THE EFFECTS OF AUDITORY SIGNAL RELIABILITY LEVEL AND SPATIAL LOCATION ON SIMULATED DRIVING PERFORMANCE

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ABSTRACT

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by Joseph V. Lenneman

Previous research has indicated an effect of signal location, system reliability and perceived trust in the utilization of automated systems and driving performance. In the current study a fictional guidance system named the smart traffic flow monitor (STFM) was used to examine the biasing effects of spatially presented auditory signals, and how varied auditory signal reliability effect simulated driving performance. The STFM was designed to mimic advanced driver assistance systems, such as adaptive cruise control, with added benefit of providing merge cues whenever the lead vehicle began to decrease its speed.

There were 60 University students who participated in the current study. The participants performed a driving task on a simulated three-lane highway scenario, which required them to merge into either the right or left lane safely after hearing instructions from an auditory merge cue. The merge cue varied between-subjects in both its spatial location and its level of reliability. Following completion of the driving tasks, subjects were asked to fill out the revised Trust in Automation Scale in order to determine subjective levels of perceived system reliability.

It was predicted that those in the spatially located merge cue group would have better driving performance and faster RTs to the merge cue than those in the central group. It was also predicted that as system reliability increased from 50%, to 70%, to 90%, driving performance and RTs would improve. Although the results demonstrated that those in the 50% reliability group had the lowest level of positive trust and the highest level of negative trust, all of the other hypotheses were rejected. It is believed that design limitations led to the lack of support for the remaining hypotheses.

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CHAPTER I

INTRODUCTION

Advanced in-vehicle technologies (IVTs) are often designed to enhance driver performance when they are faced with multiple task situations. As a result, the study and development of auditory signals designed to guide drivers through complex driving situations or alert them to impending collisions has been growing in recent years. Because of the development of more complex systems in the vehicle, drivers are becoming more reliant on automation to perform tasks that could normally be performed successfully without such assistance. Among these advanced IVTs are navigation and collision avoidance systems, which can alert the driver to which direction to go, what lane to merge into, or inform them of impending collisions.

However useful these automated systems may be when functioning properly, these types of alarms are commonly less than 100% reliable (Bliss & Gilson, 1998). Failure can be the result of a complete system break down or displaying inaccurate information to the driver. Automated systems use various signals and modalities to convey information to the user. The current study was concerned with four separate aspects of automated systems that utilize auditory signals: 1) the effects of various levels of system reliability on lane changing performance and collision avoidance, 2) the effects of spatially versus centrally located auditory cues, 3) the possible interaction effects of spatial signal location and signal reliability, and 4) how system reliability and spatial location of signals relate to hazard avoidance.

Many automobile accidents result from a failure of selective attention. Drivers either process the wrong visual image or select an inappropriate response (Trick, Enns, Mills, &

Vavrik, 2004). These decision-making processes and the risk of overloading attentional resources will affect driving performance, whether it manifests as increased RT to environmental cues, or exploration of the environment. Due to the limited amount of attentional resources available, incorporating new IVTs that are intended to improve driving performance may end up having the opposite effect, often times resulting in drivers being distracted from the road (Bliss & Acton, 2003).

A fictional guidance system named the smart traffic flow monitor (STFM) was used as a cover story to mask the purpose of the current study. The STFM was described as a general guidance system, rather than an alerting system, similar to many global positioning systems (GPS) used today. The STFM was designed to alert drivers to guide the drivers in traffic while allowing them to maintain a desired speed as well as avoid collisions with surrounding traffic. The system's features included functions that serve to help the driver maintain a desired speed and proper lane positioning.

Although it is desirable to develop a system that is 100% reliable, often this is not a realistic goal. Because of the inevitable occurrence of system failure, one of the main purposes of this study was to examine appropriate levels of system reliability by measuring how low reliability can be while maintaining system usefulness and the ability to improve performance. The current study also aimed to determine the optimal spatial location (central vs. lateralized) of the auditory signal so that the driver utilizes the system and does not ignore the instructions altogether. However, the effects of IVTs and auditory distracters must be further understood first in order to lay the foundation for the rest of the discussion within this study. The more technology changes, the more cautious researchers and engineers must be before designing and implementing systems that might distract drivers from what should be the primary task of driving.

In-Vehicle Auditory Distracters

Auditory information has a vast presence within the typical vehicle cabin. The most common of which is likely the dashboard stereo. As practiced as listening to the stereo may be for many drivers, it can have an effect on driving behavior through either distraction or the impact it may have on the driver's mood. According to Dibben and Williamson (2007), as people increase their exposure to music while driving, their performance of the primary task of driving suffers. Distraction can occur in one of three ways, 1) through visually looking at and manipulating the device that plays the music, 2) through auditory masking of other sounds, and 3) the music may trigger thoughts that are unrelated to driving.

There are numerous other distractions in vehicles besides music that can affect driving performance. For instance, Liu (2001) compared the effects that auditory (A), visual (V) and multi-modal (AV) displays in a vehicle can have on simulated driving performance. The instrumentation used by Liu attempted to mimic common global positioning systems (GPS) of 2001 by displaying text, along with an auditory modality display. Participants were instructed to perform three separate tasks in a driving simulation. Participants were asked to navigate a simulated driving scenario while performing a push-button task. The tasks were presented 1) visually, 2) auditorily and 3) bimodally (AV). In the visual modality, participants were asked to identify information icons (e.g., temperature gauge, oil light) and text road information (e.g., construction ahead or heavy fog). The auditory stimuli conveyed the same information as the visual stimuli except they were presented auditorily. There was also a bimodal display that presented both the auditory and visual stimuli simultaneously.

Liu (2001) found that auditory and bimodal displays of information resulted in decreased reaction time (RT) and a higher total number of correct turns than the visual display modality. Alternatively, exposure to only the visual modality resulted in the most unsafe driving performance, as those participants varied their lateral acceleration, lateral lane position and steering wheel position significantly more than either of the other two modality conditions. Liu attributes these findings to increased demands on drivers' attention within the visual modality. However bimodal information allows the driver to confirm the information presented to them through audition with visual information.

As Liu (2001) and Dibben and Williamson (2007) demonstrated, the use of IVTs can affect driving performance, including RT and collision avoidance. However, in order to establish the foundation for the current research's predicted hypotheses it is necessary to more specifically understand the relationship between signal location and its effect on driving. The signals presented in Liu's study were displayed from a central location, however, what happens when stimuli are presented spatially? Will spatial presentation of auditory and visual stimuli prove more beneficial to driving behavior while minimizing strains on attentional resources than stimuli presented centrally?

Spatial Attention

In order to minimize confusion later on in this thesis, there are a few key terms that need to be explained further. Information can be displayed to drivers in many different ways. When I discuss "spatially located signals", I am referring to signals that are presented in locations other than the center (in relation to the driver for the current experiement). In the following studies that will be discussed, spatially presented signals came from either the front/back or right/left side of the driver.

Redundancy refers to providing informative signals in a relevant location (e.g., spatially located auditory instructions such as “merge left” presented on the left side of the vehicle). All signals were spatially redundant in the current experiment. Signal congruence refers to whether or not the informative signal is congruent with the desired driving behavior. For instance, when measuring merge responses to auditory cues of either “merge left” or “merge right”, a congruent signal was a signal that would instruct the driver to perform a safe merge to the instructed side. If following the merge instruction would result in a merging into a congested lane, then the signal would be incongruent with the appropriate driver response.

Hatfield and Chamberlain (2007) studied the role that in-vehicle entertainment might have in diverting driver attention from the road by manipulating spatial location of the signal. They accomplished this by presenting a radio broadcast from the front speakers, an auditory sample from a movie that was presented from behind the front seats (in order to simulate modern rear seat entertainment), and a baseline condition that consisted of driving only. Results indicated that when participants heard auditory stimuli coming from speakers positioned on the back of the front seats, they approached a simulated pedestrian at a faster rate of speed than in the baseline condition. Also, those in the front speaker condition (radio) were more likely to collide with other vehicles than baseline. Hatfield and Chamberlain (2007) caution that the findings of the radio condition may reflect Type I error based on the number of tests conducted.

Spence and Read (2003) examined the effect of speech shadowing from both a front and side/rear loudspeaker while participants maneuvered through a driving simulation. Participants were required to repeat as many words as they could from a relevant stream of word triplets coming from either the front or side/rear loudspeaker. Due to the natural tendency to maintain visual attention forward while driving, participants shadowed more words correctly when the auditory stimuli were presented from the front than when they were presented from the side/rear of the vehicle during the driving task. Spatial location of the loudspeaker did not result in significant detriments to driving performance.

Although their participants performed better on the side task when shadowing the front speaker as demonstrated by faster RT and more correctly shadowed words, Spence and Read (2003) found that they also drove faster in this condition, though, these driving performance results were not statistically significant. Perhaps the absence of a significant effect of the side task location on driving was due to the participant's having to continuously shadow a word stream. The experimenters did not instruct the participants as to how they should prioritize the performance of each task. Due to the lack of instructions regarding how they should time-share the separate tasks, the participants might have placed little importance on the side task and instead developed strategies to maintain a desired level of driving performance. This concept will be further explored in later chapters of this paper.

Using spatially presented auditory information, such as those in the previous two studies, may be harmful to driving performance when those signals serve as a distraction. Participants actually drove faster when information was presented spatially than from a more "central" location. However, many IVTs are more specifically designed to inform the driver about changes to the current status of their surroundings in the hopes of increasing driver safety. It is commonly the goal of guidance systems such as the STFM and similar IVTs to attract visual attention to a particular spatial location so that the driver can then make an informed decision on what course of action to take. What are the benefits of using auditory signals to cue the driver as opposed to a visual signal? Can cross-modal links between these two modalities prove beneficial to time-sharing of information between audition and vision?

Cross-modal Links

The use of auditory signals in new IVTs may prove beneficial to driving performance by alerting drivers to possible collisions, but the effect of these signals on visual attention needs to be explored. The existence of links between auditory and visual modalities may prove helpful for drawing the visual modality to a specific location by initially alerting a different modality (e.g., auditory) (Wickens & Hollands, 2000, Singh, 2011). In fact, previous research has indicated that cross-modal links in attention exist and are determined by locations external to the driver (Eimer, Cockburn, Smedley & Driver, 2001). Because of the suggested links between auditory and visual modalities, driving performance may benefit in regards to RT and collision avoidance when drivers are faced with a hazard event. According to Wickens (2002), using auditory signals while driving will allow for better time-sharing between vision and audition of incoming information. In turn, driving performance will be maintained at an acceptable (safe) level.

Driver and Spence (1998) examined the existence of cross-modal links in spatial attention. They note that when a stimulus is expected in a particular location, participants improve their judgments of not only the target modality (e.g., audition) expected in that location, but also of a secondary modality (e.g., vision) in that location. Again, the secondary modality (e.g. vision) will be drawn to the location of the "target" presented in one target modality (e.g.

audition) even when a stimulus in the second modality might be more likely to occur in another location.

McDonald, Teder-Salejarvi and Hillyard (2000) questioned the idea that stimuli presented in one particular modality (audition or vision) would automatically attract spatial attention in other modalities to the same spatial region as a target location. In their study, participants were presented with one loud speaker and four light-emitting diodes (LEDs) in a square and one LED in the center of the square on both the right and left side of their visual field. The center LED of each square represented the target stimulus with the surrounding four lights representing a visual mask. The auditory cue from one of the loudspeakers and the mask would appear on the same side 50% of the time (valid trial) and on opposite sides the other 50% of the time (invalid trial). Participants were asked to respond to the target stimuli by pressing a button with either their right or left hand. The authors found that whether speed or accuracy was stressed, participants performed better if the target was on the same side as the cued stimuli (valid trials). The authors suggest that similar congruent spatial presentations of stimuli will enhance participant's perception of spatial attention.

Buchtel and Butter (1988) hypothesized that spatial cues in a secondary modality (e.g., audition) would be as effective as in the primary modality (e.g., vision) in attracting spatial attention to a target stimulus. Visual targets were single red LEDs on both the right and left side of the participant. Four LEDs surrounding the target in a square pattern represented the visual cue stimulus and auditory cues were small white noise bursts that came from behind the visual target. Participants responded to target stimulus by releasing a microswitch with their right thumb. Buchtel and Butter found that auditory (secondary) cues were as effective as visual (primary) cues in drawing attention to the visual target (Experiment 1). Furthermore, the RTs associated with auditory cues were faster than those of the visual cue. Buchtel and Butter suggest that when the cue and the target stimulus are in the same modality, participant responses may be delayed, and require more time than if the information is in different modalities.

According to Wickens' (2002) multiple resource theory, decreases in visual spatial task performance with visual side-task cues happens because both the visual stimuli of the primary task (e.g., driving) and the visual side-task draw on limited spatial-attentional resources, which can result in decreased performance of either one of the tasks. The decrease in performance would be the result of the lack of enough attentional resources that are required by the combination of the tasks. If the combined required attentional resources do not exceed the total capacity of available resources, then the tasks can be time shared effectively.

Typically drivers prioritize the task of driving as imperative, and would allocate more resources to this task, resulting in decreased performance of the side-task. With auditory spatial cues being a side-task to driving, competition for spatial-attentional resources is reduced as compared to two sets of visual-spatial cues. Therefore both the side-task and primary driving task are able to be time-shared more effectively. As a result, driving performance will not suffer as much as if the side-task was presented visually.

Johnson and Proctor (2004) reviewed auditory and cross-modal attention and concluded that auditory stimuli can be advantageous to spatial perception by making participants aware of an auditory cue that will alert the other modalities for further investigation at that particular location. Auditory stimuli can be perceived from any direction whereas visual stimuli can only be detected in the spatial region around where the person is currently looking. Therefore, the ability of auditory cues to draw visual attention to a particular spatial location suggests that information presented in the auditory modality can improve visual selection. Johnson and

Proctor also note that the spatial separation of sounds makes it easier to pay attention to one sound and ignore another, perhaps making auditory stimuli more advantageous as a side-task cue when visual attention is required elsewhere.

Although bi-modal stimulation of audition and vision were beneficial for performance in some of the studies already discussed, a number of those studies were concerned with tasks that did not involve simulated driving. However, as discussed with Wicken's (1992) multiple resource theory, using visual stimulation in a side-task while driving may have negative consequences to performance. The demand on visual attentional resources is dependent upon whether the visual stimulus used required focal or ambient visual attention. Focal visual attention focuses primarily y on object recognition and requires high visual acuity, whereas ambient visual attention is more concerned with aspects of spatial orientation (Previc, 1998). If a secondary task requires focal attention, driving performance should be worse than if the side task requires ambient attention because focal attention is more demanding upon attentional resources than ambient (Wickens, 2002).

In the current study, the use of auditory signals should have allowed for better time-sharing of incoming spatial information so that driving performance would not suffer as it would if the incoming information were presented visually. Using bi-modal stimulation (AV) in the STFM side-task would likely negatively affect driving behavior due to the overlap in spatial information and lack of attentional resources available. Therefore, the signals used in the side-task of the current study only contained auditory cues.

Auditory signals such as the ones that were used in the STFM of the current study will not require long term recall, only short term recognition. Also, the previously reviewed studies utilized simple auditory cues (e.g., white noise, radio broadcast, etc.) on driving performance, and not the use of informative signals that were implemented in the current design. The use of informative signals may be able to decrease on the overload of attentional resources, whereas non-informative signals may prove distracting to the driver. As cross-modal links between vision and audition may help our time-sharing capabilities, the use of informative signals could decrease mental effort by reducing the amount of attentional processes that are involved in making informed decisions. In terms of the current study, participants made informed decisions on whether or not to merge into an instructed lane after receiving an informative cue that is either congruent or incongruent with the correct merge decision.

Informative Signals

An "informative signal", is a signal whose meaning is inherently informative to guide attention to a particular spatial location. For example, a car horn may not be informative to the driver of the vehicle, whereas the words "front" or "back" presented to the driver visually, auditorily or bimodally can be. Drivers are able to ascertain spatial information with informative cues that may prove beneficial to information processing and reduce demands upon limited attentional resources.

Ho, Tan and Spence (2006) instructed participants to discriminate the color of a license plate after being presented with either spatially located (front or back) vibrotactile ("tactors" placed on both front of chest and middle of the back) or auditory (car horns) warning signals while also performing a rapid serial visual presentation (RSVP) task. The RSVP task was presented in front of the participants and consisted of 66 target words per session block. They used red vs. blue-plate discrimination as opposed to front vs. back in order to eliminate possible response cuing by the spatial location. Although the authors found no significant effects in the vibrotactile spatial study (Experiment 1), participants in the auditory spatial study (Experiment 2) had significantly faster RTs to the target visual task. Participants were faster in detecting change in the target car's license plate color when the target event occurred in a similar spatial location to the auditory cue than when the auditory cue's spatial location was opposite to the target event. Because of these faster RTs to spatially predictive auditory cues, Ho et al. concluded that informative auditory warning signals could direct a driver's visual attention to a particular region of space.

It is evident that cross-modal links between vision and audition exist, making it possible for auditory cues to draw visual attention to a desired location. The use of informative signals may draw attentional resources to a particular spatial location even more effectively. However, drawing visual attention to a particular spatial location could prove detrimental to driving performance when the auditory cue is a false alarm. False alarms can alert users of the system to draw their attention to a particular location when there is no reason for such an alert (Wickens & McCarley, 2008), which could be a distraction and could harm driving performance. The effects of guidance and alert signals on driving performance are directly related to the reliability of the system to provide the driver with the maximum number of hits and minimum false alarms.

Auditory cues from the STFM in the current study, or other guidance systems like it, can be beneficial when the signal is 100% reliable; however, most automated systems have the propensity to fail at some point. It is important to understand the reliability level at which continued use of the automated system would decrease performance of the simulated driving task. Furthermore, at what point do users stop relying on the system, and instead rely on their own abilities? Answering these questions will help to determine the point at which utilization of the system is advantageous, as well as the level of reliability at which the system is deemed useless or harmful to driving performance.

System Reliability and Trust

Trust in an automated system is dependent upon system reliability. In the context of the current study, system reliability refers to the system's accuracy of merge instructions and not a particular failure of the system. As reliability of the system increases, so does the operator's trust in that system (Bliss & Acton, 2003). Trust with technology has also been shown to develop similarly to trust developed with other humans; however, there are differences. Initially, automated systems are seen as more credible than their human counterparts (Madhavan & Weigmann, 2004). In fact, it seems that there is automation bias that initially occurs where participants will trust a system, even more than a human aid (Dzindolet et. al, 2003, Parasuraman & Manzey, 2010).

On the other hand, perceptions of the system's actual abilities eventually change as the user becomes more exposed to system failures. An operator who learns to mistrust a system through repeated exposure to errors will inevitably ignore or stop using that system. In large part, participants discontinue their use of automated systems that utilize cued locations due to the "cry wolf" effect (Bliss & Dunn, 200, Bliss & Acton, 2003, Wickens & McCarley, 2008). With the "cry wolf" effect, users who mistrust a system often times might choose to ignore alarms presented by that system. However, occasional failures do not reduce trust in highly reliable systems; trust will only be reduced by low reliability when failures become sustained over time (Parasuraman, 1997). When presented with an unreliable system in the current study, it was hypothesized that the operator will divert their attention to the cued location, however, after progressively learning that the system is non-predictive or unreliable, they would find less of a reason to use the system and therefore rely on their own abilities (Wickens & McCarley, 2008).

Dixon, Wickens and McCarley (2007) measured the difference between misses and false alarms on driver compliance and reliance of both a tracking task and a system-monitoring task. Participants were instructed to maintain their tracking cursor close to a designated point in the middle of the screen using a joystick while monitoring the system (e.g., the system monitoring task) for “system failure” given by an information gauge toward the bottom of the screen that alerted the participant to system failure. The monitoring task presented the participants with variations in altitude and displayed an ideal altitude for a “safe” system as well as a “safe” altitude range. They found that false alarms were negatively associated with both reliance on and compliance with the system, whereas misses were only negatively associated with reliance. Compliance with the system was lowered for users who were presented with false alarms. Performance of both the primary tracking task and system monitoring tasks suffered with false alarms as in the form of slower RT and lower accuracy in the system monitoring task. Dixon et al. (2007) suggest that RT was affected because participants had to evaluate the system failure compared to incoming raw data, which could lead to longer intervals between responses and more incorrect decisions.

False alarms will therefore affect reliance on and compliance with the automated system through the decline in the driver’s trust in the system’s ability to perform its designated function without fail. The user may also be more confident in his/her own ability to perform the task that the system was designed to do and therefore may avoid using the system altogether. In regards to driver performance, numerous false alarms might convince the user to ignore the system which could force the driver to reassess possible critical situations. Reevaluating the situation before making a decisive action would require more time, which could prove costly in case of an impending collision.

Wickens and McCarley (2008) discussed the importance of automated systems (alert and guidance systems among others) and the level at which the system's reliability affects driver performance. According to the authors, both trust and the user's dependency on the system will decrease as the level of system reliability decreases. Interestingly they note that even when system reliability is low (70% or less), the user may still continue to partially depend on the system. With systems that are 50% reliable (non-predictive), the user will rely more heavily on his/her own abilities than that of the system. On the other hand, if the system is reliable more than 80% of the time, users will generally be assisted by and rely more heavily on the automated system (Dixon & Wickens, 2006).

As noted by Parasuraman, Sheridan and Wickens (2000) and Parasuraman (2000), there can be negative effects of both highly and minimally reliable systems on use of and trust in automated systems. With a highly reliable system, the user may become complacent and fail to prepare for an action that is required of them such as a driver being unprepared to react to an impending collision. The driver's initial skill set may also diminish as a result of the lack of practice intrinsic to dependence upon the highly to fully automated system. However, occasional failures do not reduce trust in highly reliable systems; trust will only be reduced by low reliability when failures become sustained over time (Parasuraman, 1997).

Verberne, Ham and Midden (2012) further concluded that trust and reliance of an automated system within a vehicle (i.e., adaptive cruise control) would be impacted by whether or not the user and the system have the same goals. Adaptive cruise control systems update standard cruise control systems by focusing primarily on maintaining a constant following distance with a lead vehicle, rather than a constant speed. To the degree that they share a goal (i.e., distance from the lead vehicle) and that goal is not violated, users will continue to trust and utilize the system.

In the present study, a signal was deemed reliable by the extent to which it gave the driver instructions that were congruent with the appropriate driving behavior (e.g., “merge left” when the left lane is clear to merge into). Reliability was varied between highly reliable (90% hit rate, 10% false alarm), moderately reliable (70% hit rate, 30% false alarm) and non-predictive (50% hit rate, 50% false alarm), where the only system that demonstrated sustained failures was the non-predictive system. In this case, participants should have learned to ignore the system and rely on their own abilities.

The level of system reliability is not the only independent variable that was manipulated in the current study. As previously discussed, the current study also manipulated spatial presentation of the incoming auditory signal. It is now important to review what previous research has shown when both spatial presentation and level of reliability of an incoming guidance or alert signal are manipulated.

Spatial Attention, Reliability, and Spatial Redundancy

Tilak, Xholi, Schowalter, Ferris, Hameed, and Sarter (2008) studied cross-modal links in spatial attention in a complex environment and wanted to expand upon previous research of alarm system reliability to examine how cue modality, levels of mental workload and stimulus onset asynchrony (SOA) affect driving performance. Participants performed a simulated driving task while instructed to avoid “roadside mines” that would be either cued by tactile (wrist sensors) or auditory stimuli (one-second monotone beep). These cues were non-predictive as they were presented at the target location and a non-target location equally often. The authors found that RTs to the roadside mines were faster and more accurate when validly cued by either the tactile or auditory stimulus. Comparatively, tactile cues to the roadside mines resulted in more errors (as measured by accuracy to visual targets) than the auditory cues. Although the level of system reliability was not manipulated in this particular study, reliability was critical to the procedure, as the participants understood that the system was non-predictive of target events. Further studies however have varied reliability levels as another independent variable.

Alert or guidance signals presented to the driver may not only be informative, but may also be spatially redundant as well. Informative signals could prove advantageous over non-informative signals when attempting to guide attention to a particular region of space. Making these signals spatially redundant may prove even more useful in minimizing the possible overload of attentional resources by capitalizing on both the semantic and spatial meaning of the signal. This reduction in attentional load may prove beneficial to driving performance if they could allow the driver to allocate more attentional resources to the task of driving.

In their 2005 study, Ho and Spence examined the possible benefits of spatially presented auditory warning signals (e.g., car horn in Experiments 1, 2 and 3; verbal instructions “front” and “back” in Experiments 4 and 5) to emergency driving situations in a simulated driving task. Through five experiments the authors varied the reliability of the cue from non-predictive (50% cue location validity) to predictive (80% cue location validity). Participants were asked to watch a simulated driving video while responding appropriately to either a possible front or rear-end collision by using the brakes. An RSVP distracter task consisting of 17 distracter letters and 6 target digits was administered visually on a mirror directly in front of them.

In Experiment 5, participants were required to respond to spatially present verbal auditory cues with varied cue reliability. The verbal instructions “front” and “back” were redundant as they were presented from a relevant spatial location (“front” coming from the front of the vehicle and “back” coming from the rear of the vehicle). Results demonstrated that the most effective alerting system was the system used in Experiment 5, resulting in the fastest overall performance. The authors do note however that in their simulation there were no other auditory distractions that might require attention such as are typical in a real world setting (e.g., talking on a cellular telephone, listening to the radio, etc.). They caution that with these other stimuli present, similar systems as the one used in Experiment 5 might confuse the driver.

Bliss and Acton (2003) more specifically studied the possible effects of collision alarm reliability on driving behaviors such as frequency of alarm response, collision avoidance and appropriate driving responses. They used three different levels of reliability (50%, 70% and 100%) with auditory warning cues (1000 Hz sine wave pulse at 90dB SPL) coming from either the front center console (Experiment 1) or from different spatial locations (e.g., left rear, rear, or right rear of the vehicle in Experiment 2). Participants were required to determine if the alarms signaled an approaching car (true alarm) or not (false alarm). If the signal was a true alarm, they were then required to swerve in the appropriate direction in order to avoid a collision. In both experiments, the authors found that swerving reactions and RTs to a true alarm were improved when the systems were more reliable than when they were unreliable or non-predictive.

An interesting finding in Bliss and Acton (2003), however, was that the 50% reliability group avoided collisions better than the more reliable groups. The authors suggest that this outcome was due to the fact that the system was so unreliable that the participants were more cautiously attending to the rearview mirror than relying on the system. Furthermore, the experiments were run between groups and the experimenters instructed each participant on the reliability group they would be in. Therefore, participants in the 50% reliability group might have developed driving and navigation strategies in order to compensate for the non-predictive nature of the system. The authors further concluded that the signal they used (sine wave pulse) might have been too intrusive to participant's attention, as participants initially would make the correct merge decision. However, the participant would then over compensate the wheel, resulting in a collision.

Whether signals are presented to drivers spatially or centrally, the driver must be able to perceive the urgency of the information so that they can determine the proper amount of attentional resources that they should devote to processing the information. Trust in the automated system is more likely to be influenced when the environment is dynamic (such as driving) and when the system clearly indicates that it can help the user accomplish their goal (Lee & See, 2004). The benefits of auditory cues presented to drivers have already been established, but in can auditory cues convey the necessary urgency in the event of hazard?

Verbal Signals and Urgency

Drivers must be able to distinguish the level of urgency any particular situation requires so that they may respond accordingly. In order to make this distinction, the alert signal must convey information that conveys the importance of the current situation. Driving situations vary in their levels of urgency and therefore the information presented to the driver via guidance or alert systems should also vary in a way that driver's perceived level of urgency matches the situation. With the STFM which was used in the present study, not only did the system alert the driver to change lanes in order to maintain a desired speed, but it also alerted them to sudden collisions that might occur. In order to accomplish this, the alert signal must vary levels of perceived urgency across nominal to hazardous driving situations.

Hellier, Edworthy, Weedon, Walters, and Adams (2002) demonstrated that the female voice provided a greater range of urgency (e.g., verbal cues “note” – “deadly”). Participants’ ratings of urgency level changed more across monotone, non-urgent, and urgent conditions for the signals that were presented with a female voice than for a male voice. Signals that were rated at the highest level of urgency were spoken louder, and with a greater range of pitch. Because of the greater perceived range of urgency with female voice, a woman’s voice was used to record the auditory speech signals in the current study to convey different levels of urgency between the nominal and hazardous conditions.

Alert signals can also convey differing levels of urgency through the amplitude (volume) of the alert signal. According to Baldwin and May (2005), collision avoidance signals presented verbally of higher amplitude were regarded as more urgent by participants than the signals presented at lower amplitude. Participants were presented with collision avoidance system warning signals that varied in both semantic meaning (e.g., “notice” and “danger”) and presentation level. The authors found the fewest number of collisions were attributed to the combination of words at the lower perceived urgency (Notice) with the highest amplitude. The signals used in the two studies discussed varied single word signals, which also affected perceived urgency. The current study utilized two-word phrases (i.e., “merge left” or “merge right”). The only distinction in urgency between the standard and hazard trials was the amplitude at which the instructions from the STFM are presented. The signal for the more urgent hazard trials were presented at a higher decibel level.

Additionally, the use of speech signals has been shown to be more beneficial than auditory signals (e.g., tones) in a number of scenarios. Such scenarios would include "when listeners must identify a message source, when they are without special training in coded signals, or if workload or stress might cause them to forget the meaning of a code" (Haas & Edworthy, 1996, p. 190). Speech often minimizes confusion about the incoming signal is asking the driver to do because speech is naturally informative. Even if confusion of the incoming signal is minimized, which helps reduce mental workload; the underlying theories and the effects of various cues on attentional resources must be considered. Understanding these theories can help to explain when and how attentional resources may become stressed, and result in a negative impact to performance.

CHAPTER II

PRESENT STUDY

Technologies within the average vehicle are becoming increasingly complex and often place a burden on the driver's attentional resources for the system and driver to function properly. Many criteria need to be considered before implementation of such devices. In order to remain safe on the roads, we must understand exactly how our brain processes these systems and the possible consequences in the event of system failure.

As driving is naturally a visual task, presenting additional information through the auditory channel will allow for the primary driving task and auditory side task information to be time-shared and processed simultaneously better than if all sets of incoming information were presented as a single modality (Wickens & McCarley, 2008). However, presenting incoming information in separate modalities does have consequences. Even though the modalities may be different, the processing of auditory and visual information will require some central processing which will cause some resource competition (Wickens & Hollands, 2000).

Because driving is also a spatial task, alert signals presented spatially may prove more beneficial due to their ability to draw attention to a desired location. However, the cost of these signals on attentional resources might outweigh the benefits. When the driver encounters false alarms with spatially presented signals, there may be an increase in mental workload that would confound the situation by requiring the driver to re-assess the current driving environment before making a final decision of what action to take. As many real-world driving situations are often under time constraints and could have critical consequences, understanding the costs as well as the benefits of spatial versus centrally located auditory signals is crucial.

In the current study, both system reliability and spatial location (show in Fig. 1) of the auditory signal were manipulated between groups. The researchers informed participants that the study was helping to develop a "smart traffic flow monitor" (STFM) with the aim of assisting drivers to maintain speed in traffic while avoiding backups. Merge cues were presented to the driver when the lead vehicle slowed down to a point at which a merge would be required to maintain their speed. Again, auditory signals were used based on the predicted benefits of time-sharing abilities as compared to visual signals that may require more visual attentional resources than are available.

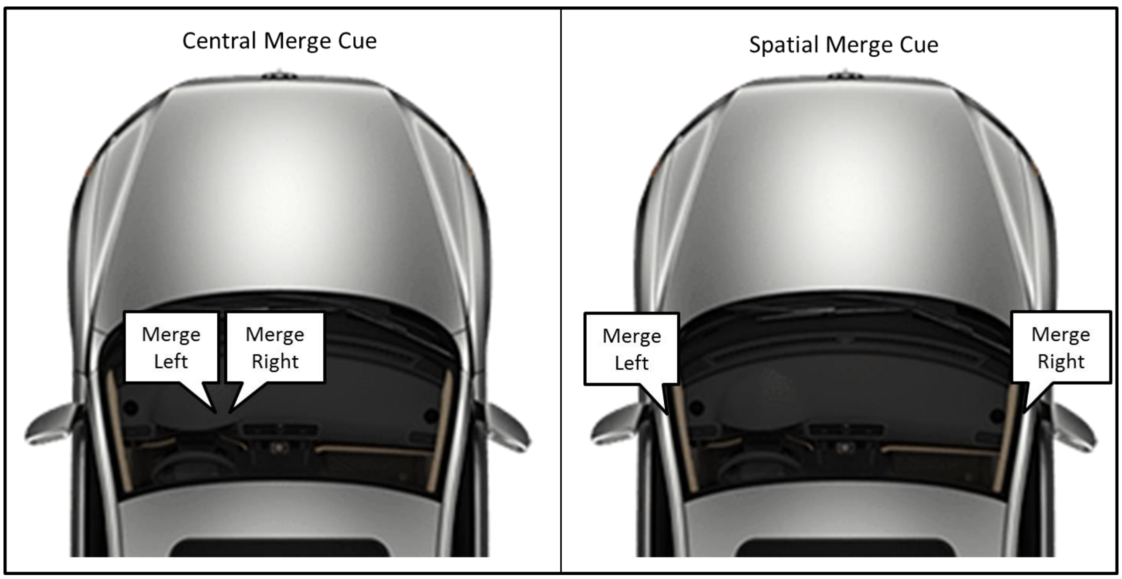

Figure 1. *Examples of the approximate spatial location of the merge cues. With the Central Merge Cue, the instruction was presented from a center position in relation to the driver's position. With the Spatial Merge Cue, the instruction was presented from the appropriate side door speaker*.

The participants started out in the middle lane of a three-lane highway with varying levels of traffic on either side. During each trial, one lane was congested, whereas the opposite lane was open. Participants performed 21 separate driving trials in which they were be required to merge either right or left one time throughout each trial. Participants were presented with merge cue instructions from the STFM and required to determine if the instructions were (in)congruent with performing a safe merge, as seen in Figure. 2. They then were required to respond by pressing a button on the rear side of the steering wheel accordingly and with the goal of merging into the open lane. Pressing the button on the right automatically merged the car right, and pressing the button on the left automatically merged the car left. Merge cue instructions were deemed congruent if the lane the participants were instructed to merge into would result in a safe merge. However, if the lane was congested and the merge would result in a collision, the merge cue was then considered incongruent and the participant should have merged into the opposite lane (which was always unoccupied).

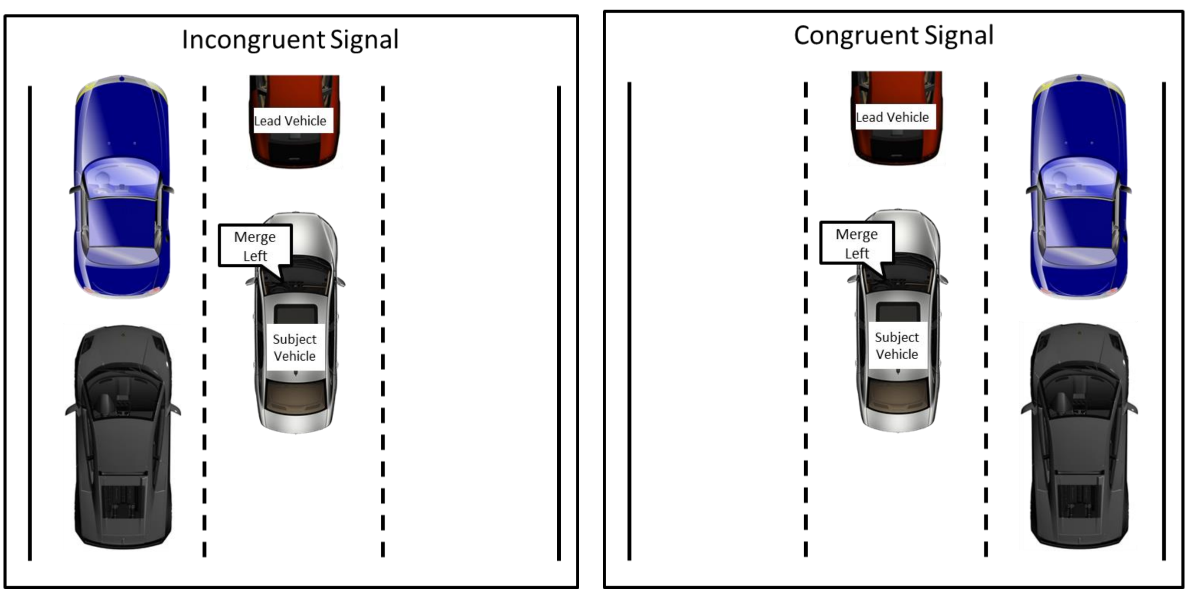

Figure 2. *Examples of congruent and incongruent merge instructions that come from the STFM. With the incongruent signal, the STFM instructs the driver to merge left when the left lane in congested and taking this action would cause a collision. With the congruent signal, the STFM instructs the driver to merge left where the traffic is clear and taking this action would result in a safe merge.*

Driving performance was measured by RT to the onset of the auditory signal, ratio of accurate merge responses upon hearing the merge cue, and the number of collisions with the lead vehicle. RT was determined by the amount of time (measured in hundredths of a second) it took the participant to respond to the auditory cue by pressing a button on the rear side of the steering wheel. The ratio of accurate merge responses was measured by the button press merge decision that participants made to the merge cue. If the merge cue was congruent, participants should have changed into the instructed lane safely. If the merge cue is incongruent, participants should have merged into the opposite lane in order to avoid a collision with the lead vehicle.

There was also a measure of driving responses to a critical event that took place during the final trial of the experiment as the lead vehicle which the participant was instructed to follow braked suddenly, requiring the driver to merge either left or right. The merge cue was presented at a higher decibel level to present a sense of urgency to the driver. Again, the auditory signal reliability and spatial location of the signal was manipulated to assess predicted effects.

Hypotheses

Previous research has demonstrated that auditory cues are able to draw a driver's attention to a particular spatial location, even if only for a short duration (Ho & Spence, 2005, Spence 2010). In particular, Ho and Spence found that predictive and redundant auditory cues were most effective in drawing attention to a relevant direction.

Hypothesis 1: Spatially redundant auditory merge cues will result in better driving performance than centrally located merge cues, as demonstrated by faster RTs to the merge cue, a higher ratio of accurate merge responses and fewer collisions with the lead vehicle.

System reliability can also impact attention and alertness as it has been demonstrated that the more reliable a system, the more RTs to an alert signal were improved (Bliss & Acton, 2003, Bustamante, Bliss & Anderson, 2007). Ho and Spence (2005) found similar results of faster RTs to an impending collision. However, when the system's level of reliability is low or unpredictive, operators tend to distrust the system and consequently may decide not to utilize it, relying on their own skill over that of the system. For example, Bliss and Acton (2003) found that the participants in the group with the lowest level of system reliability (50%) avoided rear-end collisions better than those in the higher reliability groups. They proposed that this was due to the signal they used. It was believed to be invasive to participant's attention and subsequently the researchers found that those participants in the low reliability group were more frequently checking the rear-view mirror and not relying on the system for guidance. Beller, Heesen and Vollrath (2013) had similar findings, indicating that participants in their uncertainty group showed a higher level of situation awareness. Lastly, previous research has indicated that uncertainty of a cue in one sensory domain could negatively impact the linking of modalities, whereas the less reliable signals would be less useful (Heron, Whitaker & McGraw, 2004).

Hypothesis 2: As system reliability increases from 50%, to 70% to 90% driving performance will improve as demonstrated by faster RTs to the merge cue, a higher ratio of accurate merge responses and fewer collisions with the lead vehicle.

Bliss and Acton (2003) varied the reliability and location of a signal and found an interaction that demonstrated better driving performance as measured by swerving reactions and RTs. However, because redundant auditory cues have been shown to draw attention to spatial locations, perhaps when the signal is incongruent, central presentation of the cue would be beneficial in that attention is not automatically pulled to the incorrect direction.

Hypothesis 3: There will be an interaction between system reliability and signal location such that:

A) The highest level of system reliability (90%) combined with spatially presented merge cues will result in the fastest RTs and the highest ratio of accurate merge responses.

B) Centrally located auditory merge cues will result in faster RTs to the merge cues than those presented spatially when an incongruent signal is presented to the driver.

Trust in the automated system has been shown to increase as system reliability increases, encouraging the operator to take advantage of system functionality (Bliss and Acton, 2003).

Hypothesis 4: Trust in the smart traffic flow monitor (STFM) will increase as a function of increasing system reliability from 50%, to 70% to 90% reliability.

Hypothesis 5: The highest level of system reliability (90%) combined with spatially presented merge cues will result in the fastest RTs, the highest ratio of accurate merge responses and fewer collisions in the hazard trial.

CHAPTER III

METHOD

Participants

There were 60 participants in the current study, of which 19 were male and 41 were female. Ages ranged from 18-35 years old. Participants were recruited through Central Michigan University's Department of Psychology's participant recruitment pool and were screened to ensure that they had a valid driver's license. All participants reported that they were in good health and were not taking any medications that affected their ability to drive. All participants reported that they had either normal or corrected-to-normal vision. Participants received 1 research credit per half hour of participation. All independent variables were manipulated between subjects, which split the subject pool into six separate groups of ten participants each (see Figure 3).

Signal Location	50%	70%	90%
Spatial	50% System Reliability/Spatially presented auditory merge cue Male = 4 Female = 6	70% System Reliability/Spatially presented auditory merge cue Male = 4 Female = 6	90% System Reliability/Spatially presented auditory merge cue Male = 2 Female = 8
Central	50% System Reliability/Centrally presented auditory merge cue Male = 5 Female = 5	70% System Reliability/Centrally presented auditory merge cue Male = 2 Female = 8	90% System Reliability/Centrally presented auditory merge cue Male = 2 Female = 8

Reliability

Figure 3. *Factorial of the simulated driving scenario groups between-subjects.*

Driving Simulation Overview

The driving environment used consisted of a straight three-lane highway of approximately 1.5 miles in length. The participant's vehicle started by traveling in the center lane of the highway with along side flowing traffic occupying all three lanes, including a lead vehicle the participant were instructed to follow. Vehicle speed was maintained by the simulator at 70 MPH. There were 21 experimental trials and 4 catch trials, each lasting approximately 90 seconds in length in which the participant was required to merge into another lane (either left or right) one time throughout each trial. The catch trials were similar to the experimental trials, with the exception that in these trials the lead vehicle never slowed down, the participant was never presented with a merge instruction and the participant was never required to make a merge response.

Traffic congestion and vehicle speeds were all programmed and maintained by the driving simulator. The speed of traffic varied and the lanes were either minimally or highly congested. Participants were instructed to maintain position in the center of their lane. Once every 10 seconds (+/- one second), a rotational wind disturbance of 1000 Newton meters was presented to ensure the participants maintain focus on the primary task of driving and keeping lane position throughout each trial.

Auditory cues ("merge left" or "merge right") instructed the participants to merge into the lane directly to the left or directly to the right. These cues were presented with different levels of reliability (50%, 70% and 90%) between subjects. Reliability was determined by whether or not the lane the participant was instructed to merge into resulted in a safe merge or if the merge would have caused a collision. The placement of incongruent trials was randomized which was determined by using a Latin-square.

The auditory cues presented were either from a center console in front of the participant, or from the left or right front door speakers. The spatially presented cues always correctly coincide with the side of the vehicle that they are coming from ("merge right" from the right and "merge left" from the left). Therefore, the level of reliability was not be based on signal/location redundancy, but whether or not the signal presented instructs the operator to perform a "safe" merger into either the left or right lane.

During the final trial (21/21), the lead vehicle braked abruptly, requiring the participant to suddenly make a decision to merge either left or right. At the same time, an auditory cue was presented instructing them on which lane to merge into. The cue in this final trial was either congruent or incongruent and was not determined by reliability group affiliation. Instead, congruency was distributed evenly throughout all experimental groups.

Apparatus

A Titmus i500 vision tester was used in order to test the visual capabilities of each participant prior to the driving simulation. Auditory merge cues were recorded via the Audacity ver. 1.3 audio editor and recorder. The driving simulator used in this experiment was the AAA Michigan Driving Simulator which consisted of a built up cab from a Ford Focus with a 180-degree field of view, feedback technology and realistic car audio. In order to program, record, and code driving behavior, DriveSafety DS-600c (HyperDrive ver. 1.9.35) driving simulation software was used.

Procedure

Upon arrival participants were asked to fill out three forms: a consent form, a biographical questionnaire, and a driving history form. Participants were told a cover story as to the purpose of the study. They were informed that the current system is not 100% reliable and that this particular study is looking to perfect a mathematical algorithm that will cue drivers as to which lane to merge into in order to maintain a desired speed, as well as to avoid collisions.

In order to get participants acquainted with the driving simulator and the STFM, they first went through five practice trials in which they were required to respond to the verbal instructions given to them by the STFM. The first two trials required no interaction by the participant outside of lane maintenance, whereas the final three trials introduced the merge instructions and required a merge button press response. There was no reliability manipulation in the practice runs as the simulated scenario was not populated by any other traffic than the participant’s vehicle and the lead vehicle. The lead vehicle was present to only demonstrate the average speed of the recorded trials and did not include the hazard event of hard braking. Participants were again given basic instructions of the experiment and informed that if at anytime throughout any of the trails they wanted to stop, they may. They participated in a total of 21 experimental trials lasting approximately 1.5 min. each.

After the simulated driving sessions was complete, participants were asked to complete a questionnaire concerning subjective measures of the systems level of reliability and trust (see Appendix A). The purpose of the self-report was to determine whether the reliability of the STFM was readily apparent to the participants. If so, participants in the 90% reliability group should have reported a higher percentage of perceived trust in the system than the other two reliability groups. Accordingly, the participants in the 50% reliability group should have yielded the lowest rating of perceived trust. Upon completion of the questionnaire participants received either their monetary compensation or assurance of extra credit and thanked for their participation. They were then allowed to leave the simulated driving lab.

Behavioral Measurements

Driving performance measures included collision frequency with the lead vehicle, RT and accuracy of merge responses to the merge cue. The number of trials in which the response to the STFM instruction resulted in a collision with the lead vehicle during the trials measured collision frequency. RT was determined to be the amount of time between the presentation of the merge cue and the physical button press by the participant. The accuracy of merge responses was determined by whether or not the participant pressed the appropriate button which allowed them to merge into the uncongested lane, effectively avoiding a collision on the opposite side of the vehicle.

CHAPTER IV

RESULTS

SPSS for Windows (ver. 20.0) was used for all analyses. A 3 (reliability) X 2 (spatial location) between-subjects factorial ANOVA was performed on the dependent measures of collision frequency, ratio of appropriate driving responses and RT to the merge cue. An alpha of .05 was used to determine statistical significance.

Hypotheses 1, 2 and 3A reference the ratio of accurate merge responses. The results indicated that participants were very accurate in their responses to the merge instructions. Hypotheses 1 and 2 included predictions regarding collision avoidance with the lead vehicle; however, since every participant made a merge response in every trial, there were no collisions with the lead vehicle to report. Collisions that would have resulted from an inaccurate merge response were not a dependent variable and were not described. This information will be further explored in the Discussion and Limitations sections. There were no significant results regarding lateral lane maintenance between either signal location groups, $F(1,54) = 1.36$, $p > .05$, $\varepsilon = .024$, or the various reliability groups, $F(2,54) = 4.53$, $p > .05$, $\varepsilon = .144$. Lastly, as the small effect sizes for all hypotheses indicate, increasing the sample size would not have had an impact to support the current hypotheses (for detailed results regarding all of the dependent variables by each experimental group, see Tables 1 & 2 in Appendix B).

Hypothesis 1 predicted that those who received the spatial auditory merge cue would demonstrate better driving performance, as measured by more accurate merge responses, faster RTs to the merge cue and fewer collisions with the lead vehicle. This hypothesis was not supported. In regards to merge cue response accuracy, there was no difference in performance between the spatial grouping performance (.99) and the central group (.99), which would not support Hypothesis 1. Mean RTs were worse for the spatial signal location group (2.09 s) than the central signal location group (1.96 s), which would also fail to support Hypothesis 1, $F(1,54) = 1.98$, $p > .05$, $\varepsilon = .035$ (see Figure 4).

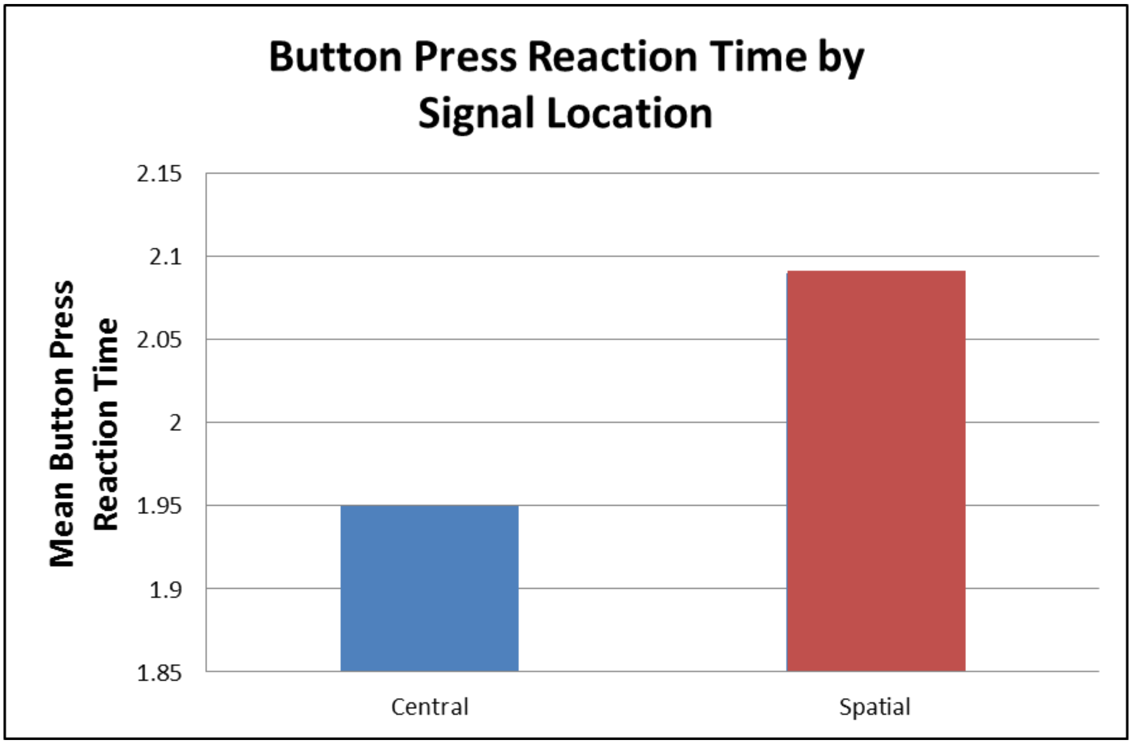

Figure 4. *Mean button press RT by signal location.*

It was predicted in Hypothesis 2 that an increase in system reliability from 50% to 70% to 90%, would result in decreasing RTs and an increase in merge response accuracy. The main effect of system reliability was examined and revealed that Hypothesis 2 was not supported. RTs actually became slower with an increase in system reliability from 50%, to 70%, to 90%, $F(2,54) = 1.09$, $p > .05$, $\varepsilon = .039$ (see Figure 5). There was no difference in the accuracy of merge responses between the 50% (.99), and the 70% reliability groups (.99), while the 90% reliability group (.98) performed very slightly worse.

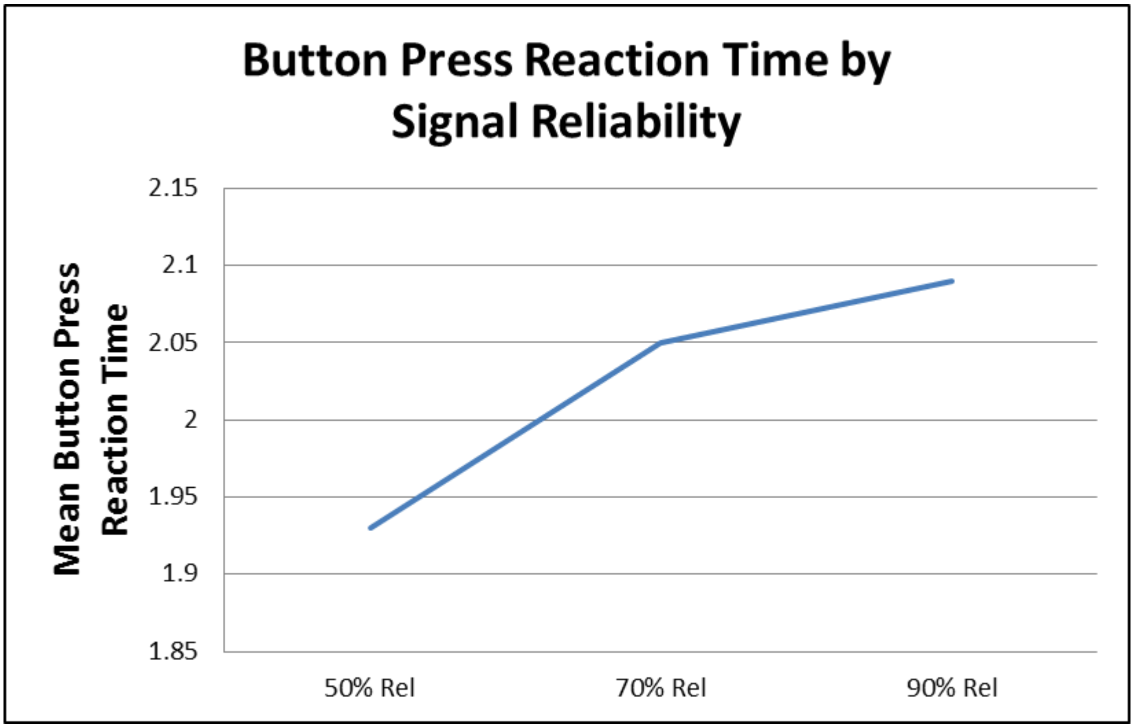

Figure 5. *Mean button press RT for each level of system reliability.*

Hypothesis 3, which predicted an interaction between signal location and system reliability, was not supported. Part A of the hypothesis proposed that those participants in the 90% reliability/spatial signal location group would have the fastest RTs and the most accurate merge responses. As displayed in Figure 6, the main effect of the interaction showed that this group actually had the slowest RT (2.26s) compared across all other groups, $F(2,54) = 2.46$, $p > .05$, $\varepsilon = .084$. This finding was not significant. In terms of the accuracy of merge responses, those in the 90% reliability/spatial signal location group were the least accurate (.98). This was in complete contradiction to the predicted hypothesis.

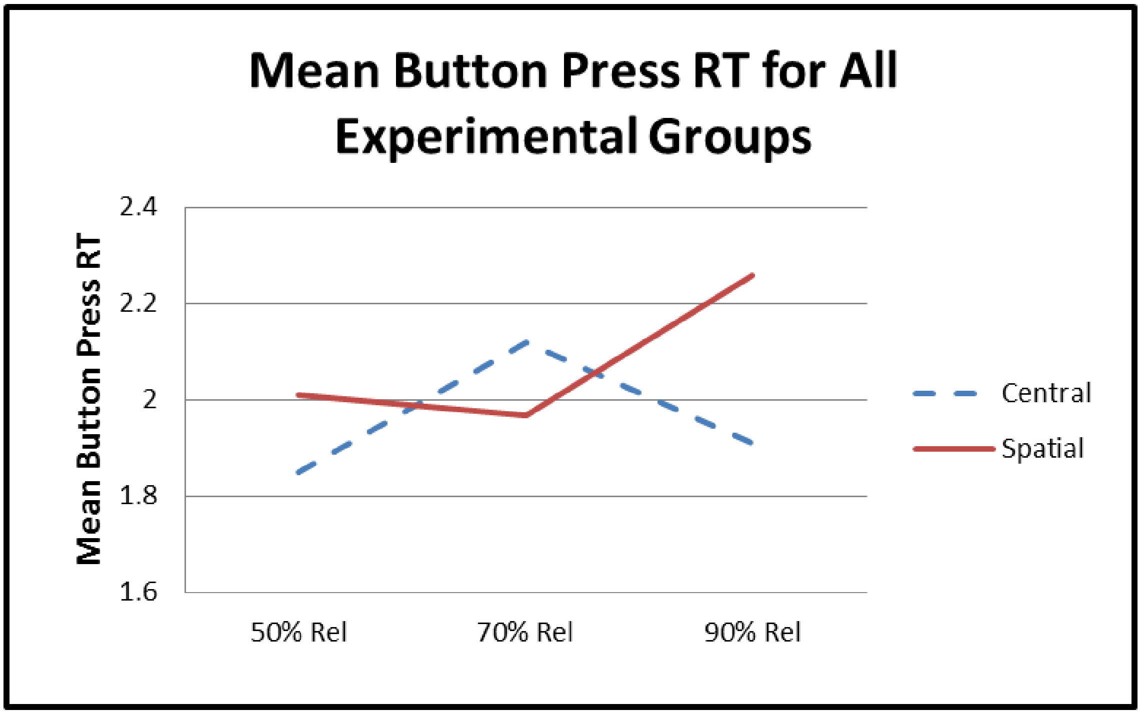

Figure 6. *Mean button press RT for each experimental group.*

Part B of the 3rd Hypothesis predicted that those in the central signal location group would have faster RTs when an incongruent signal was presented than those in the spatial signal location group. This part of the hypothesis was not supported as the RT for the spatial group was actually faster (2.30s) than those in the central signal location group (2.62s) when an incongruent signal was presented (see Figure 7). In fact, these findings were shown to be significant, $F(2,54) = 4.29$, $p < .05$, $\varepsilon = .074$. Reasons for and implications of this finding will be explored in the Discussion and Implications section of this document.

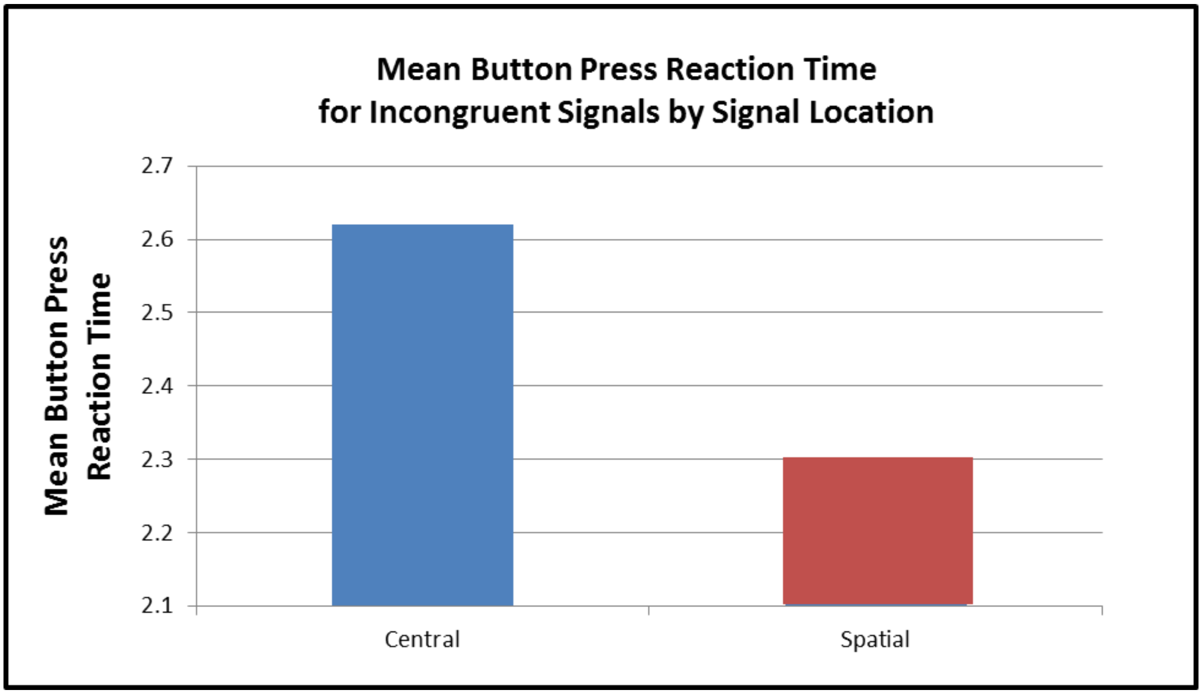

Figure 7. *Mean button press RT when presented with an incongruent signal between signal locations.*

Hypothesis 4 made predictions in regards to trust with the STFM and was measured using the Trust in Automation Scale (Appendix A). Positive trust referred to the portion of the scale that asserts that the STFM is reliable, whereas negative trust referred to the portion of the scale that asserts that the STFM is unreliable. It was predicted that as system reliability increased from 50% to 70% to 90%, there would be an increase in positive trust in the system as demonstrated in the Trust in Automation scale (Appendix A). There was a significant main effect of positive trust in the predicted direction from a 50% reliability group (3.19), to the 70% reliability group (3.61), followed by the 90% reliability group (4.129), $F(2,54) = 3.56$, $p < .05$, $\varepsilon = .117$. The results for negative trust (distrust) were not significant; however, they did trend in the predicted direction, $F(2,54) = 1.23$, $p > .05$, $\varepsilon = .044$ (see Figure 8). Therefore, Hypothesis 4 was partially supported.

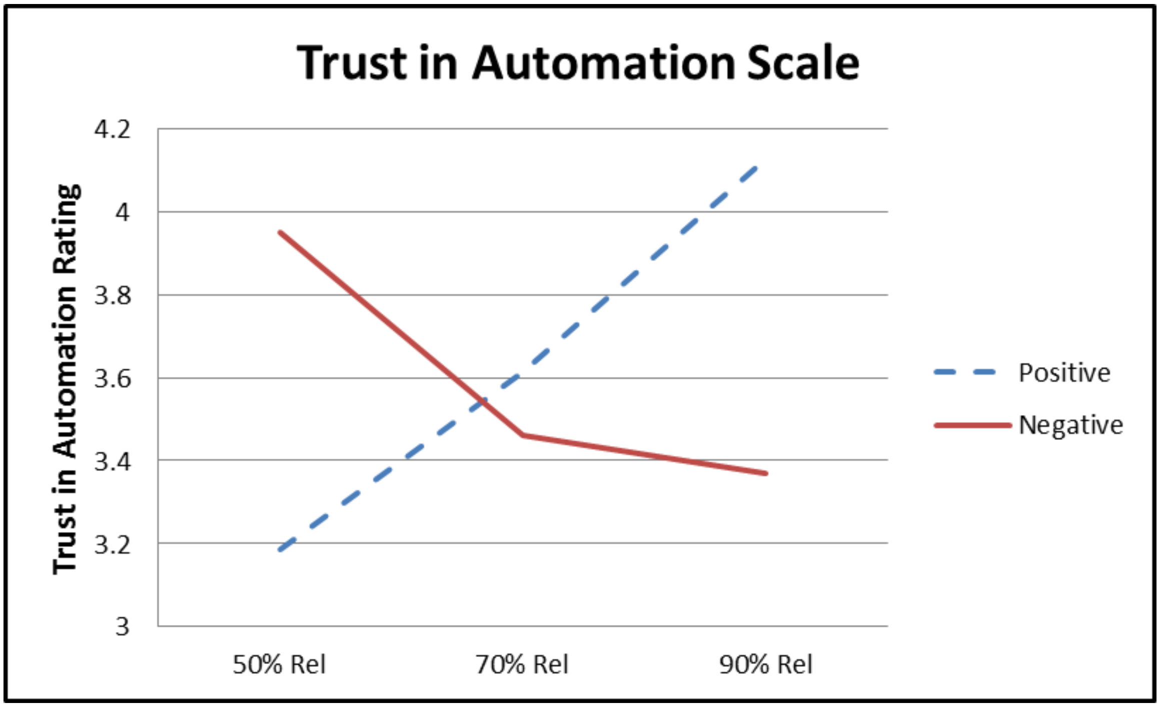

Figure 8. *Positive and negative trust in automation between system reliability groups.*

Hypothesis 5 referenced the final "hazard trial" and predicted a significant interaction effect, proposing that those in the 90% reliability/spatial signal location group would have the best performance in terms of accurate merge responses and RTs. Again, this hypothesis was not supported as there was no significant interaction effect, $F(2,48) = .47$, $p > .05$, $\varepsilon = .019$. For the hazard trials, interestingly those in the 50% reliability group had the fastest RTs; 50% spatial (1.59s) and 50% central (1.41s) (see Figure 9). In terms of merge response accuracy, there were only three incorrect responses in total and they were all in response to incongruent signals.

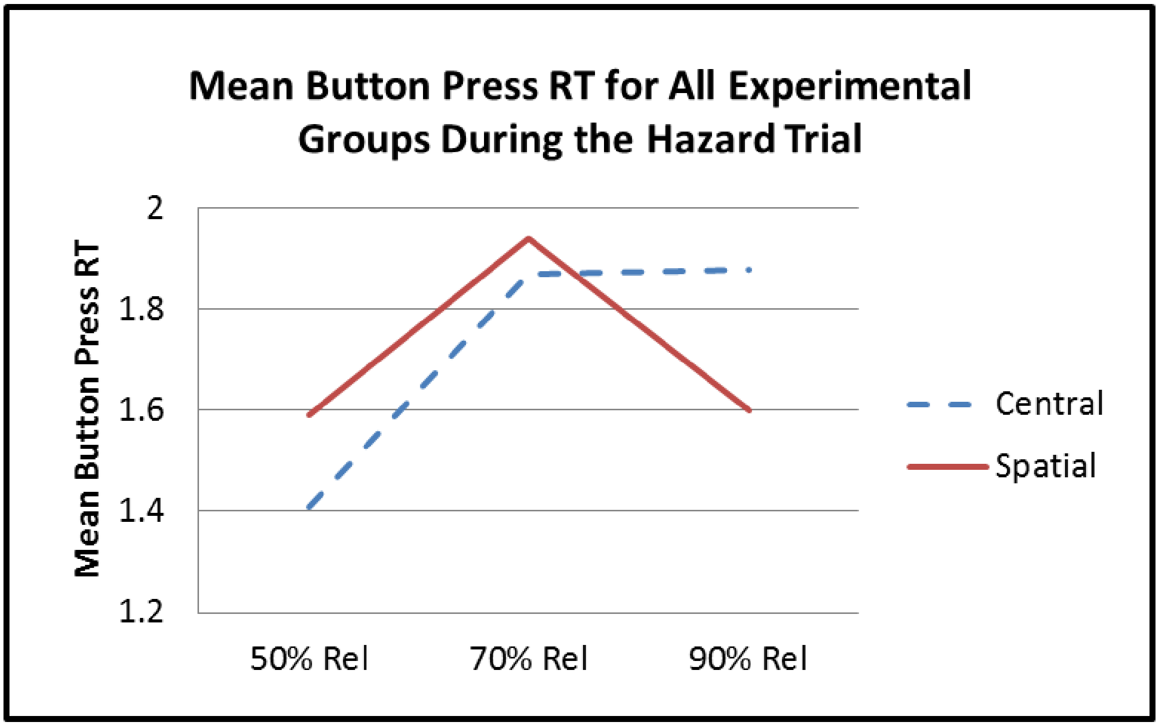

Figure 9. *Mean button press RTs for all experimental groups during the hazard trial.*

CHAPTER V

DISCUSSION

The purpose of the current study was to further understand the impact of IVTs, such as adaptive cruise control, lane departure warning and other advanced driver assistance systems, on driving performance. In particular, this study sought to investigate the implications of both system reliability and signal location on collision avoidance, merge response accuracy and RT to a possible collision event. The current study used a between subjects design, varying system reliability and signal location, in order to test the predicted hypotheses.

Previous research indicated that RTs to true alarms were faster when presented from a spatially relevant location ("left" presented to the left of the driver, "right" presented to the right of the driver) than those who were presented the same alarm from the center console (Bliss & Acton, 2003). Driver and Spence (1998) found a "biasing" effect of a cue presented in one modality (audition) on a secondary modality (e.g., vision) as participants' vision was drawn to the side of the auditory cue, even if the "target" was likely to appear elsewhere. Based on their results, it was predicted in Hypothesis 1 that those in the spatial signal location group would be more accurate in terms of their merge responses and have faster RTs to the presentation of the merge cue. This hypothesis was not supported. It is possible that the tasks became too predictable for there to be any observable benefit from the spatially presented merge cues.

Hypothesis 2 predicted an increase in accuracy and a decrease in RTs in line with an increase in reliability; however those in the current 50% reliability group generally performed better than those in the 70% and 90% reliability groups. One possible reason for this phenomenon could be that those in the 50% group began to disuse the system and developed strategies to respond to the merge cue that were superior than those utilized by the other groups.

In fact, Bliss and Acton (2003) noted that the participants in their 50% reliability group attended to the rearview more frequently than those in the other reliability groups. Again, the non-predictive system could have led these participants to develop a “cry wolf” effect mentality. This could also be an explanation in the current study as to why those in the 50% reliability group displayed the least amount of positive trust and the most amount of negative trust in the STFM.

As can be observed in the merge cue response accuracy results, all groups were very accurate in their responses, including those who received the non-predictive merge cues. Therefore, it is possible that the participants in the 50% reliability group learned that the system was non-predictive and, in order to perform as well on the task as possible, may have stopped waiting for the merge cue altogether and used other stimuli to help them predict when a request for action would occur. It is predicted (and discussed in the limitations section) that the timing and speed of the lead vehicle deceleration in the various scenarios was not varied enough and may have been the reason for this effect.

If the above assertion is to be considered, the 50% group should have had the lowest level of trust in the system, and this is exactly what the results showed. As predicted in Hypothesis 4, trust in the automated system increased as a function of system reliability; increasing from 50% to 70% to 90%. Combined with the predicted strategies developed by the low reliability group, this result could have had an impact on Hypotheses 2 and 3A.

Indeed, none of the remaining hypotheses were supported. Hypothesis 3 (A&B) predicted an interaction between signal location and system reliability. For prediction 3A, the combined 50% group was the most accurate and had the lowest RTs, with the 50% central group having the best results in both categories. Interestingly, the 90% spatial group, which was predicted to have the best performance for this Hypothesis, was not only the least accurate, but also had the slowest RTs. This may be a case where the system's high level of reliability becomes detrimental such that the participant begins to become over-reliant on, or misuse the system (Parasuraman & Riley, 1997). To call back to an earlier concept, it is possible that the strategy of waiting for the merge cue (which would be highly reliable), processing it and then responding was not as effective as the strategies employed by the other experimental groups.

One of the more interesting results came from Hypothesis 3B. In this hypothesis, it was predicted that those in the spatial group would perform worse in terms of RTs to an incongruent merge cue. This prediction was based on the proposed biasing that would occur when a signal was presented to either side of the participant, as opposed to directly in front of them. This biasing effect should have been detrimental to RT performance when the participant was given an incorrect instruction, based upon attention being hypothetically "drawn" to the incorrect side. It was thought that they then would have taken longer than those in the Central group to reassess and make the correct merge button press. The results showed that those in the spatial group actually had faster RTs to the merge cue than those in the central group. It is worth repeating that participants were very accurate in terms or their merge response button presses.

One theory as to why those in the spatial group performed better than those in the central group for these conditions is that the central group was unintentionally biased toward the center of the vehicle. Therefore, they may have not been as prepared to scan back and forth from side to side as those in the spatial group. This lack of preparation for a potential hazardous event occurring toward the participant's side may require more time to process and, in turn, RTs would increase.

The experimental design also included a final hazard trial where the lead vehicle would brake suddenly. The intent was to see the impact of the previous trials on behavior when the participant had a significantly and unexpectedly shorter amount of time to process and make their merge decision. As seen with the other behavioral hypotheses, the 50% reliability group performed the best in regards to RTs. Therefore it is possible that whatever strategy they developed throughout the first 20 trials of the study, carried over to the final trial and was similarly as effective in regards to performance with the hazard event as with the base trials.

The combination of varying task strategies, as well as an overall desire by the participants to perform well on the tasks may have led to the discrepancies in predicted versus actual results for the reliability groups. The anomalies regarding the spatial location of the merge instruction results are not as readily understood. Although predictions have been made regarding these outcomes, future research should continue to explore the possible negative aspects of "biasing" attention toward a central location.

Limitations

One of the key limitations to the study was that by removing the functionality of both the brake an accelerator the driving scenario was more autonomous than originally intended. There were complications in programming the driving simulation to incorporate varied traffic flow that would have been interactive with the participant's vehicle. In order to maintain traffic flow that was not predictable, the ability to brake and accelerate was removed from the participant's control. However, making this decision may have contributed to the misuse or disuse of the STFM system resulting in participants that either became complacent or relied on their own predictive skills (over the signals presented by the system), respectively.

Another factor that may have contributed to the disuse of the STFM is that the behavior of the lead vehicle may have become too predictable. Although there were 12 simulated scenarios (16 including the catch trials) of varying duration, varied lane congestion and the order was randomized for each participant, the lead vehicle slowed down at the same pace (with the exception of the hazard trial) during each trial. This may have led to those in the 50% reliability groups being able to predict when the signal would occur and already have a decision made for which direction to merge. Of course, this could be the case for all of the experimental groups, but the belief is that those in the 70% and 90% reliability groups would be more reliant on the system than those whose system was completely non-predictive. The results of Hypothesis 4 support this assertion as those in the 50% reliability group had the lowest amount of positive trust and highest amount of negative trust in the system.

Recognizing that the number of female participants was more than twice the number of male participants, the data was analyzed to determine if there was any impact of gender on the current results. It was found that females were generally slower in terms of RTs than males. However, the interactions aren't interpretable since both the 90% Spatial and 90% Central groups only had 2 males in them each. Therefore it isn't possible to draw any firm conclusions, but it is worth noting that the lack of gender balance could have played a role in the lack of support for the predicted hypotheses.

Summary

The current study sought to further understand the possible implications of system reliability and signal spatial location on driving behavior in a collision avoidance scenario. With the exception of Hypothesis 4, the predicted hypotheses were not supported. It appears that the lack of trust in the automated system displayed in the 50% reliability group actually aided performance, as those participants developed strategies that would allow them to perform better than if they were to rely on the merge cue alone. In fact, previous research has shown that those who distrust an automated system may learn to disuse it (Parasuraman & Riley, 1997) and may also have greater situation awareness (Beller, Heseen & Vollrath, 2013) than those who are presented with more reliable automation.

These outcomes are believed to be the result of design limitations that may have led to the system to become too predictable. The speed at which the lead vehicle slowed down and the distance from the participant's vehicle at which the signal was presented was consistent across all trials (with the exception of the final hazard trial). This is of little concern when the participants are actually utilizing the automated aide; however it may have supported improved performance when they did not.

Overall, the results of the current study support the notion that trust in automation can impact the utilization of automated systems. The implications for those who learn to disuse automation and their development of alternative performance strategies are not clearly understood in the current study and could be further explored. Future research could focus on the potential interaction of signal location, reliability and the impact trust will have on driving behaviors associated with systems similar to the STFM. The role of autonomous driving aides in vehicle is increasing; making the understanding of how drivers utilize, or rely on these systems, increasingly important.

Implications

One of the more interesting findings throughout the course of this study was that those participants in the spatial signal location group had faster RTs to the merge cue than those in the central signal location group when an incongruent signal was presented. Future research could focus on a potential "narrowing" of attention that might be the ill-effect of a centrally located alert signal. Easterbrook (1959) discussed that motivation and concentration of a particular task can increase emotion, and that as emotion increases, the more likely we are to limit the range of cues we will utilize to perform that task. It is not clearly understood in the current research if the "narrowing" effect is the cause of the peculiar results, or if they are due to a more inherent design flaw. However, paying particular attention to this aspect of the current study could prove beneficial in terms of understanding how directional signals impact a driver's behavior.
It is possible that using spatial signals serve to broaden the driver's attentional field, whereas using centrally located signals can narrow it. If there are, indeed, negative implications to biasing a driver's attention toward the center of the vehicle with auditory cues presented from that space, this would support the explanations described in this paper as to the differences in signal location performance when the system presents an incongruent signal.

In a more applied realm, IVTs are alerting drivers to the surrounding environment more frequently as automobile manufacturers gradually transition to fully autonomous vehicles. Typically systems such as lane departure warning (with or without steering correction), and blind-spot alert will alert the driver through visual cues, however auditory cues are also used. It will be important to fully understand the relationship between the location of these cues and the impact on driving behavior in situations such as, but not limited to, the one presented in this paper. Understanding proper spatial signal location could directly feed into design decisions that will impact driver safety.

Trust is another key component to the current research that may have major implications on real world systems. As demonstrated in Hypothesis 4, as reliability of a system decreased, so too did the trust in it, and subsequently, lack of trust of in the STFM lead to disuse of the system in the current research. The balance between possible complacency and disuse of a system is a delicate one and must be strongly considered when designing advanced driver assistance systems. The more automation becomes incorporated into everyday vehicles, the more important it becomes for drivers to be prepared to take appropriate action in the case of system failure.

APPENDICES

APPENDIX A

REVISED TRUST IN AUTOMATION SCALE

Revised Trust in Automation Scale

Instructions: Below is a list of statements for evaluating trust between yourself and smart traffic flow monitor (STFM). For each statement, rate your feeling of trust or your impression of the STFM while performing the driving task. Please circle the number that best describes your feelings or your impressions.

Please indicate your feelings or impressions:	**not at all**			**somewhat**			**extremely**
1. The STFM is deceptive.	1	2	3	4	5	6	7
2. The STFM behaves in an underhanded manner.	1	2	3	4	5	6	7
3. I am suspicious of the STFM's output	1	2	3	4	5	6	7
4. I am wary of the STFM.	1	2	3	4	5	6	7
5. The STFM's actions will have harmful or negative outcomes	1	2	3	4	5	6	7
6. I am confident in the STFM.	1	2	3	4	5	6	7
7. The STFM provides security.	1	2	3	4	5	6	7
8. The STFM has integrity	1	2	3	4	5	6	7
9. The STFM is dependable.	1	2	3	4	5	6	7
10. The STFM is reliable.	1	2	3	4	5	6	7
11. I can trust the STFM.	1	2	3	4	5	6	7
12. I am familiar with the STFM.	1	2	3	4	5	6	7

APPENDIX B

TABLES

Table 1. *All dependent variable results for all experimental groups (standard error is in parentheses). Reaction times are presented to the hundredth of a second. RMSE represents lateral lane deviations . Trust is based on a seven-point scale. Accuracy is the ratio of accurate merge responses throughout all of the experimental trials.*

	50% Reliability		70% Reliability		90% Reliability	
	Central	Spatial	Central	Spatial	Central	Spatial
Congruent RT	1.85 (.110)	2.01 (.110)	2.12 (.110)	1.99 (.110)	1.91 (.110)	2.26 (.110)
Incongruent RT	2.33 (.188)	2.22 (.188)	2.62 (.188)	2.12 (.188)	2.91 (.188)	2.57 (.188)
Cong Lane RMSE	.346 (.011)	.374 (.011)	.368 (.011)	.337 (.011)	.375 (.011)	.347 (.011)
Incong Lane RMSE	.351 (.014)	.395 (.014)	.380 (.014)	.364 (.014)	.379 (.014)	.377 (.014)
Hazard RT	1.41 (.252)	1.59 (.252)	1.87 (.252)	1.94 (.252)	1.88 (.252)	1.60 (.252)
Hazard RMSE	.356 (.018)	.396 (.018)	.406 (.018)	.368 (.018)	.389 (.018)	.369 (.018)
Positive Trust	3.13 (.354)	3.24 (.354)	3.87 (.354)	3.36 (.354)	4.21 (.354)	4.04 (.354)
Negative Trust	3.92 (.397)	3.98 (.397)	3.02 (.397)	3.90 (.397)	3.52 (.397)	3.22 (.397)
Accuracy	.99	.98	.98	.99	.98	.98

Table 2. *All dependent variable results for each independent variable (standard error is in parentheses) for main effects. Reaction times are presented to the hundredth of a second. RMSE represents lateral lane deviations in meters. Trust is based on a seven-point scale. Accuracy is the ratio of accurate merge responses throughout all of the experimental trials.*

	Signal Location		Reliability		
	Central	Spatial	50% Rel	70% Rel	90% Rel
Congruent RT	1.96 (.078)	2.09 (.078)	1.93 (.078)	2.05 (.078)	2.09 (.078)
Incongruent RT	2.62 (.133)	2.30 (.133)	2.28 (.133)	2.37 (.133)	2.74 (.133)
Cong Lane RMSE	.363 (.008)	.353 (.008)	.360 (.008)	.352 (.008)	.361 (.008)
Incong Lane RMSE	.330 (.010)	.379 (.010)	.373 (.010)	.372 (.010)	.378 (.010)
Hazard RT	1.72 (.178)	1.71 (.178)	1.50 (.178)	1.91 (.178)	1.74 (.178)
Hazard RMSE	.384 (.013)	.378 (.013)	.376 (.013)	.387 (.013)	.379 (.013)
Positive Trust	3.74 (.250)	3.55 (.250)	3.19 (.250)	3.61 (.250)	4.13 (.250)
Negative Trust	3.49 (.281)	3.70 (.281)	3.95 (.281)	3.46 (.281)	3.37 (.281)
Accuracy	.99	.99	.99	.99	.98

APPENDIX C

INFORMED CONSENT FORM

CMU
CENTRAL MICHIGAN
UNIVERSITY

Title of Project: The Effects of Auditory Signal Reliability Level and Spatial Location on Simulated Driving Performance

Investigator: Joseph V. Lenneman Phone: (517)862-4022

This study is being conducted as partial fulfillment of the requirements for the degree of Master of Psychology for Joseph V. Lenneman.

You are eligible to participate in this research if you are in good health. The following information is provided to help you make an informed decision whether or not to participate. If you have any questions, please do not hesitate to ask.

Purpose: The purpose of the following experiment is to study and assess how varied auditory guidance signal reliability and spatial location effect simulated driving performance through ttthe analysis of driving performance measures.

Procedure: I understand that if I decide to participate in this research project I will be performing a visual detection task and a driving simulator task.

Timetable: I understand that the session will take about one hour to complete.

Risks: I understand that there are minimal risks involved in participating in the research project. I also understand that any information provided during the course of the study that might reveal my participation in any use of illegal drugs or alcohol will remain confidential.

Benefits: I understand the benefits of the information gained from this research project will be used to further understand the potential risks and benefits of using various level of signal reliabilty and spatial location for auditory cues within a vehicle.

Subjects initials:

Compensation: I understand that as a CMU student I will receive 3 credits for participation in the research project.

In case of emergency: I understand that if I experience discomfort or adverse reactions during the experiment I can have the investigator call CMU Public Safety. I can also call the investigator if I have questions or concerns after the experiment. Further, I understand that CMU is not liable for any medical costs as a result of participation in the experiment.

Confidentiality: I understand that any information obtained during this study that could identify me will be kept strictly confidential and will not be released in any individually identifiable form without prior consent unless required by law. The information may be published in scientific journals or presented at scientific meetings, but my identity will be kept strictly confidential. I also understand that video is being collected (to monitor behavior) and that the video image will also be kept confidential, under lock and key in the Department of Psychology at Central Michigan University for a minimum of 5 years. My identification will not appear on the video.

Right to refuse or withdraw: I understand that participation is entirely voluntary and that I can withdraw my consent at any time. My compensation will be prorated to the next half-hour.

Conditions of consent: I understand that I must be 18 years-of-age or older, and in good health.

Questions: I understand that the investigator will answer any questions about the research, either now or later. If I have any questions later I can contact Dr. Richard Backs (989-774-6497), Department of Psychology, Central Michigan University, Mt. Pleasant, MI 48859.

Your signature below indicates that you have voluntarily decided to participate in this research project as a subject and that you have read and understood the information presented in this form.

______________________	______________________	__________
Participant's Signature	Participant's Printed Name	Date

In my judgment, the subject is voluntarily and knowingly giving informed consent to participate in this research project.

______________________	______________________	__________
Investigator's Signature	Investigator's Printed Name	Date

PLEASE SIGN BOTH COPIES, KEEP ONE AND RETURN THE OTHER TO THE INVESTIGATOR.

APPENDIX D

BIOGRAPHICAL QUESTIONAIRE

CENTRAL MICHIGAN UNIVERSITY

ENGINEERING PSYCHOPHYSIOLOGY RESEARCH LABORATORY

DEPARTMENT OF PSYCHOLOGY

Title of Project: THE EFFECTS OF AUDITORY SIGNAL RELIABILITY LEVEL AND SPATIAL LOCATION ON SIMULATED DRIVING PERFORMANCE
Investigator: Joseph V. Lenneman **Phone:** 517-862-4022

Subject #: **Date:**

Time:

DEMOGRAPHIC INFORMATION

Birth date: **Corrected Vision:**

Gender: MALE | FEMALE

Smoker: YES | NO ______per day

Are you currently taking any medication? YES | NO

If yes, what kind? _______________

Please circle the conditions that apply to you:

Cardiovascular Disease	ADD/ADHD	Cognitive Deficits
Neurological Disorders	Alcoholism	Diabetes
Cerebrovascular Disease	Sensory Deficits	Asthma

To what ethnic group do you belong?
Please check one of the following categories:

___Caucasian/White (non-Hispanic): Persons with origins in any of the original peoples of Europe, North Africa, or the Middle East.

___African-American/Black: Persons with origins in any of the black racial groups of Africa.

___Oriental/Asian or Pacific Islander: Persons with origins in any of the original peoples of the Far East, Southeast Asia, the Indian subcontinent, or the Pacific Islands.

___American Indian or Alaskan Native: Persons with origins in any of the original peoples of North America, and who maintain cultural identification through tribal affiliation or community recognition.

___Hispanic: Persons of Mexican, Puerto Rican, Cuban, Central or South American, or other

Spanish culture or origin, regardless of race.

___Other (Please Clarify): ____

DRIVING INFORMATION

Do you currently drive a car? YES | NO

Make: Model:

How many miles per year do you drive?

VISUAL INFORMATION

UFOV Classification:

Visual Angle: Plane 1__________ Plane 2__________

APPENDIX E

INSTRUCTIONS

Recite verbatim:

Thank you for your participation in this experiment. The purpose of our study is to test a system called the smart traffic flow monitor (STFM). The system offers instructions similar to many common adaptive cruise control systems used today. The instructions that you will hear are provided so that you may maintain a desired speed while in traffic by offering merge instructions when a lead vehicle slows down. These instructions provided by the STFM will be presented auditorily and will be either “merge left” or “merge right”. As the system is still in its’ developmental stages, it is not 100% reliable. You will not be required to accelerate as the car will be in cruise control mode, however you will need to do your best to maintain position in the center of your lane by using the steering wheel. After hearing the auditory signal presented by the STFM, you will be required to make a button press merge response in a timely manner. There are buttons behind the steering wheel which the researcher will show you. Pressing the button on the right side of the wheel will result in a merge into the right lane and the button on the left side of the wheel will result in a merge into the left lane. **DO NOT** press the button until you hear the instructions from the STFM as this will require the trial to be redone. Upon hearing the ENTIRE merge instructions you must determine if the instructions provided would result in a safe merge into the directed lane or not. You must then press the button underneath the wheel that will allow your vehicle to make a safe merge. If the instructed lane is open, press the button corresponding to that lane to perform a safe merge. If the instructed lane is occupied by another vehicle, you must press the button opposite to the STFM’s instructions. For example, if the system tells you to “merge right” and the right lane is occupied, then you must press the left button to safely merge left. Are there any questions? You will be given some practice trials to get familiar with the system and then there will be a number of experimental trials lasting about 1 minute in length each. The session will then conclude with a short survey and you will be allowed to leave. Again, thank you for your participation.

Between each trial, I will ask you if the vehicle is in park. If it is not, please put it into park at this point. Furthermore, you will need to keep the steering wheel straight in between trials as well.

APPENDIX F

IRB APPROVAL

DATE: February 14, 2011
TO: Joseph Lenneman
FROM: Central Michigan University Institutional Review Board 1
PROJECT TITLE: [155797-2] THE EFFECTS OF AUDITORY SIGNAL RELIABILITY LEVEL AND SPATIAL LOCATION ON SIMULATED DRIVING PERFORMANCE
REFERENCE #:
SUBMISSION TYPE: Annual Continuation
ACTION: APPROVED
APPROVAL DATE: February 14, 2011
EXPIRATION DATE: February 25, 2012
REVIEW TYPE: Full Committee Review

Thank you for your submission of Annual Continuation materials for this project. The Central Michigan University Institutional Review Board 1 has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Full Committee Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this committee. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this committee.

This project has been determined to be a More than Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of February 25, 2012.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact the CMU IRB office at (989) 774-6401 or cmuirb@cmich.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Central Michigan University Institutional Review Board 1's records.

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