- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |--- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Worse |--- Better
Much worse than other drivers Much better than other drivers

5. **Please rate your overall driving safety during the simulation.**

Extremely Dangerous |--- Perfectly Safe

6. **Rating Scale for Mental Effort Score.** ________________

Participant:____________________

Exp 1 - Texting

Actual Performance

1. **Estimate the percentage of time that you spent entirely within your lane.** _________________%

2. **Estimate your average response time to noticing the pedestrians' movement.** _________________ Seconds

3. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side in the lane by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate your overall driving safety during the simulation.**

Extremely Dangerous |-- Perfectly Safe

6. **Rating Scale for Mental Effort Score.** _________________

APPENDIX C: SAMPLE DATASHEETS FOR EXPERIMENT 2

Participant:______________________________

Exp 2 - Driving Safety and Mental Effort

No Game 1

1. Please rate your overall driving safety on the following scales.

Extremely Dangerous |-- Perfectly Safe

Worse |-- Better
Much worse than other drivers Much better than other drivers

2. Rating Scale for Mental Effort Score. ____________________

Participant:____________________________

Exp 2 - Driving Safety and Mental Effort

Guessing Game 1

1. Please rate your overall driving safety on the following scales.

Extremely Dangerous |-- Perfectly Safe

Worse |-- Better

Much worse than other drivers   Much better than other drivers

2. Rating Scale for Mental Effort Score. ____________________

Participant:______________________________

Exp 2 - Driving Safety and Mental Effort

No Game 2

1. Please rate your overall driving safety on the following scales.

Extremely Dangerous |-- Perfectly Safe

Worse |-- Better
Much worse than other drivers Much better than other drivers

2. Rating Scale for Mental Effort Score. ____________________

Participant:__________________________

Exp 2 - Driving Safety and Mental Effort

Guessing Game 2

1. Please rate your overall driving safety on the following scales.

Extremely Dangerous |-- Perfectly Safe

Worse |-- Better
Much worse than other drivers Much better than other drivers

2. Rating Scale for Mental Effort Score. __________________

Participant:________________________

Exp 2 - Methods and Cues

Please describe the methods or cues that you used in order to choose the speed that you drove in this condition.

No Game 1:

No Game 2:

Guessing Game 1:

Guessing Game 2:

Participant:______________________

Exp 2 - No Game 1

1. **Estimate the percentage of time that you spent entirely within your lane.** _________________%

2. **Estimate your average response distance to the pedestrians.** _______________ feet

3. **Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

Participant:______________________

Exp 2 - No Game 2

1. Estimate the percentage of time that you spent entirely within your lane. _________________%

2. Estimate your average response distance to the pedestrians. ________________feet

3. Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.

Extremely Dangerous |--Perfectly Safe

4. Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.

Worse |--Better
Much worse than other drivers Much better than other drivers

5. Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.

Extremely Dangerous |--Perfectly Safe

6. Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.

Worse |--Better
Much worse than other drivers Much better than other drivers

Participant:________________________

Exp 2 - Guessing Game 1

1. **Estimate the percentage of time that you spent entirely within your lane.** __________________%

2. **Estimate your average response distance to the pedestrians.** ________________ feet

3. **Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Extremely Dangerous |-- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

Worse |-- Better
Much worse than other drivers Much better than other drivers

Participant:________________________

Exp 2 - Guessing Game 2

1. **Estimate the percentage of time that you spent entirely within your lane.** __________________%

2. **Estimate your average response distance to the pedestrians.** _________________ feet

3. **Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.**

   Extremely Dangerous |--- Perfectly Safe

4. **Please rate how well you stayed in the center of your lane without weaving from side to side by placing a mark on the scale below.**

   Worse |--- Better

   Much worse than other drivers Much better than other drivers

5. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

   Extremely Dangerous |--- Perfectly Safe

6. **Please rate how well you performed the pedestrian identification task by placing a mark on the scale below.**

   Worse |--- Better

   Much worse than other drivers Much better than other drivers

APPENDIX D: EXPERIMENT 1 DESCRIPTIVE STATISTICS

Table D. 1: Descriptive Statistics - Objective Performance Measures

	SDLP					% TIL				
	Baseline	**Repeat**	**PASAT**	**20 Questions**	**Text**	**Baseline**	**Repeat**	**PASAT**	**20 Questions**	**Text**
Mean	0.230	0.220	0.215	0.210	0.289	97.7	98.7	98.3	98.7	94.3
Median	0.226	0.202	0.205	0.197	0.287	99.0	99.6	99.4	99.7	96.8
Std. Dev	0.028	0.058	0.032	0.038	0.051	2.93	1.92	2.41	1.94	4.66

	Steering Entropy					Response Time				
	Baseline	**Repeat**	**PASAT**	**20 Questions**	**Text**	**Baseline**	**Repeat**	**PASAT**	**20 Questions**	**Text**
Mean	0.514	0.535	0.537	0.596	0.632	0.942	0.948	0.987	1.025	1.215
Median	0.515	0.510	0.539	0.598	0.626	0.907	0.937	0.987	1.008	1.218
Std. Dev.	0.019	0.068	0.061	0.066	0.043	0.108	0.083	0.108	0.054	0.128

Table D. 2: Descriptive Statistics - Subjective Performance Measures - Pre and Post Task

	Pre Task Predicted % Time in Lane					Post Task Rated % Time In Lane				
	Baseline	**Repeat**	**PASAT**	**20 Q**	**Text**	**Baseline**	**Repeat**	**PASAT**	**20 Q**	**Text**
Mean	96.3	94.0	90.2	88.1	85.1	94.5	93.1	93.1	91.7	82.3
Median	97.0	95.0	90.0	90.0	87.5	95.0	95.0	95.0	94.0	80.0
Std. Dev.	3.0	4.2	6.7	6.8	8.5	4.7	5.0	6.4	7.6	9.9

	Pre Task Predicted Response Time					Post Task Rated Response Time				
	Baseline	**Repeat**	**PASAT**	**20 Q**	**Text**	**Baseline**	**Repeat**	**PASAT**	**20 Q**	**Text**
Mean	0.8	1.0	1.2	1.3	1.4	1.0	1.1	1.2	1.4	1.6
Median	0.8	1.0	1.1	1.2	1.2	1.0	1.0	1.1	1.2	1.5
Std. Dev.	0.1	0.2	0.4	0.6	0.8	0.3	0.3	0.4	0.8	0.8

	Pre Task Lane-keeping Safety					Post Task Lane-keeping Safety				
	Baseline	**Repeat**	**PASAT**	**20 Q**	**Text**	**Baseline**	**Repeat**	**PASAT**	**20 Q**	**Text**
Mean	72.9	71.8	65.0	62.1	56.3	75.9	69.0	70.8	66.9	43.1
Median	71.0	74.0	66.0	67.0	57.0	77.0	65.0	71.0	66.0	46.0
Std. Dev.	17.9	15.6	18.4	16.6	17.5	10.8	12.9	10.6	12.2	19.7

	Pre Task Lane-keeping - Other Drivers					Post Task Lane-keeping - Other Drivers				
	Baseline	**Repeat**	**PASAT**	**20 Q**	**Text**	**Baseline**	**Repeat**	**PASAT**	**20 Q**	**Text**
Mean	74.1	73.5	65.3	61.5	62.3	73.3	69.1	68.3	67.1	48.1
Median	74.0	76.0	63.0	64.0	61.0	73.0	72.0	71.0	65.0	50.0
Std. Dev.	13.3	12.3	14.0	13.9	15.0	14.6	11.7	11.2	12.6	19.9

Table D. 2 (Cont): Descriptive Statistics – Subjective Performance Measures – Pre and Post Task

	Pre Task Identification Safety					Post Task Identification Safety				
	Baseline	Repeat	PASAT	20 Q	Text	Baseline	Repeat	PASAT	20 Q	Text
Mean	80.0	73.3	65.8	62.1	53.8	77.3	70.0	71.6	64.7	45.1
Median	82.0	76.0	65.0	61.0	52.0	82.0	71.0	71.0	61.0	46.0
Std. Dev.	12.8	14.2	15.2	17.5	20.8	10.5	12.4	13.3	17.5	24.4

	Pre Task Identification - Other Drivers					Post Task Identification - Other Drivers				
	Baseline	Repeat	PASAT	20 Q	Text	Baseline	Repeat	PASAT	20 Q	Text
Mean	74.9	71.9	66.8	61.9	59.9	75.8	68.9	68.5	65.5	48.4
Median	78.0	75.0	70.0	64.0	57.0	73.0	70.0	67.0	62.0	48.0
Std. Dev.	15.7	15.3	14.8	14.0	19.6	9.5	10.7	7.4	14.3	19.1

	Pre Task Overall Safety					Post Task Overall Safety				
	Baseline	Repeat	PASAT	20 Q	Text	Baseline	Repeat	PASAT	20 Q	Text
Mean	82.5	78.4	67.7	63.9	58.5	78.4	68.9	70.5	67.6	46.1
Median	88.0	81.0	69.0	66.0	62.0	81.0	72.0	72.0	70.0	48.0
Std. Dev.	11.4	10.8	13.0	14.1	17.7	8.9	11.5	11.2	14.9	18.9

	Pre Task Mental Effort					Post Task Mental Effort				
	Baseline	Repeat	PASAT	20 Q	Text	Baseline	Repeat	PASAT	20 Q	Text
Mean	N/A	11.9	45.2	64.5	24.5	25.3	44.0	59.5	64.3	71.1
Median	N/A	10.0	43.0	60.0	20.0	25.0	39.0	55.0	60.0	70.0
Std. Dev.	N/A	8.2	23.5	22.6	16.4	9.1	19.5	22.4	20.6	24.7

APPENDIX E: EXPERIMENT 1 CORRELATIONS

Table E. 1: Correlations (with p values between objective and subjective changes in performance (from baseline) within the repeating words task.

Objective Measure	Predicted LK Safety	Rated LK Safety	Predicted ID Safety	Rated ID Safety	Predicted TIL	Predicted RT	Rated TIL	Rated RT	RSME
TIL	-.127	.412	.100	**.704****	-.307	.117	**.535***	-.478	.005
	.651	.127	.723	.003	.266	.677	.040	.071	.986
SDLP	-.146	**-.662****	.235	-.206	.285	-.232	-.256	.301	-.094
	.605	.007	.399	.461	.303	.406	.357	.275	.738
Entropy	.426	.000	.292	-.056	-.144	-.223	.236	.162	.292
	.114	1.000	.290	.842	.608	.425	.398	.565	.290
ID	.150	.183	**.603***	.379	.111	-.409	.154	.118	-.238
	.595	.514	.017	.164	.693	.130	.583	.675	.394

APPENDIX F: EXPERIMENT 1 ANOVA RESULTS – HYPOTHESIS 5

Lane Keeping Safety Ratings:

Effect of distraction: $F(2.062, 28.875) = 28.917$, $p < 0.0005$, partial $\eta^2 = 0.674$
Effect of Pre vs. Post: $F(1, 14) = 0.020$, $p > 0.05$, partial $\eta^2 = 0.001$
Interaction Effect: $F(4, 56) = 8.172$, $p < 0.0005$, partial $\eta^2 = 0.369$

Identification Ratings:

Effect of distraction: $F(1.827, 25.582) = 21.340$, $p < 0.0005$, partial $\eta^2 = 0.604$
Effect of Pre vs. Post: $F(1, 14) = 0.425$, $p > 0.05$, partial $\eta^2 = 0.029$
Interaction Effect: $F(4, 56) = 3.100$, $p = 0.022$, partial $\eta^2 = 0.181$

APPENDIX G: EXPERIMENT 2 DESCRIPTIVE STATISTICS

Table F. 1: Descriptive Statistics - Objective performance measures.

	SDLP					% TIL				
	Baseline	**Wind**	**Distracted**	**D+W**	**Baseline 2**	**Baseline**	**Wind**	**Distracted**	**D+W**	**Baseline 2**
Mean	0.271	0.313	0.261	0.287	0.269	96.4	95.0	97.7	96.5	96.6
Median	0.274	0.304	0.258	0.283	0.252	97.0	95.5	99.0	97.5	98.0
Std. Dev	0.091	0.064	0.047	0.046	0.090	5.38	4.45	2.43	2.98	5.29

	Speed (MPH)					Standard Deviation of Speed (MPH)				
	Baseline	**Wind**	**Distracted**	**D+W**	**Baseline 2**	**Baseline**	**Wind**	**Distracted**	**D+W**	**Baseline 2**
Mean	54.8	52.3	56.4	52.8	54.8	0.11	2.98	2.58	3.23	0.11
Median	54.8	52.3	56.4	54.3	54.8	0.11	2.63	2.31	2.88	0.11
Std. Dev	0.02	5.32	5.08	4.90	0.03	0.01	0.99	0.95	1.38	0.01

	Response Time (seconds)					Response Distance (meters)				
	Baseline	**Wind**	**Distracted**	**D+W**	**Baseline 2**	**Baseline**	**Wind**	**Distracted**	**D+W**	**Baseline 2**
Mean	1.01	1.05	1.11	1.13	1.02	24.7	24.5	27.9	26.7	24.9
Median	0.96	0.99	1.11	1.10	0.99	23.4	23.2	27.9	27.7	24.2
Std. Dev	0.235	0.225	0.211	0.167	0.213	5.76	5.19	4.92	4.19	5.22

Table F. 2: Descriptive statistics for subjective measures taken immediately after experimental trials.

	Overall Safety					Overall Safety - Other Drivers				
	Baseline	Wind	Distracted	D + W	Baseline 2	Baseline	Wind	Distracted	D + W	Baseline 2
Mean	74.8	57.1	48.9	38.3	67.2	69.2	54.2	48.5	42.3	65.3
Median	78.5	52.3	55.2	36.6	66.0	68.5	52.7	53.3	39.5	63.2
Std. Dev	17.9	17.2	22.0	17.6	19.9	17.8	15.1	19.6	13.6	17.6

	RSME				
	Baseline	Wind	Distracted	D + W	Baseline 2
Mean	62.2	70.1	80.2	83.9	60.5
Median	55	60	80	80	55
Std. Dev	23.0	23.3	24.4	24.6	29.4

Table F. 3: Descriptive statistics for subjective measures taken after completion of all experimental scenarios.

	% TIL Subjective Rating				Response Distance Subjective Rating			
	Baseline	**Wind**	**Distracted**	**D + W**	**Baseline**	**Wind**	**Distracted**	**D + W**
Mean	91.3	90.7	84.9	84.1	44.5	46.1	51.8	53.7
Median	93	90	87	85	42	45	50	50
Std Dev.	6.9	7.5	8.5	8.1	8.0	11.8	12.5	14.1

	Lane-keeping Safety				Lane-keeping Safety - Other Drivers			
	Baseline	**Wind**	**Distracted**	**D + W**	**Baseline**	**Wind**	**Distracted**	**D + W**
Mean	64.5	68.4	53.6	51.5	62.6	67.5	52.6	49.8
Median	63.3	68.1	54.0	53.3	65.8	67.9	55.1	48.8
Std Dev.	17.9	17.1	19.5	19.8	16.0	16.0	13.8	19.0

	Identification Safety				Identification Safety - Other Drivers			
	Baseline	**Wind**	**Distracted**	**D + W**	**Baseline**	**Wind**	**Distracted**	**D + W**
Mean	69.2	65.2	49.7	50.3	66.6	65.4	47.9	48.0
Median	71.8	70.7	53.2	59.1	67.1	61.7	50.4	48.3
Std Dev.	20.3	19.9	20.4	22.3	18.6	18.4	17.3	20.2

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