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Effects of Visibility and Alarm Modality on Workload, Trust in Automation, Situation Awareness, and Driver Performance

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EFFECTS OF VISIBILITY AND ALARM MODALITY ON WORKLOAD, TRUST IN AUTOMATION, SITUATION AWARENESS, AND DRIVER PERFORMANCE

by

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ABSTRACT

EFFECTS OF VISIBILITY AND ALARM MODALITY ON WORKLOAD, TRUST IN AUTOMATION, SITUATION AWARENESS, AND DRIVER PERFORMANCE

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Driving demands sustained driver attention. This attentional demand increases with decreasing field visibility. In the past researchers have explored and investigated how collision avoidance warning systems (CAWS) help improve driving performance. The goal of the present study is to determine whether auditory or tactile CAWS have a greater effect on driver performance, perceived workload, system trust, and situation awareness (SA). Sixty-three undergraduate students from Old Dominion University participated in this study. Participants were asked to complete two simulated driving sessions along with Motion Sickness Susceptibility Questionnaire, Background Information Questionnaire, Trust Questionnaire, NASA Task Load Index Questionnaire, Situation Awareness Rating Technique Questionnaire, and Simulator Sickness Questionnaire. Analyses indicated that drivers in the tactile modality condition had low perceived workload. Drivers in the heavy fog visibility condition had the highest number of collisions and red-light tickets. Drivers in the heavy fog condition also reported having the highest overall situation awareness. Drivers in the clear visibility condition trusted tactile alarms more than the auditory alarms, whereas drivers in the heavy fog condition trusted auditory alarms more than tactile alarms. The findings of this investigation could be applied to improve the design of CAWS that would help improve driver performance and increase safety on the roadways.

This thesis is dedicated to my immensely supportive family.

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INTRODUCTION

Driving is cognitively and physically demanding. Drivers must continuously attend and perceive incoming environmental information like traffic flow, traffic lights, pedestrians, and navigational sign boards while physically operating and controlling the vehicle. These demands could increase when drivers encounter deteriorating weather conditions like fog and rain. Such weather conditions often lead to low visibility that could render visual incoming information be less salient. Drivers may also lose situation awareness under low visibility conditions that could jeopardize safety.

The United States Department of Transportation's Federal Highway Administration (FHWA) reported that between 2002 and 2012 there were approximately 1,311,970 weather related vehicle crashes in the United States, in that 480,338 people were injured and 6,253 people were killed. The FHWA also reported that fog conditions contribute to more than 38,700 vehicle crashes annually, in that over 16,300 people were injured, and 600 people were killed in the United States (FHWA, 2014). Data from this report reflect a diversity of vehicles that may or may not be equipped with collision avoidance warning systems (CAWS).

Over the years, technologies like computer systems and collision avoidance sensors have improved, resulting in increased reliability of CAWS. In spite of the advances in technology, modern CAWS remain less than fully reliable for detecting potential collisions. Factors like weather conditions, road conditions, speed of the vehicle, and the structure of certain objects could contribute to the accurate detection of potential collisions (Honda, 2015). Human factors psychologists have extensively studied how automation reliability impacts performance (Bliss & Acton, 2003; Bliss, Liebman, & Brill, 2010; Maltz & Shinar, 2007; Parasuraman & Riley, 1997). The present study represents a continuation of such work. Specifically, the planned manipulation of visibility and alarm modality represents further examination of simulated driver performance during alert situations (Scott & Gray, 2008; Shah, Bliss, Chancey, & Brill, 2015).

The present study considers the effects of two competing alarm modalities (auditory & tactile) on driver performance under three different visibility conditions [heavy fog (18m), moderate fog (31m) & no fog]. Prior researchers (Cavallo, Colomb, & Dore, 2001; Konstantopoulos, Chapman, & Crundall, 2010) have investigated the effects of low visibility on speed and hazard detection tradeoff, visual search tasks, and ergonomic assessment of headlight positioning. Most such researchers have investigated the effects of fog by using a car following task.

A thorough literature review revealed no empirical research to investigate the combined effects of collision alarm modality and visibility conditions on drivers' performance, trust in automation, perceived workload and situation awareness (SA). It is necessary to study trust in automation, workload, and SA as these are constructs that are important in understanding and predicting human-automation performance in complex environments or systems (Parasuraman, Sheridan, & Wickens, 2008).

The plan for research implementation is to evaluate these influences jointly in simulated environment that depicts real world driving scenarios and challenges. In the real world weather conditions are not always ideal and visibility levels tend to vary. Therefore, it is important to investigate if CAWS that are found to be effective in improving driver performance under ideal weather conditions (e.g. Scott & Gray, 2008) are also effective in improving driver performance under different visibility conditions. It is also important to understand which collision alarm modality would work best in these visibility conditions. Results will therefore provide a significant contribution to the driving and transportation literature. The results may also provide guidelines and design implications to improve CAWS.

Visibility

Weather can significantly degrade driver performance. Deteriorating or severe weather conditions like fog and rain could decrease visibility and could increase the risks associated with driving. In aviation, researchers conducted a considerable amount of research to analyze the effects of weather on pilots' decision making and flight skills (Wiegmann, Goh, & O'Hare, 2002; Wiggins & O'Hare, 1995; Wiggins & O'Hare, 2003). However, in surface transportation there is still very little known about how visibility conditions affect drivers' decisions and performance. Researchers have proposed no strategies for improving drivers' situation awareness and performance during weather incursion.

Driving is a complex everyday task that is performed by young and old people alike. According to the Federal Highway Administration (FHWA) people between the ages of 16 and 65 drive an average of 13,476 miles annually (FHWA, 2014). Mueller and Trick (2012) assessed the behavioral adjustments made by young novice, young experienced and old experienced drivers under clear and foggy conditions. The average years of driving experience for each group was six months, three years and 25 years, respectively. Young novice drivers held a G1 driving license which is obtained by passing a written driving test (similar to the United States written permit test) or G2 license which is obtained by holding a valid G1 license for at least one year and by passing a road test (Mueller & Trick, 2012). Drivers holding G1 and G2 licenses had restricted access to driving on certain roads and during particular times of day. However, drivers holding G2 licenses had fewer restrictions than G1 license holders. A full G license is obtained after holding a G2 license for one year and by passing a second road test. Participants with G licenses had at least 2 year of driving experience and an unrestricted license. Participants were asked to apply their brakes, coming to a complete stop when they encountered a hazardous event on the roadway. The researchers found that all participants drove significantly faster in the clear condition than in the foggy condition. They also found that young novice drivers had collisions in both clear and foggy conditions, whereas experienced drivers drove without collisions in all visibility conditions.

Besides behavioral adjustments such as braking, drivers also must make perceptual adjustments when driving in low visibility conditions. Caro, Cavallo, Marendaz, Boer, and Vienne (2009) examined how fog affects the perception of relative motion and the detection of headway change. They found that reaction time to lead vehicle depth changes increased in the low visibility condition. Therefore, the researchers suggested that low visibility (fog) condition led to a decrease in perceived relative motion. It is no surprise that perceptual abilities decline with age and that visibility plays an even more important role for older drivers. In a car following task, older drivers maintained a longer headway under clear visibility conditions than younger drivers. However, older drivers are more likely to maintain a short headway than younger drivers during foggy conditions, suggesting that older drivers may be more liable to have collisions under foggy conditions (Ni, Kang, & Andersen, 2010). Similar results were reported by the same authors in the Kang, Ni, and Anderson (2008) article where they found that drivers tended to follow too closely to the lead car under high density fog conditions and maintained greater headway distance under clear conditions.

In opposition to these results, Broughton, Switzer, and Scott (2007) found that in clear visibility condition drivers followed too closely to the lead car, whereas drivers maintained greater headway distance during foggy conditions. Broughton et al. (2007) also suggested that there are two groups of drivers, the “laggers” and the “non-laggers.” The laggers keep longer, safer distances from the lead car whereas the non-laggers follow too closely to maintain visibility, especially under low-visibility conditions. The researchers also advocate that even though the laggers maintain a safe distance from the lead car, they could serve as roadway hazards for the cars following them (Broughton, Switzer, & Scott, 2007).

It is important to consider that prior researchers (Broughton, Switzer, & Scott, 2007; Ni, Kang, & Andersen, 2010; Kang, Ni, & Anderson, 2008; Caro, Cavallo, Marendaz, Boer, & Vienne, 2009) often used a simple car following task to measure the effects of visibility on driving performance. Brooks et al. (2011) were first to measure the effects of visibility by having participants drive through the simulated driving environment without the presence of a lead car. Consequently, the driving task resembled the real world setting where drivers do not usually engage in a car following task in their daily commute. Participants were divided into six feedback groups that were formed by the combinations of the three components (task priority, presence of an auditory indicator and the speedometer availability). There were six visibility conditions; one clear visibility and five levels of fog-reduced visibility (178m, 70m, 31m, 18m, and 6m of visibility) (Brooks et al., 2011). Researchers in this study were interested in assessing the speed choices drivers made under different visibility environmental conditions and if the choices had an effect on driving performance. The results suggested that fog had a significant effect on lane keeping behavior and lane keeping was significantly degraded under conditions when the visibility distance was the shortest (6m) (Brooks et al., 2011). The researchers also reported that drivers tend to drive at slower speeds when the visibility level is lower. But, drivers tend to maintain high speeds even in foggy conditions. The mean speed of drivers in the 6m visibility condition ranged from 60.8km/h to 82.9km/h across group conditions. However, in

Brooks et al. (2011) the researchers did not include other traffic in the virtual scenario. Therefore, the results mentioned above may not generalize to congested driving environments.

Situation Awareness

Situation awareness (SA) occurs when perception of the elements in the environment facilitates human decision making (Endsley, 1995). In other words, SA includes being aware or knowing what is going on in the environment. As proposed by Endsley (1995), there are three levels of SA. Level 1 involves perceiving elements of information within your present environment. In the context of driving, perceiving the location of other vehicles on the road, one's own vehicle location, pedestrians, traffic lights, and construction objects constitute Level 1 SA. Level 2 SA involves integrating the information from Level 1 and understanding significance of information element interrelationships and how elements relate to specific events (Endsley, 1995). In the context of driving, this might involve knowing that there is a pedestrian at an intersection and that the traffic light is turning from yellow to red. Level 3 involves integrating all the information collected from Levels 1 and 2 and predicting actions that will take place in the near future (Endsley, 1995). In the example mentioned above, maintaining Level 3 SA could lead to a prediction that the pedestrian will start walking as soon as the traffic light turns red.

Though SA helps improve performance, incomplete or inaccurate SA could degrade performance. Incomplete SA might suggest that there could be a failure in perceiving information and comprehending the meaning of the perceived data (Endsley, 1995). The purpose of CAWS is generally to increase SA; however, if CAWS provide drivers with false alarms or information that is not comprehensible, then drivers' SA may actually be degraded.

Situation awareness has also been defined as an external consciousness that drives behaviors needed to accomplish a goal (Smith & Hancock, 1995). From this definition, stress, cognitive workload, and other factors affecting consciousness would also affect SA. Situation awareness is not a snapshot event; rather, it is a continuous process of knowledge building and action taking in a given situation (Smith & Hancock, 1995).

Attention is a limited resource and this recourse could be negatively affected by the abovementioned factors. Directed attention is needed to attain SA. If multiple time sharing tasks were to be performed concurrently (e.g., looking at the navigation system for instructions while driving), could deplete attentional resources available to successfully complete the primary task. Therefore, to avoid depletion of attentional resources and to maintain high situation awareness, system designers and practitioners must follow the Multiple Resource Model proposed by Wickens (2002). In this experiment the auditory and tactile CAWS will direct drivers' attention to potential collision events and will therefore help drivers attain SA.

Multiple Resource Theory (MRT)

The Multiple Resource Model assesses humans' potential to perform in high resource demanding tasks (Wickens, 2002). Multiple Resource Theory (MRT) is employed to predict human performance based on attention and workload demands in a multi-task environment. Workload and attention are two constructs that are depicted by this model. Attention is associated with awareness. Workload relates to the resources part of the model. Resources are limited and allocable (Wickens, 2002). There are only two resources, such that, resources that are elemental for perception are different from the recourses that are fundamental for response selection and response execution (Wickens & Holland, 2000). Wickens' Multiple Resource Model indicates that two tasks that are structurally similar, and are competing for same resource, will interfere with each other more than two tasks that demand separate recourses (Wickens, 2002).

Wickens (2002) suggested that cross-modal time-sharing tasks (i.e. visual & auditory) will be more advantageous than intra-modal time-sharing tasks (i.e. visual-visual, or auditory-auditory) because of the possibility that different modalities use different resources. Auditory and visual modalities use different resources while progressing though the stages of cognition (i.e. perception, working memory, and responding) (Wickens & Holland, 2000). Therefore, cross-modal tasks do not interfere with each other. However, peripheral factors could also be responsible for placing the intra-modal states at a disadvantage. If the two intra-modal channels are far away from each other, then this would lead to added cost and could impact performance. Additionally, if the two intra-modal channels are too close to each other, then this could lead to masking effect and could also impact performance. Hence, using different modalities (i.e. cross-modality) is more effective for cognition (attention and workload) and performance than using the same modality for tasks that are time-shared (Wickens, 2002).

From this logic, for the present study the primary modality at work for driving is vision. Therefore, having a visual modality for CAWS would interfere with the driving task and would lead to depletion of attentional resources. On the other hand, auditory and tactile modalities are not the primary modalities required for the driving task and therefore should not interfere with the primary task or cause depletion of attentional resources. Therefore, for the present study the auditory and tactile modalities will be used to present collision avoidance warning alarms to drivers.

Alarm Modalities

Wickens Multiple Resources Model incorporates visual and auditory modalities. Tactile modality is not yet included in the model. Hence, there are some constraints in using the Multiple Resource Theory for tasks involving other modalities other than visual and auditory. However, using Wickens's Multiple Resource Theory as a foundation, many researchers have used different modalities of alarms to help capture drivers' attention without negatively impacting the primary task. A study by Almén (2002) directly compared auditory and tactile alarm modalities to investigate the effects that these modalities had on drivers' attention control. In that study the researcher used an auditory device to call out participants' own names as the auditory alarms. The auditory device used a male voice to call out participant names. For the tactile condition, car body vibration (similar to driving on the rumble bars on the road) was used. There were four conditions (i.e. auditory, tactile, auditory & tactile, & a control). Participants in the control group did not experience any alerts. The secondary task was to read out the numbers presented on the computer screen that was placed on the front passenger seat. The researchers measured reaction time, time to collision, distance to the stimuli events at the start of braking, and lateral position on road. Almén (2002) found that presenting auditory and tactile signals simultaneously yielded better results than the modality alarms being presented individually.

Almén's (2002) research is not without detractors. One major concern is that the participants were not informed about the alerting systems that they were to experience during the task nor were they even introduced to either of the modalities of alarms prior to the task. Therefore, participants may have exhibited a startle effect. Also, participants in the tactile condition did not know what the alert was signaling. If the drivers are unaware of the alerting signal, then the alert will have no effects on their attention control.

Besides this, the researcher also used different alarms along with the different modalities of alarm. The researcher mentioned that “name” is a strong stimulus and humans tend to react instantaneously to their names (e.g. cocktail party effect) (Almén, 2002). Using names as auditory alarms provides an undue advantage to this modality as compared to the tactile modality.

A study by Scott and Gray (2008) reported contradicting results. The researchers investigated which of the three modality conditions (i.e. visual, auditory or tactile) would be most helpful for avoiding rear-end collisions. Scott and Gray (2008) found that the drivers in the warning conditions outperformed drivers in a no-warning condition. The researchers also concluded that tactile alarms evoked the fastest reaction times as they successfully captured drivers’ attention and helped avoid rear-end collisions. Similar results were obtained in a study by Ho, Reed, and Spence (2006) who reported that vibrotactile cues helped maintain drivers’ attention levels and drivers had faster brake reaction times in this condition.

Extending Ho et al.’s research, Mohebbi, Gray, and Tan (2009) investigated the effect of auditory and tactile rear-end collision warning alarms on driving performance while drivers were engaged in a simulated cell phone conversation. The researchers predicted that the simulated conversation would cause auditory load and therefore auditory warnings might not be as effective as tactile warnings in reducing the brake reaction time impairments caused by the conversations. In this study the researchers calculated the brake reaction time by calculating the time to onset the brake after the warning has been presented. The researchers found that tactile warnings were indeed more effective than the auditory rear-end collision warnings in reducing the brake reaction time impairments caused by conversing on the cell-phone while driving.

In recent years, researchers have studied the effects of using dynamic CAWS alarms to improve driver performance (Gray, 2011; Meng, Gray, Ho, Ahtamad, & Spence, 2014). Gray (2011) investigated the effects of using looming auditory warnings (i.e. signals based on the expansion of an object's size) as rear-end collision avoidance alarms on response speed and accuracy of the drivers. The results of this study indicated that the use of looming auditory alarms produced fastest and most accurate brake reaction time (BRT). Meng, et al. (2014) extended these findings to the looming tactile alarms. They found that dynamic looming tactile alarms emitted from the hands to the torso of the driver could be used to indicate the potential collision information to the drivers. Also, the researchers found that like looming auditory alarms, looming tactile alarms too helped drivers in attaining faster BRT. Though the method and alarms used in these research studies differ from those for the present study, the application of tactile alarm signals in automotive cockpits is of foundational importance to the manipulation of modality.

Based on the results of the existing literature, it is unclear which alarm modality would be most effective for increasing driver awareness and performance without increasing workload. Gallace and Spence (2008) suggested that information from only one sensory modality can enter consciousness at a given time; and that spatial and temporal characteristics of the information can affect the speed of processing the information. The researchers suggested that tactile sensory system is substantially different from other sensory modalities. Specifically, information presented in the tactile modality unlike other sensory modalities (e.g. auditory or visual) is inseparable from the spatial information in the brain. Therefore, unlike other sensory modalities, information presented in the tactile modality gets processed along with the spatial information (Gallace & Spence, 2008).

Because tactile alarms are in direct contact with the body, they may possess some advantages over traditional auditory alarms. Tactile alarms could be used to present private and personalized information in environments that feature auditory cluttering (Jones & Sarter, 2008). Also, unlike auditory alarms, tactile alarms can be presented specifically to particular individuals for whom the information is relevant (Jones & Sarter, 2008). This principle of affordance can be applied to the context of driving. Tactile alarms, unlike auditory alarms, could be presented to the driver alone. This would be helpful for capturing a drivers' attention in a noisy environment (e.g. roadway, & radio noise) without startling other passengers in the car.

In terms of practical application, the use of auditory alarms is restricted to the population with normal or corrected-to-normal hearing. People with auditory disabilities will not be able to take the advantage of the auditory CAWS. However, humans do not lose their sense of touch but sensitivity may vary. Recently, in an aviation setting, Brill, Lawson, and Rupert (2014) found that participants under the simulated noise-induced-hearing loss condition, had accurate localization when using the 3D audio and tactile situation awareness systems (TSAS) simultaneously compared to using just the 3D audio cue. Therefore, drivers could always make use of the tactile CAWS as it is more generalizable and usable than the auditory CAWS.

Collision Avoidance Warning System (CAWS)

Automation systems are described as unmanned systems that are thought to be more efficient, accurate and low cost compared to humans. However, most of the automation systems still requires human operators (Parasuraman & Riley, 1997). This is because humans are more flexible and can use their knowledge and experience while responding to probabilistic and unforeseen conditions. Therefore, automation industries are hesitant in removing humans completely out of the automation system (Parasuraman & Riley, 1997).

CAWS are automation systems that are responsible for sensing, detecting, and providing decisions about the impending collision events. To understand the function of CAWS it is important to understand the stages and levels of automation. Parasuraman, Sheridan, and Wickens (2000) proposed four different stages of automation by conceptually referring to the human information processing system. First stage is the acquisition stage. In this stage the automation system selectively attends and processes the sensory information (Parasuraman et al., 2000). Second stage is the information analysis stage that involves the inferential processing of the incoming information to increases the operator's perception (Parasuraman et al., 2000). Third stage is the decision making stage. This stage involves the use of conditional logic design to make decisions (Parasuraman et al., 2000). Fourth stage is the action implementation stage. This involves the automation system to execute the choice of action. Each of these information processing stages has levels of automation that helps identify how automatized is that stage of an automation system. Sheridan and Verplank (1978) proposed that there are ten levels of automation. As the level of automation increases the role of humans in operating these systems decreases. Level one of the automation implies that human operators do all the work and only implementation of the job is executed by the automation system (Sheridan & Verplank, 1978). Whereas, level ten of the automation system implies that all the work is done by the automation system and it informs the human operators only the system decides it should (Sheridan & Verplank, 1978).

Based on these design principles, the CAWS used in the present experiment represents the stage one, stage two and stage three of automation as proposed by Parasuraman et al., (2000). At stage one, CAWS senses the impending collision events. CAWS at stage two processes the information and informs the drivers about the impending collision events. At stage three, CAWS uses the conditional logic set by the designers to make decisions about the impending events as being potential collision events or not. For example, an alarm will sound if an object is within 100ft of the car. The CAWS used in the present study are considered to have high level of automation (level 10) for all three stages as the collision avoidance automation system does the "whole job if it decides it should be done, and if so tells human, if it decides he should be told" (Sheridan &Verplank, 1978). The CAWS only provides decision aids. Human operators have to decide whether the decision provided by CAWS is accurate. The automation system, therefore, leaves the last stage of action implementation on human operators. Humans in this stage can choose to disregard the automation aid or can execute an action in response to the automation aid's decision to complete the task successfully. It is usually the action implementation stage when humans may over rely on the automation aid systems and may comply with the automation system without verifying the information. This leads human operators to engage in automation bias (Parasuraman & Manzet, 2010). If the automation system is accurate then it can increase human performance whereas inaccurate automation can cause omission or commission errors. Omission error involves human operators to not respond to a situation because the automation aid failed to indicate them to do so. Commission error involves human operators to respond to a situation because the automation aid indicated them to do so; regardless of the automation aid being incorrect (Parasuraman & Manzet, 2010). These errors could be detrimental and could jeopardize safety in general.

Goal and Purpose of the Study

Previous researchers focused on analyzing and understanding how collision avoidance systems could help improve driving performance and what measures should be taken to improve CAWS. However, there is no research study that has examined the effects of CAWS' modalities on driving performance, situation awareness, workload, and trust simultaneously under different visibility conditions. The goal of the present study was to investigate the effects of alarm modality (auditory & tactile) and visibility conditions (heavy fog, moderate fog, & clear) on driver performance, workload, situation awareness and trust in automation. This experiment was a follow up study to a previous preliminary investigation conducted by Shah, Bliss, Chancey, and Brill (2015) that focused on evaluating the effect of alarm reliability (i.e. 70% & 90%) and alarm modality(i.e. auditory & tactile) on workload, system trust, and driver performance.

The present experiment was an attempt to learn more about the advantages and disadvantages of using the auditory and tactile modalities for providing task relevant information to the drivers during a driving task that has visual channel primarily at work. Additionally, the present experiment also investigated driving behaviors and driver performance under uncertain environments.

Driver Performance Hypotheses

In this experiment, driver performance was assessed by measuring the number of simulated collisions the drivers made per trial. Besides this, number of red-light tickets, and number of speed exceedances was also measured.

Number of collisions. It was hypothesized that drivers will have highest number of simulated collisions in the low visibility (18m) condition. This hypothesis was adopted from Brooks et al. (2011) who reported that drivers maintain high speeds until visibility significantly reduces and are incapable of stopping to avoid collisions. It was also hypothesized that drivers will have fewer collisions in tactile alarm modality condition than in the auditory alarm condition (Shah et al., 2015). Additionally, it was hypothesized that increased workload will lead to increased number of collisions. This hypothesis was elaborated from the Multiple Resource

Theory by Wickens (2002) suggesting that performance decrement can be observed in high workload situations. In this experiment, the following research questions were examined: Does increased SA lead to fewer number of collisions?; Does higher trust in CAWS lead to fewer number of collisions?; Does high perceived reliability for CAWS lead to fewer number of collision?

Red-light tickets. Decreasing visibility also decreases level 1 situation awareness (SA) among drivers. Drivers in the heavy fog condition may not be able to perceive the red-light early enough to stop in time at the intersection. Therefore, it was hypothesized that drivers in the heavy fog condition will have greater number red-light tickets than drivers in the clear visibility condition. This hypothesis was elaborated from Endsley (1995).

Number of speed exceedance. Mueller and Trick (2012) reported that drivers in the clear visibility condition drove faster than drivers in the foggy conditions. Therefore, it was hypothesized that drivers in the clear visibility will have greater number of speed exceedance than drivers in the moderate and heavy fog visibility conditions.

Situation Awareness Hypothesis

It was hypothesized that the tactile alarms will lead to higher SA than the auditory alarms across all visibility conditions. This hypothesis was elaborated from Gallace & Spence (2008) who reported that information provided via tactile modality is inseparable from spatial information.

Research question (SA). Endsley (1995) stated that information about the relevant elements in the environment that are perceived directly from the senses or displays serve as a base for SA. Therefore, in general, drivers in the clear visibility will have access to the necessary environmental information that is relevant to the task (i.e. seeing a pedestrian at a distant intersection). Such information will not be available to the drivers in the moderate, and heavy fog conditions until they are in close proximity to a particular stimuli. Additionally, in this experiment all the drivers across visibility groups had same amount of aid from the CAWS. Therefore, it was expected that drivers will have high situation awareness (SA) across visibility condition. In the present experiment the following research question was examined: will drivers in the clear visibility condition have higher SA than the drivers in the moderate fog (31m) and heavy fog (18m) conditions?

Trust in Automation Hypothesis

It was hypothesized that drivers will be more likely to trust the tactile collision avoidance warning system (CAWS) than the auditory CAWS (Shah et al., 2015). Additionally, it was hypothesized that drivers who perceive the reliability of CAWS to be high will have higher trust in the system than the drivers who perceive the reliability of CAWS to be low. This hypothesis was elaborated from Shah et al. (2015).

Research question (trust). Drivers in the decreased visibility conditions (i.e. 18m & 31m) will rely on CAWS to garner important information about their surroundings to successfully navigate through the environment. As mentioned above, tactile CAWS is believed to be more effective in alerting drivers of the potential collisions than the auditory CAWS (Ho, Reed, & Spence, 2006; Mohebbi, Gray, & Tan, 2009; Scott & Gray, 2008). Therefore, will drivers in the low visibility conditions have higher trust in the tactile CAWS than the drivers in clear visibility condition?

Workload Hypotheses

It was hypothesized that drivers in the tactile alarm condition will have low perceived workload than drivers in the auditory alarm condition (Shah et al., 2015). Smith and Hancock

(1995) stated that SA is directly related to mental workload. Therefore, it was predicted that drivers with low SA will have high perceived workload.

METHOD

Experimental Design

The present study employed a 3 (visibility level) x 2 (alarm modality) split-plot design. Visibility level (represented as varying amounts of simulated fog) was a between-subjects variable that had three levels (18m, 31m, or clear). Visibility was manipulated between-subjects to ensure that all participants received only one visibility treatment to avoid any extraneous effects, ceiling and floor effects on the gathered data. Alarm modality was a within-subjects variable that had two levels (auditory and tactile). Alarm modality was manipulated within-subjects to avoid any individual differences while comparing the effectiveness of the alarms on driver performance. In the real world, CAWS systems are not 100% reliable as factors like weather deterioration and speed of the vehicle affect the reliability of collision detection (Honda, 2015). Therefore, alarms at 70% reliability threshold were used to ensure veridicality of the unreliable system (see Wickens & Dixon, 2007). All alarms were 70% reliable to evenly divide the number of true alarms per trial and to represent the typical reliability of real-world collision avoidance warning systems (CAWS). The CAWS in the present study represented a miss-prone system (i.e. missed detecting a potential collision). In the present experiment, participants were exposed to 20 potential collision events per trial but received collision avoidance alarms for only 14 potential collision events. Participants received no alarms for the remaining six potential collision events. It is important to note that true alarms and misses occurred randomly across sessions. Several dependent variables were measured per session, including perceived workload, number of collisions, number of red-light tickets, frequency of speed exceedance, situation awareness, and trust in alarm systems.

Participants

G* power software (Faul, Erdfelder, Lang, & Buchner, 2007) version 3.1.9.2 was used to conduct a power analysis to determine the total sample size needed for the study. Determining correct sample size will help avoid Type II error (failing to reject a null hypothesis when it is false). Target power level (1 –β) was specified as .80 and α at .05. In addition to following convention, these values were chosen to achieve an appropriate balance between Type I and Type II error. The partial η^2 for the main effects of visibility on headway distance reported by Broughton, Switzer, & Scott (2007) was used to estimate the effect size required for the power analysis. The partial $\eta^2 = .0729$ determined effect size = .2804. Using an effect size from a prior study that had similar visibility conditions (i.e. clear, fog 1, & fog2) would provide more accurate results for the sample estimation. The power analysis suggested that 36 participants would be required to find an effect. However, 70 participants were recruited for this experiment. In the present experiment, instead of the car-following task, drivers were asked to drive through a simulated virtual environment similar to their regular driving experience. Hence, there is possibility of variance in the simulated environment. Therefore, the sample size was increased to account for variance, to avoid Type II error, and to have equal number of people in each condition.

Seventy undergraduate students from Old Dominion University were recruited via the SONA system, a research participation pool system that is maintained by the Department of Psychology. However, three students scored greater than 19 on the Motion Sickness Susceptibility Questionnaire (MSSQ) and therefore were not allowed to participate in the experiment (see

Materials section for more information). In addition, two participants failed to follow the instructions; one participant did not have a valid driver's license and was therefore not from the population of interest; and one participant's data were not collected because of the equipment malfunction. Therefore, data from seven recruited participants could not be used. However, all participants still received credit for participating, per IRB guidelines. The analyzed sample consisted of 63 participants (19 male, 44 female). There were equal numbers of participants in each group (n = 21). All participants were required to be at least 18 years old and possess a valid driver's license. The mean age of participants was 20.75 (*SD* = 3.81, min = 18, max = 36). Participants were screened for driving infractions. Thirty-eight participants reported having no driving infractions and 25 participants reported having at least one driving infraction. All participants reported having normal to corrected-to-normal vision, hearing, and sense of touch. Twenty-nine participants indicated that they play video games. Seventeen participants reported playing simulated driving video games for an average of 2.21 hours per week (*SD* = 1.91) and 27 participants reported playing non-driving video games for an average of 5.00 hours per week (*SD* = 5.58).

The present experiment was 1.5 hours long. Upon completion of the experiment, participants received 1.5 SONA credit point as an incentive. Participants could use the granted SONA credit points as extra credit for their designated on-campus higher level psychology undergraduate course or to fulfill a research credit requirement for one of the lower level psychology courses.

Materials

Informed Consent Form. Each participant first read and signed the Informed Consent Form (Appendix A) if they wished to participate in the experiment. The form included a brief description of the experiment, potential risks, and benefits associated with participating in the experiment. The form also stated that the participants could quit the study at any time without being penalized and would still receive their SONA points as incentives.

Background Information Questionnaire. Participants completed a Background Information Questionnaire (Appendix B) to provide demographic information such as age, sex, ethnicity, years of driving experience, infractions in driving (driving violations), and experience with video games.

Motion Sickness Susceptibility Questionnaire. After completing the Background Questionnaire, participants were screened for simulator sickness using a Motion Sickness Susceptibility Questionnaire (MSSQ) (short version, see Appendix C). The Motion Sickness Susceptibility Questionnaire (MSSQ) has high reliability with Cronbach's alpha = 0.87 and a test-retest reliability of $r = .90$. The predictive validity for motion sickness is $r = .51$(Golding, 2006). As recommended by Golding (2006), participants who scored greater than or equal to 19 on the (MSSQ) short were not allowed to participate in the study but they still received the incentives (Golding, 2006).

NASA Task Load Index. Participants completed the NASA Task Load Index (NASA-TLX) questionnaire (Appendix E) after each driving session. The questionnaire is a subjective scale that is used to assess perceived mental workload. Participants rated the task based on the perceived mental, physical and temporal demands. Participants also rated their own perceived level of performance, effort and frustration. This scale has acceptable test-retest reliability $r = .769$ (Battiste & Bortolussi, 1988). In the present experiment, the NASA TLX questionnaire had acceptable reliability with cronbach's alpha = .704. Participants completed the NASA TLX scale after each modality condition to determine which modality condition induced lower mental workload.

Trust Questionnaire. Participants completed a trust questionnaire (Appendix F) after each modality session of the experiment. The trust scale was created by Jian, Bisantz, and Drury (2000). The questionnaire assessed participants' trust in a particular automation modality. The scale includes 12 items that reflect trust between people and automation. Item examples include, "The alarm system is deceptive", "I am suspicious of the alarm system's outputs", and "The alarm system is reliable." Researchers have suggested that general trust, human – human trust and human – machine trust are conditions that are similar to each other (Jian, Bisantz, & Drury, 2000). Therefore, the abovementioned trust scale could be used to test either of these conditions. The ratings of trust were negatively correlated with distrust for all the above three conditions, r = -.96, r = -.95, r = -.95 respectively (Jian, Bisantz, & Drury, 2000). That is, if people have high level of trust in a system, then they are also less likely to distrust that system. In the present study, the trust questionnaire had a high reliability with cronbach's alpha = .911.

Situation Awareness Rating Technique Scale. Participants also completed the Situation Awareness Rating Technique (SART) questionnaire (Appendix G) after each experimental driving session (i.e. under each visibility conditions) (Taylor, 1990). SART is a ten-question self-rating technique that is quick to administer. It assesses users' SA based on the following ten dimensions: situation familiarity, focus of attention, concentration, quantity of information, quality of information, situation instability, situation complexity, situation variableness, arousal level, and spare mental capacity. It has a seven-point rating scale ranging from 1(low) to 7(high) (Stanton et al., 2013). The above mentioned dimensions are categorized into three main components of SA [i.e Attentional Demand (D), Attentional Supply (S), & Understanding of the Situation (U)]. Attentional Demand (D) includes situation instability, situation complexity, and situation variableness. Attentional Supply (S) includes arousal level, concentration of attention, focus of attention, and spare capacity. Understanding of the situation (U) includes information quality, information quantity, and familiarity (Taylor, 1990). The overall SA is calculated by using the following formula: Situation Awareness (SA) = Understanding (U) – [Demand (D) – Supply (S)] (Stanton et al., 2013).

SART was the best candidate for measuring SA in this study. It was convenient to administer the questionnaire after the task (i.e. driving) avoiding obstruction of the actual task (Stanton et al., 2013). Drivers usually do not complete questionnaires while driving. Therefore, SART helped maintain this realism. Though some researchers have criticized the construct of SA and its measurement (see Stanton et al., 2013), the construct still retains scientific and intuitive appeal among human factors researchers and practitioners. One of the biggest advantages of using the SART questionnaire in this experiment was that it allows fast and quantitative assessment of SA across diverse domains (Stanton et al., 2013). Therefore, it seems more generalizable than other SA measures. In the present study, the SART questionnaire had an acceptable reliability with cronbach's alpha = .636.

Simulation Sickness Assessment. After completing all driving experimental sessions, participants completed the Simulator Sickness Questionnaire (Appendix D). The simulator sickness questionnaire (SSQ) was derived from the Motion Sickness Questionnaire (MSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993). It is a useful tool for identifying whether participants are experiencing simulator sickness. Kennedy et al. (1993) conducted a factor analysis and found that there were three distinct clusters that were interpretable from the SSQ questionnaire. Researchers identified Oculomotor, Disorientation and Nausea as the interpretable factors and used them as the basis of the SSQ scale. There are 16 symptoms listed and participants rated these symptoms based on degree of severity to which they experienced them after the simulator usage. Some of the symptoms stated in the SSQ are "headache", "difficulty focusing", "vertigo", and "nausea". It has a four point rating scale ranging from 0 (None) to 3 (Severe). According to Kennedy, Stanney, Crompton, Drexler, and Jones (1999), the original SSQ questionnaire has a split-half reliability of r = .80 (as cited in Kennedy et al., 2003). In the present study, the SSQ questionnaire had an acceptable reliability with cronbach's alpha = .774.

Equipment. STISIM *Drive* 3.01.01 Model 100 Series Simulation Software was used to create virtual scenarios of a city. The scenarios consisted of roads, parked and moving vehicles, buildings, pedestrians, traffic lights, intersections, bridges, and constructions sites. Two city scenarios were created for the present experiment. Each scenario featured the same events; however, the order of the events was counterbalanced. A Dell PC with Microsoft® Windows Vista™ x64 Enterprise was used to run the STISIM simulation. The driving simulation provided participants with a 90° horizontal and vertical field view with a 1920 X 1080 high-resolution display (Kennedy, 2012).

Participants were seated on the gaming Playseat (see Appendix H) and were asked to use the Logitech G27 16-Button Racing Wheel, 6-speed sifter/ gear and pedals to provide responses such as acceleration, braking, swerving, and turn signal indications (Kennedy, 2012) . The steering wheel (See Appendix H) provided rotation up to 900° (degrees). A DPL 1800 MP Front Projector was used to project scenario display on a 76 ½-in. white smart board screen that was placed 126 inches away from the projector (Kennedy, 2012). The smart board screen was covered with a plain white wrinkle free cloth to help eliminate the glare from the projector and ambient light. Along with the virtual scenarios, the virtual side and rear view mirrors, a dash board with speedometer, selected transition gear information, and turn signal indicators was also displayed on the projection screen.

Participants were asked to wear a vibrotactile band on their wrist during all experimental sessions to ensure that only the treatment conditions were manipulated across sessions while all other variables were held constant. The vibrotactile belt was made of a Velcro fastening band that had a single tactor attached to it (see Appendix H). EAI (Engineering Acoustics, Inc., Casselberry, FL) model C2 tactor (Chancey, Sitz, Schmuntzsch, Brill, & Bliss, 2014) was used to provide the vibrotactile alarms. The tactor was 3 centimeters (cm) long in diameter, .08 cm in height, and weighed 17 grams (Chancey e al., 2014). The band was placed on the dorsal side of their left hand regardless of the dominant hand. The tactor was placed so that it would directly touch participants' skin (see Appendix H), similar to the belt worn by the participants in a study conducted by Chancey, et al. (2014).

Auditory and tactile alarm sound files represented a sinusoidal waveform to ensure clarity of alarms presented. The duration of the auditory and tactile alarms was 3 sec (3000 ms) long because human ears do not respond immediately to the onset of a sound. It takes approximately 200 to 300 ms before a pure tone is detected (Sanders & McCormick, 1993). Therefore, presenting a 3000 ms alarm ensures gradual onset of the tone in the drivers' ears. It takes approximately 140 ms for the sound to decay so that it is no longer perceived further (Sanders & McCormick, 1993). Auditory and tactile alarms were set at 1000 Hz frequency and had a 9 millisecond (ms) inter-pulse interval (IPI), because alarms with 9ms IPI are reported to be perceived as urgent (Baldwin & Lewis, 2013). Baldwin and Lewis (2013) suggested that as IPI decreases, the level of perceived urgency increases. It is important that drivers perceive CAWS as urgent because perceived urgency would make drivers respond quickly to alarms and would therefore increase the probability of avoiding potential collisions. Gateway G max-2000, twopiece speakers were used to emit the auditory alarm sounds. Tactile alarms were presented using the auxiliary sound port of the same speakers.

Dell A425 2.1, PC speakers were used to play 59 dB pink noise. The pink noise was played as a background noise during both the auditory and tactile conditions. The purpose of the pink noise was to mask the auditory sound that generates from the buzzing tactor to ensure that the participants in the tactile modality condition had no redundancy effect bias. In the real world there will be some amount of noise emitted from the roadways (i.e. road joints, & car passing by) that is pertinent to the driving task. Therefore, the pink noise also served as an environmental noise to help depict realism.

Procedure

Upon arrival, participants were asked to read and sign the Informed Consent Form. Participants then completed the Motion Sickness Susceptibility Questionnaire (MSSQ–Short) and the Background Questionnaire. The MSSQ was provided first so that the researcher could score the test while the participants completed the background information questionnaire to evaluate whether the participant was susceptible to motion sickness. Participants who scored 19 or greater on the MSSQ-Short questionnaire were not allowed to participate in the study as they would be at a high risk of experiencing motion sickness during the experimental session.

After participants passed the susceptibility threshold, the researcher randomly assigned them to one of the visibility conditions. The researcher then provided participants the instructions for the tasks that they were to perform. Participants were asked to complete a familiarization session that would help them learn to operate the driving simulator, and also acquaint them to the kind of collision events they may experience during the actual experimental session. No alarms were presented during the familiarization session. Participants were allowed to repeat the familiarization session multiple times until they felt comfortable using the driving simulator. After completing the familiarization session, participants were introduced to the type of alarm that was congruent to the one that they were to experience in their first experimental driving session.

Participants then completed a driving session for one type of visibility condition under each modality condition (auditory and tactile). That is, each participant was exposed to both alarm modality conditions in a random order and participants were also randomly placed in either of the visibility conditions (heavy fog (18m), moderate fog (31m) and clear) (See Figure 1). There were two types of scenarios created for each visibility level. Each scenario featured 20 collision events consisting of an equal number of vehicle and pedestrian events. Both the alarm modalities and the virtual driving scenarios were counterbalanced to avoid any learning and order effects that could bias the results. All participants were asked to follow all the traffic rules and regulations. Participants were also asked to maintain a 30mph speed limit for both driving sessions.

Each driving session was approximately 10 minutes long. After each driving session, participants were asked to complete a NASA-TLX questionnaire, trust questionnaire, and a SART questionnaire. A five-minute break was provided between the first and the second driving session to avoid the carryover effects of fatigue. After completing both the sessions, participants were asked to complete the Simulator Sickness Questionnaire (SSQ). Participants were then debriefed, thanked, and dismissed.

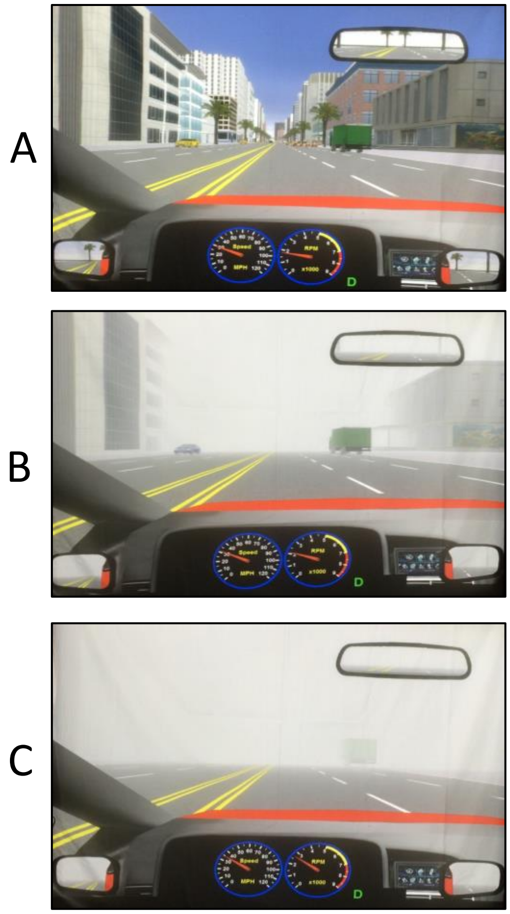

Figure 1. Screen-shots of simulated visibility conditions. A = Clear; B = Moderate fog (31m); C = Heavy fog (18m).

RESULTS

The data were entered into the Statistical Program for the Social Sciences (SPSS) software and examined to ensure that there were equal number of participants in each group, and there were no missing scores. The data were screened for normality and outliers. Data for trust, workload, and situation awareness (SA) were normally distributed. However, data for performance measures (i.e. number of collisions, number of red-light tickets, & frequency of speed exceedance) were not normally distributed. Analyses of variance (ANOVA) is robust to the normality assumption. Because assumption of normality was the only assumption that was violated, the approximation of the *F*-test distribution is good and the *p* –value resulting from these *F*- test are also very close to that yielding from the exact randomization test (Maxwell & Delaney, 2004). Therefore, no corrections for normality were employed. There were no outliers present in the workload, trust, SA, and number of red-light tickets data. There were some outliers in the speed exceedance and collision data. However, no outliers were deleted or transformed from the data. All the outliers were treated as extreme scores.

A 3 x 2 split-plot Analyses of Variance (ANOVA) was employed to determine if the manipulated variables had an effect on the dependent variables of interest. An alpha level of $p < .05$ was determined to indicate statistical significance. Levene's test indicated that the assumption of homogeneity of variance was met for all the dependent variables.

Number of Collisions

The results indicated that there was no main effect of alarm modality on the number of collisions, $F(1, 60) = .007$, $p = .933$, *partial* $\eta^2 = .000$, observed power = .051. Additionally, there was no interaction between alarm modality and visibility condition on the number of collisions, $F(2, 60) = .639$, $p = .531$, *partial* $\eta^2 = .021$, observed power = .152. However, there was a significant main effect of visibility on the number of collisions, $F(2, 60) = 7.483$, $p = .001$, *partial* $\eta^2 = .200$. Drivers in the heavy fog visibility condition had the highest number of collisions and the drivers in the clear visibility condition had fewest collisions (see Figure 2). The Bonferroni post-hoc comparison revealed that the drivers had a significantly higher mean collision rate in the heavy fog visibility condition than in the clear visibility condition ($M_D = 2.524$, $SE = .657$, $p = .001$). There was no significant difference in drivers' mean collision rate between the moderate fog condition and clear fog conditions ($M_D = 1.000$, $SE = .657$, $p = .400$) or between the heavy fog and moderate fog conditions ($M_D = 1.524$, $SE = .657$, $p = .071$). There was a significant linear trend in the means of collision, $F(1,123) = 20.041$, $p < .001$. Therefore, the number of collisions increased as the visibility level decreased.

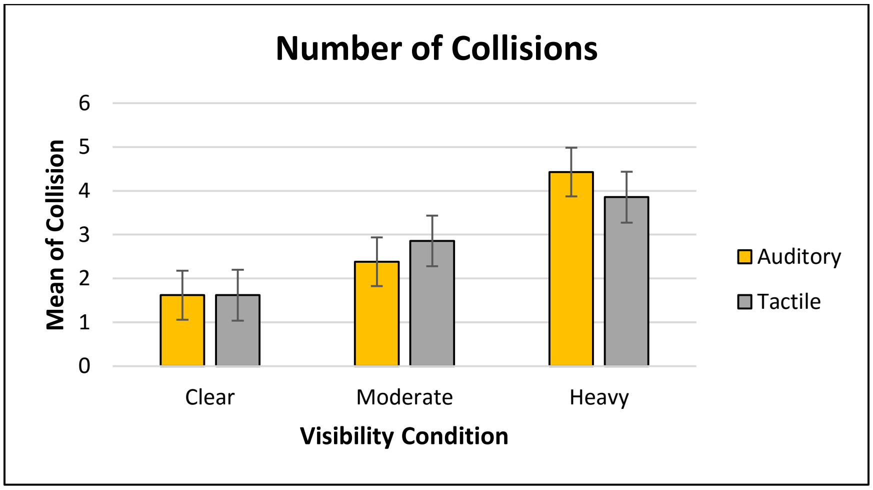

Figure 2. Average number of collisions across alarm modality and visibility conditions. The error bars represent standard error.

Correlational Analysis. Spearman Rho correlation analyses were employed to measure specific relationship hypotheses. One-tailed analyses were employed because the hypotheses were directional. For the auditory condition, as the drivers' trust in CAWS increased the number of collisions also increased ($r_s = .254$, $p = .022$) However, for the tactile condition, as the drivers' trust in the CAWS increased, the number of collisions decreased ($r_s = -.304$, $p = .008$). Additionally, in the tactile condition, increases in drivers' perceived reliability estimates for the CAWS were associated with decreases in the number of collisions ($r_s = -.397$, $p = .001$). In the auditory condition, increases in drivers' perceived reliability estimates were related to more frequent collisions ($r_s = .229$, $p = .036$). Workload was significantly related to the number of collisions. As drivers' workloads increased, the number of collisions also increased in auditory and tactile conditions ($r_s = .245$, $p = .027$; $r_s = .237$, $p = .031$, respectively). In the tactile condition, there was a significant correlation between the SA and number of collisions. As drivers' SA increased, the number of collisions decreased ($r_s = -.239$, $p = .030$). There was no relationship between SA and number of collisions in the auditory condition (r_s = .075, p = .278). Means, standard deviation, skewness, kurtosis, and correlation analyses for the dependent variables are listed in Appendix I.

Number of Red-light Tickets

A split-plot ANOVA was employed to investigate the effects of alarm modality and visibility condition on the number of red-light tickets received by the drivers. A Levene's test indicated that the assumption of homogeneity of variance was met. There was no effect of modality on the number of red-light tickets received by the drivers $F(1, 60) = .034$, $p = .855$, *partial* $\eta^2 = .001$, observed power = .054. Also, there was no interaction between alarm modality and visibility condition for the number of red-light ticket received by the drivers $F(2, 60) = .638$, $p = .532$, *partial* $\eta^2 = .021$, observed power = .152. There was a significant effect of visibility on the number of red-light tickets received by the drivers $F(2, 60) = 13.248$, $p < .001$, *partial* $\eta^2 =$ .306. Drivers in the heavy fog condition had the greatest number of red-light tickets followed by the drivers in the moderate condition. Drivers in the clear condition had the fewest number of red-light tickets (see Figure 3).

Follow-up Bonferroni post-hoc analyses suggested that the mean number of red-light tickets received by drivers in the heavy fog condition (M = .929, SE = .098) was significantly greater than that the number received by the drivers in the moderate fog condition (M = .429, SE = .098) (p = .002), and in the clear condition (M = .238, SE = .098) (p < .001). However, the mean number of red-light tickets received by the drivers in the clear visibility condition was not significantly different from that received by the drivers in the moderate fog condition (p = .523). There was a significant linear trend in the means of the red-light tickets, $F(1,123) = 31.829$, $p <$ .001. Therefore, the number of red-light tickets increased as the visibility level decreased.

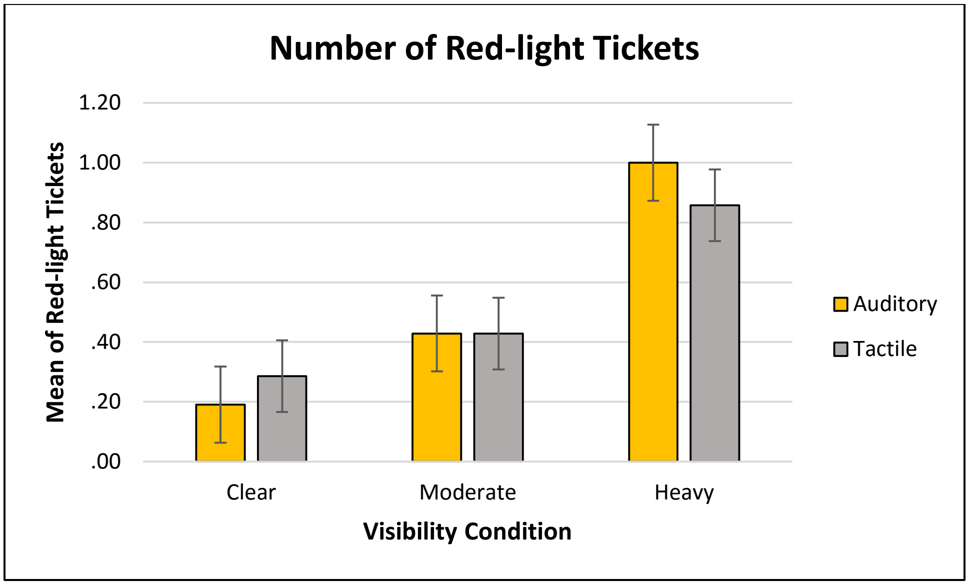

Figure 3. Average number of red-light tickets received by drivers across visibility and alarm modality conditions. The error bars represent standard error.

Number of Speed Exceedance

A univariate analysis of variance was employed to investigate the effects of visibility on the frequency of speed exceedance by drivers. The Levene's test suggested that the assumption of homogeneity of variance was met. There was no significant visibility effect on frequency of speed exceedance by the drivers $F(2, 123) = .117$, $p = .890$, *partial* $\eta^2 = .002$, observed power = .068.

Situation Awareness

The split-plot ANOVA analysis revealed that there was no significant effect of alarm modality on situation awareness (SA) $F(1, 60) = .569$, $p = .454$, *partial* $\eta^2 = .009$, observed power = .115. However, there was a significant main effect of visibility on SA, $F(2, 60) = 3.737$, $p = .030$, *partial* $\eta^2 = .111$. Drivers in the moderate fog visibility condition had the lowest SA ($M = 19.714$, $SE = 1.078$), followed by drivers in the clear visibility condition ($M = 22.429$, $SE = 1.078$). Drivers in the heavy fog visibility condition had the highest SA ($M = 23.810$, $SE = 1.078$). The Bonferroni post-hoc comparison revealed that the mean of SA in the heavy fog condition was significantly different from the mean of SA in the moderate fog condition (M_D = 4.095, *SE* = 1.524, *p* = .028). There was no significant difference in the means of SA between the heavy fog condition and the clear visibility condition (M_D = 1.381, *SE* = 1.524, *p* = 1.000), or between clear visibility and the moderate fog visibility condition (M_D = 2.714, *SE* = 1.524, *p* = .240). Means of SA across alarm modality and visibility conditions are shown in Figure 4.

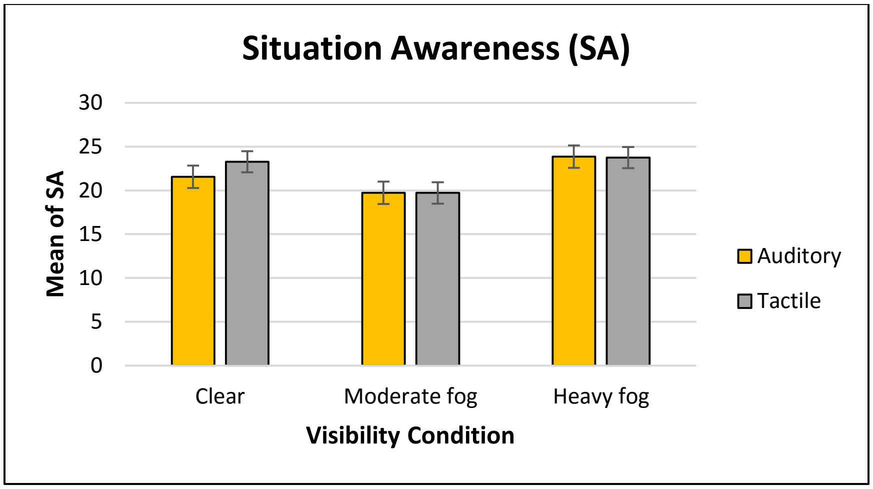

Figure 4. Drivers' situation awareness across visibility and alarm modality conditions. The error bars represent standard error.

To try to pinpoint SA differences, the data were further analyzed by SA component. A one-way ANOVA was conducted to investigate the effects of visibility on the three components of SA: attentional demand (D), attentional supply (S), and understanding of situation (U). Levene's test indicated that the assumption of homogeneity of variance was met. There was no significant effect of visibility on attentional supply $F(2, 123) = 1.109$, $p = .333$, or attentional demand $F(2, 123) = .423$, $p = .656$. There was a significant effect of visibility on the understanding component of SA, $F(2, 123) = 4.928$, $p = .009$. Drivers in the heavy fog condition had higher understanding of the situation (*M* = 16.191, *SD* = 3.195) than those in the clear (*M* = 15.310, *SD* = 3.516) or the moderate fog conditions (*M* = 13.905, *SD* = 3.377).

Follow-up Bonferroni post hoc analyses indicated that the drivers' understanding of the situation in the heavy fog condition was significantly higher than understanding in the moderate fog condition (p = .007). There was no difference in drivers' understanding of the situation between the moderate fog and clear conditions (p = .174), and heavy fog and clear conditions (p = .698). Means of the different components of SA across the visibility conditions are shown in Figure 5.

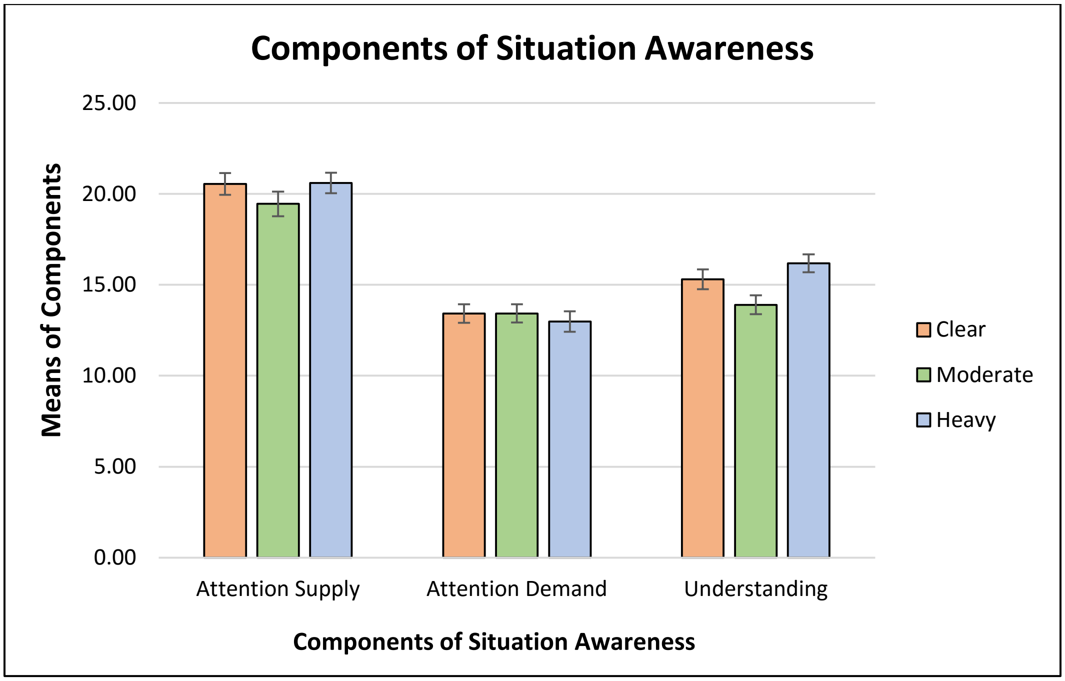

Figure 5. Components of situation awareness (SA) across visibility conditions. The error bars represent standard error.

Workload

There was a significant main effect of alarm modality on drivers' perceived workload $F(1, 60) = 4.413$, p = .040, *partial* η^2 = .069. Drivers experienced higher mean perceived workload when auditory alarms were presented (M = 48.548, SE = 2.147) than when tactile alarms were presented (M = 45.479, SE = 2.225). Means of drivers' overall perceived workload levels for different modalities across visibility conditions are shown in Figure 6.

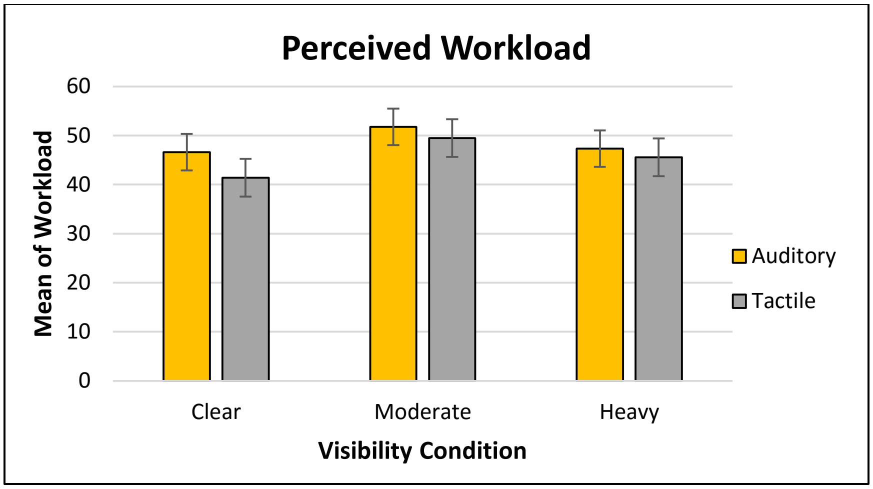

Figure 6. Average perceived workload across alarm modality and visibility conditions. The error bars represent standard error.

A paired-samples t-test was then conducted to compare the levels of workload (i.e. Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, & Frustration) in the auditory and tactile conditions. The results indicated that there was a significant difference in the means for physical demand, $t(62) = 2.288$, $p = .026$, $d = .172$ and for temporal demand, $t(62) = 2.083$, $p = .041$, $d = .212$. Drivers perceived higher physical demand in the auditory modality condition ($M = 16.778$, $SE = 1.565$) compared to the tactile modality condition ($M = 14.651$, $SE = 1.545$). Additionally, drivers perceived higher temporal demand in the auditory modality condition ($M = 19.032$, $SE = 1.591$) compared to the tactile modality condition ($M = 16.397$, $SE = 1.547$). The means, standard errors, and confidence intervals for each level of workload across modality conditions are listed in Table 1.

Table 1

Means, standard errors, and confidence intervals for each level of workload across modality condition.

Measure	Modality Level	Mean	*SE*	95% Confidence Interval	
				Lower Bound	Upper Bound
Mental	1	25.206	1.598	22.011	28.401
	2	24.286	1.612	21.063	27.508
Physical	1	16.778	1.565	13.649	19.907
	2	14.651	1.545	11.563	17.738
Temporal	1	19.032	1.591	15.851	22.213
	2	16.397	1.547	13.304	19.490
Performance	1	29.762	1.105	27.553	31.970
	2	29.048	1.269	26.510	31.585
Effort	1	21.476	1.606	18.265	24.687
	2	20.048	1.580	16.890	23.206
Frustration	1	18.571	1.671	15.231	21.912
	2	17.778	1.777	14.225	21.331

Note. Modality level 1 = Auditory. Modality level 2 = Tactile

Trust in CAWS

There was no effect of alarm modality on drivers' trust in CAWS, $F(1, 60) = .190$, $p = .664$, *partial* $\eta^2 = .003$, observed power = .071. Also, there was no effect of visibility on drivers' trust in CAWS, $F(2, 60) = 1.598$, $p = .211$, *partial* $\eta^2 = .051$, observed power = .325. However, there was a significant interaction between alarm modality and visibility condition on drivers' trust in the CAWS, $F(2, 60) = 4.579$, $p = .014$, *partial* $\eta^2 = .132$. The follow-up analysis on simple effects indicated that there was a significant effect of alarm modality on trust, but for only the auditory condition, $F(2, 60) = 5.213$, $p = .008$, *partial* $\eta^2 = .148$. For the auditory modality condition, the heavy fog condition resulted in drivers having higher trust in the CAWS ($M = 87.857$, $SE = 4.292$) than both clear ($M = 69.000$, $SE = 4.292$) and moderate fog visibility condition ($M = 73.810$, $SE = 4.292$). Bonferroni pairwise comparison indicated that for the auditory modality condition, there was a significant difference in drivers' trust scores between heavy fog and clear condition (*p* = .003), and heavy fog and moderate condition (*p* = .024). There was no significant difference in drivers' trust scores between clear and moderate condition (*p* = .431). For the tactile condition, there was no significant difference in trust score between the visibility conditions (see Figure 7). There was a significant correlation between trust and perceived reliability of the automation system. As drivers' trust in the CAWS increased, the perceived reliability of the automation system also increased in the auditory and tactile conditions ($r_s = .708$, $p < .001$; $r_s = .734$, $p < .001$, respectively).

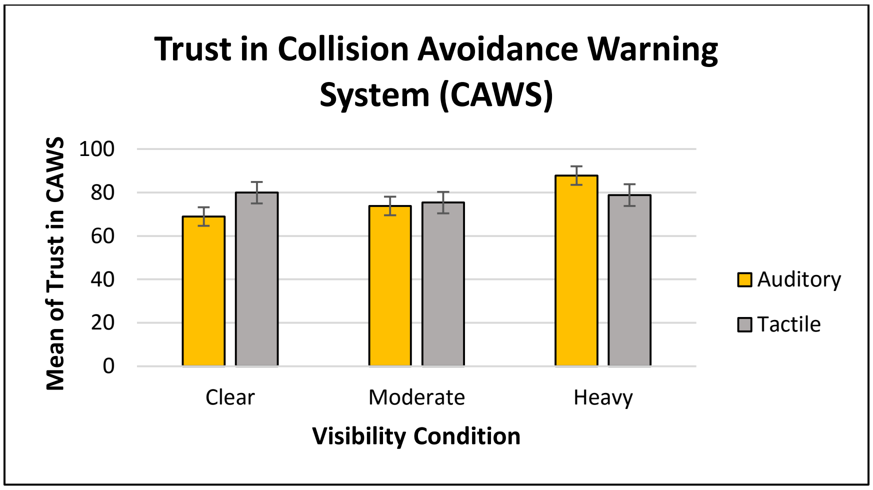

Figure 7. Drivers' trust in the CAWS across visibility and alarm modality conditions. The error bars represent standard error.

Post-Experiment Simulator Sickness

The descriptive data suggest that the drivers' simulator sickness scores ranged from 0 to 860.05. Higher scores indicate greater magnitude of simulator sickness. The overall mean for simulator sickness was 192.073 (*SD* = 221.875). Drivers in the moderate fog condition had higher means for the simulator sickness (*M* = 243.153, *SD* = 249.570) compared to the drivers in the clear visibility condition (*M* = 164.770, *SD* = 212.473), and the heavy fog condition (*M* = 168.296, *SD* = 202.637).

DISCUSSION

In the past, researchers investigated the effects of different modality of collision avoidance warning systems (CAWS) on driver performance in clear weather conditions. However, the effects of CAWS on drivers' performance under low visibility conditions is still unknown. Additionally, it is still unclear which modality best provides relevant information to drivers without interfering with the driving task. This experiment was an attempt to increase knowledge about the effectiveness of the alarm modalities for increasing SA, trust in automation systems, and driver performance without increasing workload across different visibility conditions. The results of this experiment are discussed in the following paragraphs.

Driver Performance

In this experiment, drivers' performance was reflected by the frequency of speed exceedance, number of collisions, and number of red-light tickets. The results show that there was no effect of visibility on the frequency of speed exceedance. This is a valuable finding because all drivers were instructed to follow the speed limit and were reminded by speed-limit signs placed at intervals in the virtual scenario. Therefore, no variance in drivers' number of speed exceedance across visibility conditions suggest that all participants were following the instructions provided by the researcher. The results of the present study contradicted the findings reported by Brooks et al. (2011) who suggested that drivers tend to drive at higher speed even during low visibility conditions.

The results indicated that there was a significant linear trend in the means of the collisions and red-light tickets; such that, as the visibility level decreased, the number of collisions and red-light tickets also increased. However, there was no significant difference in the number of collisions made by drivers in the clear visibility and moderate fog condition or between the moderate fog and heavy fog condition. There was also no significant difference between the number of red-light tickets received by the drivers in the clear visibility and moderate fog condition. Failing to detect significant differences between groups despite the significant linear trend indicates the lack of power to detect an effect. That is, the amount of data collected in the present study was not sufficient to detect the apparent effect of visibility on the dependent variables. However, collecting more data to increase power also increases the probability of committing a Type II error.

Drivers in the heavy fog visibility conditions had the greatest number of collisions and most red-light tickets, supporting the hypotheses that drivers will have highest number of simulated collisions in the low visibility (18m) condition; drivers in the heavy fog condition will have greater number red-light tickets than drivers in the clear visibility condition. Due to low visibility, drivers in the heavy fog condition may have neglected to detect critical information (i.e. vehicles, pedestrians, and traffic lights) early enough to process the information and select and execute an appropriate response. From this, it is reasonable to expect that because of low visibility, the drivers in the heavy fog condition would have had the lowest SA.

However, the results indicated that drivers in the heavy fog condition had the highest SA. Further analysis revealed that there was no relationship between SA and the number of collisions in the auditory condition. However, there was a negative relationship present in the tactile condition: increased SA led to decreased number of collisions. It is possible that information presented to drivers via tactile modality got perceived faster than that presented by the auditory modality. Therefore, the results support Gallace & Spence (2008) finding that tactile modality is different from other modalities as it is closely associated with spatial information in the brain.

Hence, it is suggested that tactile modality was more effective than the auditory alarms in providing environmental information to the drivers and thereby increased drivers' SA.

Another possible explanation for this could be that SA was measured after the experimental task using the SART questionnaire. Therefore, participants' ability to recall and rate their level of awareness affected the scores on SA. Adding further complexity, some researchers have suggested that the dimensions of the SART represent workload more than SA (Stanton et al., 2013). The current results revealed that drivers had lower perceived workload in the tactile condition than in the auditory condition; and that drivers who had high perceived workload in the auditory and tactile condition had greater number of collisions than the drivers who had low perceived workload. Therefore, visibility and workload may have a joint effect on the number of simulated collisions caused by drivers.

Brake reaction time usually represents an important measure of driver performance. It is typically measured by calculating the time drivers take to brake after an onset of an event stimulus. However, in the current experiment drivers in the clear visibility condition were able to view the potential stimulus events much earlier than the drivers in the moderate fog (31m) and heavy fog (18m) visibility conditions. Therefore, due to anticipatory and vigilant behavior, the drivers had numerous brake reaction times for each collision event. Because of this, it was difficult to compute an accurate brake reaction time in this present experiment. Future researchers may elect to closely examine brake reaction time as an additional performance measure.

Situation Awareness

The results suggest that there was a significant effect of visibility on SA. Drivers in the heavy fog visibility condition had higher SA compared to the drivers in the other two visibility conditions. This is contradictory to the expectation. It was hypothesized that there would be an increase in SA across visibility conditions, but the drivers in the clear visibility condition would have higher SA than drivers in the other visibility conditions. Further analysis revealed that drivers in heavy fog reported having higher understanding of the situation than the drivers in the other visibility conditions. Because the drivers in the heavy fog condition had less visibility and knowledge of the environment, it is possible that they relied on the information provided by CAWS to understand the environmental situation and thereby reported having higher SA than other visibility conditions. The CAWS in this experiment likely directed drivers' attention to the potential collision events, enhancing SA. Another possibility could be that drivers in the heavy fog and clear visibility conditions were more vigilant than drivers in the moderate fog condition. Drivers in the clear visibility condition had more visibility so were encouraged to search the virtual environment to look for potential collision events. Drivers in the heavy fog condition were also more vigilant, because they understood that potential collisions would be harder to detect.

It is important to pay heed to the method by which SA was measured to understand the results in this experiment. As mentioned above, SA was measured using the self-rating SART questionnaire post-trial. The questions involved general statements on each dimension of SA. Therefore, it is possible that participants were unable to accurately gauge their level of SA in a given task. Participants' performance and perceived workload may have influenced their perception of SA; therefore affecting the mean ratings of SA across conditions.

Workload

Drivers perceived higher workload in the auditory alarm condition than in the tactile alarm condition. This result supports the stated hypothesis and echoes a similar finding by Shah et al. (2015). Tactile alarms effectively provided critical task relevant information to the drivers and captured their attention without increasing workload. Therefore, it follows that the tactile modality taxes different cognitive resources than the auditory modality. This finding supports Wickens' Multiple Resource Theory because using a sensory modality that is different from the primary modality already taxed would effectively capture attention without increasing mental workload.

Trust in Automation System

Shah et al. (2015) found that drivers in a clear visibility condition reported higher mean trust for tactile alarms than auditory alarms. Similar results were found in the present experiment. Drivers in the clear visibility condition trusted the tactile CAWS more than the auditory CAWS. However, the overall hypothesis that drivers would trust tactile CAWS more than auditory CAWS across visibility conditions was not supported. Drivers in the heavy fog condition trusted the auditory CAWS more than the tactile CAWs. For the moderate condition, there was no significant difference in drivers' trust scores between the tactile and auditory CAWS.

The average values for trust indicate that there was a statistically non-significant relation of visibility with trust in CAWS. Drivers in the decreased visibility conditions had higher trust in the CAWS than the drivers in the clear visibility condition. Therefore, because people rely on automation that they trust (Lee & See, 2004), drivers in the decreased visibility conditions should rely on the CAWS more than drivers in clear visibility conditions. Drivers who over-rely on automation system (i.e., CAWS) are more likely to follow automation aids without critically analyzing its information and therefore may engage in automation bias (Parasuraman & Riley, 1997). Automation bias is defined as being a type of decision making error in which humans blindly follow an automation system even when it is unreliable (Parasuraman & Riley, 1997).

This leads to humans making commission errors. Commission errors are errors caused by human "operators" when they follow unreliable and inappropriate automation aid directives and can therefore degrade performance (Parasuraman & Riley, 1997).

Drivers in heavy fog had higher trust in the auditory condition than the tactile condition. However, these drivers also had greater number of collisions in the auditory condition compared to the tactile condition. The CAWS in this experiment were only 70% reliable, but drivers still trusted and relied on such systems. The results indicated that drivers trusted and over-relied on the auditory CAWS and therefore engaged in automation bias that led to performance decrement. Such results provide a rationale for the automobile industry to take efforts in improving the reliability levels of the CAWS that would provide accurate information even in clear visibility and in uncertain environments (i.e. weather degradation).

Limitations

All the available SA measures like Situation Awareness Global Assessment Technique (SAGAT), Situation Present Assessment Method (SPAM), Situation Awareness Subjective Workload Dominance (SA-SWORD), and Situation Awareness Rating Technique (SART) have both advantages and limitations. For this study either SPAM, SAGAT or SART could have been administered to measure SA. SPAM is a real-time freeze free probe technique used to measure SA in a simulator or computer based environment (Stanton et al., 2013). SAGAT is also a simulation based freeze probe technique used to measure SA. SAGAT and SPAM are administered during the actual task of the experiment (Stanton et al., 2013). According to Jones and Kaber (2005), SAGAT should be administered multiple times during a trial and while doing so, the scenarios cannot be paused during the first three to five minutes of the trial; and the pauses should not occur within one minute of each other (as cited in Stanton et al., 2013, p. 254).

Given that each scenario in the present study is only approximately ten minutes long hinders successful administration of the SAGAT and hence, it was not used to measure SA. SPAM too could not be used to measure SA as it is not compatible with the driving simulator that was used to create the virtual driving scenarios for the present study. Therefore, using SART to measure SA was the most feasible option in the present study.

In the present experiment, all participants used the same driving simulator. However, drivers in the moderate fog condition reported higher scores on the Simulation Sickness Questionnaire (SSQ) than the drivers in the other two visibility conditions. Therefore, it is possible that simulator sickness may have led drivers in the moderate condition to experience higher workload, and have lower situation awareness, as well as lower understanding and supply of attention compared to the drivers' in the other two conditions. Hence, is likely that simulator sickness may have had an underlying extraneous effect on the collected data.

There is limited research available on the effects of visibility conditions on driver performance. Brooks et al. (2011) measured drivers' choice of speed while driving under different visibility conditions ranging from 178m to 6m. Therefore, it was difficult to quantify moderate and heavy fog visibility distance while creating the simulated environments. After testing various visibility distances while creating the scenarios, the visibility level for moderate and heavy fog conditions were reasonably picked to be 31m and 18m respectively to avoid any ceiling or floor effects in the present experiment. Therefore, in the present experiment the focus was not to have moderate and heavy fog visibility conditions numerically equidistant from each other but rather was on making the visibility conditions to conceptually resemble and represent the moderate and heavy fog conditions from the real world environment.

CONCLUSION

Overall, this experiment was an attempt to further enhance our knowledge about the effectiveness of the different modalities of alarms as CAWS and to provide significant contribution to the literature regarding human performance and safety. A follow-up study should be conducted to validate the findings. Testing theories with direct replication would be beneficial in testing the reliability of effects found in the present experiment and would therefore help provide predictions that are testable and generalizable (Simons, 2014). Conceptual replication could be beneficial in testing construct such as SA, workload, and trust to validate the effects of such constructs on human-automation performance. One approach would be for researchers to employ physiological measures along with subjective measures to test ambiguous constructs such as workload and situation awareness. Eye-tracking could be used to measure mental workload. May, Kennedy, Williams, Dunlap, and Brannan (1990) found that as workload increases the range of saccadic eye-movements decreases. Therefore, if auditory CAWS truly increase drivers' workload, then one can expect to see a decrease in drivers' range of saccadic eye-movements. Eye tracking is also found to be a plausible measure for SA. Eye tracking measures, particularly gaze fixation, provide information about the processes that lead to high or low SA (Moore & Gugerty, 2010). For instance, contradicting to the expectation, drivers in the heavy fog condition reported having high SA in the present study. However, the process that led to such results is unknown. Using eye-tracking to measure drivers' vigilant behavior and visual attention may help in understanding the underlying process that leads to attaining high or low SA.

It was found that tactile modality induced lower workload than auditory modality while providing crucial task related information to the drivers. Therefore, tactile modality seems to be a promising modality for CAWS. However, the results of the present experiment were based on the results obtained from testing young college students with mean age of 20.75 years. Therefore, it is important to test other driving populations (i.e. novice drivers, older adults, & truck drivers) as well to verify the generalizability of the results. For instance, truck drivers usually are required to drive long hours to deliver goods in a timely manner. Factors such as stress, fatigue, and over-exertion are associated with prolonged driving hours that could adversely affect SA, workload, and driving performance. To improve driver performance, practitioners could consider implementing tactile CAWS in vehicles to alert drivers particularly distracted drivers without increasing their workload to help increase SA and thereby increase safety on roadways.

Future researchers and practitioners could use the data from the present experiment to help create more effective CAWS to increase safety on the roadways. As mentioned above, there are significant numbers of fog related vehicle crashes occurring in the United States alone. Foggy conditions are found in almost all parts of the world. Extending these research findings to improve the vehicle CAWS would help increase safety on the roadways around the world.

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APPENDIX A

OLD DOMINION UNIVERSITY INFORMED CONSENT FORM

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, and to record the consent of those who say YES.

TITLE OF RESEARCH: Effects of Visibility and Alarm Modality on Workload, Trust in Automation, Situation Awareness, and Driver Performance.

RESEARCHERS

James P. Bliss, Ph.D., Associate Professor, Responsible Project Investigator, College of Sciences, Psychology Department

Smruti J. Shah, B. S. Graduate Student, College of Sciences, Psychology Department

DESCRIPTION OF RESEARCH STUDY

Through this study it is an attempt to identify which collision avoidance warning systems' modality works best at improving driver performance. If you decide to participate, then you will be one of the 78 participants. Participation will take approximately 1 hour and 30 mins. The study will be conducted in MGB, Room 324. During your participation you will be asked to follow a route to a destination. Your task is to drive as you normally do and follow all the traffic rules and regulations. While doing so you are asked to avoid collisions with any objects, pedestrians or cars. You will also be asked to complete a few questionnaires.

EXCLUSIONARY CRITERIA

To participate, you must be 18 years or older. You must have a valid driver's license. You must have normal or corrected to normal vision and hearing. Participants must have a normal sense of touch.

Note: If you have already participated in Project CITYDRIVE, then you cannot participate in this study.

RISKS AND BENEFITS

RISKS: If you decide to participate in this study, then you may experience symptoms of motion sickness such as nausea, eyestrain, or fatigue. To reduce the likelihood of this happening, we are limiting your performance in the simulator to 10-minute sessions, and we are using a simulator that has a rapid screen refresh rate and narrow field of view. As with any research, there is some possibility that you may be subjected to risks that have not yet been identified.

BENEFITS: No direct benefits for participation will be provided.

COSTS AND PAYMENTS

The researchers want your decision about participating in this study to be absolutely voluntary. The main benefit to you for participating in this study is that you will receive 1.5 SONA research credit that can be applied to any higher level psychology classes.

NEW INFORMATION

If the researchers find new information during this study that would reasonably change your decision about participating, then they will inform you.

CONFIDENTIALITY

All information obtained about you in this study is strictly confidential unless disclosure is required by law. The results of this study may be used in reports, presentations and publications, but the researcher will not identify you.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. You will not be penalized for quitting the study and will still receive the incentives. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled. The researchers reserve the right to withdraw your participation in this study, at any time, if they observe potential problems with your continued participation.

COMPENSATION FOR ILLNESS AND INJURY

If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of harm, injury or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Dr. James P. Bliss at 757-683-4439 or Dr. George Maihafer (IRB Chair) at 757-683-4520.

VOLUNTARY CONSENT

By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, please contact the researcher at the number above.

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should contact Dr. George Maihafer (IRB Chair) at 757-683-4520.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study.

Participant's Printed Name & Signature	**Date**

INVESTIGATOR'S STATEMENT

I certify that I have explained to this participant the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the participant's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

Investigator's Printed Name & Signature	**Date**

APPENDIX B

BACKGROUND QUESTIONNAIRE

Participant ID #________________ Date:_____________ Time:_______________

1. **Sex**
   a) Male
   b) Female

2. **Age___________**

3. **Ethnicity**
   a) Caucasian
   b) African American
   c) Asian
   d) Native Hawaiian or Other Pacific Islander
   e) American Indian or Alaska Native
   f) Hispanic/ Latino
   g) Other

4. **Do you currently have hearing loss or impairment?**
   a) Yes
   b) No

If you answered "YES" to the above question then please answer then next question.

5. **Are you currently wearing hearing aids that correct the loss or impairment?**
   a) Yes
   b) No

6. **Do you have normal (or corrected to normal) vision?**
   a) Yes
   b) No

7. **Have you ever been diagnosed as color deficient ("color blind")?**
   a) **Yes**
   b) **No**

8. **Since how many years are you driving with a valid driver's license? Please answer in years only.**
   Years: ________

9. **How many hours a week do you drive an automobile?**
   ____

10. **Have you received any tickets for traffic violation?**
    a) Yes
    b) No

11. **Do you play video games?**
    a) Yes
    b) No

***If, you answered 'YES' to the above question then please answer the following questions:**

12. **How many hours per week do you spend playing non-driving video games?**
    ____

13. **How many hours per week do you spend playing simulated driving video games?**
    ____

APPENDIX C

MOTION SICKNESS SUSCEPTIBILITY QUESTIONNAIRE

Participant #___________ Condition: ___________ Date: ___________ Time: _______

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

1. **As a CHILD (before age 12),** how often have you **Felt Sick or Nauseated** (mark the appropriate box with an X):

	Not Applicable - Never Travelled	Never Felt Sick	Rarely Felt Sick	Sometimes Felt Sick	Frequently Felt Sick
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your MOST RECENT Experience Only (in the last 10 years), for each of the following types of transport or entertainment please indicate:

2. **In the last TEN YEARS,** how often have you **Felt Sick or Nauseated** (mark the appropriate box with an X):

	Not Applicable - Never Travelled	Never Felt Sick	Rarely Felt Sick	Sometimes Felt Sick	Frequently Felt Sick
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

APPENDIX D

SIMULATOR SICKNESS QUESTIONNAIRE (SSQ-SHORT)

Participant #____________Condition:____________ Date:_____________ Time:_________

This questionnaire is designed to find out if you are experience simulator sickness. Please indicate the degree to which you currently experience each of the symptoms below using the following scoring:

0 = None, 1 = Slight, 2 = Moderate, and 3 = Severe

SSQ Symptom	***Degree of discomfort***
General discomfort	
Fatigue	
Headache	
Eyestrain	
Difficulty focusing	
Increased salivation	
Sweating	
Nausea	
Difficulty concentrating	
Fullness of head	
Blurred vision	
Dizzy (eyes open)	
Dizzy (eyes closed)	
Vertigo	
Stomach awareness	
Burping	

APPENDIX E

NASA-TLX

Participant #________ Date:________ Time:________ Group: ________

Instructions: Place a mark (/) on each scale that represents the magnitude of each factor in the task you just performed.

Demands	**Ratings for task**
Mental Demand	Low [__________________________] High
Physical Demand	Low [__________________________] High
Temporal Demand	Low [__________________________] High
Performance	Excellent [__________________________] Poor
Effort	Low [__________________________] High
Frustration	Low [__________________________] High

Demands clarification:

Mental Demand – How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)?

Physical Demand – How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)?

Temporal Demand – How much time pressure did you feel due to the rate or pace at which the task or task elements occurred?

Performance – How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort – How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration – How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

APPENDIX F

TRUST QUESTIONNAIRE FORM

Participant ID#: _______ Modality: ________ Date: ______ Time: _______

Below is a list of statements for evaluating trust between people and automated systems. Please circle the number that best describes your feeling or your impression of the alarm system you have just utilized during the task.

1= not descriptive statement of the alarm system impression

12= very descriptive statement of the alarm system impression

1.) The alarm system is deceptive

1 2 3 4 5 6 7 8 9 10 11 12

2.) The alarm system behaves in an underhanded manner

1 2 3 4 5 6 7 8 9 10 11 12

3.) I am suspicious of the alarm system's outputs

1 2 3 4 5 6 7 8 9 10 11 12

4.) I am wary of the alarm system

1 2 3 4 5 6 7 8 9 10 11 12

5.) The alarm system's actions will have a harmful or injurious outcome

1 2 3 4 5 6 7 8 9 10 11 12

6.) I am confident in the alarm system

1 2 3 4 5 6 7 8 9 10 11 12

7.) The alarm system provides security

1 2 3 4 5 6 7 8 9 10 11 12

8.) The alarm system has integrity

1 2 3 4 5 6 7 8 9 10 11 12

9.) The alarm system is dependable

1 2 3 4 5 6 7 8 9 10 11 12

10.) The alarm system is reliable

1 2 3 4 5 6 7 8 9 10 11 12

11.) I can trust the alarm system will accurately indicate problems to respond to

1 2 3 4 5 6 7 8 9 10 11 12

12.) I am familiar with this alarm system

1 2 3 4 5 6 7 8 9 10 11 12

According to you, how reliable is this alarm system? Please write your answers in whole numbers between 0 and 100.

____

APPENDIX G

SITUATION AWARENESS RATING TECHNIQUE (SART)

(ADOPTED FROM TAYLOR, 1990)

Familiarity with the situation

1) How familiar are you with the situation experience? Do you have high familiarity with this experience (high) or is it unfamiliar to you (low)?

   1 2 3 4 5 6 7

Focusing/Divided attention

2) How much is your attention divided in the situation? Is your attention focused on the situation (high) or is it divided (low)?

   1 2 3 4 5 6 7

Information quantity

3) How much information have you received and understood in the situation? Have you received a lot of relevant information (high) or not at all (low)

   1 2 3 4 5 6 7

Instability of the situation

4) How likely is the situation changeable? Is the situation highly unstable to change suddenly (high) or is it a stable situation (low)?

   1 2 3 4 5 6 7

Concentration of attention

5) How much are you concentrating on the situation? Is your attention concentrated on many aspects of the situation (high) or focused on only one (low)?

   1 2 3 4 5 6 7

Complexity of the situation

6) How complicated is the situation? Is it complex with number of closely related parts (high) or is it simple situation (low)?

1 2 3 4 5 6 7

Variability of the situation

7) How much is the situation varying? Are there a lot of variables to attend to (high) or are there very few variables to attend to (low)?

1 2 3 4 5 6 7

Arousal

8) How aroused are you in the situation? Are you highly aroused (high) or are you low on arousal (low)?

1 2 3 4 5 6 7

Information quality

9) How much degree of quality information value have you received in the situation? Have you received good quality of information (high) or poor quality of information (low)

1 2 3 4 5 6 7

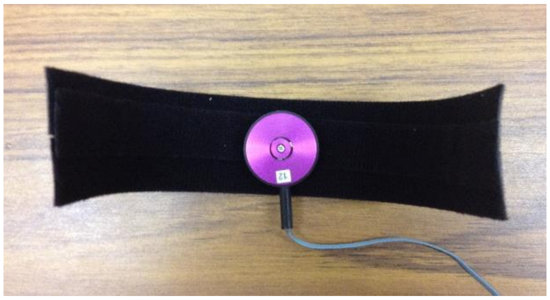
Spare mental capacity

10) How much mental ability do you have to apply to new variables in the situation? Do you have a lot of spare capacity (high) or you don't have any spare capacity (low)?

1 2 3 4 5 6 7

APPENDIX H

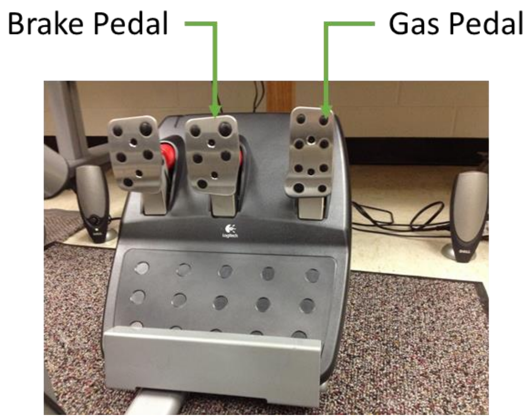
PICTURES OF THE EXPERIMENTAL EQUIPMENT



Velcro belt with tactor attached

Position of the vibrotactile belt on the posterior side of the hand.

Logitech G27 steering wheel



Logitech pedals

Playseat

APPENDIX I

CORRELATION MATRIX TABLE

Means, standard deviation, skewness, kurtosis, and correlation information for the dependent variables.

	M	SD	Skewness	Kurtosis	Aud Collision	Tac Collision	Aud Trust	Tac Trust	Aud Perceived Reliability	Tac Perceived Reliability	Aud Workload	Tac Workload	Aud SART	Tac SART	Aud Speed Exceedance	Tac Speed Exceedance	Aud Red-light Ticket	Tac Red-light Ticket
Aud Collision	2.810	2.782	1.722	4.370	1													
Tac Collision	2.778	2.773	1.756	4.327	.373**	1												
Aud Trust	76.89	20.961	0.407	-0.309	.254*		1											
Tac Trust	78.06	22.592	-0.228	-0.654	0.009	-.304**	.505**	1										
Aud Perceived Reliability	62.04	20.262	-0.226	-0.575	.229*	0.084	.708**	.319**	1									
Tac Perceived Reliability	61.13	22.551	-0.840	0.082	-.045	-.397**	.430**	.734**	.546**	1								
Aud Workload	48.55	16.923	-0.096	-0.435	.245*	0.135	-.154	-.082	-.008	-.019	1							
Tac Workload	45.48	17.691	0.029	-0.921	0.181	.237*	-.207	-.247*	-.092	-.184	.787**	1						
Aud SART	21.71	6.004	0.301	-0.019	0.075	0.163	0.127	-.149	.256*	-.022	0.067	0.095	1					
Tac SART	22.25	5.744	-0.261	-0.513	0.03	-.239*	-.004	0.089	0.034	0.162	0.077	-.064	.537**	1				
Aud Speed Exceedance	4.635	4.787	2.056	4.821	0.003	0.242*	0.027	-.051	0.003	-.227*	0.103	0.028	-.122	-.207	1			
Tac Speed Exceedance	4.683	5.086	1.777	3.134	0.171	0.264*	0.019	-.108	0.054	-0.166	0.139	0.137	-.141	-.293**	0.717**	1		
Aud Red-light Ticket	0.540	0.668	0.857	-0.360	0.219*	0.285*	0.237*	-0.073	-0.003	-0.141	0.036	0.079	0.224*	0.186	0.148	0.043	1	
Tac Red-light Ticket	0.524	0.592	0.629	-0.526	0.127	0.135	0.217*	0.089	0.139	0.061	-.190	-0.172	0.226*	0.088	0.143	0.175	0.446**	1

* < 0.05 level (1-tailed); ** < 0.01 level (1-tailed).

Note. Aud = Auditory. Tac = Tactile

VITA

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PUBLISHED ABSTRACTS

Ringleb, S. I., Chancey, E.T., Hanson, J., **Shah, S.**, Hoch, M., Barber, H., Kennedy, K., & Bliss, J.P. (2014). Virtual reality assessment modules - The combination of biomechanics and human factors to assess military performance. *7th World Conference of Biomechanics*. Boston, MA.

RESEARCH PAPERS PRESENTED AT PROFESSIONAL MEETINGS

Strater, L., Flynn, J., Kennedy, R. K., Procci, K., Proaps, A. B**., Shah, S. J.** (2014). Me and my VE: Part 3. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting,* 2397-2401. Chicago, IL.

Shah, S. J., Bliss, J. P., Chancey, E. T., & Brill, J. C. (2015). Effects of alarm modality and alarm reliability on workload, trust, and driving performance. *Proceedings of the Human Factors and Ergonomics Society 59th Annual Meeting,* 1535-1539. Los Angeles, CA.

HONORS AND AWARDS

Honors College "Collegium Honorum" (ODU)	May, 2013
Magna Cum Laude (ODU)	May, 2013
Dean's List (ODU)	Fall 2009; Fall 2010; Spring 2011; Fall, 2011; Spring 2012; Fall, 2012 and Spring, 2013
Academic Honors Scholarship – Honors College (ODU)	Fall, 2010; Spring, 2011; Fall, 2011; Spring, 2012; Fall, 2012; Spring, 2013
International Student Leadership Award (ODU)	2012- 2013 School year

CERTIFICATIONS

Graduate Teacher Assistant Instructor Institute Certificate - (ODU)	January, 2014
Preparing for Future Faculty (PFF) Certificate - (ODU)	May, 2015
Modeling and Simulation Engineering Certificate - (ODU)	December, 2015
Graduate Research Achievement Day – Certificate of Participation (ODU)	April, 2016