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IMPACTS OF DISTRACTION ON DRIVING: AN ANALYSIS OF PHYSICAL, COGNITIVE, AND EMOTIONAL DISTRACTION

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IMPACTS OF DISTRACTION ON DRIVING: AN ANALYSIS OF PHYSICAL, COGNITIVE, AND EMOTIONAL DISTRACTION

By

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A THESIS

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Acknowledgments

Sincerest thanks to my family, friends, and advisor, Dr. Jeon, for supporting me in my academic pursuits.

Abstract

Traditionally, driver distraction has been categorized into four types: visual, biomechanical, auditory, and cognitive. However, the place of emotion in distracted driving research is undefined. This research investigates the influence of emotional distraction on driving performance. In total, seventy-eight participants were recruited and placed into one of four conditions: physical (visual-biomechanical), cognitive (cognitive-auditory), emotional (anger), and control. The results demonstrated that emotional distraction degrades driving performance as much as or more than other distraction types. The causes for these results, underlying mechanisms, and other considerations are mentioned in the discussion section.

1. Introduction

Driver distraction has been estimated to be a causal factor in 10% - 50% of vehicle crashes (Wang et al., 1996; NHTSA, 1997; Ranney, 2000). The NHTSA estimated that 3,328 people were killed in distraction-affected crashes in 2012 (NHSTA, 2014). As a result, driver distraction has become an area of high priority in research. Distracted driving has garnered more investigation lately from researchers and policymakers alike because of the increased prevalence of IVIS use while driving and the risks that they pose to driver safety (Ranney, 2008). This research can provide a foundation for informing IVIS design and inform policy change surrounding driving behavior.

Despite this increased interest in distracted driving research, there remains an incomplete understanding of the impacts of various types of distraction on driving performance. Understanding these impacts is difficult due to the complexity of the problem. The effects of secondary tasks on driving depend on the goals of the driver, the requirements of the secondary task, the strategies the driver employs while task-switching, and the demands placed on the driver by the road environment. While significant progress has been made in understanding the influences of many representative secondary tasks in many environments, some fundamental research remains to be done. It is beneficial for researchers to decompose distraction into several types. The types that are traditionally considered are: visual, auditory, biomechanical, and cognitive (Young & Regan, 2007). These types have proven to be useful because each one draws from its own attentional resource pool. Consequently, each distraction type can influence driving differently, and can also be mitigated through different means. However, useful these delineations may be, it is possible that the current list of distraction types is incomplete, and may benefit from the addition of one or more types of distraction. Of course, for a new type of distraction to be considered it should meet several criteria. First, it should fall under the definition of a distraction. Second, it should be mediated by a different mechanism than other distraction types, such that practical intervention, with the aim to mitigate driving performance degradation, can be significantly different from intervention for other distraction types. For example, if there is no means to mitigate the influence of a biomechanical distraction on driving performance without mitigating the influence of auditory distraction simultaneously, then those distraction types are not worth distinguishing from one another in an applied research perspective. Third, the effect must be significant. Although the term *significant* is ambiguous, it is certainly less important to identify a distraction type that has little negative effect on driving when compared to a distraction type that strongly degrades driving performance. Finally, it must happen often. Again, *often* is relative. However, it is more worthwhile to invest effort into investigating distractions that are prevalent in natural driving behavior. It is the purpose of this project, being applied in nature, to investigate the place of emotion amongst the more traditionally accepted distraction types. It is unrealistic to determine if the emotional distraction meets all of the criteria outlined here in this study alone. The primary purpose of this study is to determine if the influence of emotion can be called significant, in relation to other distraction types. The other criteria will also be discussed but are not addressed directly in the experimental design.

This thesis provides a brief overview of some distracted driving literature and emotion literature to substantiate the position that emotional influences on driving are a real-world phenomenon which may be mediated by different mechanisms from other distraction types. Evidence to this end would suggest a need to include emotional distraction as an additional type of driver distraction and establish a clear need for further research in the field of affective influences on driving performance.

1.1 Defining Driver Distraction

Before any discussion of distracted driving, it is first necessary to define the terms. What is driver distraction? There is no consensus among distracted driving researchers on the definition of distracted driving. However, there are a few largely accepted definitions. In the International Conference on Distracted Driving, (ICDD) a group of experts collaborated to define driver distraction as:

> a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver's awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes (Hedlund et al., 2005, pp. 2).

Lee, Young & Regan (2008) define driver distraction as "…the diversion of attention away from activities critical for safe driving toward a competing activity"(pp. 34).

Finally, Pettitt et al. (2005, pp. 11) define driver distraction as:

> (A) delay by the driver in the recognition of information necessary to safely maintain the lateral and longitudinal control of the vehicle due to some event, activity, object or person, within or outside the vehicle that compels or tends to induce the driver's shifting attention away from fundamental driving tasks by compromising the driver's auditory, biomechanical, cognitive or visual faculties, or combinations, thereof.

Pettitt et al.'s definition highlights the potential oversight that this research is attempting to remedy through the inclusion of an emotional dimension in the distracted driving discussion. Lee's definition succinctly encapsulates the common elements of all three definitions mentioned here, so his is the definition of the driver distraction construct going forward.

It is important to note the relationship between inattention and distraction. Some researchers contend that inattention and driver distraction are dichotomous (Lee et al., 2008) while others say that driver distraction is a form of inattention (Victor, Engstrom & Harbluk, 2008). This research will side with Victor et al. in the view that inattention is a term at a higher taxonomic level and not dichotomous with distraction. Other researchers (Caird & Dewar, 2007) also argue about the nuances of inattention as internally triggered as opposed to distractions as externally triggered interferences. These arguments are not germane to the goals of this paper, but it does provide a flavor of the state of the research. In any case, potential differences in internal and external emotional triggers were not investigated in this study. Most important to determine was, whether the effects are real, significant, and distinct from other types of distraction.

1.2 Effects of Distracted Driving

Driving is a complex, dynamic, physically and mentally demanding task. Drivers are required to attend to their environments, adapt to and track changes in that environment, predict potential hazards, obey speed limits, and understand traffic rules all via simultaneous manipulation of steering wheel, pedals, and sometimes shifters. Because driving is such a demanding task, it requires high levels of mental and physical resources. However, these resources are limited and competition often arises when more than one task is undertaken simultaneously. Despite this, it is not uncommon for drivers to eat, talk on the phone, change the radio dial, etc. while driving. A large effort has been put into understanding the effects of secondary tasks such as these on driving performance. This effort is in the wake of cell phone use and its observed impact on crash risk (Asbridge et al., 2013; Lee et al., 2013). Research findings have suggested that multitasking while driving can result in behavioral effects such as increased reaction time (Hancock et al, 2003; Strayer et al. 2003; Morel et al., 2005), reduction in necessary visual information processing (McKnight & McKnight, 1993; Barkana et al, 2004), and increased lane deviation (Reed & Green, 1999), all of which can lead to increased risk of crashes (NHTSA, 2014). Secondary tasks redirect driver attention and physical resources which can interfere with a driver's ability to perceive, process, and react to driving-relevant information.

Although generally speaking there are obvious consequences to distracted driving, there are also interesting differences between each of these distraction types. Different distractions may yield different outcomes in otherwise similar conditions. The negative effects of different distraction types may also be mitigated most efficiently by using different methods. Therefore, it is important to distinguish the types and understand why these distinctions are used.

1.3 Distracted Driving Taxonomy

Since it is practically impossible to provide a cure-all prevention or intervention for distracted driving – because advice like "don't drive distracted" does not work –, it is beneficial to decompose distracted driving into types and approach the issue more subtly. Traditionally, driver distraction has been categorized into four types: visual, auditory, biomechanical, and cognitive (Young & Regan, 2007). By using types defined by their independent resource pools, it is possible to understand the influence of each type of distraction on driving performance by applying Multiple Resource Theory (MRT; Wickens, 2002), which describes how the influence of a secondary task on a primary task is dependent upon the overlap between the two tasks in demand for the same resources. MRT provides a mechanism that explains how a secondary task can influence a primary task in complex environments like a driving environment. MRT also provides a framework for understanding how to mitigate the influence of distracted driving. For example, from MRT a Human Factors expert should know not to recommend an alarm system that alerts a visually distracted driver of an upcoming road hazard by using a visual indicator. Instead, a better alarm system should use a sensory channel that is not in competition with the primary task for common resources, such as the auditory or haptic channels. Thus, it is helpful to delineate distractions into these categories because it can help researchers understand when and how a secondary task is likely to influence driving behavior.

However useful this categorization may be, the current distraction types do not describe any naturally occurring behavior. If you look out onto a highway, you cannot see a driver who is only *visually* distracted or only *biomechanically* distracted. Instead, you will notice that drivers will engage in secondary tasks that fall under multiple distraction types. Talking to a passenger, for example, will certainly require auditory resources and cognitive resources to some extent. However, that is not the full picture because drivers will also frequently look at a passenger while talking to them, and that requires visual resources and biomechanical resources. Thus, it is difficult to capture natural driving behavior while remaining beholden to these distraction types. Consequently, it is difficult to generalize findings from studies designed using conditions defined by these traditional distraction types. To circumvent this issue, this study used different, more ecologically representative distraction types: Physical, Cognitive, and Emotional. These distraction categories are neither meant to be a comprehensive categorization that includes each possible driver distraction, nor is it meant to better explain underlying reasons for behavior via mechanisms such as MRT. Instead, these categories were chosen because they better capture the types of secondary tasks that drivers frequently attempt while driving. Below is a justification for using these types followed by an introduction to each of the new distraction types.

1.4 Justification for New Categories

In a widely cited study by Neale et al. (2005), the frequency of distracted driving behaviors was recorded. The results showed that the most frequent distracting secondary activities were interacting with wireless devices, passenger related interactions, and internal distractions (Figure 1.)

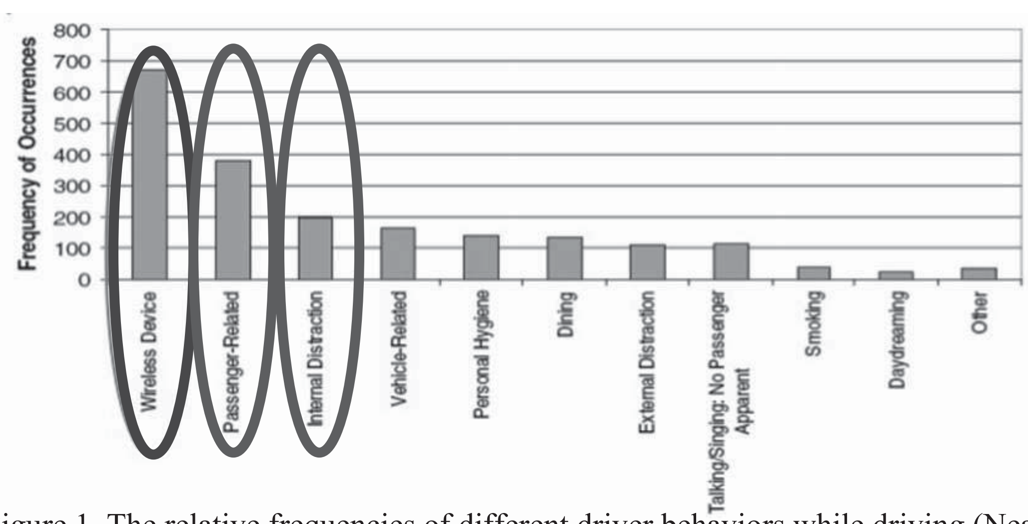

Figure 1. The relative frequencies of different driver behaviors while driving (Neale, et al. 2005)with circles around three relevant driver behaviors.

Interactions with wireless devices and passenger-related distractions could be interpreted as physical and cognitive distractions, as they are defined here. Internal distractions, although vague, probably includes, in part, emotional distraction. Although it is true that these behaviors still cannot be completely encapsulated by the proposed categories, these categories are at a useful level of abstraction for the purposes of comparison and evaluation of emotion, which is ultimately the goal of this research project.

1.5 Physical Distraction

Physical distraction describes a diversion of physical resources necessary for safe driving toward a competing activity. This is a combination of the biomechanical and physical distraction types outlined in the traditional categories. There are limited physical resources, many of which cannot be easily divided, such as gaze direction and hand position. Safe driving depends on the driver's ability to keep his or her eyes on the road and hands on the steering wheel, among other things. Any tasks that affect a driver's ability to do this are likely to be a source of driving performance degradation. Physical distraction is an intervention at the level of sensation. That is, there is an interference that is blocking the reception of sensory cues all together, which prohibits further information processing necessary for adaptation to changes in the environment. To illustrate, suppose a woman is driving her car down a highway. There is a lot of traffic and she is following closely behind a car in front of her. As she is driving, she is rummaging through her purse for something. As she is looking in her purse, she is unable to look at the road. While she is visually and biomechanically occupied with her purse she does not notice the car ahead of her is stopped. She collides with the car ahead of her.

In this example, the woman's crash was a result of a physical distraction. When she was looking into her purse, she was not able to receive driving-relevant information. The physical requirements of her secondary task (e.g., looking in her purse, and feeling inside the purse with her hand) interfered with her ability to complete the driving task adequately. This example also illustrates a noteworthy point; distractions cannot always be neatly placed into exclusive categories. The driver's behavior could also demand significant cognitive resources or involve an emotional reaction. It might be better to think of distraction to lie on several distinct and independent continua, such that it is possible for a situation to be described as distracting in multiple ways (i.e., cognitive, physical) and at multiple degrees of severity (i.e., high, low). While many cases do not fit neatly into one category of distraction, *physical distraction* describes situations in which secondary-task interference is *primarily* the result of a visual and/or biomechanical secondary task.

1.6 Cognitive Distraction

Cognitive distraction is a result of a competition between the driving task and secondary task for cognitive resources. Unlike the physical distraction condition, which is characterized by an intervention at a sensory level, cognitive distraction is defined by a "looking but not seeing" phenomenon. Cognitive distraction describes situations in which the driver may be looking at the road and all of the relevant information is available, but he or she is unable to process the information because the necessary mental resources are dedicated to secondary tasks. Cognitive distraction is defined by the disruption of a primary task via competition for common resources from a cognitive task unrelated to the primary task (Stutts et al., 2005).

To illustrate, imagine a man is on his way to the grocery store. He is trying to remember the list of items he needs to buy. While he is rehearsing this list in his head, he does not realize that the car ahead of him has stopped and he crashes into it. This is an example of cognitive distraction. The man had all of the driving-relevant information available to him but he did not process it because his mental resources were dedicated to an unrelated cognitive task, and so he was not able to react appropriately to changes in his environment.

For the purposes of this investigation, cognitive distraction refers to degradation as a result of competition for cognitive and/or auditory resources. Therefore, cognitive distraction, here, refers to the two remaining categories of the traditional set. The reason for including auditory distraction in the definition of cognitive distraction is because the two often co-occur, in conditions such as conversations, which research has shown to be highly prevalent (Neale et al., 2005).

Effects

Studies have shown that auditory inputs and speech responses can interfere with the driving task and impair performance (Patten, Kircher, Ostlund & Nilsson, 2004; Strayer & Drews, 2004; Treffner & Barrett, 2004). Studies have demonstrated cognitive distraction is associated with fewer saccadic eye movements, failure to direct gaze into periphery, and negligence of dashboard instruments (Harbluk, Noy, & Eizenman, 2002; Harbluk, Noy, Trbovich, & Eizenman, 2007). These *cognitive tunneling* effects can result in similar driving performance deficits as in physical distraction. Alm and Nilsson (1995) showed that a non-visual cognitive task showed similar delayed braking results (about .5

seconds delay) as a visual-biomechanical dialing task. This result was later confirmed by Lable et al. (1999).

1.7 Emotional Distraction

The results of many varied studies in affective science converge to consistently demonstrate that affect and emotions influence most (if not all) of our daily tasks. Trivial tasks, to which we appear to attribute little or no apparent conscious effort, and even difficult tasks, which are usually viewed as a matter of cold logic, are impacted by the emotional system (Lazarus, 1991).

Despite the obvious connections of emotion to cognitive tasks and physical tasks, including tasks required for safe driving, there is relatively little research demonstrating clear causal effects of situation-state emotion on driving performance (exceptions: Jeon, 2012; Abdu, Shinar, & Meiran, 2012). Studies showing the direct causal effects both investigated the effects of anger. However, these studies do not show decrements in all facets of driving behavior. They show that angry drivers have slightly higher mean speeds (Jeon, 2012; Abdu, Shinar, & Meiran, 2012) and more lane deviations (Jeon, 2012), but there is no evidence of impairment of reaction times or other measures of skilled performance (Abdu, Shinar, & Meiran, 2012). The data suggest that angry drivers are more likely to engage in risky driving behaviors, which can manifest themselves in many driving performance parameters, but they do not necessarily lose their ability to react to the dangerous situations.

2. Situation Awareness

Emotion is known to influence driving behavior (Jeon, 2012; Deffenbacher et al., 2003), but it is not known what mechanism is responsible for this influence. Endsley's situation awareness (SA) model (Endsley, 1995) is one potential mechanism. SA involves three levels: perception, comprehension, and projection. Success on all three of those levels explains how humans can adapt in dynamic environments to complete complex tasks, such as driving. Each of these levels is related to perceptual and cognitive processes demonstrated to be influenced by emotion in contexts outside of driving. These processes include attention, perception, interpretation, judgment, and decision-making. How each of these processes is impacted by emotion is detailed below.

Attention and Perception

Attention is the means by which people actively process the vast amount of information through senses, memory, and cognitive processing (Rao, 2003). Research in this area has revealed two major facts. First, positive moods tend to be associated with global processing (Derryberry & Tucker, 1994) and second, negative moods conversely result in a narrowed attentional scope (Easterbrook, 1959). Moreover, positive emotions are often engendered by exploratory processing whereas negative valence emotions are associated with narrowed, vigilant processing (Rathunde, 2000).

Interpretation

Mood-congruent interpretive biases have been found in other domains, such as faces, and verbal interpretations (Sprengelmeyer et al., 1997; Eysenck, Mogg, May, Richards, & Mathews, 1991). These studies reveal that anxious people (a negative valence emotion) tend to interpret neutral stimuli as being more dangerous than non-anxious people.

While it remains uncertain if these results are generalizable, the data suggest that drivers' abilities to interpret ambiguous signage or environmental cues can be influenced by their emotional state.

Judgment

Judgment is the process by which people cope with ambiguity in the environment and predicting future events (Blanchette & Richards, 2010). Classic experiments by Johnson and Tversky (1983) demonstrate that people's perception of future risk is influenced by their emotional states. In their experiment the negative mood group estimated the risk of future negative events at a higher rate than did the control groups.

The Affect Infusion Model (AIM; Forgas, 1995) further dissects the relationship between emotion and judgment by decomposing cognitive processing into four types: direct access processing, motivated processing, heuristic processing, and substantive processing. The first two, direct access and motivated processing, are reconstructive strategies; they do not require the assimilation of new information, as such they are predicted to be unaffected by emotion. However, the second two; heuristic and substantive processing, are constructive strategies in which people require new information to form their judgments. These two processes are predicted to be much more strongly influenced by affect. In fact, several studies have shown mood-congruent effects associated with heuristic and substantive processes (Isen, 1984; Clore & Byrne, 1974).

Decision Making

Decision making is a process that describes how people select among different options (Blanchette & Richards, 2010). Decision making is generally considered to follow the process of judgment in which people estimate the likelihood of different outcomes. Judgment informs decision making. Therefore, it could be said that decision making follows situation awareness. However, the two are distinct processes such that decision making is dependent upon information from the situation awareness process, but the decision making process does not necessarily reflect the level of situation awareness of the driver. For example, a driver can be aware of a hazard, but choose to ignore it, which suggests that the two processes are distinct.

Raghunathan and Pham (1999) showed that people in other negative moods have biases for high-risk/high-reward options while anxious people show preferences for low-risk/low-reward options. Isen and Geva (1987) found that people in positive valence moods also show risk-averse biases.

Abdu et al. (2012) proposed that the influences of anger on driving could be mediated by decision making rather than situation awareness. Their conclusion came after their study showed that drivers were not impaired in their driving performance relative to a control condition but they did drive through red lights at higher rates. Therefore, decision making exists as a second possible mechanism for explaining the effect of emotion, or at least anger, on driving performance.

Additional Considerations

Driving is considered by most experts to be a visual-manual-spatial task (Young & Regan, 2007). By applying MRT, it is possible to predict which of the categories should have a larger effect on driving performance. Wickens (2002) suggests that since driving is a visual-manual task (visual, biomechanical), it should overlap greatly in demand for the same resources and result in relatively large degradation when compared to cognitive distraction (cognitive, auditory) which are not listed among the characteristic demands of a typical driving task.

Some evidence supports Wickens' hypothesis (Hurwitz & Wheatley, 2002; Tijernina, Palmer & Goodman, 1998). Importantly, there remains a possibility of interference even when two tasks do not use the same resources, especially if the demands of one or both tasks are high (Wickens, 2002). Cognitive tasks, while supposed by Wickens to play a less significant role in performance errors, can actually result in dual-task interference and performance degradation if the cognitive task or driving task is sufficiently demanding.

3. Hypothesis

This research aims to compare the relative impact of cognitive, physical, and emotional distraction (anger) on driving performance in order to assess the place of emotion in distraction research. A secondary goal is to begin to unpack the mechanisms mediating the relationship between emotion and driving.

Physical distraction is expected to result in increased reaction times to hazardous events, increased probability of collisions and near-misses of hazards, and corresponding increased brake pressure. It is also hypothesized that physical distraction will result in greater numbers of glances at the IVIS as the driver is asked to complete the physical task and larger degree of lane deviations compared to the other conditions because of the combination of visual and biomechanical distraction.

Cognitive distraction is expected to be associated with similar deficits in driving performance: increased reaction delays, increased brake pressure, increased risk of collisions and near-collisions. However, it should demonstrate a different visual gaze pattern from physical distraction. Cognitive distraction is expected to correspond to a relatively fixed gaze with little or no fixation in the periphery or at the instrument panel (i.e., speedometer). It is hypothesized that the lack of eye fixations to appropriate environmental cues happens because of a proactive interference of the cognitive demands of the secondary task with the attentional/perceptual level of the SA model. Of course, this interruption of the SA process at an early stage disallows further cognitive processing in interpretation, judgment, and decision making.

Emotional distraction, however, is hypothesized to likely intercede at many of the processing levels of the SA model. Anger, specifically, as a negative valence emotion is expected to lead to a similar cognitive tunneling effect as the cognitive distraction and should result in similar eye movement patterns (i.e., fixated ahead, few/no glances in periphery or in instrument panel). However, it is also possible for emotional distraction to intervene at the level of decision making. In the case of anger, again as a negative valence emotion, it is expected that there should be high-risk/high reward decisions made in ambiguous situations (e.g., stop light is about to turn red, the driver will risk the traffic violation).

4. Method

4.1 Participants

A total of seventy-eight participants were recruited to participate in this study: 18 in the physical distraction condition (Age: *M* = 22.6, *SD* = 7.37), 17 in the cognitive distraction condition (Age: *M* = 19.6, *SD* = .94), 25 in the emotional distraction condition (Age: *M* = 20.1, *SD* = .97), and 18 in the control condition (Age: *M* = 24.3*SD* = 11.29). Numbers of participants in each conditions were controlled. The reason there were 25 participants in the anger condition was to allow for the possibility of excluding participants who do not self-report being angry. This can be considered justifiable since the objective is to study the influence of anger. However, to avoid any potential argument regarding selecting the angriest people, all 25 participants were kept. The large variance in age and experience were due to the inclusion of two volunteers who were considerably older than the remainder of the sample. It is unlikely that any potential effects of age or experience would influence overall means for any condition with the inclusion of only one outlier. Each participant reported had a valid driver's license and at least 2 years driving experience: The physical distraction condition (Experience: *M* = 6.59, *SD* = 7.64), the cognitive distraction condition (Experience: *M* = 3.76, *SD* = 1.15), the emotional distraction condition (Experience: *M* = 3.95, *SD* = 1.22), and the control condition (Experience: *M* = 7.69, *SD* = 11.29). The gender distribution was balanced across all conditions (Table 1), except for the emotional distraction condition. This decision was made because gender has been demonstrated to have an impact on emotion (Fischer, 2000), but gender has no demonstrated effect on driving for other distraction conditions. All participants gave informed consent. Upon completion of the experimental tasks each participant was awarded course credit.

Table 1. Participant demographic statistics

Condition	Participants	Age in years M (SD)	Gender	Experience in years M (SD)
Physical	18	22.6 (7.4)	M: 11 F: 7	6.59 (7.64)
Cognitive	17	19.6 (.94)	M: 11 F: 6	3.76 (1.15)
Emotional	25	20.1 (.97)	M: 12 F: 13	3.95 (1.22)
Control	18	24.3 (11.3)	M: 11 F: 6	7.69 (11.29)

4.2 Design

A between-subjects design was employed. There were four conditions in total: physical, cognitive, and emotional (anger) distraction, as well as control conditions. The physical distraction condition required participants to complete a physical task while driving. The cognitive distraction condition required participants to complete a secondary cognitive task while driving along a predetermined route in the simulator. The emotional distraction condition required participants to drive the prescribed driving route after an angry mood was induced with no additional secondary tasks. The control condition consisted of a neutral mood induction and the participant was only asked to drive the route. Participants in all conditions drove the same route. More detailed descriptions of each task condition and the rationale behind them follows.

Mood Induction

For all experimental conditions and the control condition there was an emotion induction procedure. In the physical, cognitive, and control conditions a neutral emotional mood was induced. In the angry driving condition an angry mood was induced. Both neutral and angry moods were induced via the same method: reading and writing. Participants in the emotional distraction condition were asked to read a short passage designed to make him/her angry and write about a past experience that made him/her angry for 12 minutes. Participants in other conditions were asked to read a short passage reporting events of a person's day and then write a chronology of their recent events, a task intended to be emotionally neutral (Bodenhausen et al., 1994; Jeon et al., 2011a). This emotion induction methodology is prevalent in the field of affective science (e.g., Bodenhausen et al., 1994; Ellsworth & Smith, 1988, Jeon, 2012). Participants were urged to refer to two sample paragraphs (Bodenhausen et al., 1994; Jeon et al., 2011a) in the instruction sheet to help them write their own paragraphs. Participants were allowed to write about as many experiences as they wish during the allotted 12 minutes, but they were told they must write for the entire 12 minute period.

Implicit Performance Measure

Implicit performance measures have previously been used to assess situation awareness (Jeon, 2012). By evaluating the driver's ability to cope with driving hazards on a Likert scale, it is possible to gain insight into the SA of the driver at the time leading up to the hazardous event. If a driver is able to easily avoid an accident, that suggests that they were able to attend, perceive, interpret, judge, and make an appropriate decision in accordance with Endsley's SA model (1995). If a driver narrowly avoids a collision or collides that implies poor SA. The implicit performance measure used in this study is a subjective rating scale with scores of 0, 1 and 2: 0 corresponds with a smooth avoidance, 1 corresponds with a close call, 2 corresponds with a collision. The judgment to assign a 0, 1, or 2 was made by the researcher each time that a driver met a hazard in the driving scenario. Each drive contained nine hazards and each driver completed the full course, so there were nine implicit performance scores for each participant.

Driving Scenario

The driving scenario consisted of a combination of city driving and highway driving. The scenario began in a city environment (speed limit 30 miles per hour) with the car parked on the side of the road. The roads were all two-way roads with many cars travelling both ways at all times. As the participant followed the prescribed course, they were required to take turns, obey traffic lights, yield for oncoming traffic, etc. The driver then left the city environment and went to a more suburban area which had fewer cars but more curves and nearby pedestrians (speed limit 30 miles per hour). Further along the course the participants merged onto a highway (speed limit 65 miles per hour). There were few cars on the highway, but the high speeds and added obstacles (construction work) provided additional challenges. All of these environments were designed to be representative of typical driving environments that a driver may face. This course had a total of two turns. Participants were not aware of the route beforehand. The researcher instructed participants prior to beginning the scenario that there would be turns and they would be told with ample time when and where to turn. In total, the drive lasted between 10-15 minutes.

Hazardous events

There were nine hazardous events along the prescribed course. The hazards were inserted to test how the participant coped with changes that required actions from the driver to safely avoid collisions. Below is a table describing each of the hazardous events in the driving scenario.

Table 2. Hazardous events in the driving scenario

Predictable Hazardous Events
Event 1. Swerving car
Event 2. Swerving motorcycle
Event 3. Traffic signal suddenly changed into yellow in the intersection
Event 4. Suddenly u-turning car in front of the participant
Event 5. Running boy from behind the parked car
Event 6. Suddenly pulling out car
Event 7. Suddenly appearing truck in highway entrance
Event 8. Construction and lane merge
Event 9. Crossing two deer

These hazardous events allow for investigation of the differential influence of cognitive, physical, and emotional distraction in a way that maintains high ecological and external validity. For participants in the Cognitive or Physical distraction condition, these hazards were accompanied by secondary tasks. More details regarding the specifics of the tasks will follow in the Physical and Cognitive distraction sections. Participants in both conditions were instructed to complete secondary tasks within a window of time. This window was based on the distance in the scenario a few seconds before arriving at a hazard trigger event through several seconds after the hazard is present. This window should capture all of the behavior immediately leading up to any potential collisions or near collisions.

The secondary tasks used in the Physical and Cognitive distraction conditions were designed to distract the driver at semi-regular intervals for the entire duration of the driving experiment, without fatiguing them. The driving scenario required approximately 10 -15 minutes to complete. Presenting one secondary task approximately once per minute allows ample time to recover between windows to avoid driver fatigue. An additional consideration was made for the possibility of participant's predicting potential hazards at the start of each window. To avoid this, three false alarm windows were included during the drive. In total, there were 12 windows in which to complete secondary tasks and 9 hazard events, which occur simultaneously.

Eye tracking

Eye tracking was used as another behavioral measure for several reasons. First, it can be used to discriminate between physical, and cognitive/emotional distraction because drivers show different eye movement patterns in different distraction situations. They can also be used to validate the driver's glance patterns during the physical distraction to ensure physical distraction. The system used was non-invasive and was unlikely to interfere in participant's driving process.

Physical distraction condition

The participants in the physical distraction condition were asked to complete a physical task while simultaneously driving. Each participant in this condition was required to enter a 3 letter word into an electronic tablet which was positioned to the driver's right, in the approximate location of control panel of an average vehicle. Each word was to be copied by the participant as it was presented by using the keyboard on the tablet. Each of the words was selected after considering emotional content and difficulty.

Words considered emotionally charged or especially difficult were omitted. A total of 25 total words were available for drivers. Each word was presented individually and the next word only became available after entering a submission for the previous word. Opportunities to enter these words on the tablet were available in windows of time. These windows were triggered by reaching specific locations in the driving scenario. Each window lasted approximately 30 seconds and was separated by at least another 30 seconds before the next window. Participants were instructed to complete the secondary task as they felt comfortable, which allows them to modulate or compensate in their behavior to accommodate for primary task demands.

This task was chosen to introduce a definite physical disruption, i.e., the driver's eyes are removed from the road, while also attempting to mitigate the cognitive demands of the task. That is, the task required physical actions which constrained the driving-relevant information received by the driver, but it also attempted to limit the confounding effects of cognitive demands by minimizing the amount of mental effort required to complete the task. By making the task similar to those required to use IVIS, the generalizability of the results is increased. The task was designed to be similar to texting on a cell phone or using a navigation device but also minimizes the cognitive demands associated with the use of those IVISs.

Cognitive distraction condition

In the cognitive distraction condition drivers were asked a set of questions designed to simulate a conversation previously used in a study investigating the influence of naturalistic conversation on driving (Rakauskas, 2004). These simulated conversation took place within the same windows of time as the physical distraction condition. The reading of the question was started before the window began, to ensure that drivers were talking and/or thinking when encountering a hazard rather than listening. The questions were screened for emotional content through use of a survey given to laboratory members. Lab members were asked which questions they would be most likely to pursue into conversation without being very emotional. The set are different from traditional cognitive distraction tasks. N-back tasks, arithmetic question, or other difficult tasks are often used as cognitive distractions (Caird et al., 2008). However, the cognitive demands imposed by secondary tasks are more often conversations, or menu navigation, map reading, rather than complex math problems or demanding memory tasks. By using a cognitive task more akin to naturalistic conversation this condition gains ecological validity and possibly external validity, something worth striving for in applied research.

Emotional distraction condition

Anger while driving is a common experience for many people. ‘Road rage’ is a term often used to describe the subjective experience of anger while driving. Because many people have first-hand experience with angry driving, it provides a more salient example of the influence of affect on driving performance than other emotions such as sadness or anxiety might. Additionally, experimental results have shown that anger is associated with greater performance deficits than many other emotions (Jeon, Yim, & Walker, 2011; Jeon, Walker & Yim, 2014). It is associated with deficits in infractions, lane deviations, speeding, and collisions (Deffenbacher, Deffenbacher, Lynch, & Richards, 2003; Jeon et al., 2011b; Underwood, Chapman, Wright, & Crundall, 1999). It is because of these reasons that anger was chosen to represent the potential effect of emotion on driving performance. By choosing the most salient, and potent of the emotions with regard to driving behavior we can either highlight the importance of emotion in driving or correctly dismiss it.

Anger was induced by asking participants to recall a past event which made them angry. They were given 12 minutes (e.g., Bodenhausen et al., 1994; Ellsworth & Smith, 1988, Jeon, 2012) to write about a past event that made them angry, a method which has been successful in the past. This method of affect induction was selected over others such as showing pictures or video because it has shown promise for inducing affect for longer periods of time compared to traditional induction methods (Jeon, 2012), which helps because the driving scenario lasted approximately 10 to 15 minutes.

Participants were asked to read a short passage then write for 12 minutes about something that made them angry in the past. There was no secondary task or interference from the researcher for the driving portion of the session.

Control condition

The control condition contained a neutral emotion induction consisting of writing and reading tasks related to mundane activities, designed to be as unrelated to affect as possible. This can be verified through the self-report numbers. The control condition simply required the participants to drive the predetermined course without experimental manipulations.

4.3 Apparatus

Driving Simulator

Figure 2 shows the Driving Simulator, a mid-fidelity National Advanced Driving Simulator (NADS) MiniSim version 1.8.3.3. The simulation software runs on a single computer, running Microsoft Windows 7 Pro on an Intel Core i7 processor, 3.07 GHz and 12 GB of RAM, and relays sound through a 2.1 audio system. Three Panasonic TH-42PH2014 42" plasma displays with a 1280x800 resolution each allow for a 130 degree field of view in front of the seated participant. The center monitor is 28 inches from the center of the steering wheel and the left and right monitors are 37 inches from the center of the steering wheel. The MiniSim also includes a real steering wheel, adjustable car seat, gear-shift, and gas and brake pedals, as well as a Toshiba Ltd. WXGA TFT LCD monitor with a 1280x800 resolution to display the speedometer, etc. Environmental sound effects are also played through two embedded speakers. These sounds included engine noise, brake screech, turn indicators, collisions, etc. In the present experiment, all participants experienced the same pre-defined route and properties for the driving task.

Figure 2. Equipment setup. From left to right, the NADS simulator, the tablet and stand used during physical distraction, Facelab 4.5 laptop.

Eye tracker

The FaceLab 4.5 eye tracker system was used to record head and eye movements during the study. The eye tracker was mounted on the console directly in front of the driver and did not obstruct the driver's vision. It recorded several characteristics of interest including head position, head rotation, eye position, eye rotation to calculate the gaze position.

Tablet

An iPad2 was used to simulate an IVIS. A survey was created and presented to participants using a survey software called PollDaddy. The center of the tablet was 28 inches from the ground, and angled . The angle of the screen was 30 degrees from vertical. The angle and position were not intended to simulate the center stack in a car, but were representative of interactions with IVISs in general.

4.4 Procedure

For all conditions baseline affective states were measured. Each participant rated their current affective states using a seven-point Likert scale (1: no feeling – 7: strong feeling). The affective states included nine adjectives regarded as important and relevant to driving related tasks: fearful, happy, angry, depressed, confused, embarrassed, urgent, bored, and relieved (Jeon & Walker, 2011d). Then participants completed a Simulator Sickness Test which included 1) rating their current physical states on 17 categories on an eleven-point scale (0: not feeling – 10: strongly feeling) and 2) completing a short (approximately 2 minutes) driving scenario and 3) rating their physical states again on the same 17 categories, and scale. If participants felt any symptoms of simulator sickness (e.g., light headedness, dizziness, nausea, etc.) while completing the driving task, the simulator was stopped and the participants were excused from the experiment. Participants were also excused if any one of their ratings was five or more points higher than the pre-sickness evaluation or if any three ratings were three or more points higher than the pre-sickness evaluation. All participants whose scores did not indicate signs of simulator sickness were eligible to continue with the experiment.

While the participants were driving the simulator sickness scenario, the researcher calibrated the eye tracker. This required several pictures to be taken and measurements from the fixed-base of the simulator to the eyes of the participant and from the eyes to the center monitor. Participants who were able to be tracked 80% or higher for head-tracking and 60% and higher for iris/pupil-tracking were considered eligible to move on with the study. Those who were ineligible were dismissed and given full participation credit.

After calibration, participants completed the mood induction task (neutral for Cognitive, Physical and Control, Anger for Emotional distraction group), which required participants to read a short passage and write for 12 minutes.

After emotion induction, all participants self-reported their emotional states on the same 9 dimensions using the same 7 point scale as before they completed their emotion induction task.

After the emotional state was recorded, all participants drove the predefined scenario, which lasted approximately 10 - 15 minutes. They were encouraged to drive as they would drive in the real world, following or disregarding any traffic and safety rules as they do typically while driving. After completing the drive, participants completed the third affective state rating and short questionnaire for demographic information.

Finally, participants completed the electronic version of NASA Task Load Index (NASA TLX; Hart, 2006) to provide measurements of perceived workload for the overall driving task while under an induced affective state, and provided comments regarding the study. All the participants were debriefed on the purpose, expected results and potential applications of the findings.

4.5 Dependent Variables for Driving Performance

Driving performance data were collected both by manual logging and automatic system logging. (1) Manual log: During the drive, a trained experimenter recorded the number of all driving errors, as well as the implicit performance on all nine hazard events. The implicit performance score for each event was scored as 0: smooth management; 1: near accident with brake screech sound; or 2: crash with objects. Manually counted number of errors include four general driving performance categories which anger has negatively influenced (e.g., Deffenbacher et al., 2003; Dula, Martin, Fox, & Leonard, 2011; Jeon et al., 2011a; Jeon et al., 2011b; Underwood et al., 1999, Jeon, 2012). Lane deviations, traffic infractions, speeding, and collisions were all manually counted by the researcher. Specifically, these variables were chosen because anger easily leads to aggressive behaviors and these aggressive behaviors in driving situations largely capture the description of road rage (Burns and Katovich, 2003).

(2) System log: Additional driving performance data were automatically logged in the driving simulator. Automatically logged data include five driving performance categories: Lane Deviation (deviated feet from the center of the road), Speed, Steering Wheel Angle, Brake Pedal Force, and Collision. The first four variables contain various data such as average, standard deviation, maximum, and minimum. Other driving performance measures such as the lane-change-test (e.g., Mattes, 2003) or headway distance measures (e.g., Ma and Kaber, 2005) were not used in this study because the primary driving tasks in those experimental methodologies have additional cognitive demands that might interfere with the task conditions by adding confounding cognitive demands and by increasing cognitive load unnecessarily. Although this is important to address, it lies outside the bounds of this research project. The system log data recorded here corresponds with the window during which participants completed their secondary tasks. For data collection, each window was defined by coordinates within the scenario file. After the complete data set was extracted from the simulator, it was filtered via a

Matlab code that selected windows of data defined by positional coordinates, which was one of the variables recorded in the system log.

Table 3. Hazard event locations. The event start and end locations (x,y) are below.

Hazard	Start		End	
	X	Y	X	Y
Hazard 1	5030.5	-11835.7	4959.3	-11407.2
Hazard 2	4957.15	-9835.7	4958.15	-9112.55
Hazard 3	4954.92	-6594.78	4955.38	-6192.42
Hazard 4	4339.79	-4414.95	4296.6	-3987.4
Hazard 5	4066.94	-2962.05	3379.72	-3128.99
Hazard 6	2810.1	-3466.71	1299.62	-3625.87
Hazard 7	-1121.76	-8390.96	-3384.69	-9509.22
Hazard 8	-9728.39	-9512.91	-11402.8	-9513.52
Hazard 9	-16750	-9509.22	-17325.9	-9510.59

Positional coordinates were used to define the windows rather than time because, first, it ensures that driver behavior during the hazardous events is captured. Second, the traffic light hazard (3rd hazard) would present difficulties in data collection because some drivers stop at the light while others drive through. If the windows are based on time and driver speed varies significantly, it cannot be ensured that drivers were at the same point in the scenario for the duration of that window. These windows also corresponded with periods during which drivers completed secondary tasks. Secondary task periods were defined extemporaneously, but were started before drivers approached each hazard event and ended after the hazard had passed. The reason that these were not strictly defined periods was to maintain the realistic feel of a natural conversation. Defining bounds for conversational periods would likely lead to unnatural behavioral responses from drivers.

Descriptive statistics were taken from the system log records after the test session was completed. These statistics include means, standard deviations, minimum and maximum. These statistics were used as dependent measures because they can provide valuable insights in their own right. For example, lane position is an interesting measure. It can potentially describe the swerving of a driver. Position alone cannot target that, neither can the mean, if the distribution was equal on two sides of the mean. The standard deviation, then, can provide a good measure of lane deviations. On this basis, descriptive statics for several metrics were considered as dependent measures.

The manual and system log were recorded for all participants, focused around the hazard events. Both of these two data collections have strengths: manual allows for capture of negative or unsafe driving behavior in a quick, easy fashion, albeit subjective. The system log, in contrast, allows for the collection of objective metrics, although it can be difficult and time consuming to understand the full picture from the system log alone. It makes most sense to use both, together, if the goal is to understand driving performance and to support conclusions with objective data.

4.6 Statistics

One-way analysis of variance (ANOVA) and Tukey-Kramer HSD post hoc tests were conducted using JMP (Version 10. SAS Institute Inc., Cary, NC, 1989-2007) on all the system log results. One-way ANOVA and independent t-tests were conducted on emotion self-report questionnaires and also on NASA TLX results to determine what differences existed between the conditions for each of the dependent variables mentioned above. Effect size (Cohen's *d*) was also reported to gauge the impact that these conditions had on the driving performance parameters. Fisher's exact test was used to investigate the relative distributions of the implicit performance scores.

Eye tracking measures

The eye position and eye rotation were calculated automatically by the FaceLab 4.5 software using the eye position relative to the simulator screen, and eye rotation. This position was mapped on a Cartesian coordinate system with (0,0) at the center of the central monitor and negative x and y values on the left and below that point, respectively and positive x and y values to the right and above that point, respectively. The end result of this is a density plot visualizing where and how often participants looked while driving. Mean and standard deviation for X (horizontal) and mean and standard deviation for Y (vertical) were reported and analyzed. Additional metrics were recorded to evaluate percentage of time gaze was directed to specific instruments which remained fixed within the environment coordinate system, such as the rear view mirror and the instrument panel.

5. Results

5.1 Manipulation check

Analysis of variance (ANOVA) tests reveal there were no significant differences in self reported anger across conditions prior to mood induction $F(3, 74) = .69$, ($p = .559$). Self-reported anger in the emotional distraction condition (M = 3.64, SD = 1.96) was significantly higher than cognitive (M = 1.29, SD = .77, $t(74) = -6.07$, $p < .0001$, physical (M = 1.06, SD = .24) $t(74) = -6.8$, $p < .0001$, and control (M = 1.28, SD = .24) $t(74) = -6.21$, $p < .0001$ after mood induction. Even after finishing the driving scenario self-reported anger scores (M = 2.76, SD = 1.79) were higher for participants in the emotional distraction condition when compared to cognitive (M = 1.94, SD = 1.29) $t(74) = -1.89$, $p = .032$, physical (M = 1.39, SD = .78), $t(74) = -3.21$, $p = .001$ and control (M = 1.78, SD = 1.26), $t(74) = -2.3$, $p = .012$. These results are shown below (Figure 3). These results look as expected. The lack of difference in the pre-induction self-report suggests that the anger seen in the anger condition were due to the emotion induction and not something incidental to the experiment. The results of the anger induction also appear to linger for at least the duration of the driving scenario, suggesting that the drivers are likely angry while driving. Unpaired, two-tailed t-tests were conducted to understand if there were gender differences within each of the self-reported anger questionnaire results. Results showed that there were no significant differences for pre-induction, $t(23) = 0.077$, $p = 0.94$, post-induction, $t(23) = 0.265$, $p = 0.793$, or post-experiment $t(23) = 0.489$, $p = 0.63$, suggesting that gender did not correspond with different self-reported anger scores.

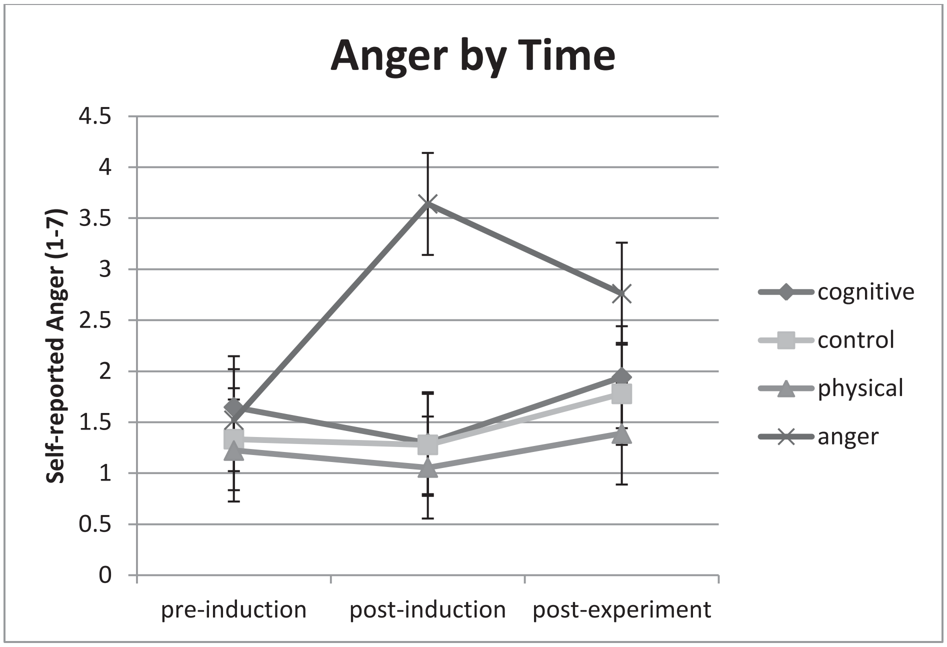

Figure 3 Anger scores as a function of time for all conditions. Error bars denote the 95% confidence interval.

5.2 Driving Performance

Manual log: Since each of these hazards is unique and occurs in a different environment with different speed limits, road conditions, etc., it is more useful to examine each hazardous event individually. Fisher's exact tests were run between all pairs of conditions for each of the hazardous events to investigate if there were differences in implicit performance scores between pairs of participants. Only hazards 1, 3, and 6 showed significant differences between any of the pairs at an alpha of .05. Each of these hazards will be examined individually.

Hazard 1 was a car swerving from oncoming traffic into the lane of the driver. For this event the distribution of the implicit performance ratings were significantly different for the cognitive and physical distraction conditions (p = .041) and the control and physical conditions (p = .027). The distributions of those scores can be seen below.

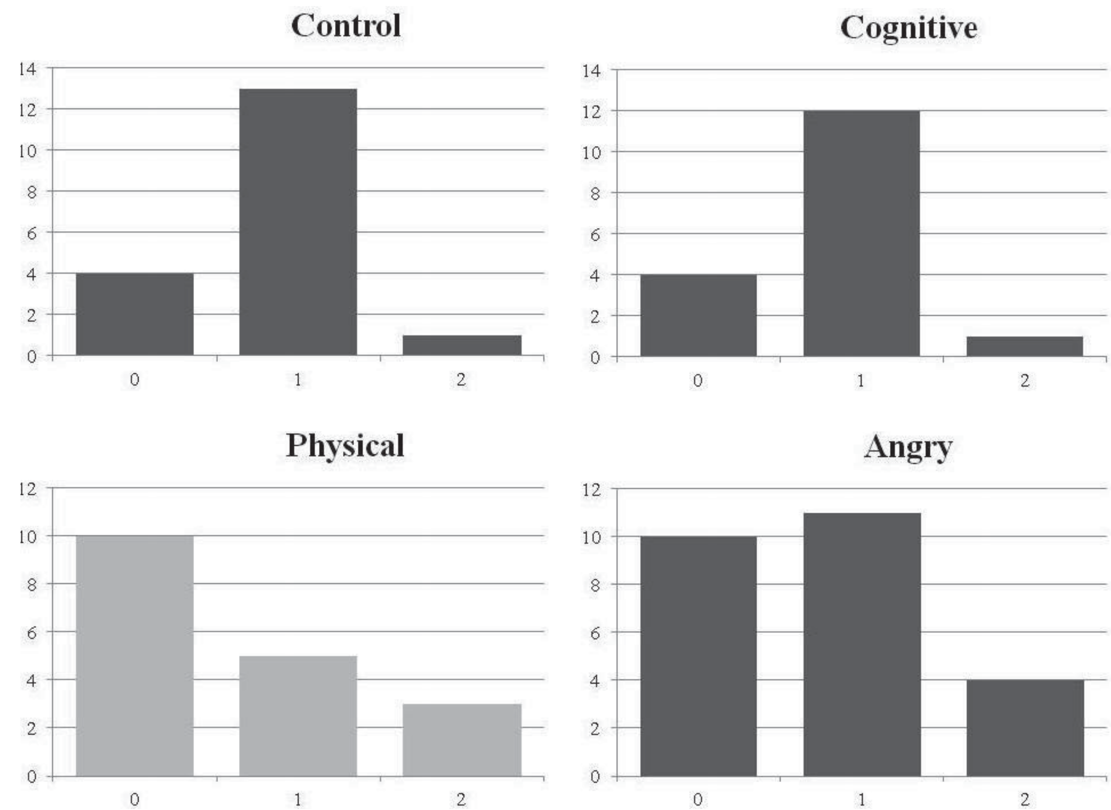

Figure 4. Hazard 1 Subjective driving performance scores across conditions.

There is a much higher proportion of 0 scores (corresponds with smooth avoidance/pass) in the physical distraction relative to the control and cognitive distraction condition. This suggests that drivers in the physical distraction condition are smoothly avoiding hazards at a higher rate than those in the cognitive or control conditions. This is an interesting result that is incongruent with hypothesis. Interpretation of this result will follow in the discussion section.

Hazardous event 3 is a traffic light that changes yellow as the driver is 4.3 seconds away. In this event the distribution of the implicit performance measures were significantly different for the anger condition relative to the cognitive (p = .0004), and control (p = .026). The physical and cognitive conditions were also significantly different (p = .013). These relationships are shown below (figure 5).

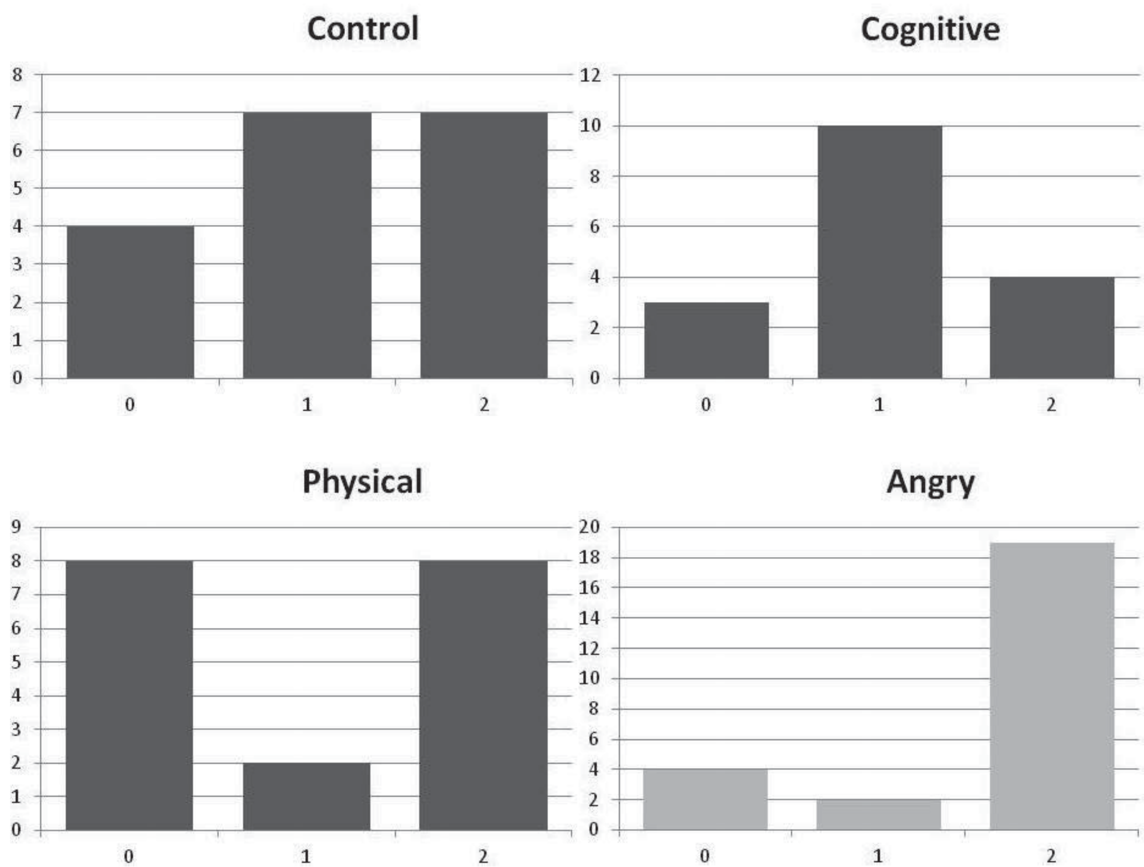

Figure 5. Hazard 3 Subjective driving performance across all conditions.

Event 6 was a hazard in which a parked car pulled into the road immediately in front of the participant without using a turn signal. In this event the control was found to be significantly different from both the physical (p = .007) and cognitive condition (p = .018). These results can be seen below (Figure 6).

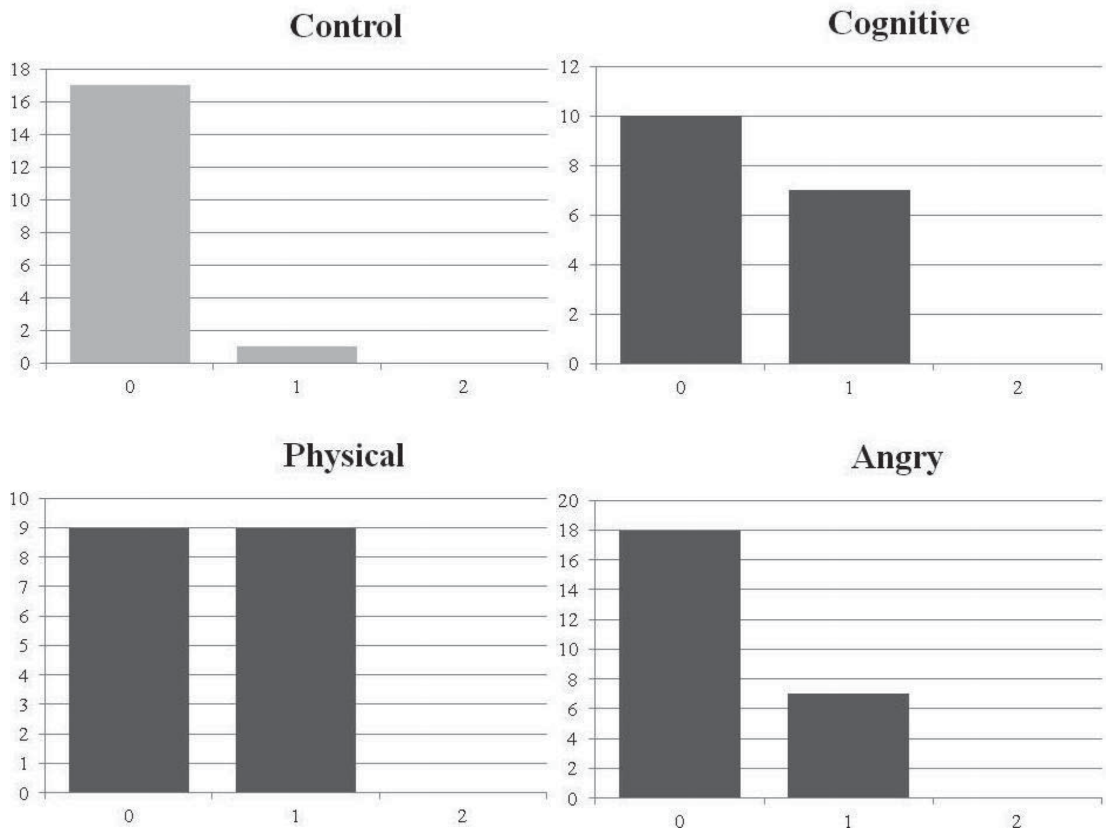

Figure 6. Hazard 6 Subjective driving performance scores across all conditions.

System log: As was done in the above manual log section, the system log was also examined for each of the hazards individually, reporting all statistically significant results and interesting non-significant results for Tukey-Kramer HSD tests.

Table 4. System log driving performance statistics. Mean and (standard deviation) are reported on the next page. Bold indicates that there significant differences on ANOVA and subsequent Tukey Kramer HSD ($p < 0.05$)

Hazard	Condition	Speed (mph)	Brake Pedal Force (lbs)	Lane Deviations (meters)	Accelerator Pedal Positions (n/1.0)
Hazard 1	Emotional	40.7 (.56)	0 (0)	3.81 (4.8)	0.211 (.04)
	Cognitive	42.1 (.51)	0 (0)	3.89 (4.8)	0.215 (.05)
	Control	40 **(.49)**	0.05 (.18)	3.79 (4.8)	9.205 (.06)
	Physical	39.5 **(1.0)**	0.3 (.69)	3.74 (4.9)	0.236 (.06)
Hazard 2	Emotional	35. (7.7)	6.7 (19.3)	3.9 (4.8)	0.19 (.14)
	Cognitive	36.8 (6.8)	6.7 (19.6)	4 (4.7)	0.21 (.13)
	Control	35.5 (6.7)	7.4 (20.0)	3.9 (4.7)	0.2 (.14)
	Physical	34.6 (7.6)	7.1 (20.8)	3.9 (4.7)	0.18 (.14)
Hazard 3	Emotional	**31.7 (5.7)**	**13.1** (17.6)	**0.76** (3.1)	0.19 (.15)
	Cognitive	**16 (10.8)**	**45.2** (40.2)	**.91** (2.9)	0.13 (.17)
	Control	20.5 (9.2)	30.5 (30.2)	0.44 (2.6)	0.15 (.13)
	Physical	21.9 (8.9)	25.6 (26.4)	1.1 (3.2)	0.14 (.15)
Hazard 4	Emotional	22.4 (14.0)	24.4 (48.7)	3.7 (4.8)	0.29 (.25)
	Cognitive	22.6 (12.4)	19.5 (35.8)	3.6 (4.9)	0.25 (.21)
	Control	22.4 (12.3)	17.9 (39.4)	3.7 (4.8)	0.27 (.21)
	Physical	21.9 (13.9)	26.7 (51.6)	3.7 (4.8)	.26 (.21)
Hazard 5	Emotional	24.7 (11.9)	13.6 (29.6)	3.3 (4.9)	0.24 (.20)
	Cognitive	23.6 (10.9)	11.2 (30.1)	3.3 (4.8)	0.24 (.17)
	Control	24.3 (11.0)	9.9 (24.9)	3.2 (4.9)	0.24 (.19)
	Physical	23.6 (11.7)	12.3 (31.3)	3.3 (4.8)	0.24 (.19)
Hazard 6	Emotional	36.3 (9.3)	4.4 (17.3)	3.8 (4.8)	0.24 (.16)
	Cognitive	36.7 (8.8)	3.6 (13.2)	3.9 (4.7)	0.22 (.13)
	Control	36.5 (8.1)	4.2 (16.3)	3.8 (4.8)	0.23 (13)
	Physical	37 (8.1)	4.2 (17.1)	3.8 (4.8)	0.22 (.14)
Hazard 7	Emotional	53.4 (5.3)	0.4 (.86)	3.6 (6.2)	0.39 (.17)
	Cognitive	54.2 (4.8)	0.37 (1.1)	3.7 (6.1)	0.39 (.18)
	Control	52.9 (5.2)	1.1 (3.6)	3.7 (6.1)	0.39 (.19)
	Physical	56.6 (4.0)	0.15 (.44)	3.7 (6.2)	0.42 (.20)
Hazard 8	Emotional	50 (6.5)	2 (4.0)	3.5 (5.1)	0.27 (.19)
	Cognitive	44.2 (7.1)	2.4 (5.0)	3.5 (5.0)	0.25 (.18)
	Control	43.4 (7.6)	3.2 (7.4)	3.5 (5.1)	0.26 (.20)
	Physical	56.2 (5.1)	1.6 (3.8)	3.5 (5.1)	0.25 (.18)
Hazard 9	Emotional	64.5 (5.5)	7.9 (12.9)	3.6 (4.9)	0.26 (.16)
	Cognitive	63.3 (5.9)	9.4 (16.4)	3.7 (4.9)	0.25 (.13)
	Control	56 (9.6)	21.3 (32.4)	3.8 (4.9)	0.24 (.18)
	Physical	63 (6.5)	10.9 (18.4)	3.6 (5.0)	0.24 (.16)

Hazard 1: Car from oncoming traffic swerves into participant's lane.

Two-way ANOVA analysis revealed that there were differences in mean speed between groups F(3,74) = 3.17, p = 0.029. For this event Tukey-Kramer HSD tests revealed that participants in the physical distraction condition (M = 1.03) displayed higher standard deviations than the control conditions (M = .487) for the speed standard deviation (p = .0487; d = .88). There was also a similar tendency between the physical and the cognitive (M = .505) (p = .0659; d = .85) and between the physical and emotional (M = .563) conditions (p = .0766; d = .76). However, these did not lead to conventional statistical difference. Likewise, ANOVA F(3,74) = 2.00, p = 0.12, and Tukey-Kramer HSD revealed that the physical distraction condition (M = 4.89) tended to yield larger standard deviations in lane deviation than the cognitive distraction condition (M = 4.77) (p = .108; d = .78) and higher maximum brake pedal force than control (p = .109; d = .766). All other measures were not significant or nearing significance.

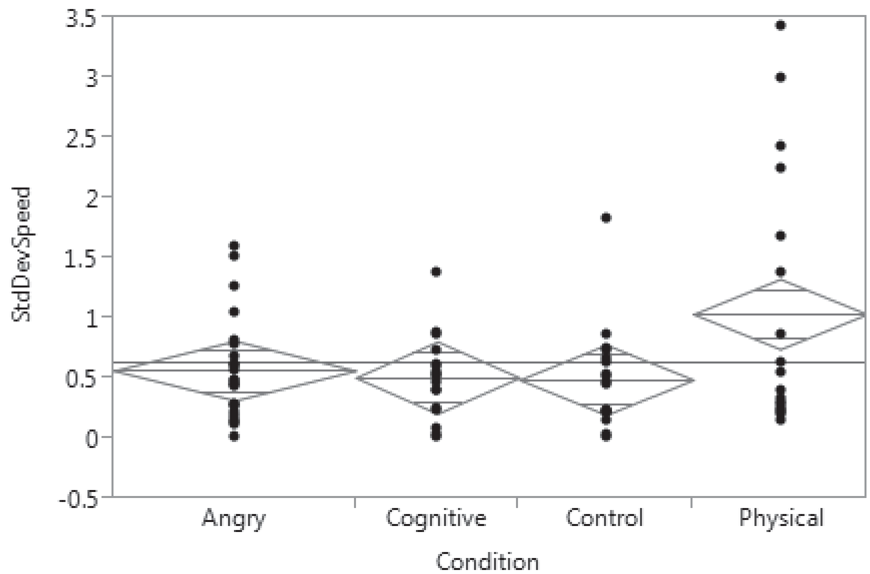

Figure 7. Standard deviation of speed for Hazard 1.

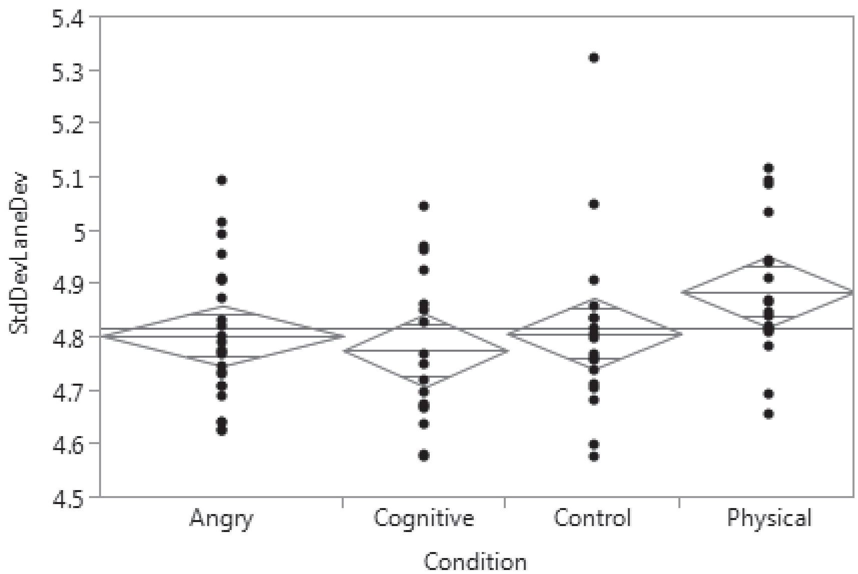

Figure 8. Standard deviation of Lane Deviation for Hazard 1.

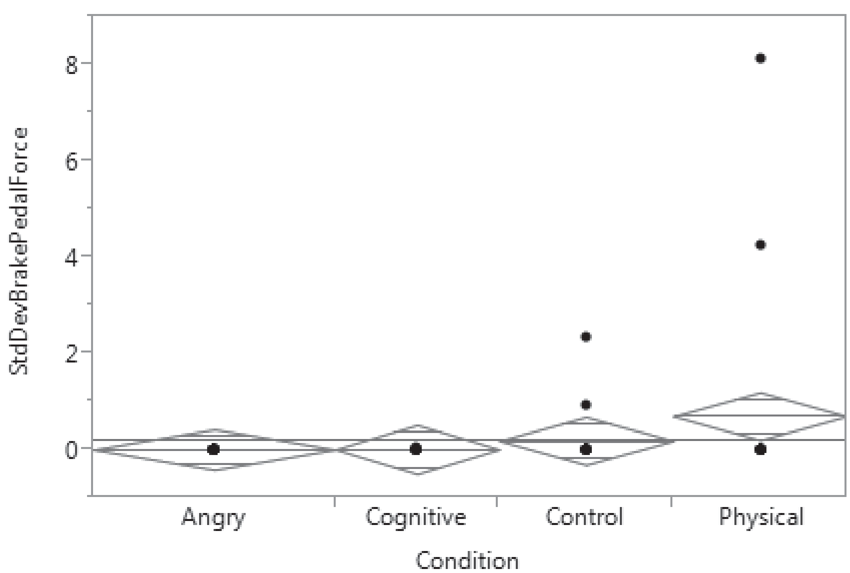

Figure 9. Standard deviation of Brake Pedal Force for Hazard 1

Hazard 2: Moped drives into road from the sidewalk

There were no significant results observed in this hazard event.

Hazard 3: Traffic light turns yellow upon approach

This event yielded many significant and interesting results. Two-way ANOVA results showed that the mean speed was different between groups $F(3,74) = 4.31$, $p =$ 0.007.Tukey-Kramer HSD tests revealed that mean speed (mph) was significantly higher for anger (M = 31.7) than cognitive (M = 16.0; $p = .0064$; $d = 1.06$) and numerically higher than control (M = 20.5; $p = .0783$; $d = .75$). ANOVA results also showed that there were inter-group differences in speed standard deviation $F(3,74) = 3.11$, $p = 0.03$. Tukey Kramer HSD showed speed standard deviation (mph) was significantly lower for the angry condition (M = 5.72) relative to the cognitive (M = 10.8; $p = .0255$; $d = .90$). Minimum speed (mph) was also higher for the anger condition (M = 25.2) relative to the cognitive condition (M = 8.59; $p = .0210$; $d = .931$). Interestingly, maximum speed showed no statistically significant differences between conditions $F(3,74) = 0.46$, $p =$ .709. ANOVA analysis demonstrates that there were differences in mean accelerator pedal position (%) between groups $F(3,74) = 2.94$, $p = 0.039$. Tukey Kramer HSD showed significantly higher (signifying pressing down on the pedal) for the anger (M = 19.2) condition relative to the cognitive (M = 12.5; $p = .0476$; $d = .83$). ANOVA $F(3,74) = 3.13$, $p = 0.031$ and subsequent Tukey-Kramer HSD showed the mean brake pedal force (lbs of force) was also lower for anger (M = 13.1) relative to cognitive (M = 45.2; $p = .0177$; $d = .95$) as well as the standard deviation of brake pedal force, ANOVA $F(3,74) = 2.65$, $p = 0.055$., Tukey Kramer HSD ($p = .0348$; $d = .87$). There were no other significant, near significant or interesting results for this event.

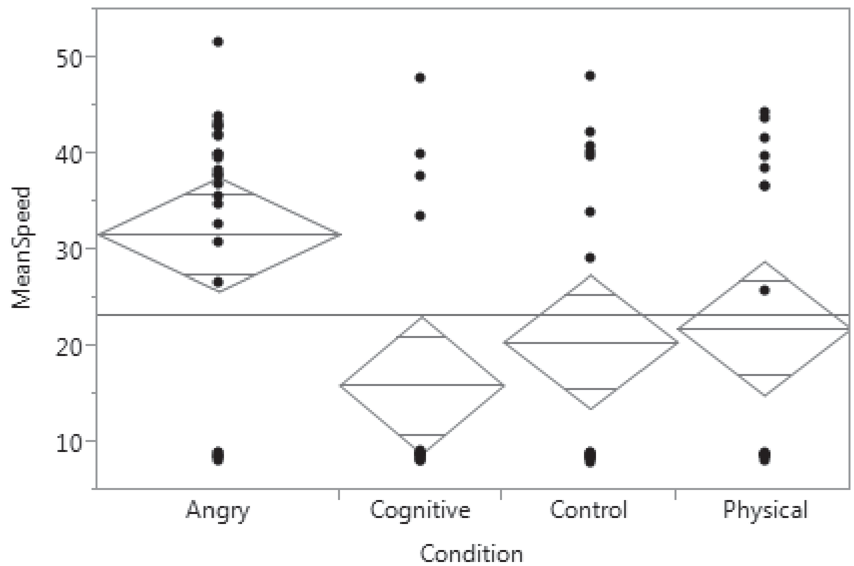

Figure 10. Mean speed for Hazard 3

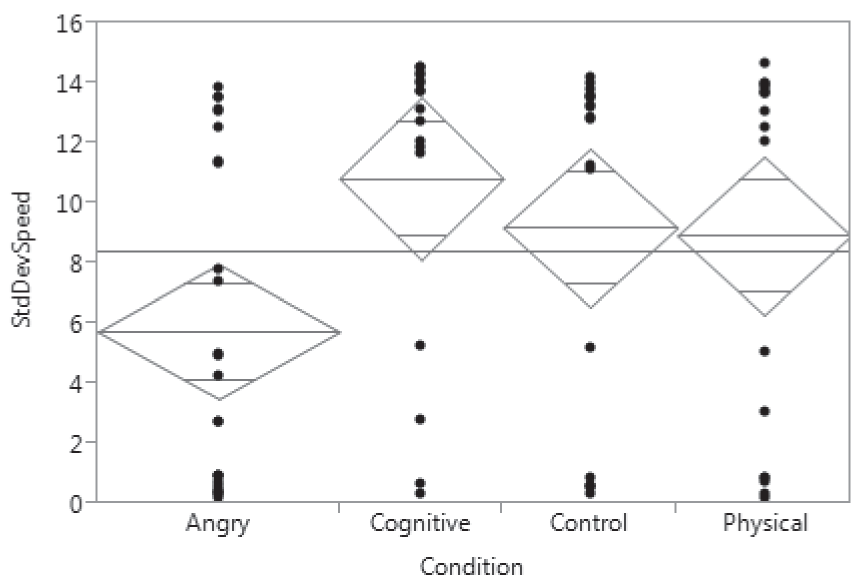

Figure 11. Speed standard deviation for Hazard 3

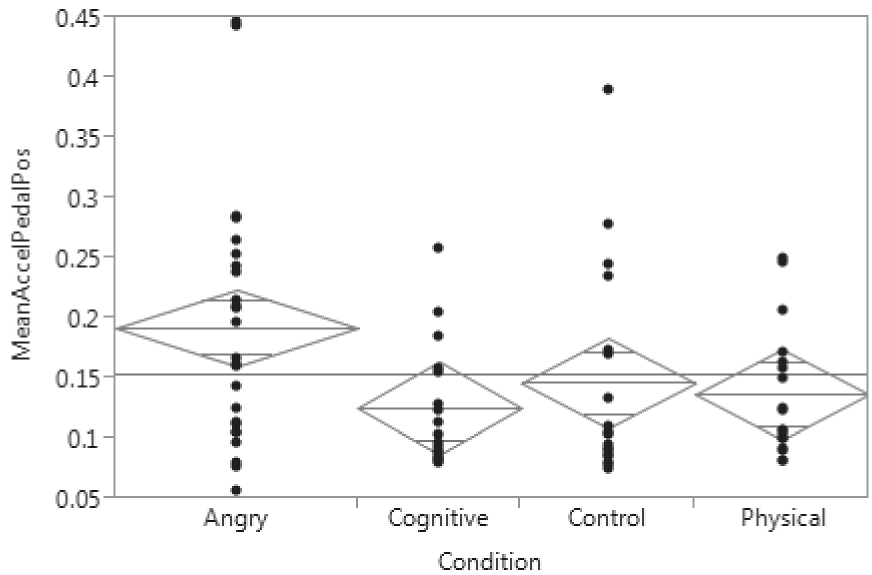

Figure 12. Mean Accelerator Pedal Position for Hazard 3.

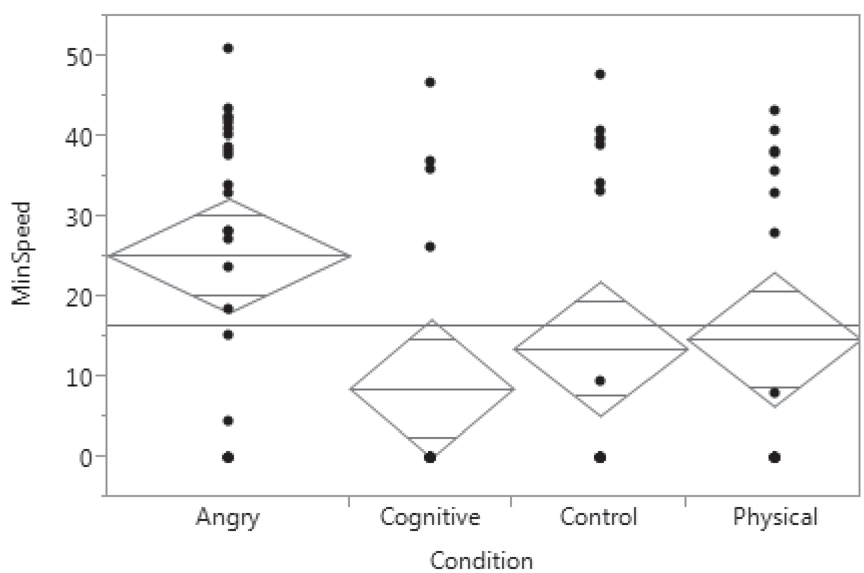

Figure 13. Minimum speed for Hazard 3

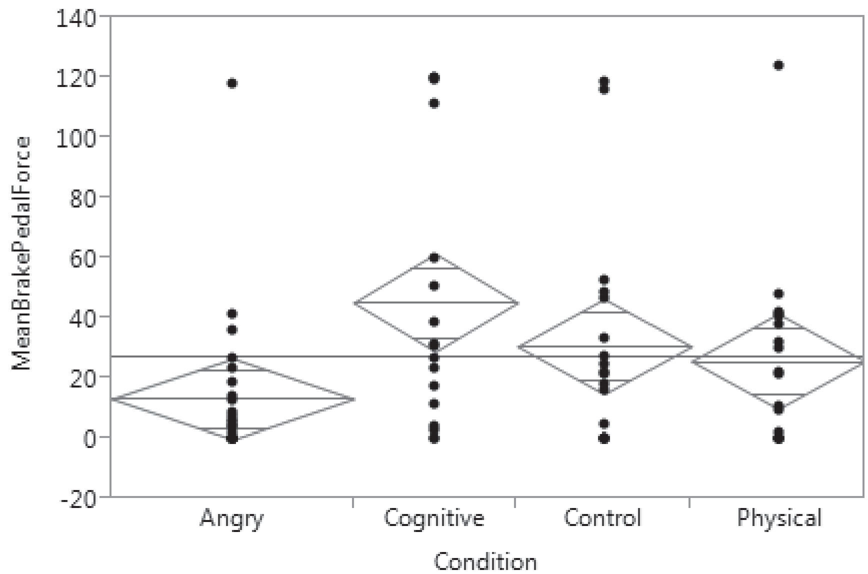

Figure 14. Mean Brake Pedal Force for Hazard 3

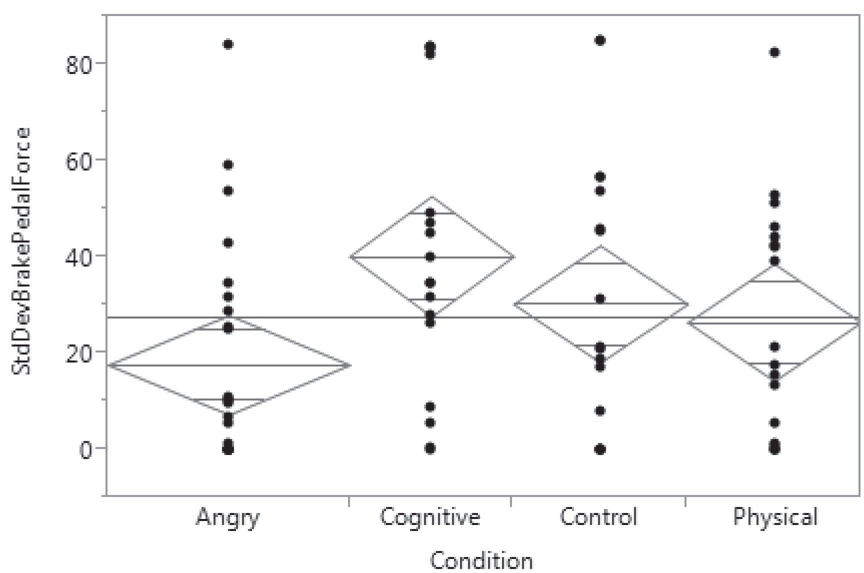

Figure 15. Brake Pedal Force standard deviation for Hazard 3

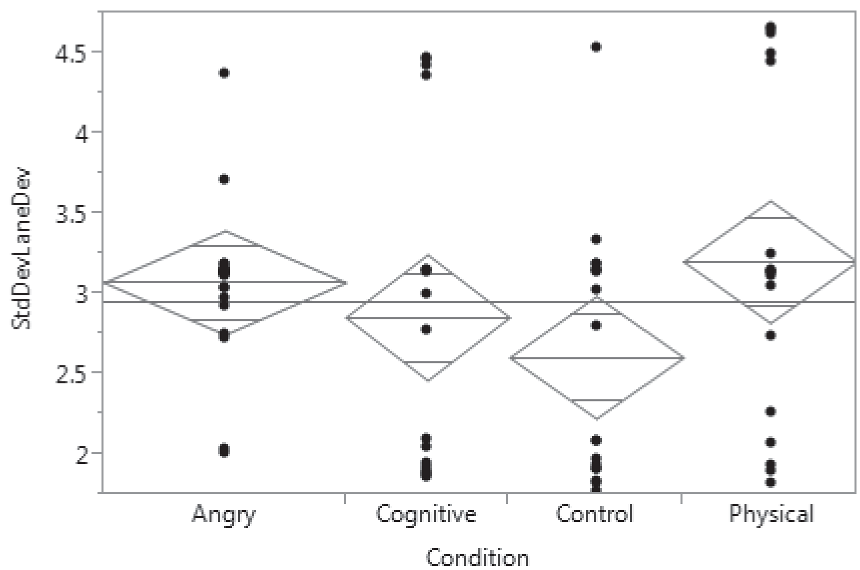

Figure 16. Lane Deviation standard deviation for Hazard 3

Hazard 4: Car makes a “u-turn” in from a parked position in front of participant

ANOVA results showed differences between groups in minimum speed $F(3,74) = 4.46$, $p = 0.006$. Tukey Kramer HSD tests showed participants in the cognitive distraction condition (M = 5.07) had significantly higher minimum speeds (mph) than the anger (M = .967; $p = .0055$; $d = 1.3$) and physical conditions (M = 1.24; $p = .0206$; $d = 1.0$). There were no other significant, near significant or otherwise interesting results from this event.

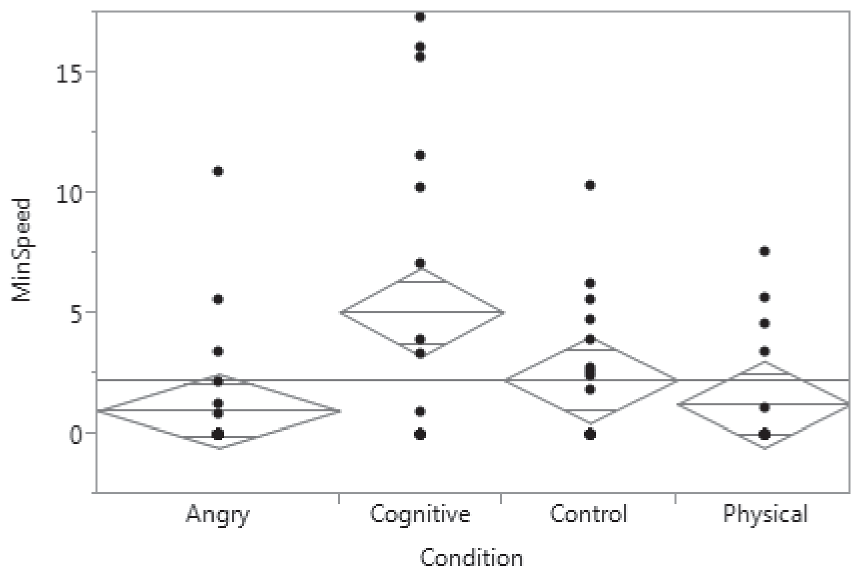

Figure 17. Minimum speed for Hazard 4

Hazard 5: Child runs into the street

There were no significant, or near-significant differences for this event. This result, in itself, is interesting and warrants discussion.

Hazard 6: Parked car pulls in front of participant without using signal

ANOVA results showed differences between groups in maximum accelerator pedal position $F(3,74) = 2.76$, $p = 0.048$.Tukey-Kramer HSD tests demonstrated that participants in the anger condition had a numerically higher max accelerator pedal position (%) (M = 60) than participants in the cognitive distraction condition (M = 46.3; $p = .0695$; $d = .76$). No other significant differences, or otherwise interesting results were found.

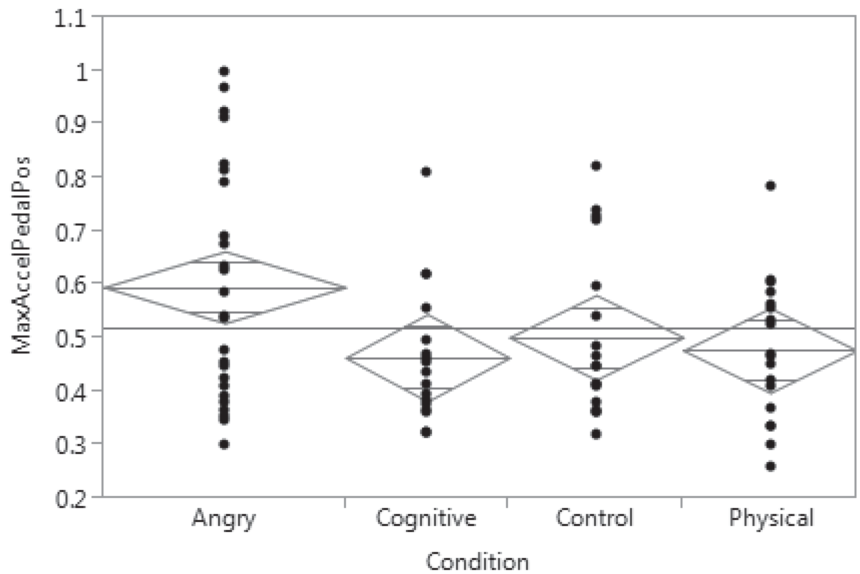

Figure 18. Max Accelerator Pedal Position for Hazard 6

Hazard 7: Semi does not yield lane while participant was merging onto highway

There were no significant, or otherwise interesting results found for this event.

Hazard 8: Construction in lane

There were no significant, or otherwise interesting results found for this event.

Hazard 9: Deer jump into the road

Two-way ANOVA results showed differences between groups in mean brake force $F(3, 72) = 2.23$, $p = 0.09$. According to Tukey-Kramer HSD tests, mean brake pedal force (lbs of force) was numerically higher for the control condition (M = 21.3) than the anger condition (M = 9.4; $p = .0779$; $d = .77$).

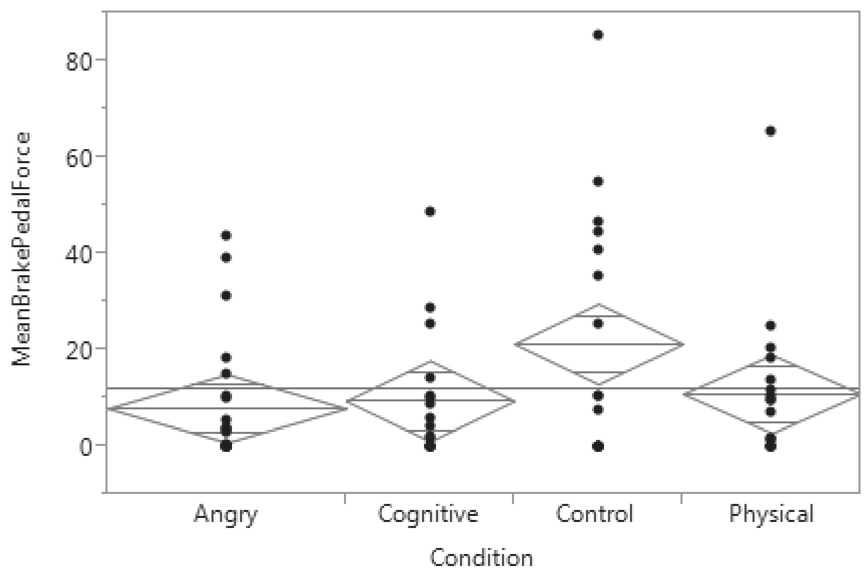

Figure 19. Mean Brake Pedal Force for Hazard 9

5.3 Workload

There were no statistically significant differences between conditions for any of the NASA-TLX subjective workload subscales, including mental workload F(3, 73) = .792, p =.502, physical workload F(3,73) = 1.72, p = .170 and overall workload F(3,73) = .518, p = .671. This result is contrary to predictions. Interpretations of this result will follow in the discussion section.

5.4 Eye Tracking

One-way ANOVA results showed that were no significant differences across conditions in variance in gaze position on the X- axis F(3,66) = 1.17, p = .328, and also on the Y-axis F(3,66) = .944, p = .425. Students t-test results on the eye tracking results shows that participants in the cognitive distraction condition had fewer glances to the instrument panel area than the anger condition t(66) = -2.78, *p* = .035; *d* = .94. However, there were no other statistically significant differences including standard deviations in x and y, as predicted.

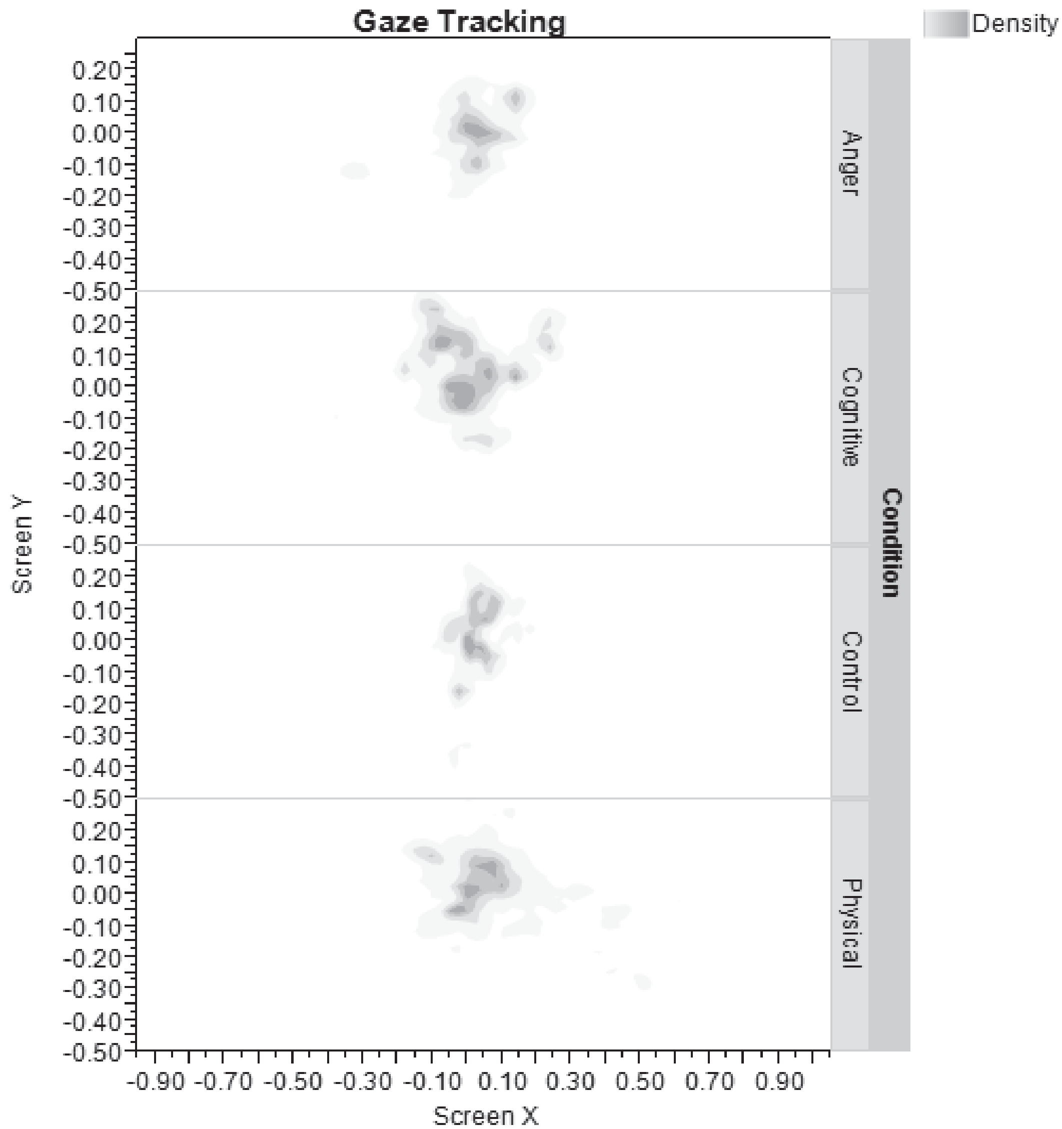

Figure 20. Eye tracking density plot for all participants over the entire drive.

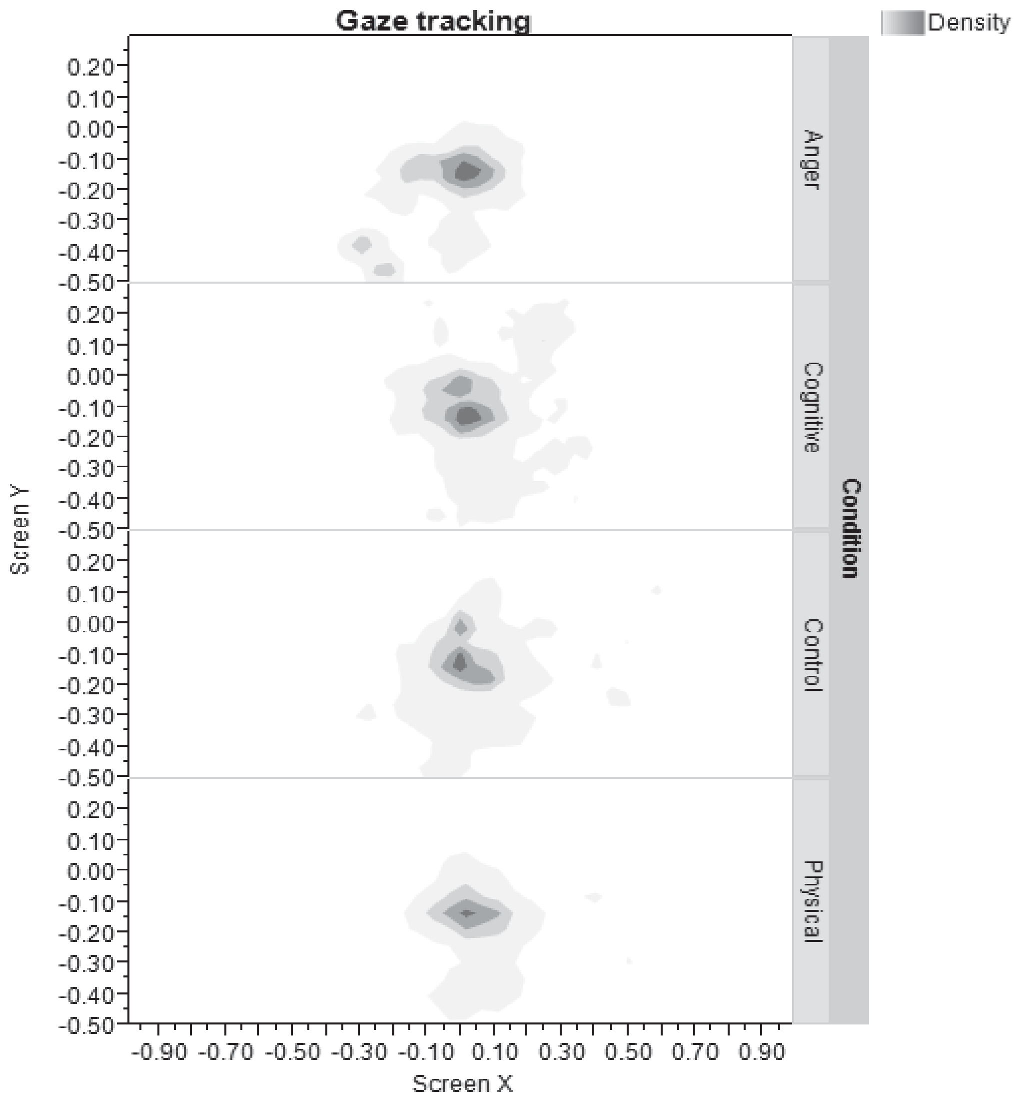

Figure 21. Gaze tracking density plot for all participants over the entire drive.

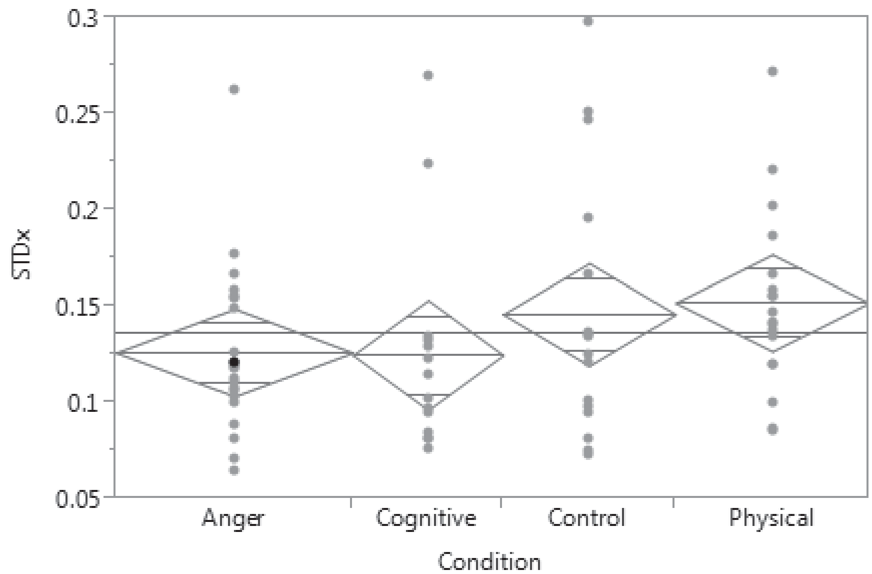

Figure 21. Standard deviation of X (hortizontal) across all hazardous events

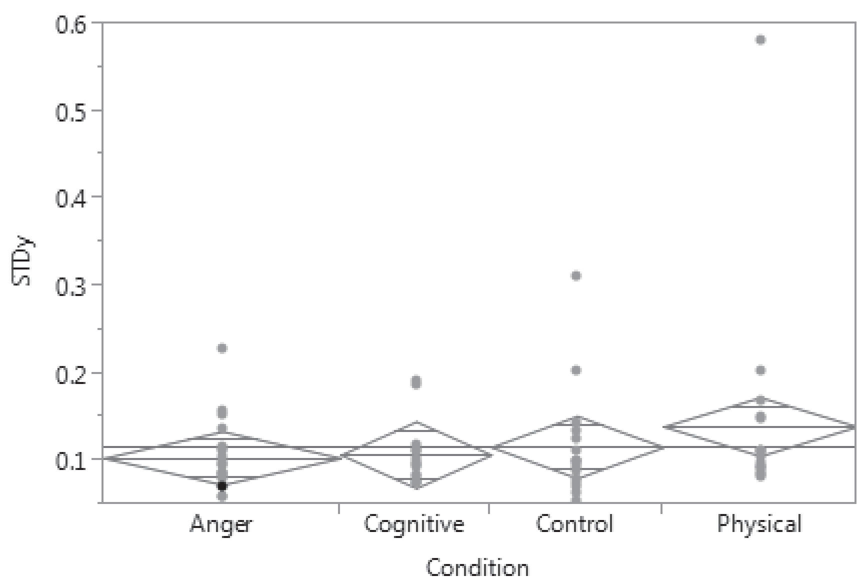

Figure 22. Standard deviation of Y (vertical) across all hazardous events

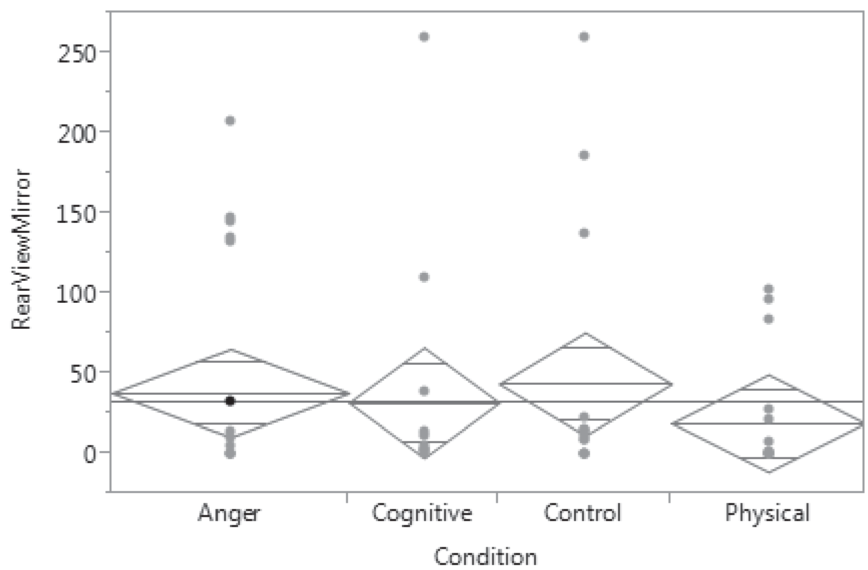

Figure 23. Number of glances at the rear view mirror across all hazardous events

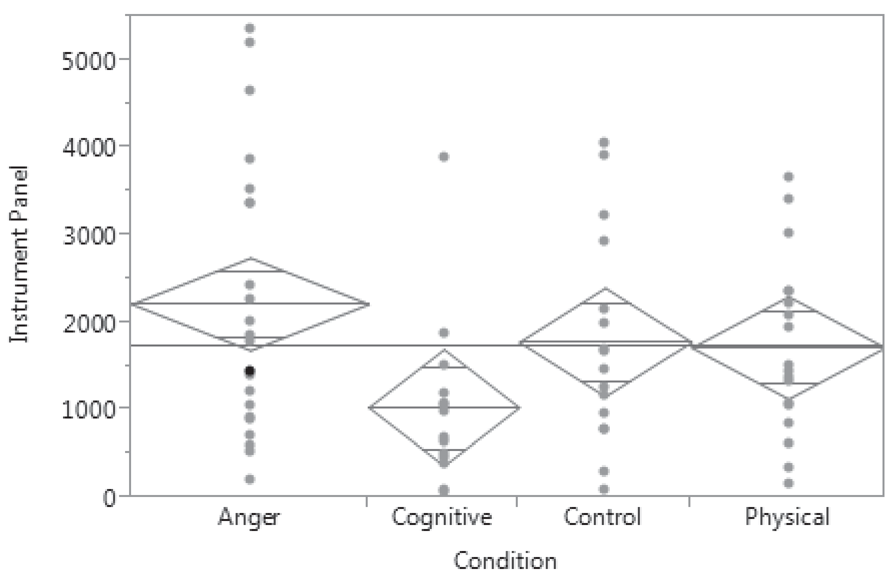

Figure 24. Number of glances at the instrument panel across all hazardous events.

6. Discussion

Fewer significant differences are to be expected in this study since the experiment was designed to be as ecologically valid as possible in order to avoid over-prediction of real world effects of distraction on driving performance. As Young and Regan (2007) mentioned, there are a number of distracted driving studies that over-predict crash rates and other negative consequences of distraction because of their lack of ecological validity. This study was designed to give participants more freedom to behave as they would in their day to day driving. As a result, participants in this study are likely compensating and modulating their driving behavior in a way that would mitigate the effects of secondary tasks. This likely makes the effects smaller and harder to detect, as was found in this study. However, the payoff for this type of experimental design is that it should be more representative of real world driving and, so, more generalizable.

To better understand the patterns of driving behavior associated with each of these conditions, it is important to view each of the hazards individually. The hazards will be analyzed below, beginning with the interesting results and following up with the non-significant differences.

Significant results

The first hazardous event (Swerving car) demonstrates the influence of the visual-manual secondary task. Drivers in the physical distraction condition showed degraded speed control, lane control, and brake control, as demonstrated by the differences in deviations of speed, lane position, and brake pressure. The increased variance in speed in this case is possibly related to the difference in brake pressure. As shown by the standard deviations in brake pressure, the drivers in the physical distraction were braking harder than drivers in other conditions. Additionally, the drivers in the physical distraction condition were deviating more in their lanes. The drivers who are completing the visual-manual task are swerving in their lanes, glancing between the tablet and road, and braking when a car "suddenly" appears in their lane. Drivers in other conditions were able to adapt to the hazard without braking. However, there was no observed difference in the implicit performance measures possibly because the drivers in the physical distraction condition were swerving to the right of the lane, away from the oncoming car, making collision avoidance an artifact of otherwise unsafe driving behavior.

The most interesting results came from the third hazardous event (Traffic (or Yellow) signal). The results for the third event point to significantly different driving behavior between the anger and other conditions. The angry drivers drove faster, on average, but not when comparing maximum speeds. Angry drivers also hit their brakes less frequently. This means that drivers in the angry condition are driving through the light at a higher rate than drivers in the other conditions.

The reasons for this are left to speculation. However, it is possible to get hints as to the underlying mechanisms by looking at the situation awareness scores and the eye tracking data. The results show that it did not happen. Additionally, if situation awareness mediates the effects of anger, then there should also be a difference in gaze tracking variance in both x and y axes. The results showed that there was a difference, although not near significance. It would also be expected that if the relationship is mediated by situation awareness, then the performance should be worse relative to the control condition across many of the hazardous events. However, that is not what the data suggest. The yellow light event was the only hazard for which the anger condition was significantly different from the control condition in the manual and system log. The difference observed on the third hazard also reflects results shown in other decision making studies. Angry people tend to make riskier decisions at higher rates than people who are not angry. The result from this study also seems to support the results by Abdu (2012). The data from this study suggest that anger influences driving, at least in part, through decision making. Although this result does not preclude the influence of situation awareness, the primary impact of anger on driving occurs in the presence of yellow traffic lights.

For the ninth hazardous event (deer jumping into road), the participants in the control condition hit the brakes at a higher rate and harder than participants in other conditions. Drivers in other conditions were not able to react to the deer jumping in front of the car. This could be due to speed, situation awareness, decision making, or combinations of those. While drivers in other conditions showed degraded performance in terms of brake pedal force, the collision rate was equal across all conditions. This is indicative of a possible ceiling effect.

Non-significant results

There were also several hazardous events which showed little or no difference between conditions. These results and possible reasons are investigated below.

In the second hazardous event (swerving motorcycle) there were no significant differences across the conditions. In this case, the result is most likely because the hazardous event was designed so that the hazard resolves itself. The motorcycle that swerves into the road will swerve back out of the road before the driver can possibly reach it. It is impossible for a driver to collide with the motorcycle. This makes differentiation between conditions in implicit performance more difficult.

Participants in the cognitive distraction condition had higher minimum speed for the fourth event (u-turn car), meaning that the drivers in the cognitive distraction condition slowed down less than drivers in other conditions. Drivers in the cognitive distraction condition also crashed more often than in the other conditions for this event. However, there was no other condition where the cognitive condition yielded such degraded results.

The fifth hazard (boy running into the street) showed no significant difference among the conditions. This is interesting because this hazard was very well designed for testing situation awareness. In this event, there is a child that runs into the street, but for a short duration it is possible to see the child running toward the street before being occluded by parked cars on the side of the road. However, there was no difference in implicit driving performance, number of collisions, or any of the objective, system logs. This suggests the result may be an artifact of an easy task, rather than a lack of influence from the experimental distraction types. It is also possible that drivers were modulating their driving speed or task switching to their primary task because of the curve placed in the road immediately before the fifth hazardous event. It is known that drivers compensate and modulate while completing secondary tasks, if the demands in the driving environment increase, such as when encountering a turn in the road. It is expected that drivers would compensate and cope with the hazard well if their attentional resources were devoted to situation awareness, as they would be if they were paying attention to the curve in the road. It is not certain that this is what happened during this task, but it seems to be a plausible explanation with a basis in research.

The sixth hazardous event (U-turn car) showed the drivers in the angry condition were hitting the accelerator harder (accelerator pedal position), after braking for the hazardous event (brake pedal pressure). This is congruent with the prediction that angry drivers should drive faster. The remaining dependent measures like mean speed and max speed did not show significant differences.

Although neither the accelerator pedal position nor the brake pedal pressure were not significantly higher for the emotional distraction condition, according to conventional statistical standards, the qualitative story is apparent. Drivers in the emotional distraction condition hit the brakes, and subsequently hit the accelerator, harder than drivers in the other conditions. This is congruent with predictions made in the introduction. Interestingly, there were several participants in the emotional distraction condition who showed similar pressures applied to the brakes when compared to other conditions and there were several in the emotional distraction condition who pressed the brakes harder than any driver in the other conditions. It is possible that this effect is mediated by a personality trait related to aggression, such that some people are affected by affect and others are not.

The seventh hazard (Truck at highway entrance) showed a floor effect. The scenario design was such that many of the drivers reacted the exact same way, regardless of condition. The truck appeared suddenly without being visible prior, as the driver merged onto the highway. The truck also matched speeds with the driver as he or she merged onto the highway. As a result, the truck was very difficult to avoid if the driving was aware of the truck or not. Any impact that a secondary task had on situation awareness would not be predicted to influence driving performance under these conditions because driver awareness did not appear to be related to the ability to avoid this hazardous event. This was observed qualitatively, as some of the drivers glanced left (not easily identifiable in the eye tracking data) prior to merging but the truck, indicating that they were checking to see if there was adequate room to merge safely. However, even these 'aware' drivers had similar difficulty coping with this hazardous event, as seen in the implicit performance measures and data from the system log.

The eighth hazardous event (merge for construction) showed little difference because the hazard event was easily avoided across all conditions, pointing to a floor effect due to hazard design. However, the lack of differences seen in lane deviations and speed are of some concern because there should be differences observed among the conditions, in the absence of hazards, as well as in the presence of hazards. The speed for the anger condition was predicted to be higher and the lane deviation for the physical distraction condition was predicted to be higher. These predictions were unfulfilled.

<u>Workload:</u> There were no differences between experimental conditions on any of the NASA TLX workload subscales or in overall workload. This result is contrary to

expectation because two of the subscales on the workload index correspond exactly with two of the experimental conditions in this study: physical and cognitive. It would be expected that participants in the physical distraction condition would report perceptions of higher physical workload and the same is expected for cognitive workload in the cognitive distraction condition. The cause for the lower than expected workload scores is likely a result of the nature of the secondary tasks used in this study. First, the physical distraction task was a typing task, which is not physically fatiguing so participants may not attribute the demands of the task to the physical workload subscale because of some semantic disagreement. The cognitive distraction condition was a simulated conversation designed to be very naturalistic. As such, the result might be a reflection of the perceived workload of a real conversation, which is likely low relative to tasks like arithmetic or N-back tasks. So, these low scores might be a consequence of using secondary tasks which resemble real world secondary tasks, which could be perceived as having low demand on resources.

Eye Tracking: The lack of traditional statistical difference found in the eye tracking results could be a result of noise in the eye tracker data. The result may also be due to limitations of the eye tracker system, which cannot easily detect eye movements on the periphery of the simulator space, i.e. at the outer edges of the monitors. But the most likely reason for this result is that the vast majority of the driving time was spent looking forward, even in the physical distraction condition. This is because the secondary tasks comprise less than half of the time, and even less of that time is spent with the driver's gaze directed away from the road ahead. This interpretation is supported by the density plots (Figure 20) which show that the concentration of the gaze position and head position are primarily at the center of the center screen and more diffuse around the edges, with considerable amounts of gaze directed at the instrument panel as well. The head tracking density plot also supports the suggestion that the participants are not looking away from the screen very much, again showing high density of gaze positions concentrated on the center of the screen. Even participants in the physical distraction condition, who were required to look away to perform the secondary task, gazed at the center of the center screen much more than anywhere else. The difference in variance for X and Y for gaze direction was not significant because the drivers were not looking away significantly more. The data has been watered down by noise because it was analyzed over the entire drive rather than each individual event. The result may be significant if analyzed by looking at each hazardous event individually.

Speed: The lack of increased speed for the emotional distraction condition is a cause for concern given that they were predicted from the results of other simulator studies. There are a couple possible explanations for the lack of observed increased speed for the emotional distraction condition could be because: 1) there may be no real difference in speed in this task, 2) there might be a real difference in speed but the effect is washed out by confounding variables, such as awareness of the speed limit. The lack of observed increase in lane deviation for the physical distraction condition is likely due to the compensatory strategies employed by drivers who were driving in a narrowed road (construction barrier narrows road to one lane). As a result of the demanding driving environment, drivers may have been neglecting or postponing switching attention to the secondary task until the road expanded to two lanes again.

Future directions: There are a number of things that future researchers would be wise to consider when continuing in this line of research. First, among the difficulties in analyzing this data is the decision to determine where and how big the windows of data collection should be surrounding each hazardous event. If the window is too small or too large it will affect the result negatively. Second, there appear to be some hazardous events within this specific driving scenario which yielded better results than others with regard to discriminating between different distraction types. If the goal of future research is to continue teasing apart these concepts, then concentrating efforts on hazards 1, 3, and 6 would be most efficient. Third, if the goal is to continue doing research which is ecologically representative, then the effect sizes are likely to be relatively small which means the sample size will likely need to be large (20 or more per condition) in order to get significant results on many things which appeared as only trends in this study.

7. Conclusion

The purpose of this study was to bring emotion into the discussion of driver distraction research. The hypotheses were set up to investigate the relationships between distraction types and also the underlying mechanisms mediating the relationships. Below are the stated hypotheses and their outcomes from the research.

Predictions: The hypotheses made a few specific predictions about the relative performance of participants in each of the conditions: Physical distraction will result in 1) increased probability of collisions and number of collisions and near-collisions 2) higher brake pressure 3) increased glances at IVIS 4) greater lane deviation; Cognitive distraction will result in 1) increased probability of collisions and near collisions (control < cognitive < physical), 2) higher brake pressure (control < cognitive < physical) 3) lower variance than control and physical gaze position; Emotional distraction will result in 1) higher risk of collisions and near collisions (control < emotional < physical), 2) Attentional narrowing causing reduced variance in gaze position, 3) increased speed (control < cognitive < physical < emotional).

Below is a summary of the results and whether they supported the hypotheses or not.

Physical:

1) Greater performance degradation - Fisher's exact tests on implicit performance did not reveal a pattern of performance degradation at a statistically significant level, as was expected.

2) Increased brake pressure - Brake pressure was demonstrated to be higher on hazard 1 (swerving car), however, not a level of traditional statistical significance.

3) Increased gaze variance - There was evidence supporting the possibility of greater variance among the physical distraction group, however, it was not reaching levels of statistical significance.

4) Increased lane deviation - There was evidence for the increased lane deviations associated with physical distraction, as seen in hazard 1.

Cognitive:

1) Greater performance degradation – Fisher's exact tests revealed no pattern of performance degradation. In fact, there was observed improvement on hazard 3.

2) Increased brake pressure – There was no recorded increase in brake pressure associated with cognitive distraction.

3) Attentional narrowing – There was evidence supporting the possibility of less gaze variance in the cognitive distraction condition. However, the differences were not approaching statistical significance

.Emotional:

1) Greater performance degradation –Fisher's exact tests revealed no pattern of performance degradation. In fact, there was observed improvement on hazard 3.

2) Attentional narrowing – There was evidence supporting the possibility of less gaze variance in the emotional distraction condition. However, the differences were not approaching statistical significance.

3) Increased speed – There was no evidence to support the hypothesis that angry drivers drive faster.

The role of emotion in driving behavior remains largely undefined, and the mechanisms that mediate the influence of emotion on driving behavior are still unknown. However, this study gives some clues about the nature of emotional influences on driving and gives support to the notion of including it among the major influencers on driving performance, on the basis of its obvious influence on hazards like traffic lights. Interestingly, in this study there were not very many results suggesting that the physical or cognitive distractions were significantly more dangerous, i.e., more collisions, or more near-collisions. The biggest difference was observed on the traffic light hazard, in which the angry drivers performed much worse than the other conditions. Since anger showed large effects, relative to the other distraction conditions, emotional distraction meets at least the *significance* criteria outlined in the introduction. Whether emotional distraction meets the remainder of the criteria set forth remains to be discovered.

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