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An Evaluation of the Safety, Utility, and Reliability of Three-Dimensional Alarm Systems for Automotive Use

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16. Abstract

As roadways become more congested, there is greater potential for automobile accidents and incidents. Several governmental agencies, including the Federal Highway Administration, have recently developed and implemented the Intelligent Transportation System, a global effort to better manage vehicles and highway systems. As part of this effort, automobile manufacturers are now designing collision avoidance warning system; yet, there has been little investigation of alarm reliability and spatial signal location This study focused on measuring driving and alarm reaction performances to spatial and console emitted alarms of various reliability levels. Seventy participants operated a driving simulator while being presented with alarms. From previous research (Breznitz, 1983; Bliss, 1993), it was expected that drivers would perform better following reliable alarms than unreliable alarms. I was also expected that participants would perform better following spatial alarms than central alarms. Results indicated that drivers avoided collisions better following spatial alarms, but made more appropriate driving reactions following console-generate alarms. Alarm response frequency and driving reaction appropriateness were higher for reliable alarms.

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Executive Summary

For years, automobile companies and safety administrations have studied ways for drivers to avoid collisions. Recently, the Federal Government committed itself to better management of vehicles and highway systems by designing and testing the Intelligent Transportation System (ITS) (NHTSA, 1997). As a component of ITS, many car companies are designing collision avoidance warning systems (CAWS) for implementation in new car models. If properly designed and implemented, CAWS may help reduce particular types of accidents, such as rear-end collisions and roadway departures (Chen, Quinn, and Ritzmann, 1997).

In potential collision situations, auditory alarm signals may provide basic information about urgency to the operator. However, more information is often needed about how to take corrective action. Therefore, some designers have considered spatially separating alarm signals from background noise to increase threat localization ability. Such separation may lower the threshold at which signals are detected and discriminated (Bronkhorst, Veltman, and Van Breda, 1996). Although visual displays are typically best for displaying spatial information, auditory displays may be more appropriate in certain situations where visual overload is a problem (Proctor and Van Zandt, 1994).

There is evidence to suggest that operators may react better to spatial alarm signals. Rudmann and Strybel (1999) conducted research using centered and spatial auditory cues for a search task in a virtual environment. They found that spatial auditory cues led to quicker response times than centered cues generated in front of participants.

Several automobile manufacturers are considering implementation of collision avoidance warning systems with spatial auditory component. The use of spatially generated auditory signals offers promise for automotive environments. Drivers may not have to look at a head-up display, console, or rear view mirror to know from which direction cars are approaching. Rather, information about location could be provided auditorially.

While the development of spatial CAWS for automobiles may help reduce collisions, false alarms and nuisance alarms are sources of concern. Drivers may become annoyed if a CAWS continually activates when there is no danger (Tijerina and Hetrick, 1997). Furthermore, drivers may waste time and effort reacting to warnings that do not reliably signal danger. Logic suggests that particular driving situations may be more conducive to false alarms. For example, multiple false alarms could occur when a vehicle is in a parking lot where the proximity of a vehicle is close enough to set off the CAWS.

Recently, Bliss and Gilson (1998) suggested that signaling equipment should be designed to eliminate false and nuisance alarms. Also, they stated that operators should be encouraged to take every alarm seriously. One way to achieve this is to incorporate established alarm signal urgency guidelines, so operators are stimulated to respond more reliably. Such steps are critical, because research suggests that false alarms and nuisance alarms can cause significant degradations in task performance (Bliss et al., 1998).

The first goal of this study was to determine whether spatially generated auditory warnings would be more suitable than centrally generated console warnings for automotive CAWS. The literature concerning aviation CAWS supports the effectiveness of spatial audio for flight related warnings (Bronkhorst et al., 1996; Lee et al., 1993). Based on this research, we expected participants to react more quickly and appropriately to spatial alarm signals.

The second goal of this study was to determine if spatial alarms would be perceived as more reliable than console emitted alarms. Lee et al. (1993) found that pilots prefer spatial alarms because of the usefulness of threat location information. Therefore, we hypothesized that spatially presented alarms would be perceived as more reliable than console emitted alarms in automobiles. Specifically, we expected participants to respond more frequently to spatially generated alarms.

Using a 2x3 experimental design, we manipulated alarm style (central or spatial, within groups) and perceived reliability (50, 75, or 100% true alarms, between groups). Dependent measures included the frequency with which drivers reacted to alarms, alarm reaction time, alarm reaction appropriateness (whether participants reacted after a true or a false alarm), driving reaction appropriateness (whether the action was appropriate in traffic), and collision frequency (whether driving reactions caused collisions with approaching vehicles).

Participants were randomly assigned to a high-, medium-, or low-reliability group. All groups were asked to respond to alarms presented during a simulated driving task. Different alarm reliability information (50%, 75%, or 100% true alarms) was given to the participants according to group assignment. Driving task dependent measures were taken by recording the participants' actions during the driving task.

The simulated driving task consisted of two 20-minute sessions of simulated driving while reacting to collision warning alarms. The route began on I-565 at Washington Street in downtown Huntsville, AL. The driver traveled west toward the intersection of I-565 and I-65 near Decatur, AL, for the first 20-minute session. Drivers were told to maintain a maximum speed of 70 miles per hour. After a 10-minute break, participants returned to the starting point in Huntsville, AL.

During both sessions, the participants were presented alarms according to a randomized schedule. For all reliability groups (50%, 75%, and 100% true alarms), the first driving segment represented a baseline condition, during which alarm signals were generated from the center console behind the firewall. During the return segment of the trip, alarms were generated from three locations within the automobile cabin (rear, left rear, and right rear, corresponding to the origin of the approaching traffic).

Based on prior research by Lee et al. (1993), it was expected that spatial alarms would lead to more frequent and appropriate alarm reactions. However, our results regarding this hypothesis were mixed. Drivers avoided collisions better using spatial alarms, yet their initial driving reactions were more appropriate following console-generated alarms. One reason may be that driving reactions reflected the initial, reflexive reaction to the alarm.

It was also expected that spatially presented alarm signals to be perceived as more reliable than console emitted alarms. In the past, researchers have consistently and successfully used response parameters such as response frequency, speed, and appropriateness as suitable indicators of alarm trust (Bliss et al., 1998). Results did not suggest that participants found spatial alarms to be more trustworthy than console-based alarms. However, alarm response rates suggested that the cry-wolf effect did occur.

An Evaluation of the Safety, Utility, and Reliability of Three-Dimensional Alarm Systems for Automotive Use

1. Introduction

Motor vehicle accidents are the leading cause of death for persons age 6 to 27 years, accounting for over 90 percent of all transportation related fatalities (National Highway Traffic Safety Administration [NHTSA], 1996). In 1996, 41,798 persons died in motor vehicle related accidents (U.S. Department of Transportation, 1997). The cost of motor vehicle accidents totaled over $150.5 billion in 1994 (NHTSA, 1996). Although increased seatbelt usage and driver sobriety reduced fatalities from 1993 to 1996, much more could be done to reduce injuries and deaths (NHTSA, 1996).

Seventy-five percent of all accidents occur in rear-end, intersection, and road-departure situations (NHTSA, 1997). For years, automobile companies and safety administrations have studied ways for drivers to avoid collisions. In recent years, the US Department of Transportation has committed itself to better management of vehicles and highway systems by designing and testing the Intelligent Transportation System (ITS) (NHTSA, 1997). As a component of ITS, many car companies are designing collision avoidance warning systems (CAWS) for implementation in new car models. The purpose of such systems is to notify drivers about potential dangers from other automobiles and roadway departures (Hirst and Graham, 1997). If properly designed and implemented, CAWS may help reduce particular types of accidents, such as rear-end collisions and roadway departures (Chen, Quinn, and Ritzmann, 1997; Araki et al., 1996; Saneyoshi, 1996; Dingus et al., 1997; Chen, Jochem, and Pomerleau, 1995; An and Harris, 1996).

The first transportation division to implement collision avoidance warning systems was aviation. Because of the increasing popularity of air travel and the critical and complex nature of the piloting task, aircraft designers have sought ways to keep pilots informed about potential collisions with other aircraft. In response to increasing numbers of near-collisions, aviation researchers created the Traffic Collision Avoidance System (TCAS) to notify pilots of impending collisions with other aircraft. Although the TCAS system resulted in improved overall safety, pilots voiced concerns about the system generating false alarms and improper directives (Shapiro, 1994). Since that time, the computer algorithms controlling TCAS have been improved, but the false alarm issue has not been resolved completely (Bliss, Freeland, and Millard, 1999).

Since the introduction of alarm systems like TCAS, aviation-related warning systems have increased in complexity. Aircraft manufacturers initially designed warning systems (including CAWS) to generate signals from a center console. After the general warning signals activated, a central display panel would relay detailed information visually (King and Oldfield, 1997; Lee et al., 1993; Lee and Patterson, 1993). However, in certain applications, designers have implemented spatial warning systems, so that warnings emanate from a point in space corresponding to the source of the threat aircraft.

2.0 Background

Since their inception, much research has been conducted to optimize CAWS. Generally, researchers have developed methods to improve warning signal implementation technology, heighten the perceived urgency of warning signal stimuli, and incorporate spatial signals into CAWS.

2.1 Technology Research

Researchers have devoted considerable effort to improve the technological aspects of CAWS. The technology incorporated in CAWS today ranges from head-up displays to intelligent computers that go beyond notification to assume the operations of the vehicle. Currently, several different versions of automobile CAWS are being designed and tested for highway usability. These systems range from simple warnings guided by turn signal use to intelligent cars that avoid potential crashes without driver intervention (Chen et al., 1997; Tijerina and Hetrick, 1997).

One type of warning system works on the basis of a turn signal onset rule. A warning is triggered when the driver activates the turn signal and there is another vehicle in the driver's blind spot. Such an algorithm may be an effective deterrent for collisions, but relies on the driver to use the turn signals (Tijerina and Hetrick, 1997).

Other systems employ radar technology to initiate a warning when the driver is within a certain distance from another vehicle, regardless of the driver's use of the turn signal. Crash avoidance potential is high in these situations. However, nuisance or false alarm probability is also high, particularly in areas such as parking lots, or when two cars are following close parallel courses (Tijerina and Hetrick, 1997).

Some collision avoidance systems are designed specifically for avoiding rear-end collisions. A popular idea in large cities with considerable traffic, rear-end CAWS generate signals based on separation distance and the relative velocity of each vehicle. One particular rear-end CAWS combines a buzzer and a visual head-up display to relay information to the driver (Araki et al., 1996).

As an example of advanced technology for CAWS applications, Saneyoshi (1996) designed a warning system that uses advanced image recognition to detect vehicles and other potentially hazardous objects. This system includes two different warnings. The first warning sounds to motivate the driver to focus attention in front of the vehicle. The second warning sounds to stimulate the driver to take protective action such as braking or steering.

2.2 Warning Signal Type

For years, researchers have studied and developed ways to present warning signals to task operators. Researchers generally acknowledge that the auditory channel is better for conveying warning signals. Aside from research demonstrating reduced reaction time to auditory stimuli (Lilliboe, 1963), Bronkhorst, Veltman, and van Breda (1996) pointed out that in high workload situations the visual channel is often overloaded. In such cases, the use of the auditory channel for warning signals may help to reduce visual workload and shorten reaction times.

Visual channel overload has been a problem for years. In 1978 Veitengruber indicated that certain transport aircraft employed up to 800 visual alerting functions. As another example, in their review of nuclear power plant designs, Seminara, Gonzalez and Parsons (1977) stated that alarm signals activated so often that they conveyed little useful information. To avoid visual overload, the use of other sensory modalities, specifically audition, has been suggested as a means of conveying critical information to the vehicle operator (Belz et al., 1997).

Research concerning collision avoidance warning signals has focused on several variables. Horowitz and Dingus (1992) suggested that collision avoidance warning systems should include auditory warnings to supplement visual displays. They also recommend that auditory warnings be graded from mild to severe in accordance with time to collision.

Judy Edworthy and her colleagues have studied perceived urgency of warning signals for years. Haas and Edworthy (1996) experimented with auditory warnings by varying pitch, speed and loudness. They found that the most urgent signals were those that have pulses with a fairly high fundamental frequency (800Hz), sound pressure level above 40 dBlin, and a short inter-pulse interval. They also found that perceived urgency increases as fundamental frequency increases and inter-pulse interval decreases.

From the available research, the auditory modality appears to be the best way to convey warnings to vehicle operators (Belz et al., 1997; Bronkhorst et al., 1996; Horowitz et al., 1992). Furthermore, recommendations by Haas and Edworthy (1996) have provided a useful guideline for the construction of high-urgency warning signals.

2.3 Spatial Generation of Auditory Signals

In potential collision situations, auditory alarm signals that are urgent will provide basic information to the operator. However, frequently more information is needed about how to take corrective action. To provide such information, some designers have considered spatially separating alarm signals from background noise to increase threat localization ability. Such separation may lower the threshold at which signals are detected and discriminated (Bronkhorst et al., 1996). Although visual displays are typically best for displaying spatial information, auditory displays may be more appropriate in certain situations where visual overload is a problem (Proctor and Van Zandt, 1994). This has led to the development of three-dimensional auditory displays for communicating and conveying warning information.

Current technology has made it possible for pilots of fighter aircraft to receive spatial information about other traffic auditorially over headphones (Bronkhorst et al., 1996; Lee et al., 1993; Lee and Patterson, 1993). In some systems, three-dimensional auditory signals emanate from a source in such a way that the listener has the illusion that the sound originates at a virtual location in space, other than the actual sound origin. Spatial audio displays utilize directional information such as azimuth, elevation and distance to create a sphere around the listener.

Bronkhorst et al. (1996) found that spatial auditory displays and radar (visual) displays were equally effective for conveying directional information in three dimensions. This suggests that when there is high visual workload a spatial audio display might be used to convey spatial information.

Not only do spatial alarms offer the potential for enhanced detectability, Lee et al. (1993) found that fighter pilots prefer spatial signals for wingman communication and threat information. Almost 82% of the pilots surveyed found spatial audio for threat warnings of high interest. The possibility that a pilot could react to a missile launch without having to shift visual attention was of considerable interest as a way to avoid danger.

There is also evidence to suggest that operators may react better to spatial alarm signals. Rudmann and Strybel (1999) conducted research using centered and spatial auditory cues for a search task in a virtual environment. They found that spatial auditory cues led to quicker response times than centered auditory cues generated in front of participants.

Several automobile manufacturers are considering implementation of collision avoidance warning systems that include a spatial auditory component. The use of spatially generated auditory signals offers promise for automotive environments. Drivers may not have to look at a head-up display, console, or rear view mirror to know from which direction another car is approaching. Rather, information about another car's location could be provided auditorially by the spatial audio display.

Wallace, Fisher, and Collura (1996) conducted an experiment that measured response times to different types of auditory stimuli. Their study suggested that increasing the possible locations from which an alarm could sound would increase response time. However, the study was conducted in a highly controlled setting, and did not simulate a driving situation. In actual driving conditions, there would likely be greater variability in response performances, because of the increased complexity of an actual driving task. In actual driving situations, drivers must locate other traffic and decide how to react. This represents a level of task difficulty not represented in Wallace et al.'s experiment.

2.4 Signal Reliability

As noted above, much research as considered the physical aspects of warning signals. However, few researchers have concerned themselves with perceived reliability of warning signals. As noted earlier, one of the most pressing concerns about aviation CAWS is the frequency of false alarms and improper directives (Bliss et al., 1999). False alarms and nuisance alarms are also a concern for automotive CAWS. Drivers may become annoyed if the CAWS continually activates when there is no danger (Tijerina et al., 1997). Furthermore, drivers may waste time and effort reacting to warnings that do not reliably signal danger. Logic suggests that particular driving situations may be more conducive to false alarms. For example, multiple false alarms could occur when a vehicle is in a parking lot where the proximity of a vehicle is close enough to set off the CAWS.

In a recent article, Bliss and Gilson (1998) suggest that signaling equipment should be designed to eliminate false and nuisance alarms. In addition, they stated that operators should be encouraged to take every alarm seriously. One way to achieve this is to incorporate Hass et al's (1996) alarm signal urgency guidelines, so that operators are stimulated to respond more reliably. Such steps are critical, because research suggests that false alarms and nuisance alarms can cause significant degradations in task performance (Bliss et al., 1998; Breznitz, 1983; Paté-Cornell, 1986).

Those considering implementation of spatial alarm systems in automobiles have not determined empirically whether perceived reliability will impact the effectiveness of such systems. Bliss, Gilson, and Deaton (1995) found that responses to alarms degrade as alarm reliability decreases. If operators do not trust a particular alarm, responses to that alarm will be slower and limited in number, potentially rendering the alarm system useless.

Breznitz (1983) coined the phrase "cry-wolf effect" to describe the mistrust accompanying false alarms. The "cry-wolf effect" occurs when an alarm is activated several times when there is not a real threat. Operators begin to lose trust in the alarm system because the false alarm rate is higher than the true alarm rate. Breznitz also suggested that the "cry-wolf effect" degrades operator responses. Paté-Cornell (1986) later suggested that in some cases false alarms may cause total cessation of responses, making the entire warning system ineffective.

Previous research in the aviation domain suggests that perceived reliability may be greater for spatial alarms than for alarms generated from a central console. For this reason, and because of the potential interaction between reliability and spatial signal source, it is critical to examine these variables in a realistic task performance situation.

2.5 Goals and Hypotheses

The first goal of this study was to determine whether spatially generated auditory warnings would be more suitable than centrally generated console warnings for automotive CAWS.

The literature concerning aviation CAWS supports the effectiveness of spatial audio for flight related warnings (Bronkhorst et al., 1996; King and Oldfield, 1997; Lee et al., 1993; Lee and Patterson, 1993). Furthermore, Begault and Pittman (1994) found that target acquisition was faster for spatial audio in a flight simulator. Based on this research, we expected participants to react better to spatial alarm signals. Specifically, we expected reaction times to be quicker, alarm reactions (responding or ignoring) to be more appropriate, and driving reactions (swerving and braking) to be more appropriate.

The second goal of this study was to determine if spatial alarms would be perceived as more reliable than console emitted alarms. Lee et al. (1993) found that pilots prefer spatial alarms because of the usefulness of threat location information. We therefore hypothesized that spatially presented alarms would be perceived as more reliable than console emitted alarms in automobiles. Specifically, we expected participants to respond more frequently to spatially generated alarms.

Based on past research regarding the "cry-wolf effect" (see Bliss et al., 1998), it is anticipated that participants would respond to alarms of high reliability more frequently. However, past research has yielded mixed results for reaction appropriateness (Bliss, 1993; Bliss et al., 1998). For that reason, we made no hypothesis regarding alarm reaction appropriateness.

3.0 Methodology

3.1 Experimental Design

The current experiment was conducted according to a 2x3 experimental design. The independent variables were alarm style (central or spatial, manipulated within groups) and perceived reliability (50, 75, or 100% true alarms, manipulated between groups). Dependent measures reflected driving performance following alarm signals. The metrics used included the frequency with which drivers reacted to alarms, alarm reaction time, alarm reaction appropriateness (whether or not participants took action following a true or a false alarm), driving reaction appropriateness (whether the action they took was appropriate in traffic), and collision frequency (whether their reaction to the alarms resulted in a collision with the approaching vehicle). We also measured background experience with driving and alarm reaction tasks, and we monitored symptoms of simulator sickness (Kennedy et al., 1993).

Before beginning participation, participants were randomly assigned to a high-, medium-, or low-reliability group. All groups were asked to respond to alarms presented during a driving task. Different alarm reliability information was given to the participants according to each group. Following the procedure outlined in previous alarm mistrust research (Bliss et al., 1995), participants were told the alarm system reliability prior to participation. They then expected the alarm system to be 50%, 75%, or 100% reliable.

Driving task dependent measures were taken by recording the participants' actions during the driving task. A pilot study (N=13) was conducted to help identify procedural problems that might occur during the driving and alarm response tasks.

3.2 Participants

A power analysis was conducted to determine how many participants would be needed for a power of 0.80 at the $\underline{p}=.05$ level. The power analysis indicated that using 20 participants per group (total N=60) would yield statistical power of more than .80.

Data were collected from 70 undergraduate volunteers. The volunteers were students who received course credits for their general psychology classes at The University of Alabama in Huntsville. All were licensed drivers living in the Huntsville, AL area. Of the 84 participants who initially volunteered, 13 were used as pilot participants, one was disqualified due to cybersickness symptoms, and the remaining 70 were used as regular participants. Forty participants were male, and 30 were female. The proportion of males to females in each experimental group was approximately equal (40M, 30F). The average age of participants was 22.1 years old. The average amount of driving experience was 6.6 years.

3.3 Materials

A driving simulator owned by the Distributed Simulation Group at the U.S. Army Aviation and Missile Command Center (AMCOM - Redstone Arsenal, AL) was used as a vehicular platform during the primary, driving task (see Figure 1). The simulator was a military HMMWV™ (multipurpose vehicle) modified to serve as an automotive simulator. The front window of the HMMWV faced three large (94" high X 70" wide) screens. The total horizontal field of view was 135°; each individual screen's horizontal field of view was 45°. The vertical field of view was 33.75°. The simulator was high in physical and functional fidelity (Hays and Singer, 1989); steering, brakes, accelerator, and gearshift controls were functional, and visual and auditory stimuli faithfully represented environmental changes according to driver actions. In addition to the front view screens, participants also viewed a rear-view mirror display inside the vehicle cabin. This display was a 14" flat-panel display that showed a rearward view of terrain.

The simulated driving environment was a virtual world that faithfully represented a 1000 square-mile area from Decatur, AL (West) to Huntsville, AL (East); and from the Tennessee State Line (North) to Arab, AL (South). The corridor was approximately 20 miles long, and 50 miles wide. The researchers developed the initial design for the environment with assistance by personnel from Boeing's Advanced Computing Group. Translation of the design occurred at the Army-NASA Virtual Innovations Laboratory (ANVIL) at Marshall Space Flight Center. Finally, the environment was created by personnel at the Aviation and Missile Command's (AMCOM) Distributed Simulation Center. Personnel at AMCOM created the virtual driving environment using Multi-Gen (Creator)™, an off-the-shelf, Silicon Graphics based modeling and rendering program. After initial modeling was completed, AMCOM personnel refined it and incorporated it into existing distributed interactive simulation software.

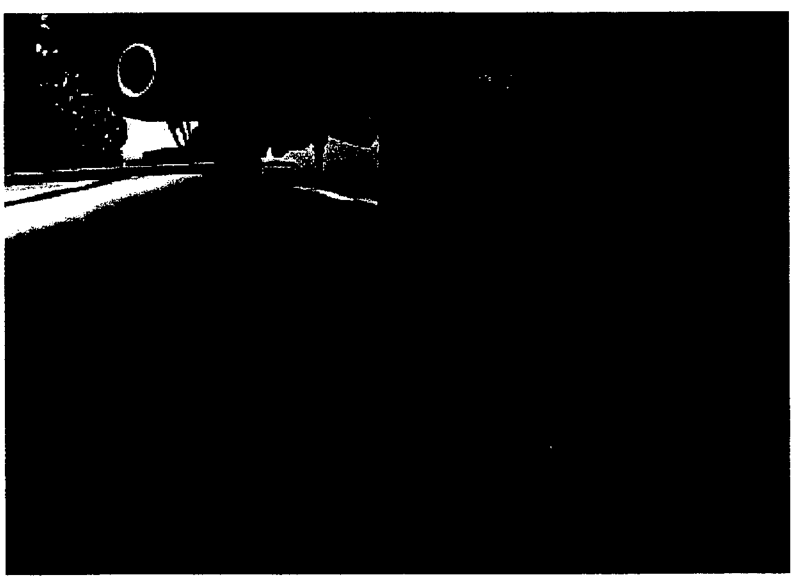

Figure 1. The HMMWV™ driving simulator.

To create a simulated environment of I-565, the researchers selected and placed polygons and lines to create the road, background, overpasses, exit ramps, road signs, and landmarks found on I-565. Colors and texture maps were then placed on certain objects in the environment to give a realistic look to the model (see Figure 2).

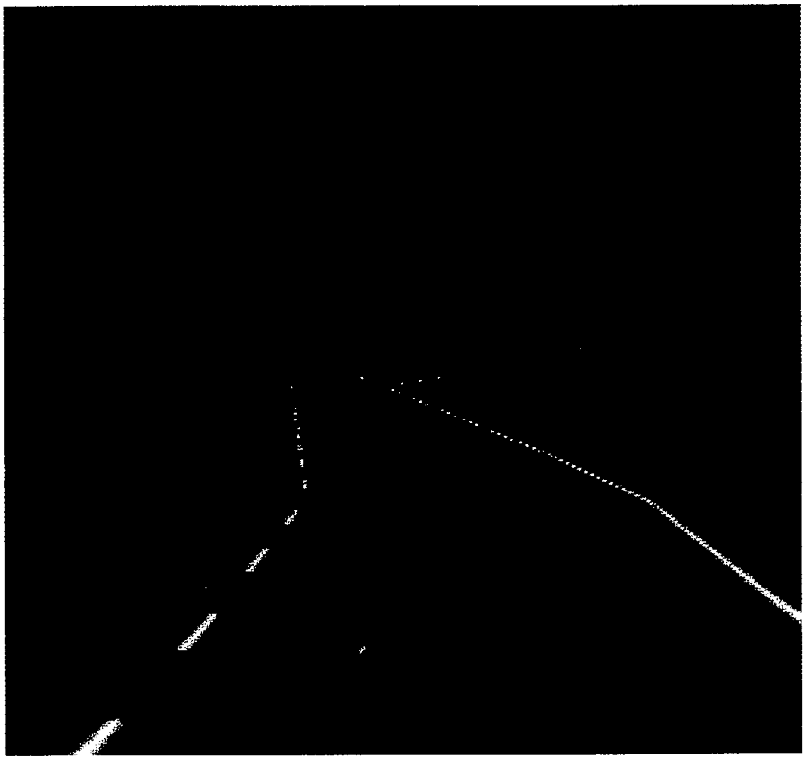

Figure 2. A sample scene from the driving environment.

Once the model was incorporated into the driving simulator, participants were able to drive through the simulated environment. Each participant viewed computer-generated imagery that changed to match the simulated vehicle's movement. The environment consisted of polygons, colors, lines and texture maps. There were approximately 255 stationary polygons in the environment plus moving objects such as vehicles. Objects such as road surfaces, roadside signs, overpasses and trees were given a realistic appearance by placing texture maps on polygon surfaces. This technique also facilitated real-time rendering of the model. The visual scene update rate for the view screens was approximately 20 Hz. The update rate for the rear-view mirror display was 60 Hz.

While driving in the simulation, participants were required to react to intermittent alarms. The alarms originated from either a center front console located behind the automobile cabin firewall or from various locations within the automobile cabin (rear, left rear, or right rear). The alarm stimulus was digitized from a signal obtained from the Huntsville Chrysler Electronics Division. The stimulus consisted of regular 1000 Hz. sine wave pulses at approximately 90 dB(A). After obtaining the digitized signal, personnel from AMCOM incorporated the alarms into the driving simulation at predetermined locations. Designed initially for use in Dodge Neon™ automobiles, the chimes were in general accordance with Haas et al.'s (1996) guidelines for high urgency alarms. Haas et al. recommend that chimes have pulses with a fairly high fundamental frequency (800Hz), sound pressure level above 40 dBlin, and a short interpulse interval.

Participants completed several questionnaires during the experiment. Before the experiment began, participants completed three forms. The Informed Consent Form described the purpose of research, risks, benefits, and withdrawal procedures (see Appendix A). The Background Questionnaire included information about age, driving experience, sex, vision, hearing, and computer game familiarity (see Appendix B). Participants also completed Kennedy et al.'s (1993) Simulator Sickness Questionnaire (SSQ). This form was used to identify participants who were at high risk for simulator sickness (see Appendix C).

Participants were given a set of instructions that explained the experimental tasks, including steps involved in a small training exercise and the actual experiment (see Appendix D). The training exercise familiarized the participants with the vehicle and how to navigate through the simulated environment. Participants were also told about the alarm system and its associated reliability level.

Midway through the experiment (after driving the first half of the intended route), each participant completed the SSQ again. This allowed the researchers to monitor the physical condition of the participant and the progression of any simulator sickness symptoms (see Appendix C).

At the end of the driving task, each participant completed two questionnaires. The SSQ was administered as a final metric for cybersickness. The Opinion Questionnaire included questions related to perceived alarm volume, reliability, urgency, and complexity. This questionnaire also allowed participants to give comments about the experiment in general (see Appendix E).

3.4 Procedure

After arranging a participation time with the researchers, each participant drove to the Building 5400 on the Redstone Arsenal (Huntsville, AL), where the experiment took place. Participants were escorted to a waiting area, where they read and signed the Informed Consent Form and completed the Demographics and SSQ Questionnaires. Participant Instructions were also reviewed at this time.

After answering any questions about the experimental task, the experimenter led each participant into the simulator room and driving simulator (see Figure 1). At this time, participants were familiarized with the driving simulator. To complete the familiarization task, the participant started the vehicle, engaged the transmission, and drove down the road for approximately 2 miles. After reaching the 2-mile point, drivers were instructed to make a left hand turn, make a right hand turn, accelerate, and brake. Participants were encouraged to check their rear view mirror frequently. Upon hearing an alarm, participants were told to scan the rear view and front view displays to locate the approaching vehicle, and then to respond appropriately (swerve in the proper direction).

After familiarization, the researcher then repeated the experimental task instructions. Participants were told the percentage of true alarms to expect during the experiment

(50%, 75% or 100%). After the participant indicated that he or she understood the instructions, the experimental task began.

The experimental task consisted of two 20-minute sessions of driving while responding to collision warning alarms. The route began at the on-ramp to I-565 from Washington Street in downtown Huntsville, AL. The driver traveled west from that point to the intersection of I-565 and I-65 near Decatur, AL, for the first 20-minute session. Drivers were told to maintain a maximum speed of 70 miles per hour (the simulator could travel no faster than this, so participants were told to keep the accelerator pressed to the floor). After a 10-minute break, participants drove from the I-565/I-65 intersection east on I-565 to the Washington-Jefferson Street, Huntsville AL exit. During the 10-minute break between the sessions participants rested and completed the SSQ.

During both sessions, the participants were presented alarms according to the schedule in Appendix F. For all reliability groups (50%, 75%, and 100% true alarms), the first driving segment represented a baseline condition, during which alarm signals were generated from the center console behind the firewall. During the return segment of the trip, alarms were generated from three locations within the automobile cabin (rear, left rear, and right rear, corresponding to the origin of the approaching traffic).

Personnel at AMCOM programmed a semi-automated computer interface (the Auto-Psych™ tool) to assist the researchers with data collection. The computer interface was responsible for generating alarm signals, starting and ending the simulation, and storing driver response data (response speed, frequency, and appropriateness) that were recorded by the researchers after each alarm signal. As a supplementary data collection tool, an 8-mm video camera was placed just outside of the simulator's driver's-side door to record the alarms and each participant's vocalizations and movements.

After participants had completed the driving task, they were asked to complete the SSQ and Opinion Questionnaires. If their SSQ scores indicated signs of simulator sickness, they were required to wait for one-half hour before departing. They were then debriefed and dismissed.

4.0 Project Results

We began our analyses by coding the experimental data into files. After collating and entering the questionnaire data and the driving performance data that were automatically recorded, we analyzed the videotape for each participant's performance to determine the reaction times to alarms. Unfortunately, due to equipment malfunction, many of the videotapes did not include sound, and were therefore useless. Ultimately, we were able to code alarm reaction frequency, alarm reaction appropriateness, driving reaction appropriateness, collision frequency, and questionnaire data for all 70 participants. However, we were able to code alarm reaction time data for only 32 participants. Therefore, results regarding alarm reaction time should be interpreted with caution.

After coding the data, we performed descriptive analyses to determine measures of central tendency and variability for all variables. Simultaneously, we assessed the normality of our variables and determined that it was appropriate to use parametric statistical methods.

To determine if our hypotheses were supported, we calculated one-way analyses of variance (ANOVAs) for alarm reaction frequency, alarm reaction time, appropriateness of alarm-instigated driving reactions, appropriateness of alarm reactions, and collision frequency. The results of those ANOVAs are reported below.

Although the interaction of signal source location (spatial or console) and reliability (50%, 75% or 100% true alarms) and the main effect for signal source location were not significant for alarm reaction frequency ($\underline{p} > .05$), there was a significant main effect for reliability, $\underline{F}(2,67)=27.695$, $\underline{p}<.001$. Tukey post-hoc comparisons indicated that all three reliability levels were significantly different from each other (see Figure 3).

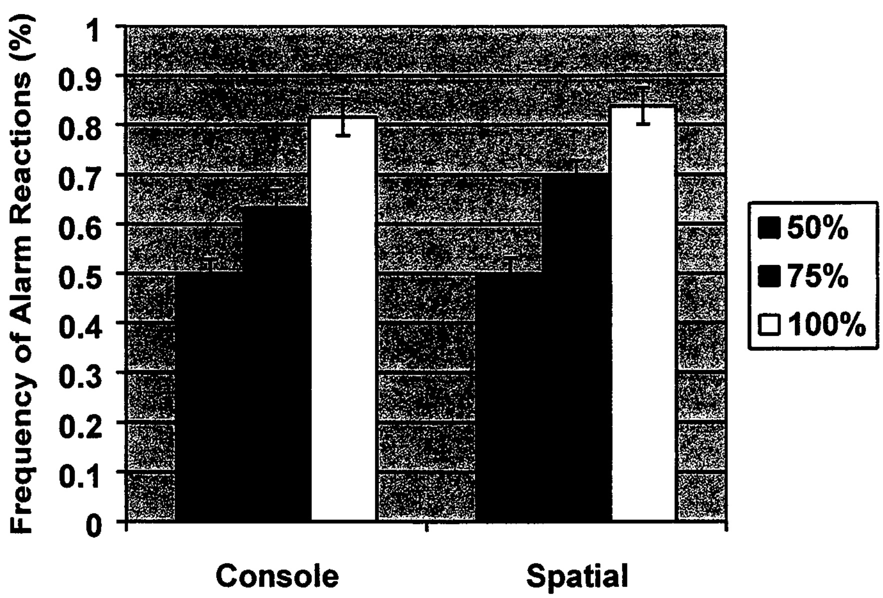

Figure 3. Frequency of alarm reactions as a function of signal source location and reliability.

There was no statistically significant interaction, nor significant main effects of alarm signal source location or reliability for reaction times ($p > .05$). It is possible that the low number of data points may have precluded statistical significance, however.

Participants did differ with regard to their driving reactions to alarms (see Figure 4). While our ANOVA did not indicate a significant interaction between signal source location and reliability, drivers responded more appropriately to alarms generated from the center console than to spatially separated locations, $F(1,67)=16.708$, $p<.001$. There was also a main effect for alarm reliability, $F(2,67)=21.595$, $p<.001$. Participants took more appropriate corrective action to alarms of higher reliability than those of lower reliability. Tukey post-hoc tests indicated that the 75% group (and therefore the 50% group) was significantly less appropriate than the 100% group; however, there was no significant difference between the 50% and 75% groups. The ANOVA for alarm reaction appropriateness (whether drivers reacted to true alarms and ignored false) yielded no significant interaction nor main effects, $p > .05$.

Participants did differ, however, with regard to the frequency with which they collided with approaching traffic (see Figure 5). We found a statistically significant interaction between signal source location and reliability, $F(2,67)=3.677$, $p=.031$. There was also a main effect for signal source location; participants collided with proportionately more traffic following console-based alarms than following spatially generated alarms, $F(1,67)=39.834$, $p<.001$. There was no main effect on collisions for alarm reliability ($p > .05$).

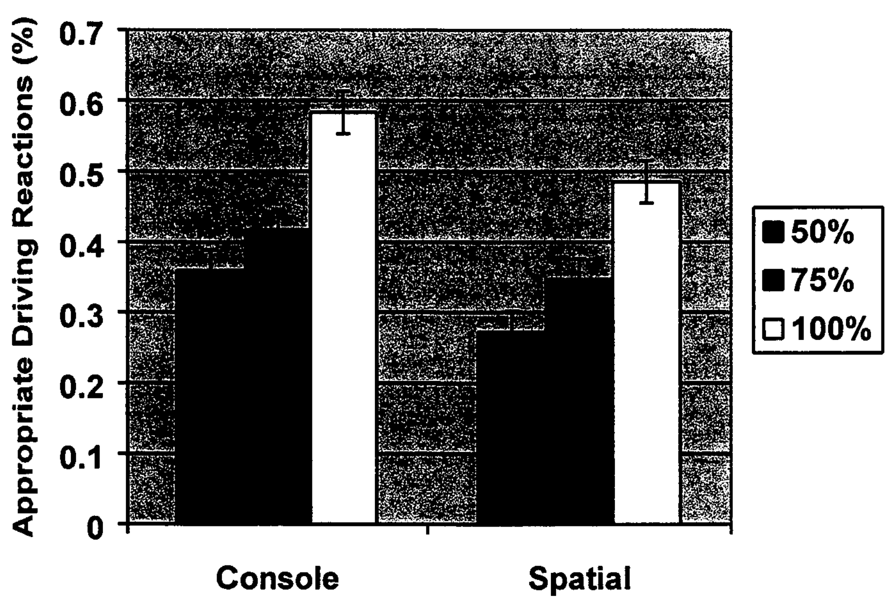

Figure 4. Appropriateness of driving reactions as a function of signal source location and reliability.

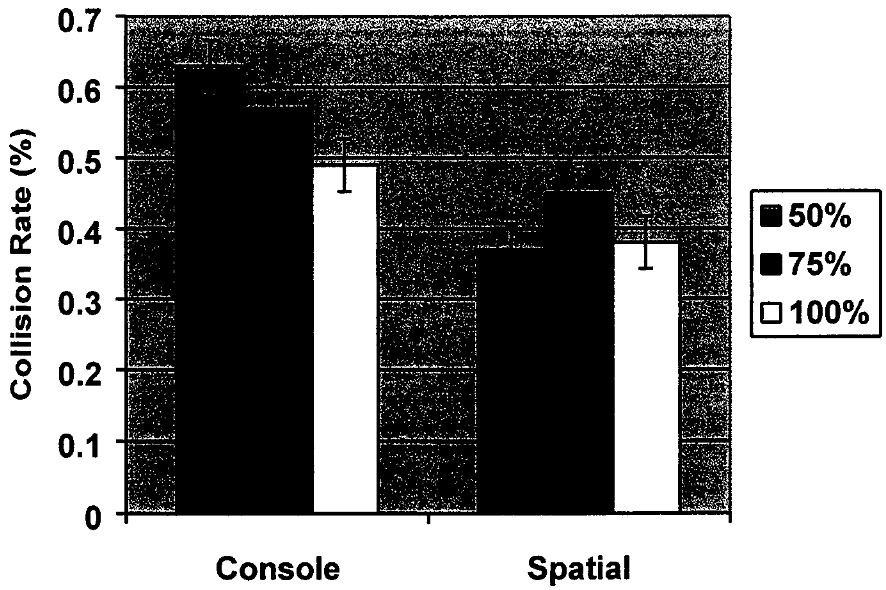

Figure 5. Alarm reaction collision rates as a function of signal source location and reliability.

To determine the extent to which participants suffered from simulator sickness, we calculated scores from the pre-immersion, mid-immersion, and post-immersion portions of the Simulator Sickness Questionnaire (Kennedy et al., 1993). The scores are shown graphically in Figure 6. Factor analyses of the SSQ have yielded three constructs tapped by the questionnaire: Nausea, Oculomotor Distress, and Disorientation. Additionally, a global score (Total Severity) may also be computed. Figure 6 shows the progression of these symptoms for the duration of the experiment. The figure shows that symptoms were highest during immersion, and that they had begun to subside immediately after immersion. From the profile of scores, oculomotor distress (eyestrain) was the most pronounced symptom, followed by disorientation.

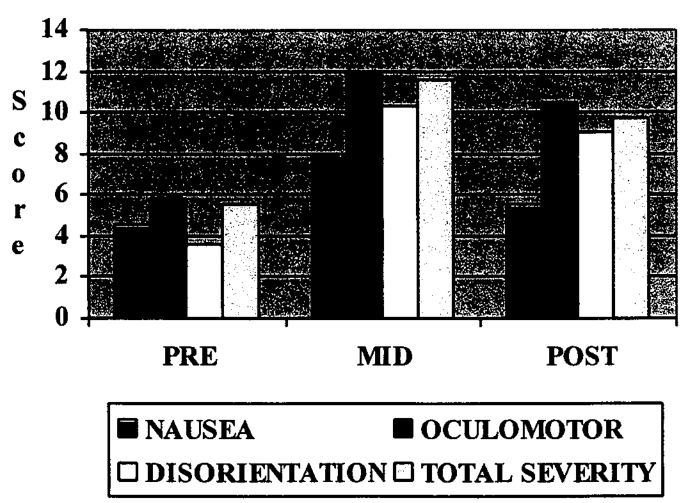

Figure 6. Cybersickness (SSQ Score) as a function of questionnaire administration period.

To determine whether task performances were related to demographics, experience or motivation, we calculated correlations between scores on the background and opinion questionnaires and the task performance measures. Because of the large number of correlations computed, we adjusted the criterion for statistical significance using the Bonferonni method (Keppel, 1991).

Only two correlations were significant. Participants who considered the alarm stimuli more urgent reacted to the alarms faster, $\underline{r} = -.51$, $\underline{p} = .003$. Also, as suggested by the earlier ANOVA, those who considered the alarms more reliable exhibited more appropriate driving reactions ($\underline{r} = -.35$, $\underline{p} = .003$).

5.0 Project Conclusions

Based on prior research by Lee et al. (1993), it was expected that spatial alarms would lead to more frequent and more appropriate alarm reactions. However, our results regarding this hypothesis were mixed. Drivers avoided collisions better using spatial alarms, yet their initial driving reactions were more appropriate following console-generated alarms. One possibility for this finding is that driving reactions reflected the initial, reflexive reaction to the alarm. However, many participants changed their minds or exaggerated their reactions following their initial decision. If such indecision is prevalent among actual drivers, spatial alarms may provide an additional source of information to help those drivers ultimately avoid a collision. Our finding also supports Lee et al. (1993), who suggested that spatially generated signals may help operators locate and respond to threat information.

It was also expected that spatially presented alarm signals would be perceived as more reliable than console emitted alarms. In the past, researchers have consistently and successfully used response parameters such as response frequency, speed, and appropriateness as suitable indicators of alarm trust (Bliss 1997; Getty et al. 1995). In the current experiment, our results did not suggest that participants found spatial alarms to be more trustworthy than console-based alarms. Not only was there no main effect of signal source location for reaction frequency, alarm reaction appropriateness, or driving reaction appropriateness, but it was also noted that there was no difference in the number of participants who labeled console or spatial alarm systems as more reliable on the opinion questionnaire (see Appendix E).

There may be several reasons for our findings. During the experiment, participants were able to view approaching traffic in the rear view mirror (and had plenty of time and opportunity to do so). Therefore, they may have considered the spatial alarms redundant with (or even subservient to) the visual displays. Additionally, to ensure stability of alarm reaction performance (Bliss 1997), participants were told about the reliability of the alarm system before they began the driving task. Therefore, they may have felt less obligated to double-check the alarms before responding. To determine whether this was the case, or whether spatial location has no effect on reliability, it is recommended that future researchers refrain from telling participants the reliability level of the alarms. Ultimately, this would be a more realistic situation, as drivers rarely know how reliable alarms systems are.

We were not surprised to see alarm reaction frequency and driving reaction appropriateness increase for higher reliability alarms. This reinforces the expectation that the cry-wolf phenomenon would occur. Past research has determined that response frequency is a stable indicator of alarm mistrust (Bliss, 1997). For the current research, the realism of the experimental paradigm was increased. Past research has involved ongoing tasks that were somewhat dissociated from the alarm reaction task (Bliss and Dunn, 2000). However, in this research the reactions required of drivers to avoid other traffic were realistic and task-relevant. It is encouraging that dependent measures such as response frequency are sensitive indicators of alarm mistrust regardless of the veridicality of task structure.

The results regarding simulator sickness were also encouraging, because they indicate that simulator sickness likely did not interfere significantly with task performance. It is interesting to note the profile of SSQ scores, as it generally matches the oculomotor-dominant profiles observed from other simulator platforms (Kennedy et al., 1995).

The correlations in this study did not reveal as much information as hoped. The observed relationship between perceived alarm urgency and reaction time is predictable, given the results of past alarm research (Bliss, 1993). Also, the positive relationship between perceived reliability and driving reaction appropriateness was expected. It is likely that participants trusted reliable alarms more, and therefore concentrated more on the driving task.

5.1 Further Research

As this project was the first step toward a program of research concerning collision avoidance warning systems, there are many avenues to pursue. The driving environment created for this research was intentionally simplistic, to allow unconfounded manipulation of reliability and signal source location and to facilitate the measurement of driving performance. Following our successful results, it is important that research be conducted that includes the presence of other traffic (besides cars overtaking the experimental vehicle). It is also important that investigators examine alarm responsiveness in a variety of traffic situations, such as parking lots, two lane roads, and interstate interchanges.

The current collision avoidance warning system was a passive one, generating alarms when other cars encroached upon the experimental vehicle. Such situations are important to consider, because of their prevalence. However, many prototype CAWS operate according to an active algorithm, where alarms are generated after the driver activates the turn signal or begins to change lanes. Such alarm systems must also be evaluated for feasibility and reliability. Drivers may be more alert in such situations (because they instigated the collision situation). Such situations may also generalize more readily to collision situations involving objects other than automobiles (i.e., car-pedestrian accidents and roadway departures).

During the current project it became apparent that our data collection methods were suboptimal. Pragmatics forced us to rely on videotapes for collecting reaction time data, and on manual data recording for measures of reaction appropriateness. In the future, we hope to improve our methods, so that data measurement may be more automated, and therefore less prone to random and systematic measurement error.

5.2 Acknowledgements

This project, funded by the University Transportation Center of Alabama (UTCA Grant No. 03UTCA-003) could not have been completed without the assistance of many people and entities. We wish to thank Frank Craig and Stephen Tanner from The Boeing Company, Mark Blasingame and Chris Daniel from the Army-NASA Virtual Innovations Laboratory, Robert Lock of Chrysler (Huntsville Electronics Division), Laurie Fraser, Greg Tackett, and Tim McKelvy from the U.S. Army Aviation Missile Command – Distributed Simulation Center, Greg Lee and Skip Clay from Nichols Research, and Doug Barclay, Christy Bates, and Jimmy Moore from Computer Sciences Corporation.

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Appendix A

HUMAN PARTICIPANTS CONSENT FORM AND VOLUNTEER AGREEMENT

The purpose of this study is to collect data about human response to alarms within an automobile setting. As a participant, you will be asked to perform duties that would normally occur while driving a vehicle (automatic transmission). You will sit in a HMMWV™ with a view of a road on a screen in front of you. You will conduct driving operations in a virtual setting modeled after Interstate 565. Operations include driving forward, braking, using the turn signals, using rear and side view mirrors, and looking to the left, right and front windows of the automobile. You will also be responding to alarm signals coming from various origins within the HMMWV™ cabin.

Risks for participating in this experiment include possible simulator sickness (generally less than 10% of participants ever experience symptoms) and possible headache and/or eyestrain. To minimize any harm, the time will be limited in the simulator to 30 minutes per session and a 10 minute break in between sessions will be given. In the event that you should experience symptoms we will remove you from the experiment and provide a place for you to rest.

Participants will benefit from participation by being exposed to cutting edge (simulator) technology, and by learning about psychological experimentation procedures. In addition, participants will have the opportunity to contribute to research that will enhance the safety of automobile drivers. Students who complete participation will receive points as a part of their general psychology class.

All questions, responses, and activities that you perform will be completely confidential. Your name will not be associated with any information given in the experiment.
If at anytime and for any reason you wish to end the experiment, you may do so without penalty. You will still receive participation credit even if you decide to end the experiment.

If you have read this consent for and volunteer to participate in this experiment, please sign and date the form below.

______________________________ ________________

Volunteer's signature Date

Appendix B

PARTICIPANT BACKGROUND QUESTIONNAIRE

1. Age_____
2. Male_____ Female_____
3. Are you a licensed driver? _____Yes _____No
4. How many years have you been driving?_____
5. Do you currently have hearing loss or impairment?
6. If so, which ear(s)_____Left _____ Right _____Both
7. Are you currently wearing hearing aids that correct the loss or impairment? _____Yes _____No
8. Do you have normal corrected vision? _____Yes _____No
9. Have you ever been diagnosed with a vision problem (e.g., lazy eye, detached retina, macular-degeneration, etc.)? If so, please list here

   ____

10. Have you ever been diagnosed as color deficient? _____Yes _____No
11. Any accidents in the past year? _____Yes _____No If so, how many? ____ How many were your fault? _____
12. Any moving violations in the past year? _____Yes _____No
13. Have you ever had your license revoked/suspended? _____Yes _____No If so, please state the reason

    ____

14. Are you right or left-handed? _______________
15. How many hours per week do you:

    _____ Use computers (work and recreation combined)?

    _____ Play driving simulator games?

    _____ Play non-driving games?

    _____ Drive an automobile?

Appendix C

SIMULATOR SICKNESS QUESTIONNAIRE

Participant_______________
Time_______________
Date_______________

SSQ PRE-VE SYMPTOM CHECKLIST

Instructions: Please fill this out BEFORE you enter the virtual environment. Circle below if any symptoms apply to you right now. (After your exposure to the virtual environment, you will be asked these questions again.)

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Boredom	None	Slight	Moderate	Severe
4. Drowsiness	None	Slight	Moderate	Severe
5. Headache	None	Slight	Moderate	Severe
6. Eye strain	None	Slight	Moderate	Severe
7. Difficulty focusing	None	Slight	Moderate	Severe
8. a. Salivation increased	None	Slight	Moderate	Severe
b. Salivation decreased	None	Slight	Moderate	Severe
9. Sweating	None	Slight	Moderate	Severe
10. Nausea	None	Slight	Moderate	Severe
11. Difficulty concentrating	None	Slight	Moderate	Severe
12. Mental depression	None	Slight	Moderate	Severe
13. "Fullness of the head"	None	Slight	Moderate	Severe
14. Blurred vision	None	Slight	Moderate	Severe
15. a. Dizziness (eyes open)	None	Slight	Moderate	Severe
b. Dizziness (eyes closed)	None	Slight	Moderate	Severe
16. *Vertigo	None	Slight	Moderate	Severe
17. **Visual flashbacks	None	Slight	Moderate	Severe
18. Faintness	None	Slight	Moderate	Severe
19. Aware of breathing	None	Slight	Moderate	Severe
20. ***Stomach awareness	None	Slight	Moderate	Severe
21. Loss of appetite	None	Slight	Moderate	Severe
22. Increased appetite	None	Slight	Moderate	Severe
23. Desire to move bowels	None	Slight	Moderate	Severe
24. Confusion	None	Slight	Moderate	Severe
25. Burping	No	Yes	No. of times_____	
26. Vomiting	No	Yes	No. of times_____	
27. Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations similar to movement in the virtual world, when not in the virtual world.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Participant #________________
Time________________
Date________________

SSQ MID-VE SYMPTOM CHECKLIST

B. Circle below if any symptoms apply to you right now. (After your exposure to the virtual world, you will be asked these questions again.)

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Boredom	None	Slight	Moderate	Severe
4. Drowsiness	None	Slight	Moderate	Severe
5. Headache	None	Slight	Moderate	Severe
6. Eye strain	None	Slight	Moderate	Severe
7. Difficulty focusing	None	Slight	Moderate	Severe
8. a. Salivation increased	None	Slight	Moderate	Severe
b. Salivation decreased	None	Slight	Moderate	Severe
9. Sweating	None	Slight	Moderate	Severe
10. Nausea	None	Slight	Moderate	Severe
11. Difficulty concentrating	None	Slight	Moderate	Severe
12. Mental depression	None	Slight	Moderate	Severe
13. "Fullness of the head"	None	Slight	Moderate	Severe
14. Blurred vision	None	Slight	Moderate	Severe
15. a. Dizziness (eyes open)	None	Slight	Moderate	Severe
b. Dizziness (eyes closed)	None	Slight	Moderate	Severe
16. *Vertigo	None	Slight	Moderate	Severe
17. **Visual flashbacks	None	Slight	Moderate	Severe
18. Faintness	None	Slight	Moderate	Severe
19. Aware of breathing	None	Slight	Moderate	Severe
20. ***Stomach awareness	None	Slight	Moderate	Severe
21. Loss of appetite	None	Slight	Moderate	Severe
22. Increased appetite	None	Slight	Moderate	Severe
23. Desire to move bowels	None	Slight	Moderate	Severe
24. Confusion	None	Slight	Moderate	Severe
25. Burping	No	Yes	No. of times_____	
26. Vomiting	No	Yes	No. of times_____	
27. Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations similar to movement in the virtual world, when not in the virtual world.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Participant #____________
Time______________
Date______________

SSQ POST-VE SYMPTOM CHECKLIST

B. Circle below if any symptoms apply to you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Boredom	None	Slight	Moderate	Severe
4. Drowsiness	None	Slight	Moderate	Severe
5. Headache	None	Slight	Moderate	Severe
6. Eye strain	None	Slight	Moderate	Severe
7. Difficulty focusing	None	Slight	Moderate	Severe
8. a. Salivation increased	None	Slight	Moderate	Severe
b. Salivation decreased	None	Slight	Moderate	Severe
9. Sweating	None	Slight	Moderate	Severe
10. Nausea	None	Slight	Moderate	Severe
11. Difficulty concentrating	None	Slight	Moderate	Severe
12. Mental depression	None	Slight	Moderate	Severe
13. "Fullness of the head"	None	Slight	Moderate	Severe
14. Blurred vision	None	Slight	Moderate	Severe
15. a. Dizziness (eyes open)	None	Slight	Moderate	Severe
b. Dizziness (eyes closed)	None	Slight	Moderate	Severe
16. *Vertigo	None	Slight	Moderate	Severe
17. **Visual flashbacks	None	Slight	Moderate	Severe
18. Faintness	None	Slight	Moderate	Severe
19. Aware of breathing	None	Slight	Moderate	Severe
20. ***Stomach awareness	None	Slight	Moderate	Severe
21. Loss of appetite	None	Slight	Moderate	Severe
22. Increased appetite	None	Slight	Moderate	Severe
23. Desire to move bowels	None	Slight	Moderate	Severe
24. Confusion	None	Slight	Moderate	Severe
25. Burping	No	Yes	No. of times_____	
26. Vomiting	No	Yes	No. of times_____	
27. Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations similar to movement in the virtual world, when not in the virtual world.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Appendix D

PARTICIPANT INSTRUCTIONS

At this point we will begin the driving experiment.

Remember that all information you give is completely confidential and your name will in no way be associated with your answers or participation. Also, you may drop out of the experiment for any reason and you will not be penalized. You will still receive appropriate credit for the time you participate.

We will begin by getting you familiarized with the simulator. Please get into the vehicle and become comfortable with the interior. Be sure to check out the side and rear mirrors as well as look out the side and front windows.

You are going to drive the vehicle as you would a regular automatic vehicle. Start the vehicle, accelerate to 50 when comfortable, stop at the stop sign, and turn left. Drive to the next light and turn right. Accelerate up to 65. Slow down and stop just as you pass the building.

Now we will accustom you to the collision avoidance alarms. As you continue to drive down the road, the alarms will sound either in front of you or to one of your sides. When this occurs, check your surroundings and respond to avoid a collision. Put your car in drive and continue down the road. Stop at the red light.

Great! You have finished the training and we will now begin the experiment. Any questions before we begin?

You will now be driving down I-565 from Washington ST to Decatur. Please stay on the road and do not exit to any roads or pull off and stop on the side of the road. Drive and pass cars as you normally would. You will be responding to alarms again in both sessions of this experiment. When you cross under the I-65 overpass, stop at the first red light and you will have a 10 minute break before driving home.

Great job! Now you may exit the vehicle and rest while completing the mid-SSQ to see how you are doing.

Ok, now let's resume the experiment. Please step back into the vehicle. Put the car in drive and start down I-565 until you each the Washington-Jefferson exit. Exit off to your right, stop the vehicle and put it in park.

Congratulations! You have completed the drive. Please exit the vehicle and follow me to complete the closing forms and receive information about this experiment.

Appendix E

OPINION QUESTIONNAIRE

Part. #: _________ Date:________ Time:__________

Thank you for participating in this research project. Please complete the following items by entering the number of your choice on the answer sheet. As before, your answers are completely confidential.

Please answer these questions about the Driving and Alarm experiment.

1. Driving the vehicle down a simulated road was______

   1. Very Stressful
   2. Slightly Stressful
   3. Neither Stressful nor Relaxing
   4. Slightly Relaxing
   5. Very Relaxing

2. Being presented with various alarms while driving was______

   1. Very Stressful
   2. Slightly Stressful
   3. Neither Stressful nor Relaxing
   4. Slightly Relaxing
   5. Very Relaxing

3. Responding to the console emitted alarms while driving was______________

   1. Very Challenging
   2. Slightly Challenging
   3. Neither Challenging nor Simple
   4. Slightly Simple
   5. Very Simple

4. Responding to the spatial alarms while driving was_____________

    1. Very Challenging
    2. Slightly Challenging
    3. Neither Challenging nor Simple
    4. Slightly Simple
    5. Very Simple

5. Which alarms were easier to hear?

    1. Console emitted   2. Spatial alarms

6. Did the alarms distract you from your normal driving routine? ___Yes ___No

7. Which alarms helped you locate the encroaching vehicle the fastest?

    1. Console emitted
    2. Spatial alarms

8. Were the gears, pedals, and steering wheel easy to maneuver? ___Yes ___No

9. Do you consider the alarm system you were presented with to be a useful tool in avoiding collisions with other vehicles? ___Yes ___No

10. How urgent did the alarm appear?

    1. Very Urgent
    2. Slightly Urgent
    3. Neither Urgent nor Unimportant
    4. Slightly Unimportant
    5. Very Unimportant

11. How reliable or trustworthy was the alarm system in detecting a possible collision?

    1. Very Reliable
    2. Slightly Reliable
    3. Neither Reliable nor Unreliable
    4. Slightly Unreliable
    5. Very Unreliable

12. How compelled were you to respond to the console emitted alarms?

    1. I did not feel compelled to respond to the alarms
    2. I felt slightly compelled to respond to the alarms
    3. I felt moderately compelled to respond to the alarms
    4. I felt greatly compelled to respond to the alarms
    5. I felt extremely compelled to respond to the alarms

13. How compelled were you to respond to the spatially emitted alarms?

    1. I did not feel compelled to respond to the alarms
    2. I felt slightly compelled to respond to the alarms
    3. I felt moderately compelled to respond to the alarms
    4. I felt greatly compelled to respond to the alarms
    5. I felt extremely compelled to respond to the alarms

14. Which alarm source seemed more reliable?

    1. Console emitted
    2. Spatial alarms
    3. Neither
    4. Both

15. Was the experiment too long or tiring? ___Yes ___No

16. Please estimate the total number of "true alarms" that you heard (how many).

____

17. Please estimate the total number of "false alarms" that you heard (how many). ______

18. Did you have a strategy for responding to the alarms? ____ If so please describe

____

____

____

19. Do you have any other thought, feelings, or comments about the experiment?

Appendix F

ALGORITHMS FOR TRAFFIC ONSET

Starting locations for traffic and alarm parameters are summarized below.
The following apply to the tables:

1. Each car should appear approximately 100 yards (meters) behind the target automobile, and should travel at a rate of 70 mph. The distribution of traffic origins should be the following:

2. The alarm distances total 18 miles, whereas the total course is approximately 20. This means that there will be 2 miles of "buffer" space to be used as necessary. That buffer should be distributed equally before the first alarm onset and after the last alarm onset, during each direction.

3. For situations where alarm reliability < 100%, some alarms will activate without a corresponding traffic appearance. Please refer to original chart for exact sequencing.

Westward (starting at the Washington St. Exit of I-565):

Alarm Number	Location of Alarm Onset
1	1.25 miles after the starting point
2	.25 miles after Alarm 1
3	.75 miles after Alarm 2
4	2.00 miles after Alarm 3
5	1.75 miles after Alarm 4
6	2.25 miles after Alarm 5
7	2.50 miles after Wall Triana intersection
8	.25 miles after Alarm 7
9	2.75 miles after Alarm 8
10	1.75 miles after Alarm 9
11	1.50 miles after Alarm 10
12	.75 miles after Alarm 11

Eastward (Starting from I-565 & I-65 intersection):

Alarm Number	Location of Alarm Onset
13	1.25 miles after the starting point
14	2.00 miles after Alarm 13
15	.50 miles after Alarm 14
16	1.00 miles after Alarm 15
17	1.50 miles after Alarm 16
18	2.25 miles after Alarm 17
19	2.50 miles after Wall Triana intersection
20	.25 miles after Alarm 19
21	2.75 miles after Alarm 20
22	1.75 miles after Alarm 21
23	1.50 miles after Alarm 22
24	.75 miles after Alarm 23

Alarm Parameters for 50% Group:

Alarm Number	Direction of Auto Approach	Validity	Alarm Origin	Course Direction	Course Segment
1	LR	F	C	HSV>I-565	HSV>WallTriana
2	LR	T	C	HSV>I-565	HSV>WallTriana
3	R	F	C	HSV>I-565	HSV>WallTriana
4	R	T	C	HSV>I-565	HSV>WallTriana
5	LR	T	C	HSV>I-565	HSV>WallTriana
6	LR	F	C	HSV>I-565	HSV>WallTriana
7	R	F	C	HSV>I-565	WallTriana>I-565
8	RR	T	C	HSV>I-565	WallTriana>I-565
9	RR	T	C	HSV>I-565	WallTriana>I-565
10	R	T	C	HSV>I-565	WallTriana>I-565
11	RR	F	C	HSV>I-565	WallTriana>I-565
12	RR	F	C	HSV>I-565	WallTriana>I-565
13	LR	T	S	I-565>HSV	I-565>WallTriana
14	LR	F	S	I-565>HSV	I-565>WallTriana
15	LR	F	S	I-565>HSV	I-565>WallTriana
16	R	F	S	I-565>HSV	I-565>WallTriana
17	LR	T	S	I-565>HSV	I-565>WallTriana
18	R	T	S	I-565>HSV	I-565>WallTriana
19	R	F	S	I-565>HSV	WallTriana>HSV
20	RR	T	S	I-565>HSV	WallTriana>HSV
21	RR	T	S	I-565>HSV	WallTriana>HSV
22	RR	F	S	I-565>HSV	WallTriana>HSV
23	R	T	S	I-565>HSV	WallTriana>HSV
24	RR	F	S	I-565>HSV	WallTriana>HSV

Alarm Parameters for 75% Group:

Alarm Number	Direction of Auto Approach	Validity	Alarm Origin	Course Direction	Course Segment
1	LR	T	C	HSV>I-565	HSV>WallTriana
2	LR	T	C	HSV>I-565	HSV>WallTriana
3	R	T	C	HSV>I-565	HSV>WallTriana
4	R	T	C	HSV>I-565	HSV>WallTriana
5	LR	T	C	HSV>I-565	HSV>WallTriana
6	LR	F	C	HSV>I-565	HSV>WallTriana
7	R	T	C	HSV>I-565	WallTriana>I-565
8	RR	T	C	HSV>I-565	WallTriana>I-565
9	RR	T	C	HSV>I-565	WallTriana>I-565
10	R	F	C	HSV>I-565	WallTriana>I-565
11	RR	T	C	HSV>I-565	WallTriana>I-565
12	RR	F	C	HSV>I-565	WallTriana>I-565
13	LR	T	S	I-565>HSV	I-565>WallTriana
14	LR	F	S	I-565>HSV	I-565>WallTriana
15	LR	T	S	I-565>HSV	I-565>WallTriana
16	R	F	S	I-565>HSV	I-565>WallTriana
17	LR	T	S	I-565>HSV	I-565>WallTriana
18	R	T	S	I-565>HSV	I-565>WallTriana
19	R	T	S	I-565>HSV	WallTriana>HSV
20	RR	T	S	I-565>HSV	WallTriana>HSV
21	RR	T	S	I-565>HSV	WallTriana>HSV
22	RR	F	S	I-565>HSV	WallTriana>HSV
23	R	T	S	I-565>HSV	WallTriana>HSV
24	RR	T	S	I-565>HSV	WallTriana>HSV

Alarm Parameters for 100% Group:

Alarm Number	Direction of Auto Approach	Validity	Alarm Origin	Course Direction	Course Segment
1	LR	T	C	HSV>I-565	HSV>WallTriana
2	LR	T	C	HSV>I-565	HSV>WallTriana
3	R	T	C	HSV>I-565	HSV>WallTriana
4	R	T	C	HSV>I-565	HSV>WallTriana
5	LR	T	C	HSV>I-565	HSV>WallTriana
6	LR	T	C	HSV>I-565	HSV>WallTriana
7	R	T	C	HSV>I-565	WallTriana>I-565
8	RR	T	C	HSV>I-565	WallTriana>I-565
9	RR	T	C	HSV>I-565	WallTriana>I-565
10	R	T	C	HSV>I-565	WallTriana>I-565
11	RR	T	C	HSV>I-565	WallTriana>I-565
12	RR	T	C	HSV>I-565	WallTriana>I-565
13	LR	T	S	I-565>HSV	I-565>WallTriana
14	LR	T	S	I-565>HSV	I-565>WallTriana
15	LR	T	S	I-565>HSV	I-565>WallTriana
16	R	T	S	I-565>HSV	I-565>WallTriana
17	LR	T	S	I-565>HSV	I-565>WallTriana
18	R	T	S	I-565>HSV	I-565>WallTriana
19	R	T	S	I-565>HSV	WallTriana>HSV
20	RR	T	S	I-565>HSV	WallTriana>HSV
21	RR	T	S	I-565>HSV	WallTriana>HSV
22	RR	T	S	I-565>HSV	WallTriana>HSV
23	R	T	S	I-565>HSV	WallTriana>HSV
24	RR	T	S	I-565>HSV	WallTriana>HSV

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