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Evaluation of Heavy-Vehicle Crash Warning Interfaces

DISCLAIMER

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13. ABSTRACT (Maximum 200 words) This document describes an evaluation of heavy-vehicle collision warning interfaces as it pertains to the auditory and visual components of a forward collision warning system. The results indicate that drivers receiving an imminent collision warning alert responded significantly quicker than drivers who did not receive an alert to a potential rear-end event. Moreover, the effects of muting other sources of in-cab audio were explored. Participants were able to perform as well or even better when the other audio sources were not muted as long as the alert was salient enough (15 dBA above in-cab noise level). If a visual component is issued as part of the alert in the instrument panel, the data suggests that it may be more effective if presented as an information component, not as the main alert component. This will assist drivers to look at the forward roadway as their first reaction instead of getting drawn to the visual component initially. Data also suggests the auditory component should be the main alerting component in order to elicit the drivers looking to the forward roadway as their first reaction. This result was found to be true in both truck-trailer combination units and motorcoaches. It should be noted that haptic alerts were not considered in this study.		
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GLOSSARY OF ACRONYMS

ABS	antilock braking system
ANOVA	analysis of variance
ATRI	American Transportation Research Institute
CAMP	Crash Avoidance Metrics Partnership
CDL	commercial driver's license
CMB	collision mitigation braking
CMV	commercial motor vehicle
CVO	commercial vehicle operations
CWI	crash warning interface
CWS	collision warning system
DAS	data acquisition system
DOT	Department of Transportation
DV	dependent variable
DVI	driver-vehicle interface
ESC	electronic stability control
FCW	forward collision warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
GPS	global positioning system
HMI	human-machine interface
HV-CWI	heavy vehicle crash warning interface
ICW	imminent collision warning
HUD	heads-up display
IP	instrument panel
IRB	Institutional Review Board
IVBSS	Integrated Vehicle-Based Safety System
LTL	less-than-truckload
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
OEM	original equipment manufacturer
RT	reaction time
TTC	time-to-collision
VTTI	Virginia Tech Transportation Institute

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CHAPTER 1. INTRODUCTION

OVERVIEW

According to the Federal Motor Carrier Safety Administration (FMCSA, 2013), in 2011 approximately 345,000 large trucks and buses were involved in crashes (fatal, injury, and property-damage-only combined) with buses involved in 16 percent of those crashes. When looking at crash type, of the nearly 288,000 crashes involving large trucks, 24 percent were rear-end crashes. Also, for the period 2001 through 2011, on average, intercity buses (i.e., motorcoaches) accounted for 13 percent of all buses involved in fatal crashes with school buses and transit buses accounting for 40 percent and 34 percent, respectively. According to the Buses Involved in Fatal Accidents Factbook 2008 (2011), approximately 10 percent of collisions involving a fatality were rear-end collisions. Another important consideration relating to buses is the societal impacts due to the nature of passenger transport. According to the American Bus Association (2008), motorcoach buses provided 751 million passenger trips in 2007 and provided access to 14.4 million residents who would otherwise not have access or the means for intercity transport. However, similar to air travel, passengers using bus transport have no control over the driver's actions, or inactions, and this can lead to unfortunate consequences. According to the Motorcoach Safety Action Plan (2012), which is an interagency cooperative effort within the United States Department of Transportation, recent history has seen a greater increase in the average number of fatalities per year over the past 10 years than in the preceding decade. In 2011, two motorcoach crashes resulted in 28 fatalities and high-profile media attention.

Additionally, a letter from the National Transportation Safety Board (NTSB, 2013) to the National Highway Traffic Safety Administration, reiterated two prior recommendations for the development of forward collision warning (FCW) standards for commercial motor vehicles (CMVs).

- Recommendation H-01-6: develop standards including human factors guidelines (e.g., mode and type of warning) and the timing of alerts

- Recommendation H-01-7: once performance standards have been established, require all new CMVs to be equipped with an FCW system

FCW systems have been commercially available for 20 years since Eaton Vorad Technologies introduced the EVT-300 FCW system in 1994 (Jones, 2001). However, most studies to date have been based on early field operational test (FOT) data that assessed the effectiveness of single, early-generation warning systems that were prone to frequent nuisance alarms and false alarms. This was common throughout both the light vehicle and heavy vehicle industry. In two separate studies (Lee et al., 2002; Bliss et al., 2003), it was reported that nuisance alarms and false alarms reduced driver acceptance of FCW systems, while a prior study by McGhee et al. (1998) indicated that poorly timed warnings were ignored by drivers who were unable to perceive the cause of the warning and, in some instances, disrupted an ongoing braking process. Further, a study by Bayly et al. (2007) summarized the key disbenefits of FCW systems by stating that disbenefits directly relate to driver acceptance due to false alarms and nuisance alarms. Thus, providing reliable object detection performance in an FCW system is crucial in gaining driver and industry acceptance.

More recent research suggests that FCW systems for heavy vehicles may potentially reduce rear-end crashes when combined with responsive systems such as collision mitigation braking (CMB) (Battelle, 2007; Fitch et al., 2009; Hickman & Hanowski, 2011; Houser et al., 2009; Najm et al., 2011; Sayer, 2011; Woodrooffe et al., 2012). In studies conducted by Battelle (2007) and Fitch et al. (2009), an FCW system for a heavy vehicle could result in a 21-percent reduction in rear-end crashes. Further, in a study conducted by Woodrooffe et al. (2012), a 24-percent reduction in rear-end crashes was found when utilizing an FCW system, while a more recent study by Woodrooffe and his colleagues (2013) estimated a 31-percent reduction in fatalities and a 27-percent reduction in injuries in rear-end crashes involving a truck-trailer combination.

To realize the potential benefits of collision warning systems (CWSs), these systems must generate appropriate driver responses to threats in a well-timed manner. However, crash warning interfaces (CWIs) must effectively convey the appropriate warning information to the driver for this to occur. In addition to the societal benefits of potential rear-end crash reductions, truck and bus carriers may realize cost savings. In a benefit-cost analysis conducted in part between the American Transportation Research Institute (ATRI) and FMCSA (Murray, 2009), it was found that for every dollar spent on an FCW system the return ranged from $1.33 to $7.22 over a 5-year period.

Original equipment manufacturers have steadily been improving FCW systems by adding capabilities such as CMB, engine braking, and integrated radar and camera sensors. While solving some of the deficiencies of early-generation systems (e.g., high false alarm rate, stationary object detection), these advancements have also produced new challenges, possibly bypassing some of the more basic concerns related to CWIs. Current FCW systems are available as OEM options and aftermarket retrofit kits. However, differences between OEM options and retrofit kits – and even more so between the different FCW system suppliers – represent another set of challenges. Differences in the timing, loudness, and sound of the auditory alert, as well as color, location, and size choice of visual alerts, can vary widely. These differences can present issues at the driver level in fleets using slip-seat operations or for drivers who change employers and/or vehicles. For example, in an annual benchmark survey conducted by the National Private Truck Council in 2013 (as reported in Schulz, 2014), approximately 69 percent of privately operated fleets utilize slip-seat operations. This fact alone conveys the importance of guidelines for FCW systems so that these systems may be easily understood by drivers across all fleets and between different trucks and buses.

RESEARCH OBJECTIVE

The goal of this research effort was to evaluate the driver response to heavy-vehicle collision warning interfaces (HV-CWI) in both heavy trucks and motorcoaches. Evaluating HV-CWI performance requires the examination of multiple aspects, such as driver response characteristics and the design of displays and controls. The scope of this project examined the visual and auditory alerts of an imminent collision warning (ICW). Auditory and visual alerts represent unique components of an HV-CWI. These particular components are of interest and will help to inform the NHTSA driver-vehicle interface (DVI) design principles as well as future regulatory efforts regarding FCW systems. In order to achieve the goals of improving the effectiveness of HV-CWIs, a multistep process was followed. This process included a review of new literature (Brown et al., 2012) to find gaps in existing research and the current design principles (Campbell et al., 2014), developing research questions as they apply to these research needs, and the design and conduct of experimental research in support of the research questions (which will be summarized in this document). This process is summarized in Figure 1.

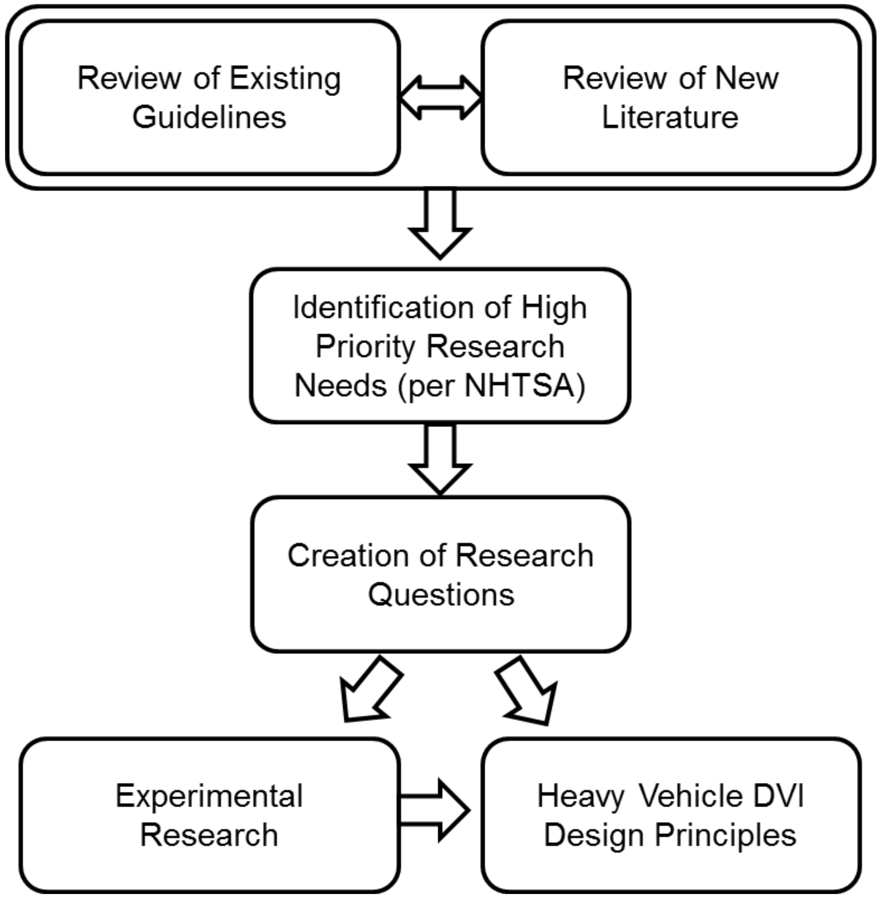

Figure 1. Process Used to Conduct Experimental Research and Create Heavy Vehicle DVI Design Principles

The following chapters document the experimental research in detail. Chapter 2 provides the justification for and presentation of the research questions. Chapters 3, 4, and 5 discuss the three experiments (noted below) performed as part of this study. Chapter 6 discusses the conclusions.

- Experiment 1: Effect of In-Cab Audio Muting on an ICW Alert
- Experiment 2: Effect of an In-Cab Visual Display of an ICW Alert
- Experiment 3: Effect of the Final Design In-Cab Auditory & Visual Alert in a Truck-Trailer and Motorcoach

For each experiment, methods, results, and a short discussion are provided.

RESEARCH FOCUS: ICW

The research focus of this study was assessing ICW alerts. ICW alerts can be considered the last line of defense to alert an inattentive or fatigued driver in near-crash, rear-end conflicts. In a worst-case scenario, a near-crash, rear-end conflict may evolve at such a rapid rate that only an

ICW alert is presented to the driver. This study assessed which aspects of an FCW alert are absolutely required. In addition, there is a potential for drivers to perceive cautionary alerts as a nuisance, which can lead drivers to ignore alerts altogether, thus reducing driver acceptance and system effectiveness.

According to Campbell et al. (2007), the potential advantages of ICW alerts include the ability to quickly address distracted driving situations and allow for easier driver comprehension. Further, previous research efforts examining FCW systems suggest that single-stage warnings are more effective under distracted driving conditions and, thus, are preferable (Kiefer et al., 2005; Kiefer et al., 1999). More specifically, Keifer et al. (1999; also cited by Campbell et al., 2007) noted that an ICW alert was the preferred warning configuration for the following reasons:

- Better driver acceptance because of fewer nuisance alarms
- Better compatibility with more effective warning algorithms
- It is a simpler mental model for drivers to comprehend
- It avoids the potential ineffectiveness of – and driver confusion arising from – cautionary warning alerts because this stage is very brief in practice

Additionally, the ICW alert presented to drivers in this study utilized a 3-s time-to-collision (TTC). This TTC was based on previous research and FCW systems currently available on heavy vehicles from vendors such as Bendix and Meritor-Wabco. NHTSA's Vehicle Research and Test Center has also conducted previous heavy vehicle research on FCW systems and provided guidance on this project related to TTC. Further, the safe conduct of this research was a priority when addressing TTC considerations as a real truck-trailer combination was used with a real lead vehicle that performed a hard-braking maneuver while the driver of the truck-trailer combination was distracted.

CHAPTER 2. RESEARCH QUESTIONS

This study conducted human performance experimentation examining CWIs. Prior work under this research effort consisted of a compilation of the existing literature and data on heavy-vehicle CWSs and identifying potential research needs based on gaps and challenges in CWI implementation. The research questions developed for the human performance experimentation were shaped by NHTSA's high-priority needs relating to the regulatory issues involved with FCW implementation. In addition, the answers obtained from this research effort were used to support the development of the chapter on heavy vehicles in the DVI Design Principles.

RESEARCH QUESTIONS

Research Question #1 (Experiment 1): In terms of reaction time, is there a benefit to muting secondary audio sources during an imminent collision warning (ICW) alert?

Research Question #2 (Experiment 2): In terms of reaction time, is there a benefit to providing drivers a simpler visual ICW alert (providing minimal information) over a more complex ICW alert (providing more in-depth information), or is having no visual alert the most effective method?

Research Question #3 (Experiment 3): Based on the findings of Research Questions 1 and 2, in terms of reaction time, is there a benefit to the final design ICW alert over a no alert condition? Are the results obtained for Class 8 truck drivers applicable to motorcoach drivers?

EXPERIMENTAL APPROACH

In order to thoroughly address each of the research questions, three different experiments were performed as part of this study. Experiment 1 was an evaluation of the auditory warning system using a Class-8 truck-trailer combination. This focused on the effects of muting secondary audio sources on driver performance during an ICW. All test conditions in Experiment 1 received a simple visual alert component. Experiment 2 was an evaluation of visual display complexity on driver performance during an ICW in a Class-8 truck-trailer combination, with the auditory condition based on Experiment 1 results used as the auditory component of the alert presented. Experiment 3 was an examination of the final design ICW (obtained from Experiment 1 and Experiment 2 results) performed in a full-size motorcoach and compared with the Class-8 truck-trailer combination results. Figure 2 provides an overview of the three experiments in this study while Table 1 provides a breakdown of each test condition conducted within the three experiments.

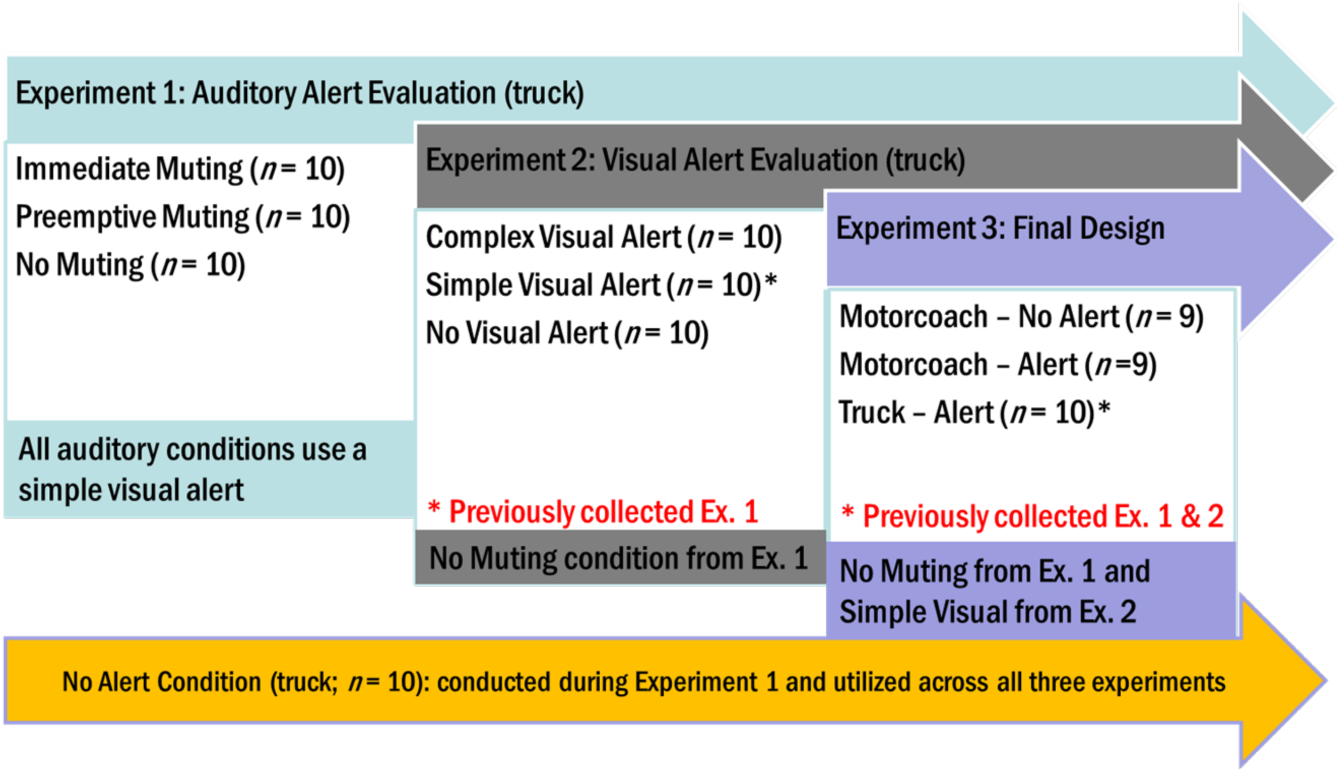

Figure 2. Experimental Design across All Three Experiments

Table 1. Study Test Conditions for Each Experiment

Condition	Alert Type	Ex.	Alert Definition
A	Immediate Muting	1	Immediate muting of secondary audio sources upon activation of alert
B	Preemptive Muting	1	Preemptive muting of secondary audio sources 0.25 s prior to alert
C	No Muting	1	No muting of secondary audio sources during activation of alert
D	No Alert	1,2,3	No alert presented (baseline)
E	Complex Visual	2	More complex visual with auditory alert, cabin sound not muted
F	Simple Visual	1,2,3	Simple visual with auditory alert, cabin sound not muted
G	No Visual	2	No visual, only auditory alert, cabin sound not muted
H	Alert – Motorcoach	3	Simple visual with auditory alert, cabin sounds not muted
I	No Alert – Motorcoach	3	No alert presented (baseline)

CHAPTER 3. EFFECT OF IN-CAB AUDIO MUTING ON AN ICW ALERT

OVERVIEW

The purpose of Experiment 1 was to examine the effect of muting secondary cabin sounds on driver reaction time to an ICW alert. The findings of this study will provide guidance about the benefit (or lack thereof) of muting secondary cabin sounds during presentation of a crash warning alert.

Research Question #1 (Experiment 1): In terms of reaction time, is there a benefit to muting secondary audio sources during an imminent collision warning (ICW) alert?

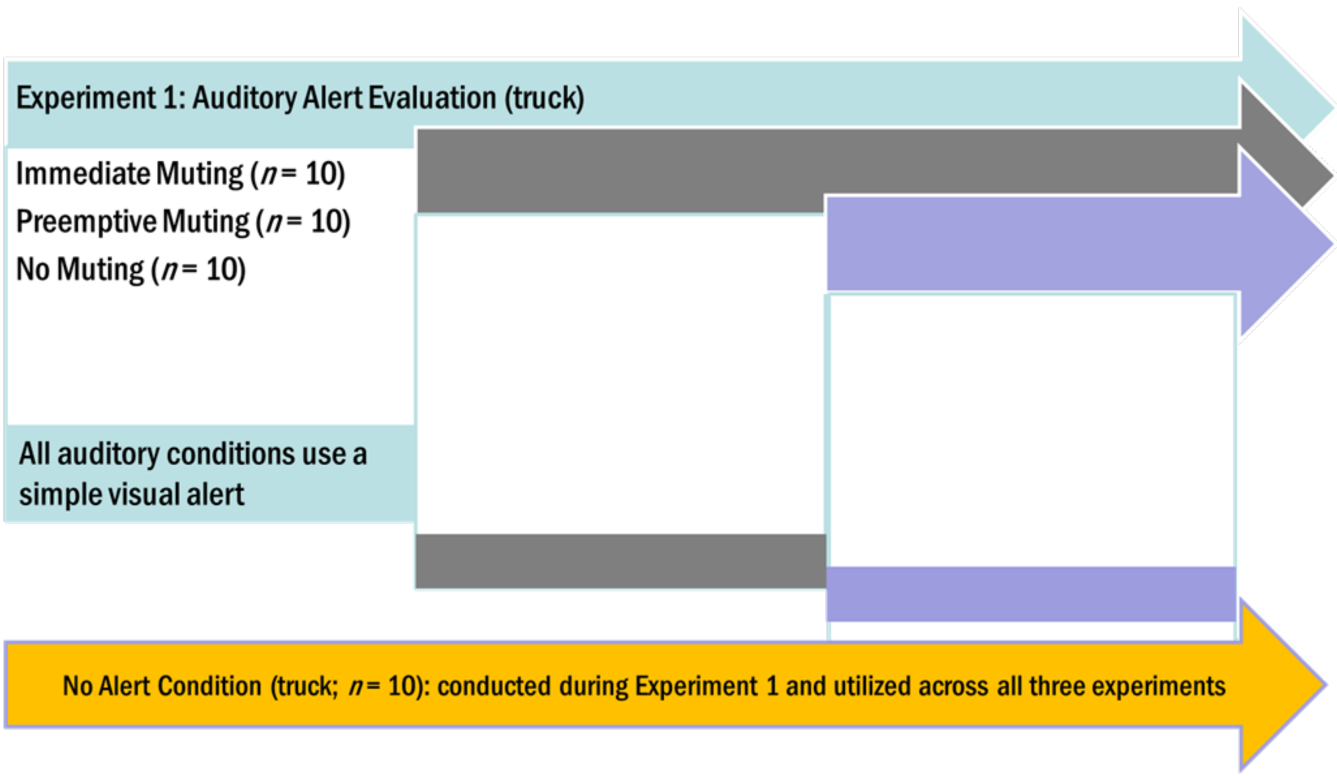

Figure 3. Experiment 1 Design Focus

EXPERIMENTAL METHOD

Participants

A total of 40 participants with valid test trials were needed to complete Experiment 1. Note that this number of participants was set by an a priori power analysis with a power of 0.8. This power analysis indicated a power of 0.8 would detect a small to moderate effect while a larger effect would indicate attaining a higher power.

All participants had a valid Class-A Commercial Driver's License (CDL; without an air brakes restriction [K] or automatic transmission restriction [E]) and a current Department of Transportation (DOT) medical card. Participants were not recruited based on age; however, Federal regulations require individuals to be age 21 or older in order to qualify for and obtain an interstate CDL. Therefore, no drivers under the age of 21 were included as participants in this experiment. Participants were also not recruited based on gender. However, the Institutional Review Board (IRB) requires that any female that is pregnant to meet with her physician to ensure she is medically fit to participate or accept any additional risks due to pregnancy. All female participants check a box on the consent form documenting that they have read and understood this requirement.

Additional requirements to serve as a participant included the following:

- Currently or recently employed (defined as within the past 6 months) in truck operations as a driver
- Not having a DOT-reportable incident within the past year
- Never having participated in a study at the Virginia Tech Transportation Institute (VTTI) that involves a surprise event.

While participants had to show a valid DOT medical card, additional vision acuity and color vision testing, along with a basic hearing test, were administered upon arrival at VTTI to ensure that the participants met the minimum requirements set forth in the DOT regulations.

Additionally, CDL driver recruitment is difficult due to the nature of the work (e.g., over-the-road drivers). Advertisements in eight local and regional newspapers were placed on six separate occasions to help achieve the number of drivers needed for this experiment. Also, when advertisements were placed in the local and regional newspapers, similar advertisements were placed on Craig's List and in the Virginia Tech daily email newsletter.

A limited number of VTTI employees who hold a valid CDL were used for initial (pilot) testing. The data from these participants were not used for analysis; instead, these participants' data were used to refine the testing and data analysis procedures as needed.

Apparatus

2007 Freightliner Cascadia

The Class-8 truck used in this study was a 2007 Freightliner Cascadia (Figure 4; Figure 5). The Freightliner Cascadia has a wheelbase of approximately 6.1 m with an approximate tare weight of 5,443 kg. The truck is equipped with an Eaton-Fuller 10-speed non-synchronized manual transmission, electronic stability control (ESC), traction control, anti-lock brakes (ABS), and super-single tires on the rear drive axles. This vehicle is similar in design and operation to most Class-8 trucks in CMV operations today, since Freightliner has the largest market share (39% in 2013) of Class-8 trucks in the United States (Park, 2013).

Figure 4. Freightliner Cascadia

Figure 5. Freightliner Cascadia Driver's Area

Utility Trailer

The trailer used in this study was a 2007 Utility 4000D-X trailer with a tare weight of 5,960 kg. The trailer is a 16.15 m (53 ft.) long dry van that is equipped with ABS and was used in an empty configuration. This trailer is similar in design and operation to most over-the-road dry van trailers in use today.

Data Acquisition System

A VTTI data acquisition system (DAS) was installed in the experimental truck in order to collect a number of vehicle variables, including speed, engine RPM, throttle position, brake application, following distance, and TTC. The DAS also has the capability to record multiple channels of time-synchronized video. The video views for this experiment include a view of the forward roadway, a wide angle of the driver's face, a wide-angle over-the-shoulder view of the driver, the driver's foot well (oriented towards the pedals), and a view of the visual display that generates the collision warning alert (Figure 6). The DAS is unobtrusive and does not interfere with the driver. The data and video were recorded and encrypted on a removable hard drive contained within the DAS.

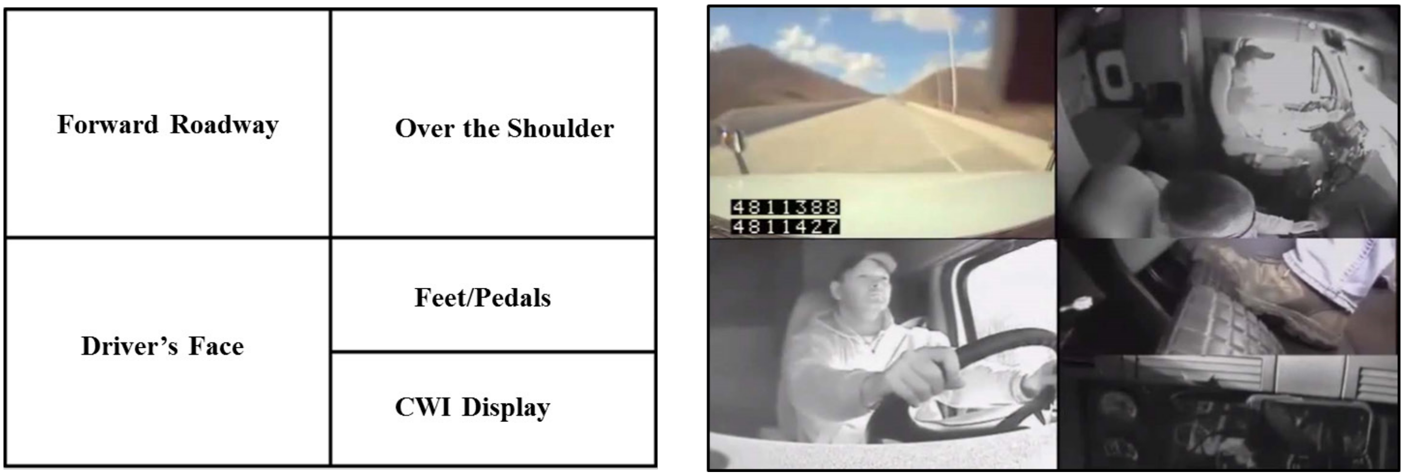

Figure 6. Video Layout as Recorded by the DAS

Collision Warning Interface

The CWI for this experiment was a single-stage alert system that provides an ICW alert when triggered. The system provided both an auditory and a visual alert. The triggering of the ICW alert was experimentally controlled via the DAS and associated instrumentation. Both the visual alert and auditory alert triggered simultaneously.

The ICW visual alert was displayed on a Samsung Galaxy Player 4.0 (Model YP-G1CWY/XAA) color display mounted on the instrument panel (IP) of the vehicle directly above the speedometer and tachometer (Figure 7). This area was chosen to represent the location of an integrated display that many suppliers and manufacturers are in the process of implementing (Figure 8). The display location is based on existing guidelines (COMSIS Corporation, 1996; Campbell et al., 2007) that suggest a position within 15° of the driver's vertical and horizontal line of sight should, upon activation, direct the driver's attention to the forward roadway.

Figure 7. Samsung Galaxy Player 4.0 Display Mounted on the IP

Figure 8. Placement Comparison with OEM FCW System (in Green) in the Right Image

The visual alert was based on existing CWI design principles (Table 2; Campbell et al., 2007) as well as the SAE J2400 standard that indicates a red background should be used for an imminent warning icon. The physical dimensions of the visual alert are 47.625 mm by 47.625 mm with a visual angle of 100.5 arc minutes as measured using a male driver approximately 1.85 m in height. Figure 9 provides the alert.

Table 2. HV-CWI Visual Alert Characteristics

Category	Criteria	Guideline
Type	Icon with text	6-2
Class	Symbolic and verbal	6-2
Background Color	Red	6-6
Symbol Color	Black	6-6
Text Color	White	6-6
Complexity	Lines of text	5-4

Figure 9. ICW Visual Alert for Experiment 1 (Image to Scale)

The auditory alert was played through external speakers located overhead. The auditory alert and volume were based on existing CWI design principles (Table 3; Campbell et al., 2007) and replicated Crash Avoidance Metric Partnership (CAMP) sound 8 (Kiefer et al., 1999). The loudness of the alert also falls within the recommendations of the Integrated Vehicle-Based Safety Systems study (Brown et al., 2007; Green et al., 2008)

Table 3. HV-CWI Auditory Alert Characteristics

Category	Criteria	Guideline
Type	Simple tones	7-2
Urgency	Faster pulses, high frequency	7-4
Loudness	15 dB above ambient, less than 90 dB	7-8
Distinctiveness	Unique sound	7-10

Sound level readings were taken with the vehicle in the test area at the test speed (72 km/h) in the gear that participants will be asked to use (9th gear). When the vehicle reached a steady state (i.e., no additional throttle manipulations were required to maintain the vehicle speed in the test area), maximum-value (using the maximum hold setting) sound pressure readings were obtained by holding the measurement wand of a Sper Scientific detachable probe sound meter (model 840012) in the area directly adjacent to the driver's right ear. This provides a sound pressure measure in the probable area of the driver's ear. These measurements are summarized in Table 4. The auditory alert was played at a level 15 dB greater than ambient and background music levels. The duration of the auditory alert was 1.10 s.

Table 4. Sound Pressure Readings from Test Vehicle

Measurement Point	Sound Pressure Level (dB)
Ambient Noise Level	69
Music	72
Music and Alert	87

Experimental Conditions

The experimental scenarios occurred on the Virginia Smart Road, which is a 3.5-km section of two-lane highway constructed to relevant Federal and state DOT standards. For these scenarios, only the subject vehicle and relevant confederate vehicles were present on the test track.

Four different test conditions were tested in Experiment 1. These test conditions assessed the effect of muting secondary cabin sounds on reaction time to an ICW alert. Music acted as the secondary cabin sounds for the experiment. Based on the results of prior research examining the effects of different music on driving performance (Brodsky, 2002), a song with a medium-paced tempo was selected (Café Amore by Spyro Gyra). The same song was played across all conditions for all participants. Test Condition A triggered the ICW with immediate muting of music, Test Condition B triggered the ICW with the music preemptively muted 0.25 s before the ICW was triggered, and Test Condition C triggered the ICW and did not mute the music. Test Condition D was the no alert condition (i.e., no alert was presented). A preemptive muting time of 0.25 s was chosen based on previous research (Keller, 1978; Sanders, 2007; Triggs, 1982) that indicated a foreperiod (i.e., preemptive) could potentially quicken reaction times. Table 5 provides a description of the conditions while Figure 10 provides a visual representation of three conditions receiving the ICW alert.

Table 5. Experiment 1 Test Conditions

Condition	Alert	Alert Definition
A	Immediate	Immediate muting of secondary audio sources upon activation of alert
B	Preemptive	Preemptive muting of secondary audio sources 0.25 s prior to alert
C	No Muting	No muting of secondary audio sources during activation of alert
D	No Alert	No alert presented

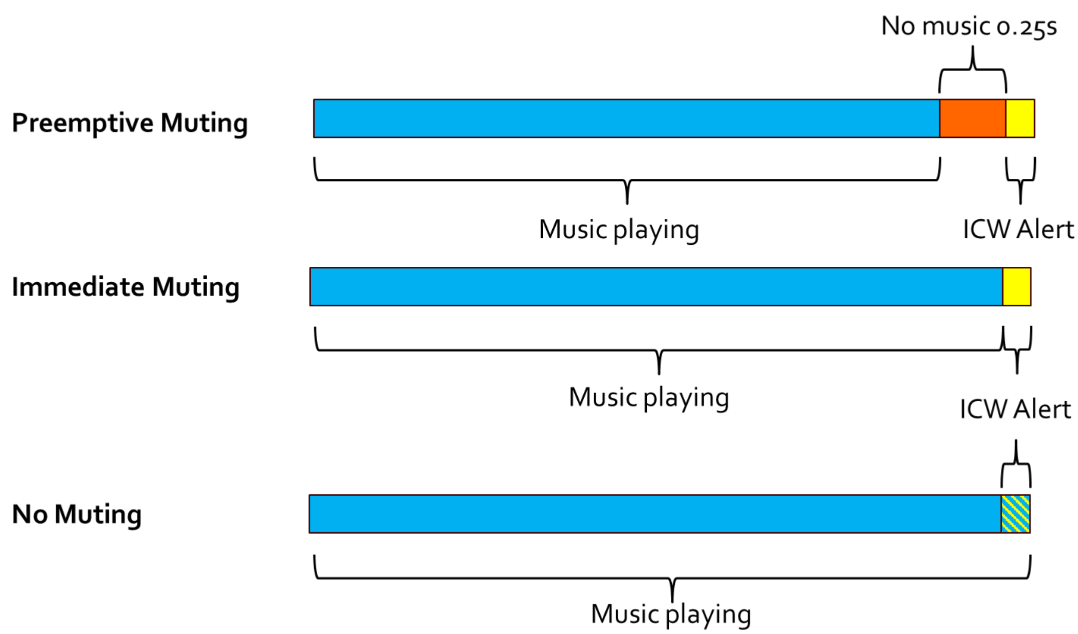

Figure 10. Visual Representation of Alert Timings

Experimental Design

This was a between-subjects design with a single exposure surprise event. All participants experienced six test trials. These test trials were the same across all test conditions and were always conducted in the same order. Each test trial was one full length of the test track. The only test trial of interest for this study was test trial six (i.e., near-crash rear-end event). Table 6 provides a description of the six test trials.

Table 6. Description of Experiment 1 Test Trials

Test Trial	Subject Vehicle	Lead Vehicle	Side Vehicle	Test Trial Description
1	Yes	No	No	No secondary task or music. Orientation drive.
2	Yes	Yes	No	No secondary task or music. Orientation drive.
3	Yes	Yes	Yes	Adjusting the radio task. Music playing.
4	Yes	Yes	Yes	Map reading task. Music playing.
5	Yes	Yes	Yes	Paperwork task. Music playing.
6	Yes	Yes	Yes	Reaching for an object task (test trial of interest). Music playing.

All in-vehicle secondary tasks were based on the results of naturalistic examinations of CMV operator distraction (Olson, Hanowski, Hickman, & Bocanegra, 2009). The same six test trials were used in all three experiments within this study. The surprise event occurred only in the sixth test trial and consisted of a 0.60-g braking maneuver by the lead vehicle while the participant was performing a task that required eyes off the road. The lead-vehicle braking event resulted in ICW activation at a 3.0-s TTC.

The no alert condition (baseline) was conducted by having the participant perform the same secondary tasks in each test trial just as those participants in the other test conditions experienced, only with no ICW presented. As a safety precaution, the lead vehicle experimenter was instructed to perform a lane exit into the adjacent lane at 1.0-s TTC in case a participant failed to respond to the ICW alert or during the no alert condition (baseline).

The lead vehicle contained a 7-inch display (Figure 11) mounted on the dash that presented the lead vehicle speed, subject vehicle speed, subject vehicle following distance (meters), and subject vehicle TTC in real time to the driver. The lead vehicle experimenter utilized this display when performing the braking maneuver and to determine if an evasive action was needed.

Figure 11. Lead Vehicle Driver's Area with Display

The purpose of the side vehicle was to replicate real-world driving conditions by having a vehicle in the left adjacent lane, thereby preventing the participant from changing lanes to avoid the lead vehicle during the braking event. Figure 12 shows the lead and side vehicle placement during the test trials.

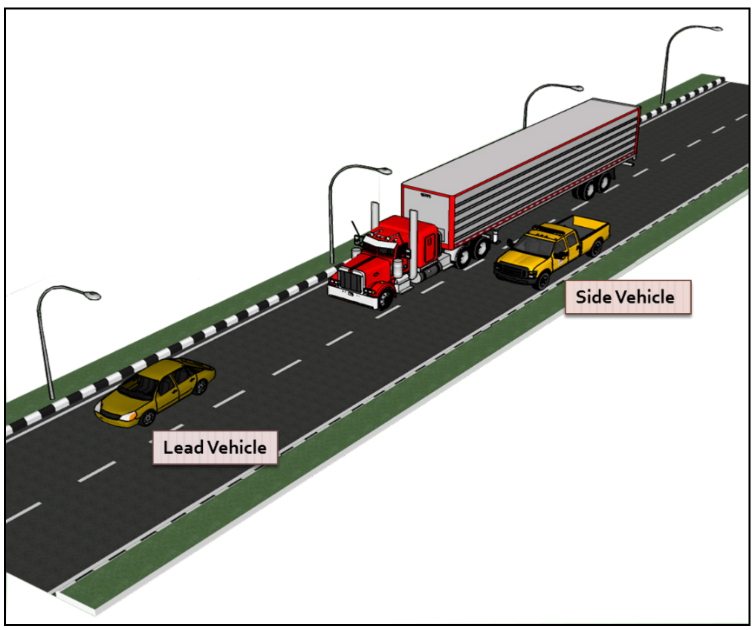

Figure 12. Vehicle Placement during Test Trials

Experimental Procedure

After participants were greeted, given the information sheet, and had vision and hearing screened, they were given an orientation to the Class-8 truck-trailer combination they would drive on the test track. Participants were not informed as to the true nature of the experiment until after their exposure to the surprise event. Once the vehicle orientation was completed, the participant was instructed to proceed to the test track for instructions prior to beginning testing.

Participants received instructions prior to the start of each test trial. For test trials 3 through 6 (those involving a secondary in-vehicle task), participants were given time to practice a similar task prior to driving.

For the first test trial, participants drove the length of the test track at 72 km/h (45 mph) with no other vehicles present and did not perform any secondary in-vehicle task.

For the second test trial, participants drove the length of the test track at 72 km/h (45 mph) with a lead vehicle present also traveling at 72 km/h (45 mph) and maintaining a 4-s headway. Participants did not perform any secondary in-vehicle task.

Test trial 3 included both the lead vehicle and side vehicle. The side vehicle traveled in the left adjacent lane and varied its position from approximately the driver's side window of the subject vehicle back to the front of the trailer. Participants were instructed to drive the length of the test track traveling at 72 km/h (45 mph) while following the lead vehicle also traveling at 72 km/h (45 mph) and maintaining a 4-s headway. During this test trial the participant was asked to perform a secondary in-vehicle task of adjusting the radio station by changing the band of the radio from AM to FM and using the manual tune buttons to find station 99.1 MHz. Upon completion of this test trial, the participant was instructed to park and receive instructions prior to the next test trial.

Test trial 4 included both the lead vehicle and the side vehicle. The side vehicle traveled in the left adjacent lane and varied its position from approximately adjacent to the driver's side window of the subject vehicle back to the front of the trailer. Participants were instructed to travel at 72 km/h (45 mph) while following the lead vehicle. During the test trial the participants performed a map-reading task of finding the two interstate highways that cross in Butte, Montana, using a trucker atlas (an atlas designed specifically for heavy-/large-vehicle drivers). Upon completion of this test trial, the participant was instructed to park and receive instructions prior to the next test trial.

Test trial 5 included both the lead vehicle and the side vehicle. The side vehicle traveled in the left adjacent lane and varied its position from approximately adjacent to the driver's side window of the subject vehicle back to the front of the trailer. Participants were instructed to travel at 72 km/h (45 mph) while following the lead vehicle. During the test trial the participant performed a paperwork task by filing a delivery invoice into a folder. Upon completion of this test trial, the participant was instructed to park and receive instructions prior to the next test trial.

Test trial 6 included both the lead vehicle and the side vehicle. The side vehicle traveled in the left adjacent lane and varied its position from approximately adjacent to the driver's side window of the subject vehicle back to the front of the trailer. Participants were instructed to travel at 72 km/h (45 mph) while following the lead vehicle. During the test trial, the participants performed a reaching-for-an-object task involving reaching for a single red pen (note that no red pen was in the cup holder) located in a group of various colored pens held in the floor moor-mounted cup holder. During this task, when the participant's eyes were off the road, the in-vehicle experimenter signaled (using a radio system the participant was unaware of) the lead vehicle to perform a 0.60-g braking maneuver from 72 km/h to 32 km/h and to maintain this speed until signaled again by the in-vehicle experimenter. Once the TTC between the lead vehicle and subject vehicle reached 3.0 s, the ICW was triggered. As a safety precaution, the researcher was monitoring the participant and would cue the participant to brake and the lead vehicle to make an evasive maneuver (using the radio system) once TTC reached 1.0 s if the participant did not react to the alert. The lead vehicle also contained a display in real time providing the lead vehicle driver with all relevant information to determine if an evasive action were needed. The no alert scenarios were conducted by having the participant perform the same secondary task as performed in the sixth test trial but no ICW was presented.

After completion of this task and braking maneuver, the researcher instructed the participant to stop the vehicle and immediately proceeded with the informed consent process. Ample time was provided for the participant to fully understand what just took place, why deception was used, and to ensure all questions were answered. Following completion of this consenting process, the debriefing questionnaire was administered, followed by the participant proceeding to the gate of the test track, exiting the track, and parking the vehicle. The participant was then compensated for his/her time and any remaining questions the participant had were answered.

Dependent Variables

Objective

There are two objective dependent variables (DV) for this experiment. The operational definitions are listed below:

- DV #1 – First Response: defined as the participant's first response when the ICW alert is presented
- DV #2 – Reaction Time: defined as the time (as measured in seconds) that elapses between the presentation of the ICW alert and the participant's response to three separate actions (look to the forward roadway, lift foot from throttle, and depress brake)

DV #1 (first response) consisted of three participant first-response options: (1) look to the forward roadway, (2) look to the visual alert, and (3) lift foot from the throttle. This dependent variable was analyzed through video reduction. DV #1 was recorded as numerical counts (e.g., number of participants that look to the forward roadway first) and presented as percentages in the results.

DV #2 (reaction time) consisted of three different reaction times. The first reaction time (RT #1 – Look Forward) was calculated based on the timing of the ICW alert presentation and the participant's first glance to the forward roadway. The second reaction time (RT #2 – Throttle Release) was calculated based on the timing of the ICW alert presentation (time between this and the adjacent RTs might denote hesitation) and the participant's foot first lifting from the throttle. The third reaction time (RT #3 – Depress Brake) was calculated based on the timing of the ICW alert presentation and the participant's foot first depressing the brake pedal. This DV was analyzed through a combination of data and video reduction. The three reaction times recorded for DV #2 were measured in seconds.

The DV objective data were placed into one of two categories: (1) valid alert (reacted to the alert) or (2) invalid alert (reacted before the alert). The operational definitions are listed below:

- Valid Alert (reacted to the alert): defined as the participant having eyes off the road and/or unaware of the lead vehicle braking and having not yet lifted his/her foot from the throttle prior to ICW alert presentation

- Invalid Alert (reacted before the alert): defined as the participant reacting to the lead vehicle braking prior to the ICW alert presentation

In the case of invalid alerts, one of two possibilities occurred: (1) participants glanced back to the forward roadway, saw the lead vehicle braking, and began braking prior to reaching a 3-s TTC and therefore no ICW alert was triggered; or (2) participants glanced back to the forward roadway, saw the lead vehicle braking, and began lifting their foot from the throttle but the ICW alert was still triggered as they reached and dropped below a 3-s TTC before they began braking. This second invalid-alert scenario could be classified as a nuisance alert.

For purposes of this study, DV objective data were only analyzed for participants with valid test trials.

Subjective

Participants' subjective feedback on their own performance and the ICW alert was also assessed via questionnaire (Appendix A). Participants provided ratings using a 7-point Likert-type scale. Additionally, several questions gathered "yes/no" responses. Open-ended responses were also collected about the auditory and visual components of the ICW alert. The subjective data set includes participants with both valid and invalid objective data.

EXPERIMENT 1 RESULTS

Overview

The following sections present the results for Experiment 1. Results, including participant demographics, along with a brief discussion, are presented.

As noted in Chapter 2, three research questions were developed to address the scope of this study. Experiment 1 was performed in order to address Research Question #1.

Research Question #1 (Experiment 1): In terms of reaction time, is there a benefit to muting secondary audio sources during an imminent collision warning (ICW) alert?

Experiment 1 evaluated the auditory alert of an HV-CWI using a Class-8 truck-trailer combination unit. This experiment focused on the effects of muting secondary audio sources on driver performance when responding to an ICW and assessed the difference in reaction times, if any, of an ICW auditory alert of an HV-CWI while muting secondary audio sources. Three different auditory conditions along with a no alert condition (baseline) were examined (refer to Table 5 for operational definitions).

- Immediate muting
- Preemptive muting

- No muting
- No alert (baseline)

Methods Refinement

Pilot Testing

The initial stages of human performance testing were used as a protocol refinement process. A protocol such as this has not been implemented in the past for heavy vehicles outside of simulator environments. A number of participant test trials during this refinement process were deemed invalid (react before the alert) due to the participants reacting to the lead vehicle braking prior to the ICW alert presentation. Subsequent revisions to the protocol during the refinement process were made in an effort to improve the success of obtaining valid (react to the alert) test trials. All protocol revisions during this refinement process were approved by the Virginia Tech IRB. It should be noted that data from participants tested during the refinement process were not used for the analyses presented herein.

Experimental Test Trials

Once all protocols were finalized, a total of 99 participants completed testing. However, only 40 (40%) of these participants had valid (react to the alert) test trials (i.e., distracted while the event of interest evolved and depressing the throttle). While the finalized testing protocol was designed to maximize the number of valid test trials, a high number of invalid (react before the alert) test trials (60%) still occurred throughout testing. It should be noted that all tasks performed by the participants, including the test trial of interest (test trial 6), have been identified in naturalistic driving studies as common tasks that CMV drivers perform (Olson et al., 2009). The objective behind using events that are naturally occurring in the CMV domain (instead of a prescriptive or artificial distraction event) was to ensure that the results are representative of how this portion of the population would transition out of the distracting event and react to an evolving near-crash, rear-end event in the presence or absence of an ICW alert. These naturally occurring events ensure ecological validity, but might require multiple additional participants to ensure the number of valid test trials is met per the power analysis. The reader is urged to consider that crashes and near-crashes are not commonly occurring events. The reason could be that drivers might look and scan the driving environment at the appropriate time as the event is starting to evolve and resolve the potential conflict prior to ICW alert presentation. This translates as well to the experimental setting creating the potential for invalid test trials.

Another potential factor impacting the participants (causing higher invalid test trials) is the presence of an experimenter in the heavy vehicle while the participants perform the tasks. This is known as the Hawthorne effect (Mayo, 1933) in which participants being directly observed often perform better or differently than if they were not being directly observed. With the attention that distracted driving has received within the media and the research community, the study participants may be attempting to act as model participants (i.e., not taking their eyes off the road for as long as they normally would in their CMV). Other research involving FCW systems has experienced similar outcomes. During one study examining the DVIs of FCWs in light vehicles using a driving simulator, Lerner et al. (2011) experienced a 38-percent rate of invalid FCW events due to the participant responding prior to the alert being triggered. Forkenbrock et al. (2011) also assessed the ICW alert of an FCW system. This assessment used an artificial task (i.e., not identified in naturalistic data) and a balloon car and still experienced an 11-percent rate of invalid test events due to the driver responding before the alert was triggered. Both of the aforementioned studies were examining light vehicles whereas the current study is examining CWIs in heavy vehicles. Heavy vehicles inherently present more of a difficult challenge when assessing DVIs due to their size, weight, and the stopping distances required. CMV operators are classified as professional drivers due to the skills needed to operate a heavy vehicle. This could potentially increase the participants' situational awareness and lessen their risk-taking in test-track settings in general and even more so when following a lead vehicle on a test track while performing secondary tasks (e.g., reaching for an object) as the consequences of not paying attention to the driving task are more tangible for these participants.

Human Performance Testing

Overview

Data recorded by the DAS installed in the test vehicle were analyzed in a manner allowing for simultaneous and time-synchronized viewing of the vehicle and experimental apparatus data along with the video stream. Two primary measures of interest were analyzed for each participant during test trial 6 (this event contained the FCW event). It is important to understand that all participants were naïve to this study (i.e., did not know an FCW system was installed in the subject vehicle) and received no prior training on either the visual alert or auditory alert. This was to ensure that all participants would remain unbiased and not assume that the lead vehicle was going to perform a hard-braking maneuver. Also, this is representative of fleets randomly assigning drivers to fleet vehicles without informing them that the vehicle is equipped with a CWS or providing the driver with any training on CWSs.

The first measure of interest was DV #1 (first response). The first response to the ICW alert was categorized in one of three ways: (1) look to the forward roadway, (2) look to the visual alert, or (3) lift foot from the throttle. It should be noted that the DAS used in Experiment 1 did not include a camera on the bottom of the visual alert display. Therefore, any glance toward the IP was counted as a look to the visual display. However, an additional camera was added to the DAS for Experiment 2 and Experiment 3 to allow for more exact eye-glance analysis (i.e., to determine if the participant looked to the visual component of the alert).

The second measure of interest was DV #2 (reaction time). Data collected from four different points in time for each participant were used during the current analyses. The first point in time recorded was when the ICW alert was triggered. Note that participants in the no alert condition (baseline) did not receive the ICW alert. Therefore, the 3.0-s TTC was used as the trigger. The second point in time recorded was when the participant first glanced to the forward roadway. The third point in time recorded was when the participant first lifted his/her foot off the throttle. The fourth point in time recorded was when the participant depressed the brake pedal.

Using the four recorded points in time, three different reaction times were analyzed:

- RT #1 – The first reaction time was the length of time from when the ICW alert was triggered to when the participant first glanced to the forward roadway.
- RT #2 – Throttle Release: The second reaction time was the length of time from when the ICW alert was triggered to when the participant first lifted his/her foot from the throttle (i.e., the point of initial deceleration).
- RT #3 – Depress Brake: The third reaction time observed was the length of time from when the ICW alert was triggered to when the participant first depressed the brake pedal.

Figure 13 depicts the four recorded points in time and the three reaction times measured.

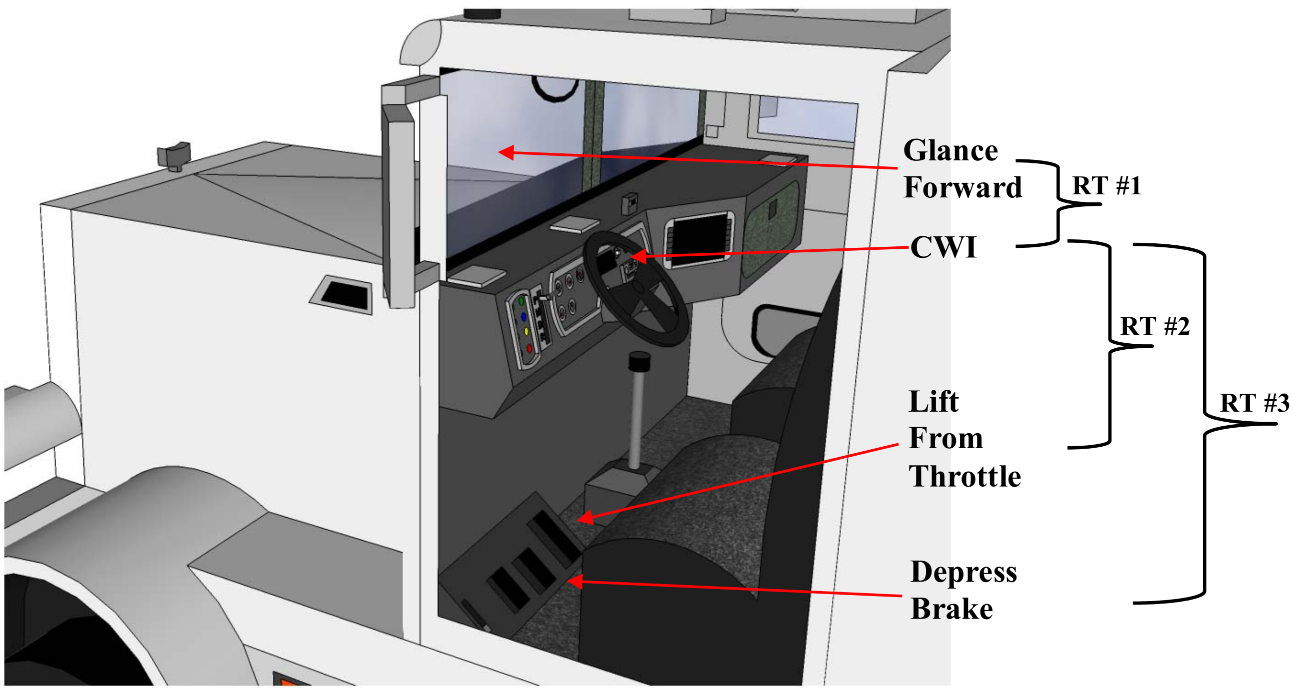

Figure 13. Four Recorded Points in Time and the Three Reaction Times Measured

Demographics

Demographics were collected and compiled for all participants tested in Experiment 1. However, for the objective data results, only demographics of those participants with valid test trials (i.e., participants that reacted to the alert) are presented in the tables below. Table 7 presents demographics (per test condition) of the 40 completed participants with valid test data. Across all participants, the mean age was 46.1 years. Thirty-nine participants were male, while one participant was female. All participants had a valid CDL (39 from the state of Virginia and 1 from the state of North Carolina), a valid DOT medical card, and no DOT-reportable accidents within the past year.

Table 7. Participant Demographics per Test Condition

Condition	*n*	Male	Female	Mean Age (years)	SD Age (years)	Minimum Age (years)	Maximum Age (years)
Immediate	10	9	1	45.3	17.6	25	76
Preemptive	10	10	0	43.8	11.9	29	66
No Muting	10	10	0	46.3	15.0	21	62
No Alert	10	10	0	48.8	13.1	29	67

During Experiment 1, additional driving and employment demographics were collected from each participant. Driving demographics include years of CMV driving experience, average mileage driven per week, and million-miler status. Employment demographics include the type of fleet operation and distance classification. This report follows FMCSA's Motor Carrier Identification Report (MCS-150) for the basic fleet operation classifications (FMCSA, 2007). The MCS-150 defines:

- For-hire – a motor carrier who receives compensation for transporting goods that are owned by others
- Private – a company that transports its own cargo, usually as part of a business that produces, uses, sells, and/or buys the cargo that is being transported

Within the trucking industry, for-hire is further subdivided into truckload and less-than-truckload (LTL) classifications. LTL shipments are generally less than 9,072 kg. Distance classifications are less straightforward. According to the United States Census Bureau's Vehicle Inventory and Use Survey (2004), distance classifications are divided into the five categories shown in Table 8.

Table 8. Distance Classifications

Distance Classification	Definition
Local	Trips 50 miles or less
Short Range	Trips between 51 and 100 miles
Short Range–Medium	Trips between 101 and 200 miles
Long Range–Medium	Trips between 201 and 500 miles
Long Range	Trips 501 miles or greater

However, motor carriers typically have many routes comprising different distances; thus, short range, short range–medium, and long range–medium are collectively referred to as short haul. For the purposes of this report, distance classifications are reported as local (trips 50 miles or less), short haul (trips between 51 and 500 miles), and long haul (trips 501 miles or greater).

Table 9, Table 10, and Table 11 provide these demographics for participants with valid test trials.

Table 9. Participant Driving Demographics

Condition	*n*	Mean Experience (years)	SD Experience (years)	Mean Miles/Week	Million Miler (*n*)
Immediate	10	20.9	16.4	1,459	5
Preemptive	10	16.7	10.8	1,380	6
No Muting	10	22.5	12.1	1,579	6
No Alert	10	23.8	17.4	2,244	6

Table 10. Number of Participants per Fleet Operation Classification

Condition	*n*	For-hire Truckload	For-hire LTL	Private
Immediate	10	2	1	7
Preemptive	10	1	2	7
No Muting	10	1	3	6
No Alert	10	3	2	5

Table 11. Number of Participants per Distance Classification

Condition	*n*	Long Haul	Short Haul	Local
Immediate	10	3	4	3
Preemptive	10	2	5	3
No Muting	10	4	3	3
No Alert	10	5	4	1

Diagnostic Assessment

Initially, diagnostic assessments were performed to determine the normality of the data, determine if any outliers were present, and if so, how those outliers affect the reaction times. Anderson-Darling normality testing indicated a non-normal distribution of data in at least one test condition for each of the three reaction times. This result warranted a closer look within the data set of each reaction time to assess the cause and effect of the non-normal distributions before proceeding with further reaction time analyses. This diagnostic assessment proceeded in order starting with RT #1.

RT #1 (Look Forward) is directly related to the participant's first response and revealed a wide distribution of reaction times. While the intent of an FCW system is to direct the driver's eyes to the forward roadway, glancing to the visual display prior to the forward roadway when the ICW alert is triggered is a potential real-world response when these systems are utilized. This, in turn, would increase the driver's reaction time looking to the forward roadway and subsequently create the distribution seen in RT #1. However, this was not considered bad data due to the potential for this to occur in real-world driving and required moving onto RT #2 for further assessment.

Similar to RT #1, when all data from each of the auditory conditions were combined, the reaction times fell across a wide distribution with a standard deviation larger than the mean. Further analysis was conducted on the interquartile range to determine the presence (or absence) of potential outliers. The analysis indicated that five values in the combined auditory data sample were greater than 1.5 times the interquartile range, thus indicating these values are potential outliers. Figure 14 provides the percentile range for reaction times of the combined auditory data sample.

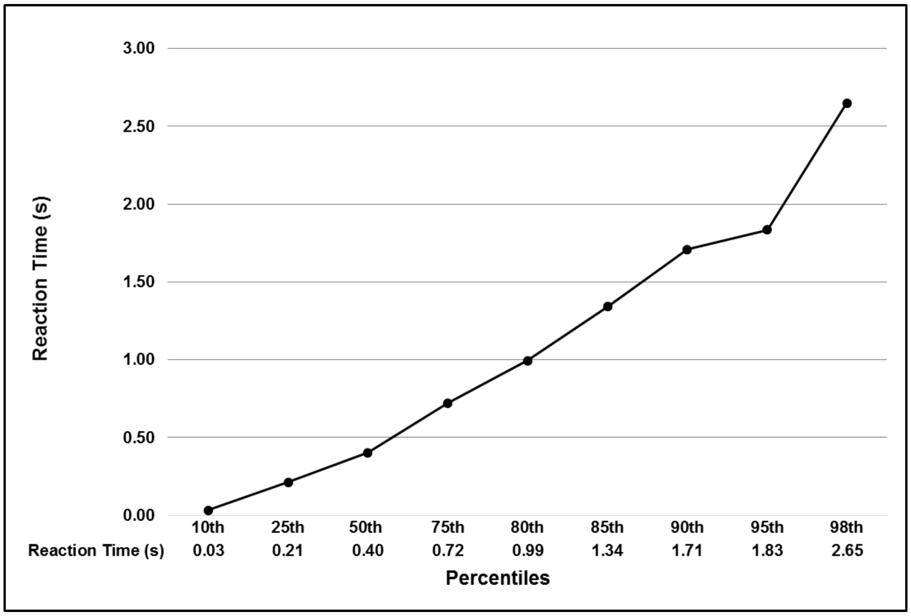

Figure 14. Percentile Range for Reaction Times (in Seconds) of the Combined Auditory Data Sample for RT #2

Two potential outliers were found in the immediate muting condition (1.70 s and 1.76 s). These two values were 2.6 times the mean reaction time for the immediate muting condition. Two potential outliers were also found in the preemptive muting condition (1.89 s and 3.69 s). These two values were 2.2 times and 4.3 times the mean reaction time for the preemptive muting condition, respectively. One potential outlier was found in the no muting condition (1.35 s). This value was 3.0 times the mean reaction time for the no muting condition. As can be seen in Figure 14, four of the five potential outliers fall at approximately the 90^{th} percentile or greater, while the other potential outlier falls slightly above the 85^{th} percentile. The 1.89-s reaction time falls above the 95^{th} percentile, while the 3.69-s reaction time falls above the 98^{th} percentile.

Prior research (Ratcliff, 1993) has indicated that the prevalence of outliers in reactions times is quite common. However, caution must be exercised when identifying data values as outliers as normal reaction time distributions can overlap the outlier distributions, making identification problematic. One must take into consideration what these reaction time measures are attempting to capture and how they apply to these research questions. Thus, a close inspection of each data value is required to ensure that any identified as potential outliers are truly outliers.

A detailed inspection of the data, including subjective responses, for these five potential outliers revealed:

- These five participants compared against the other 26 participants had a similar mean road speed of 64.4 km/h versus 63.0 km/h, respectively, when the ICW alert was activated, therefore indicating that initial speed was not a factor in the slower reaction times.

- Across these five participants, the mean distance to the lead vehicle when the brake was depressed was 35 meters, while this same mean distance was 39 meters for all other participants receiving the auditory alert.
- None of these five participants had previously experienced an FCW system.
- Both participants in the immediate muting condition (1.70 s and 1.76 s) and the one participant in the no muting condition (1.35 s) responded by looking at the visual alert before lifting their foot from the throttle.
- Both participants in the preemptive muting condition (3.69 s and 1.89 s) disregarded the alert and continued with the task.

When assessing the two participants in the immediate muting condition, one reaction time fell at the 90th percentile and the other reaction time fell just above the 90th percentile. When assessing the one participant in the no muting condition, this reaction time fell just above the 85th percentile. As mentioned previously, the intent of FCW systems is to immediately direct the driver's attention to the forward roadway, and the potential does exist for a driver to view the visual alert as a confirmation before taking action. All three of these participants glanced to the visual display prior to glancing to the forward roadway. Thus, these three participant reaction times, while outliers, will not be removed from the data sample.

When assessing the two participants in the preemptive muting conditions, their reaction times both fell above the 95th percentile, with one falling above the 98th percentile. In the case of these two participants, they disregarded the alert, which is a potential real-world possibility. However, the scope of research question #1 is to determine if participants reacting to an ICW alert have a quicker reaction time than participants that do not receive an alert. Therefore, the data analyses should not take into account participants who completely disregarded the ICW alert and continued trying to complete the task. Further, considerations must be given to engineering and design implications relating to FCW systems. It would be impractical to account for reaction times falling at or above the 95th percentile. Increasing the TTC of the ICW alert to "catch" these drivers would most likely lead to a drastic increase in nuisance alarms for the majority of drivers, thus negatively influencing driver acceptance. Further, in a Federal Highway Administration (FHWA) report (Inman & Davis, 2009) studying the effects of in-vehicle and infrastructure-based collision warnings, assessments of the 5th percentile through the 95th percentile brake response times were used. Therefore, the research team feels there is enough justification to remove these outlier reaction times from the data sample. RT #3 did not indicate any further bad data.

First Response to Alert

Video reduction was performed on the Experiment 1 data set to assess each participant's first response to the ICW alert being activated. It should be noted that this analysis does not include the no alert condition as those participants did not experience the ICW alert during the braking event.

The majority (22 of 28; 79%) of the participants' first response was to look to the forward roadway when the ICW alert was presented. Additionally, the second and third response of each participant was also assessed. Only the first three potential responses were included for each participant. Lifting the foot from the throttle is the first action to begin mitigating a potential rear-end conflict and must occur before depressing the brake; therefore, depressing the brake (a fourth potential response) was omitted from these results. Also, note that the response of looking to the visual alert may not sum to 100 percent due to some participants never looking to the visual alert component.

Following the participants' first response to ICW alert activation, the majority of participants (24 of 28; 86%) then lifted their foot from the throttle as their second response. Of the four participants who did not lift their foot from the throttle as their second response, one participant's eye glance went from the forward roadway to the IP while the eye glances of the other three participants went from the IP to the forward roadway. Additionally, 50 percent (14 of 28) of the participants looked at the IP at some point during the braking event (i.e., first, second, or third response). Note that not all participants performed a third response (i.e., 14 participants did not glance to the visual alert during the ICW alert presentation). Also, the researchers again want to emphasize that depressing the brake was not presented in this analysis as one of the first three response options. The driver lifting his/her foot from the throttle was deemed a more appropriate response to assess as this occurs before depressing the brake and is the first action to mitigate a potential rear-end conflict. Lifting the foot from the throttle in a heavy vehicle is inherently different than lifting it from the throttle in a light vehicle as transmission gearing and engine braking begin to slow forward momentum at a different rate than when lifting the foot from the throttle in a light vehicle.

Reaction Time #1 – Look Forward

Two analyses were performed on the data for this reaction time. The initial analysis performed combined all data from the three different auditory conditions and compared this combined value against the results for the no alert condition. This comparison assisted with the process of identifying if ICW alerts (in general) produced a quicker reaction time than conditions with no alert. The second analysis that was performed compared the data between test conditions.

RT #1: Combined Auditory Conditions

This analysis was performed with the data from each of the three auditory alert conditions combined. The combined data created a two-sample comparison (combined auditory alert conditions, n = 28; no alert, n = 10). Figure 15 provides the mean reaction times for RT #1.

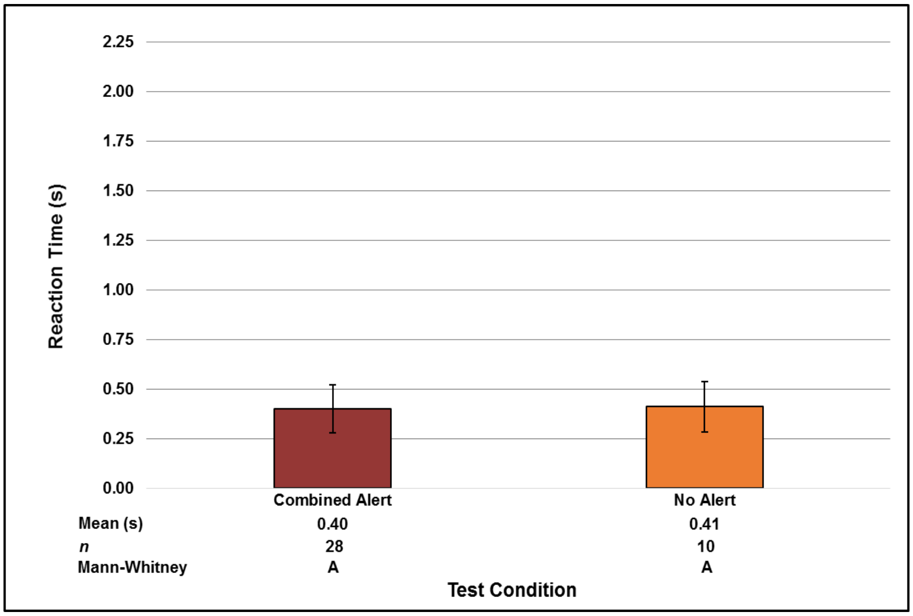

Figure 15. Mean Reaction Times (with Standard Error Bars) from ICW Alert Activation to First Glance to the Forward Roadway (RT #1 – Look Forward) for All Auditory Conditions Combined Versus the No Alert Condition

The Mann-Whitney-Wilcoxon test for RT #1 did not find a significant effect between the no alert condition (M = 0.41, SD = 0.40) and the three auditory conditions combined (M = 0.40, SD = 0.63); W = 505.5, $p = .168$. Keep in mind that this reaction time is directly linked to the participant's first response (i.e., look to the forward roadway, look to the visual display, or lift foot from the throttle).

RT #1: Between All Test Conditions

While examining the data in a combined manner did not reveal any significant effects, further analysis was conducted between test conditions. Figure 16 provides these mean reaction times. A graphical diagnostic assessment on the analysis of variance (ANOVA) model's residuals detected a pattern deviating from normality due to the identified outliers that were not removed, thus violating the ANOVA assumption which assumes a normal distribution. Therefore, the Kruskal-Wallis nonparametric statistical method was applied.

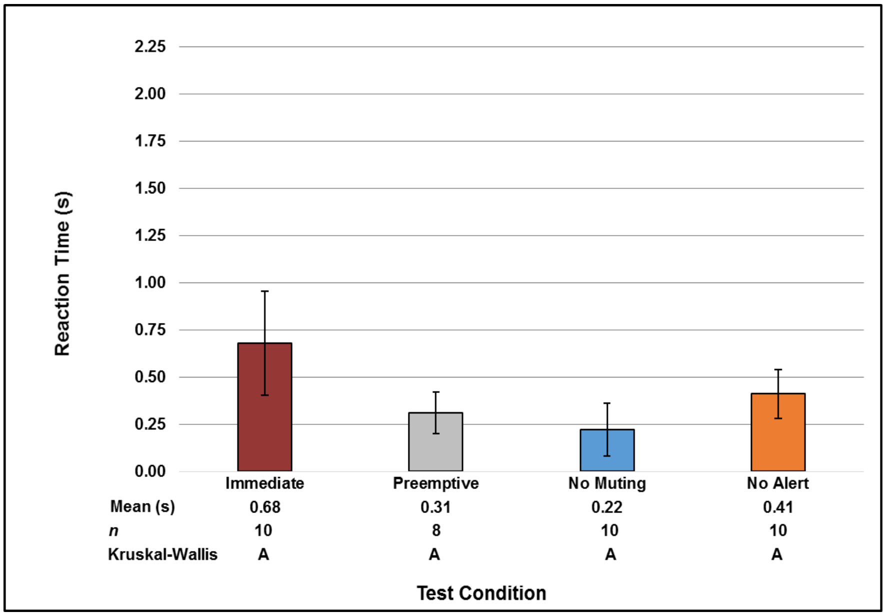

Figure 16. Mean Reaction Times (with Standard Error Bars) for RT #1 – Look Forward

The Kruskal-Wallis test did not find a significant effect between any of the test conditions for RT #1; H(3) = 4.11, $p = .249$. Again, these reaction times are directly linked to the participant's first response to the ICW alert. It should be noted that the immediate muting condition had four participants and the no muting condition had two participants that looked to the visual display as the first response, thus increasing their reaction time when looking to the forward roadway.

A subsequent analysis was conducted after removing the five participants that looked to the visual alert as their first response. Figure 17 provides these mean reaction times.

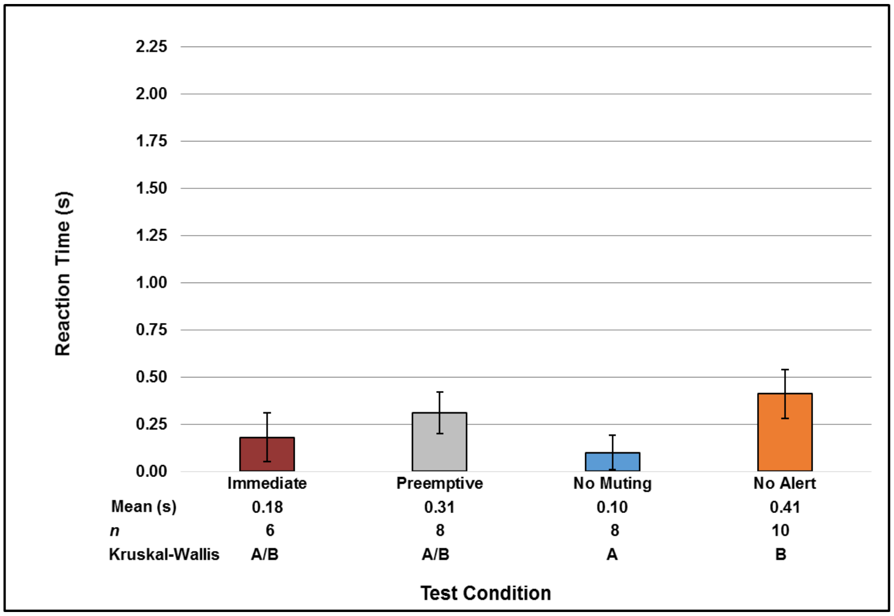

Figure 17. Mean Reaction Times (with Standard Error Bars) for RT #1 – Look Forward (Looked to the Visual Alert as First Response Removed)

The Kruskal-Wallis test did find a significant effect between the test conditions for RT #1 when accounting for those participants that did look to the visual alert as their first response; H(3) = 7.98, p = .046. A post hoc analysis using Mann-Whitney-Wilcoxon tests with a Bonferroni correction comparing each of the auditory conditions individually to the no alert condition was then performed (Table 12). The Bonferroni correction adjusted the significance level to .017. Significant effects were found between the no muting condition and the no alert condition. These findings indicate that the no muting condition produced a quicker reaction time than no alert when first glancing to the forward roadway upon activation of the ICW alert.

Table 12. Post Hoc Analysis for RT #1

Test Condition	Significance Test
Immediate versus No Alert	W = 33.0, p = .054
Preemptive versus No Alert	W = 67.0, p = .445
No Muting versus No Alert	W = 57.5, p = .007*

Reaction Time #2 – Throttle Release

Similar to RT #1, analyses of both the combined data and between each of three auditory conditions were also performed on RT #2.

RT #2: Combined Auditory Conditions

The combined data for RT #2 created a two-sample comparison (combined auditory alert conditions, n = 28; no alert, n = 10). Figure 18 provides these mean reaction times.

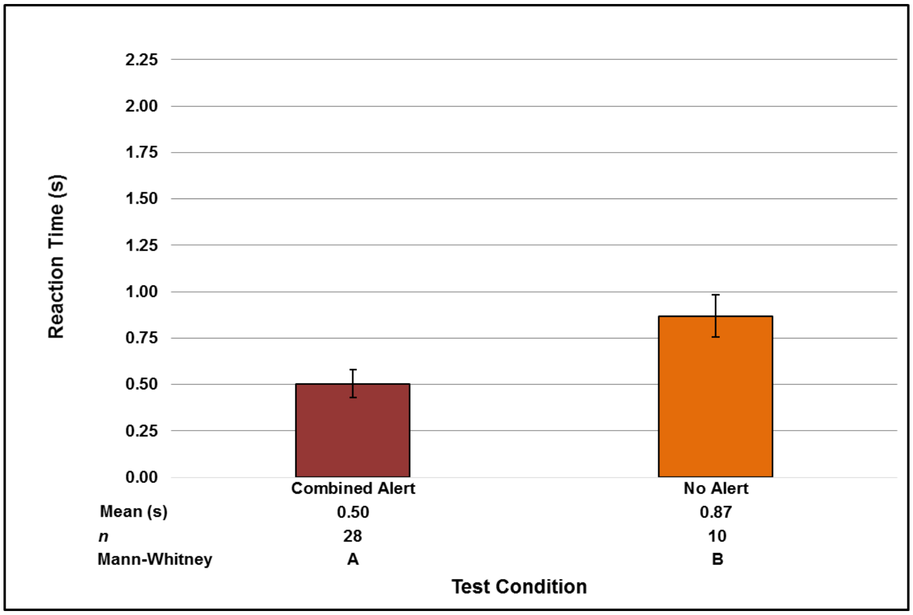

Figure 18. Mean Reaction Times (with Standard Error Bars) from ICW Alert Activation to Initial Deceleration (RT #2 – Throttle Release) for All Auditory Conditions Combined Versus the No Alert Condition

The Mann-Whitney-Wilcoxon test for RT #2 found a significant effect between the no alert condition (M = 0.87, Median = 0.86, SD = 0.36) and the three auditory conditions combined (M = 0.50, Median = 0.37, SD = 0.493); W = 468.0, p = .010. These findings indicate that an ICW alert produces a quicker reaction time for lifting the foot from the throttle.

RT #2: Between All Test Conditions

After examining the data in a combined manner, the data were then analyzed by test condition. Figure 19 provides these mean reaction times.

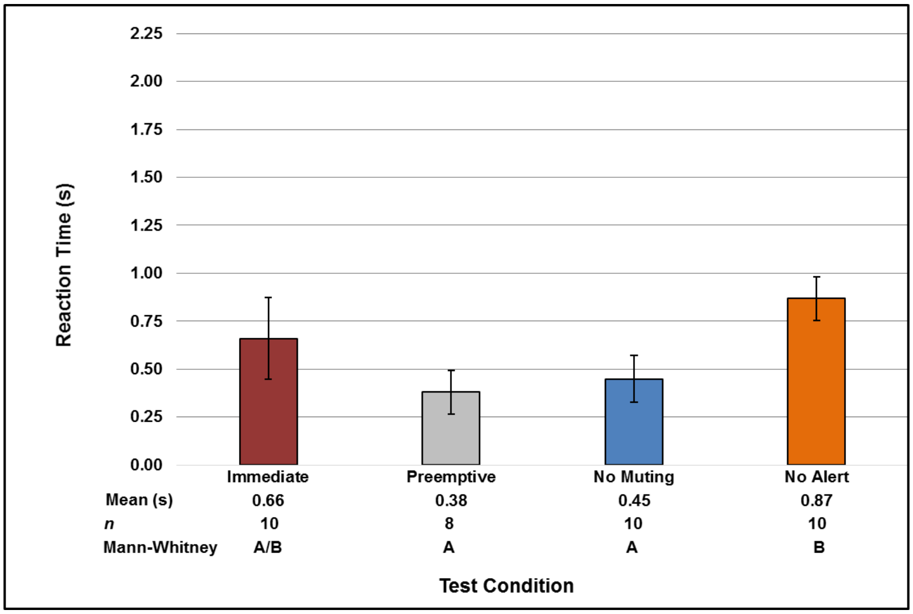

Figure 19. Mean Reaction Times (with Standard Error Bars) for RT #2 – Throttle Release

The Kruskal-Wallis test for RT #2 falls just above the .05 significance level; H(3) = 7.31, p = .063. A post hoc analysis using Mann-Whitney-Wilcoxon tests with a Bonferroni correction comparing each of the auditory conditions individually to the no alert condition was then performed. The Bonferroni correction adjusted the significance level to .017. Significant effects were found between the preemptive muting condition and the no alert condition, as well as between the no muting condition and the no alert condition. These findings indicate that the preemptive muting and no muting conditions produced a quicker reaction time than no alert. The immediate muting condition did not indicate significantly quicker reaction time than the no alert condition; however, this is due to the number of participants that looked at the visual display as their first response. It is important to note that there was no significant difference in reaction times observed between the three auditory alert conditions. Table 13 provides the results of the post hoc analysis.

Table 13. Post Hoc Analysis for RT #2

Test Condition	Significance Test
Immediate versus No Alert	W = 87.0, $p = .186$
Preemptive versus No Alert	W = 48.0, $p = .015$*
No Muting versus No Alert	W = 73.0, $p = .017$*

* significant, $p \leq 0.017$

Reaction Time #3 – Depress Brake

Similar to RT #1 and RT #2, analyses of both the combined data and between each of three auditory conditions were performed on RT #3.

<u>RT #3: Combined Auditory Conditions</u>
The combined data for RT #3 created a two-sample comparison (combined auditory alert conditions, *n* = 28; no alert, *n* = 10). Figure 20 provides these mean reaction times.

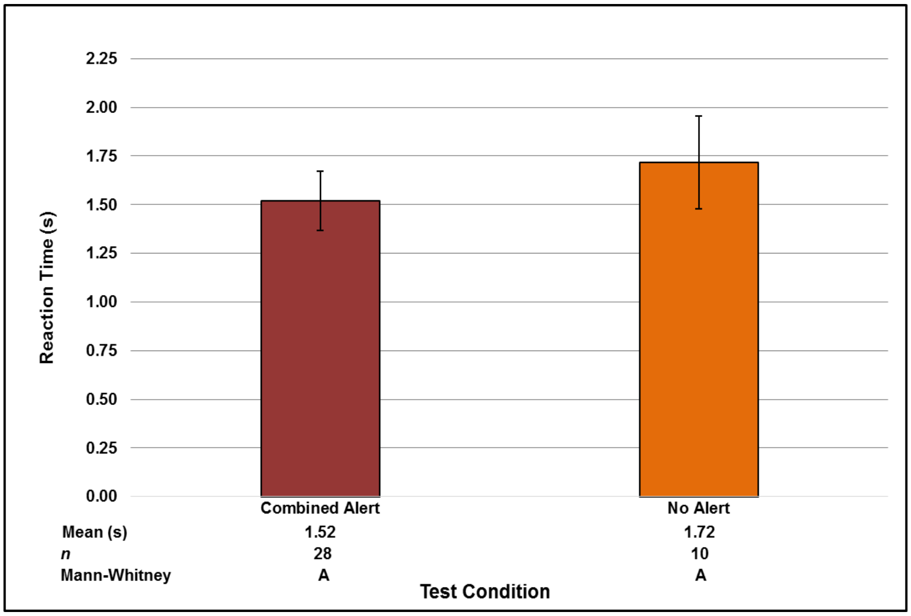

Figure 20. Mean Reaction Times (with Standard Error Bars) for RT #3 – Depress Brake for All Auditory Conditions Combined Versus the No Alert Condition

The Mann-Whitney-Wilcoxon test for RT #3 did not find a significant effect between the no alert condition (M = 1.72, Median = 1.53, SD = 0.75) and the three auditory conditions combined (M = 1.52, Median = 1.34, SD = 0.81); W = 517.0, *p* = .345.

RT #3: Between All Test Conditions

While examining reaction times of RT #3 in a combined manner did not reveal any significance, to maintain consistency the data were still analyzed between each of the three auditory conditions and the no alert condition. An ANOVA was used for this analysis. Figure 21 provides these mean reaction times for RT #3.

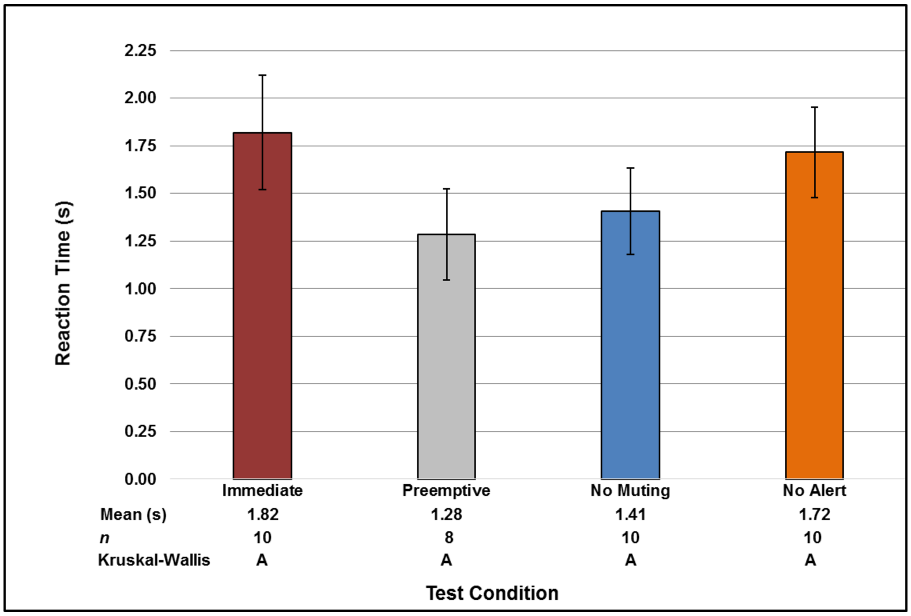

Figure 21. Mean Reaction Times (with Standard Error Bars) for RT #3 – Depress Brake

As expected, based on the analysis of the combined data, the Kruskal-Wallis test for RT #3 did not find a significant effect between any of the conditions, H(3) = 2.61, $p = .455$.

Subjective Assessment

Overview

Subjective data were also collected for each participant on the test trial of interest (braking event). Upon completion of the test trial of interest, the participant was asked to park the truck and complete the secondary consent process before proceeding with the subjective questionnaire (Appendix C). Participants in all test conditions were asked a series of questions. These questions addressed different aspects of the ICW:

- Attention-getting qualities of the alert
- Timing of the alert
- Situational awareness
- Need for the visual alert
- Previous FCW exposure

- Open-ended comments

It should be noted that an analysis of the subjective data included all participants that completed testing. This includes participants who reacted to the alert (i.e., valid test trial used for objective data analysis) and participants who reacted before the alert (i.e., invalid test trials not used for the objective data analysis). The participants that reacted before the alert could still provide a useful assessment with regard to the alert. Moreover, they might represent drivers that could potentially experience an ICW alert as they would react in real life and treat the event as a "nuisance" alert. There are compelling reasons for using this other group of participants that might not have conformed to the operational definition for a valid test trial; therefore, the reader is provided with both sets of results (i.e., reacted to alert, reacted before the alert). Note that no alert (i.e., did not receive alert) participants—and, in some instances, participants in the auditory conditions that reacted before the alert and did not receive the warning—are omitted from questions 1 through 3 given that they did not experience the alert during the event of interest.

Demographics

As mentioned previously, demographics were collected and compiled for all participants ($n = 99$) who completed testing in Experiment 1. The subjective data demographics represent all 99 participants. Across all participants, the mean age was 47.5 years. Ninety-eight participants were male, while one participant was female. All participants had a valid CDL (98 from the state of Virginia and 1 from the state of North Carolina), a valid DOT medical card, and no DOT-reportable accidents within the past year. Table 14 presents demographics for the 99 participants who completed testing while Table 15, Table 16, and Table 17 provide driving and employment demographics.

Table 14. Participant Demographics per Test Condition

Condition	*n*	Male	Female	Mean Age (years)	SD Age (years)	Minimum Age (years)	Maximum Age (years)
Immediate	25	24	1	45.4	14.5	25	76
Preemptive	23	23	0	47.2	12.8	21	69
No Muting	30	30	0	48.5	11.6	21	70
No alert	21	21	0	49.0	12.3	29	72

Table 15. Participant Driving Demographics

Condition	*n*	Mean Experience (years)	SD Experience (years)	Miles/Week	Million Miler (*n*)
Immediate	25	18.5	14.4	1,496	12
Preemptive	23	20.6	12.8	1,275	17
No Muting	30	21.9	11.2	1,593	19
No Alert	21	23.3	15.8	1,665	13

Table 16. Number of Participants per Fleet Operation Classification

Condition	*n*	For-hire Truckload	For-hire LTL	Private
Immediate	25	7	3	15
Preemptive	23	6	5	12
No Muting	30	7	4	17
No Alert	21	6	3	12

Table 17. Number of Participants per Distance Classification

Condition	*n*	Long Haul	Short Haul	Local
Immediate	25	5	14	6
Preemptive	23	4	12	7
No Muting	30	11	10	7
No Alert	21	9	8	4

Attention-getting Qualities of the Alert

The first two questions gathered participant input about the attention-getting effects of the auditory alert and the visual display.

1. How attention-getting is the auditory alert?
2. How attention-getting is the visual alert?

These two questions were answered using a 7-point Likert-type scale (Figure 22) and addressed all test conditions receiving the ICW (i.e., immediate, preemptive, and no muting).

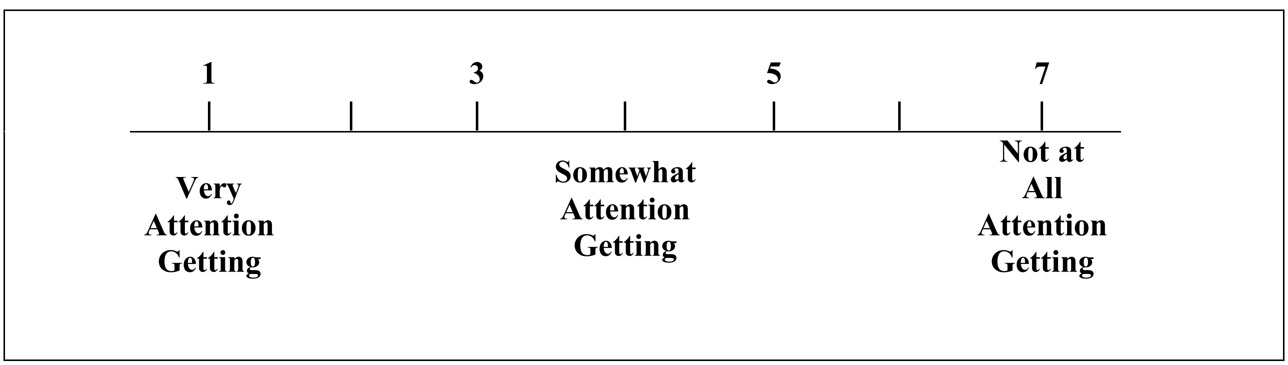

Figure 22. Scale Used to Determine the Attention-getting Quality of the Auditory and Visual ICW Alert

Figure 23 displays the mean participant ratings of the attention-getting effects of both the auditory and visual aspects of the ICW alert. Note that participants from all three auditory conditions were combined.

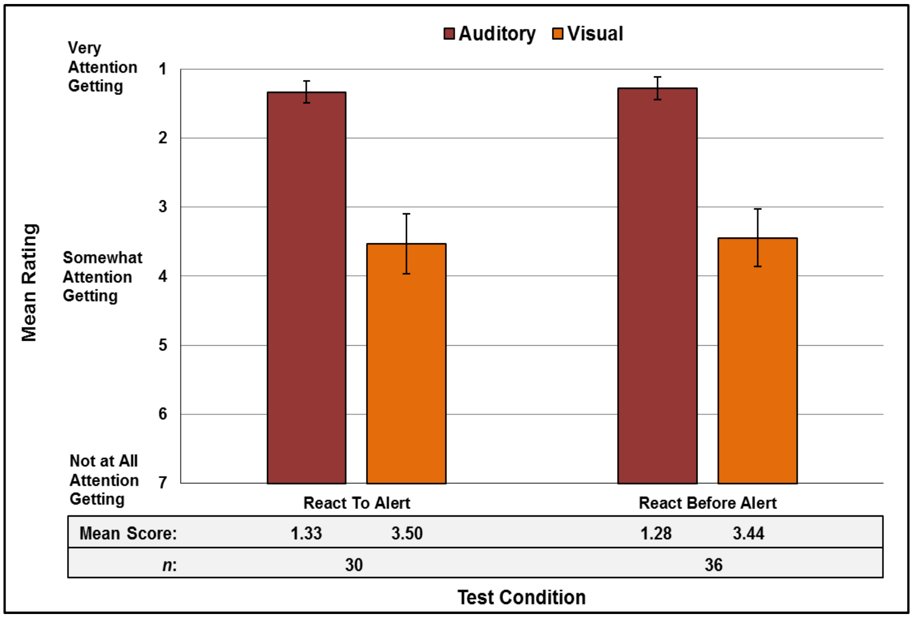

Figure 23. Participant Ratings (with Standard Error Bars) of the Attention-getting Qualities of the ICW Auditory and Visual Alerts (Combined Auditory Conditions)

Participants that reacted to the alert and those that reacted before the alert gave the attention-getting qualities of both the auditory alert and the visual alert similar ratings. Participants that reacted to the alert had a mean rating of 1.33 ("very" attention-getting) for the auditory alert and a mean rating of 3.50 (in the range of "somewhat" attention-getting) for the visual alert. Likewise, participants that reacted before the alert provided mean ratings of 1.28 ("very" attention-getting) for the auditory alert and 3.44 (in the range "somewhat" attention-getting) for the visual alert. To assess if there were any differences in attention-getting ratings between participants that reacted to the alert and participants that reacted before the alert, a *t*-test was conducted. No significant effects were found between participants that reacted to the alert and participants that reacted before the alert in either the auditory attention-getting qualities, $t(63) = -0.24$, $p = .812$, d = .06, or the visual attention-getting qualities, $t(62) = -0.15$, $p = .884$, d = .04.

A further analysis was performed using an ANOVA to assess if there were any differences in participant ratings between each of the three auditory conditions. Since no significant effects were found in the previous analysis assessing the attention-getting qualities between participants that reacted to the alert and participants that reacted before the alert, this subsequent analysis combines both groups of participants. Figure 24 provides the mean ratings of the auditory and visual attention-getting qualities across the three auditory conditions.

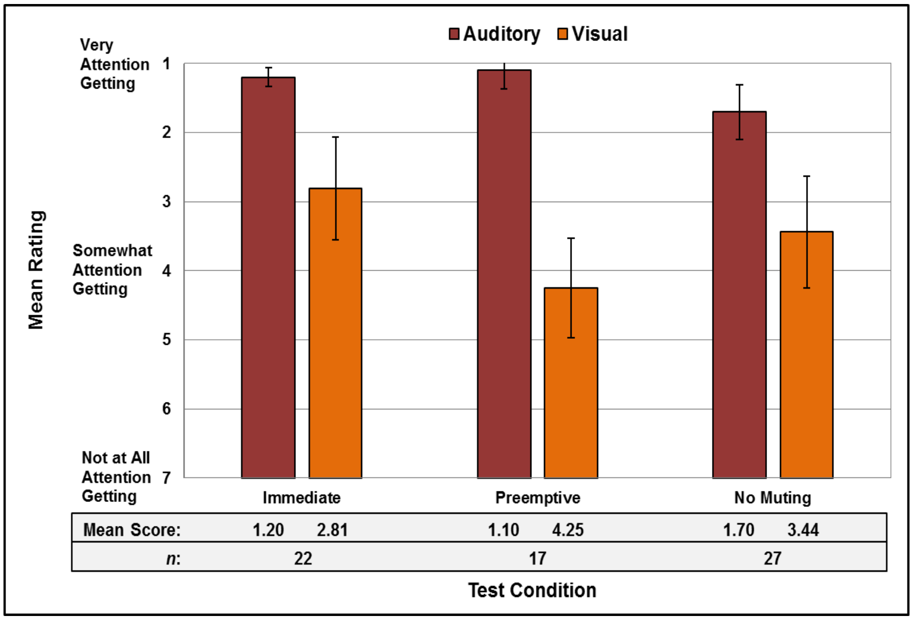

Figure 24. Participant Ratings (with Standard Error Bars) of the Attention-getting Qualities of the ICW Auditory and Visual Alerts (between Auditory Conditions)

The ANOVA did not find any significant effects in participant ratings between the three auditory conditions for either the auditory alert attention-getting qualities, $F(3, 65) = 0.65$, $p = .583$, d = .03, or the visual alert attention-getting qualities, $F(3, 65) = 1.41$, $p = .249$, d = .06.

Timing of the Alert

The third question gathered participant input on the timing of the ICW alert.

3. How appropriate is the timing of the alert?

This question was answered using a 7-point Likert-type scale (Figure 25) and addressed all test conditions receiving the ICW (i.e., immediate, preemptive, and no muting). Participants in the no alert condition and those who did not experience the ICW alert are omitted from this analysis.

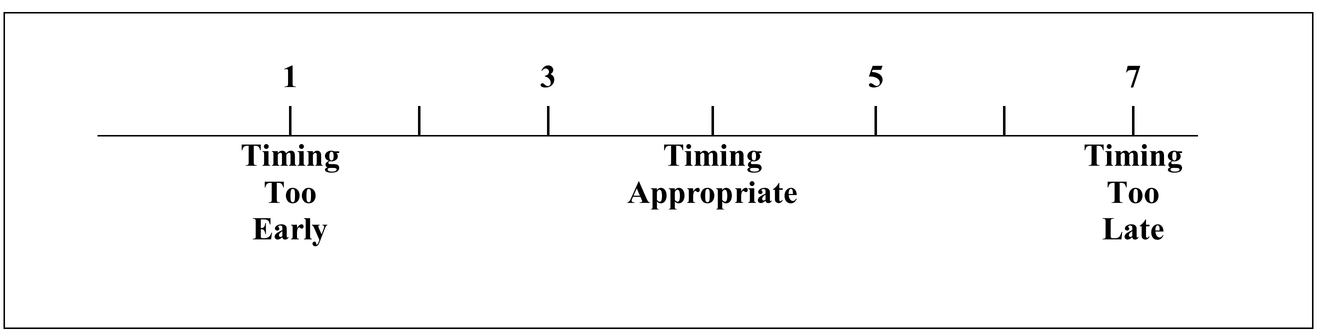

Figure 25. Scale Used to Determine Appropriateness of the ICW Alert Timing

Figure 26 displays the mean participant ratings of the appropriateness of the timing of the ICW alert.

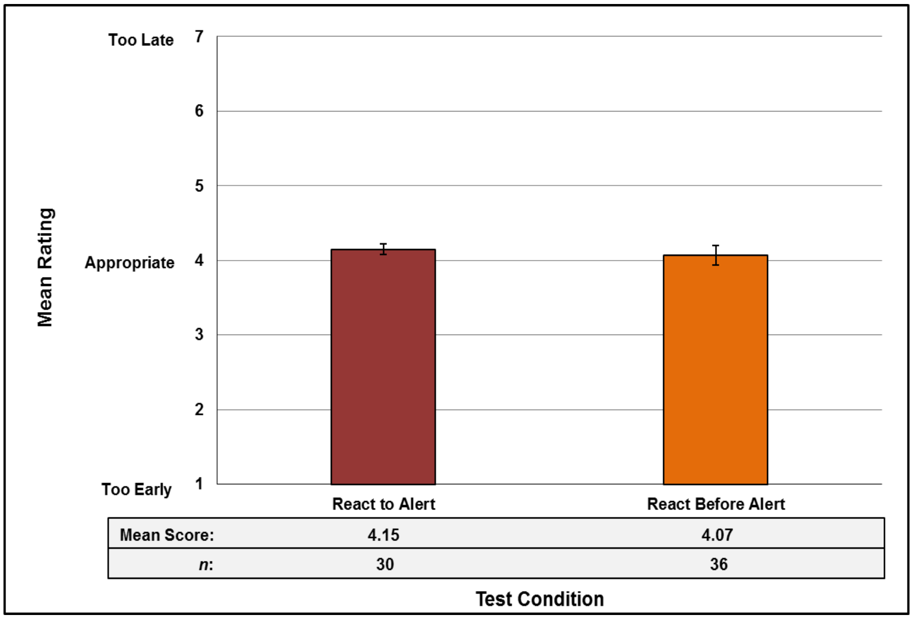

Figure 26. Participant Mean Ratings (with Standard Error Bars) for the Appropriateness of the Timing of the ICW Alert

Similar mean ratings are seen between participants that reacted to the alert (M = 4.15, SE = 0.07) and participants that reacted before the alert (M = 4.07, SE = 0.14). These mean ratings indicate that the timing of the ICW alert is "appropriate." While one can see from the eye test that no significant effect is found between participants that reacted to the alert and participants that reacted before the alert, a *t*-test was performed, $t(52) = -0.52$, $p = .602$, d = .13, to maintain consistency throughout this study.

Situational Awareness

The fourth and fifth questions gathered participant input on their situational awareness while they were performing the secondary task and during the ICW alert activation.

4. Did you see the lead vehicle braking?
5. How quickly did you become aware of what was happening in the event?

Question 4 was answered with a "yes or no" response, while question 5 was answered using a 7-point Likert-type scale (Figure 27). All participants, including the no alert condition participants, provided feedback for these two questions.

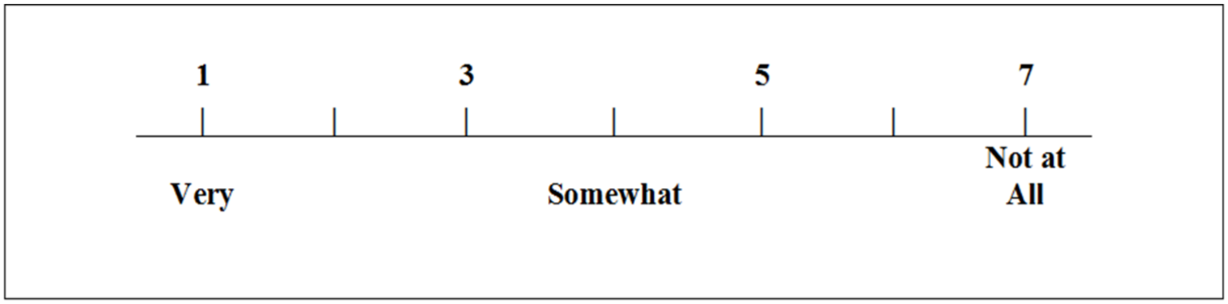

Figure 27. Scale Used to Determine How Quickly the Participant Became Aware of What Was Happening in the Event

For question 4, of the participants that reacted to the alert, 70 percent (21 of 30) did not see the brake lights of the lead vehicle, while only 33 percent (15 of 46) of participants that reacted before the alert did not see the brake lights. It is important to understand that the brake lights of the lead vehicle did not remain on for the duration of this event. The brakes were applied only until the lead vehicle slowed to the desired speed (32 km/h). This braking maneuver lasted approximately 1 s. The lead vehicle then continued at 32 km/h for the remainder of the event.

For question 5, Figure 28 provides the mean ratings with regard to how quickly the participants became aware of what was happening in the event.

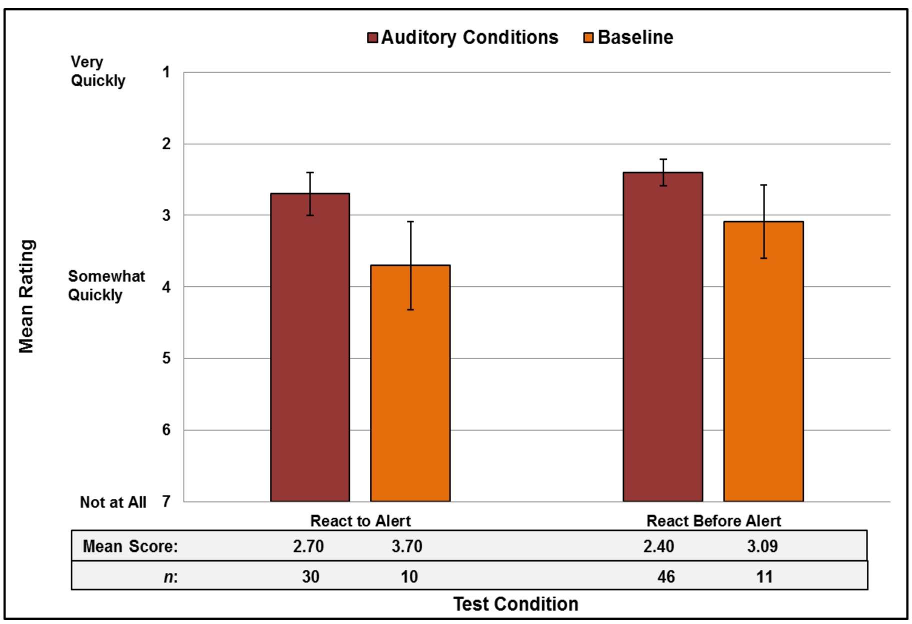

Figure 28. Participant Mean Ratings (with Standard Error Bars) of How Quickly the Participant Became Aware of What Was Happening in the Event

Participants in the three auditory conditions that reacted to the alert (M = 2.70, SE = 0.30) and reacted before the alert (M = 2.40, SE = 0.18) provided similar ratings. Note that these participants are compared against the no alert condition in Figure 28. Likewise, participants in the no alert condition who reacted after the 3-s TTC (M = 3.70, SE = 0.62) and reacted before the 3-s TTC (M = 3.09, SE = 0.51) also provided similar ratings. A *t*-test was performed to assess if any significance was found between the auditory conditions and the no alert condition.

- Reacted to the alert versus no alert (after 3-s TTC): $t(13) = 1.46$, $p = .167$, d= .56
- Reacted before the alert versus no alert (before 3-s TTC): $t(12) = 1.26$, $p = .230$, d = .46

No significant effects were found between participants who experienced the ICW alert and the no alert condition (i.e., did not receive an ICW alert). This holds true for participants that reacted to the alert (no alert equals = after 3-s TTC) and those that reacted before the alert (no alert = before 3-s TTC).

Need for a Visual Alert

The sixth question gathered participant input on the need for the visual aspect of the ICW alert.

6. Do you feel that a visual alert is needed?

This question was answered with a "yes or no" response. Note that participants in the no alert condition are omitted from this question as they did not experience the alert.

Of the participants that reacted to the alert, 73 percent (22 of 30) felt that a visual alert is necessary. Similarly, of the participants that reacted before the alert, 67 percent (24 of 36) also felt that a visual alert is necessary.

Prior FCW Exposure

The seventh question gathered participant input on any prior experience with an FCW in a heavy vehicle.

7. Have you previously driven a heavy vehicle equipped with a forward collision warning system?

This question was answered with a "yes or no" response. Participants responding with a "yes" then provided the name of the system. In some cases, participants could not remember the brand of FCW system they had previously experienced. Note that participants in the no alert condition are omitted.

Four out of the 30 (13%) participants who reacted to the alert had previously experienced an FCW system in a heavy vehicle, while 11 out of the 46 (24%) participants that reacted before the alert had previously experienced an FCW system in a heavy vehicle.

Open-ended Comments

Participants were shown the visual alert and listened to the auditory alert again while the truck was parked. Participants were then given the opportunity to provide open-ended comments about the different aspects of the visual alert and the auditory alert, such as:

- Size of the visual image
- Background color

- Text color
- Car/truck image color
- Loudness of the auditory alert
- Duration of the auditory alert
- Type of sound used

Participant responses were categorized and then descriptive statistics were calculated. Note that this includes all participants.

When responding about the visual alert, 72 percent (68 of 94) felt the size of the visual image was appropriate. However, 25 participants (27%) stated that the size of the visual alert was too small, while one participant stated that it was too big. Interestingly, several of these participants mentioned it should be the size of the entire display. When it comes to the background color, 96 percent (90 of 94) felt the background color of red is the correct color to use. An important side note—perhaps not surprisingly—is that 18 of these participants stated that red means stop, danger, and/or warning. Similarly, 89 percent (84 of 94) felt the text color of white was good as it contrasts very well with the red background. Also, 88 percent (82 of 93, one participant did not respond) felt the black color used for the images of the car and truck was appropriate. Several additional comments of interest were provided by more than one participant: (1) make the visual alert flash, (2) have the visual stay on until greater than 3-s TTC, and (3) move the visual to a different location (responses ranged from A-pillar to center stack).

When responding about the auditory alert, 80 percent (76 of 94) felt the duration of the auditory alert was sufficient. However, 17 participants felt the duration of the auditory alert was too short. As for the loudness of the auditory alert, 78 percent (73 of 94) felt it was appropriate. Fourteen participants did, however, state that it was not loud enough. Interestingly, five participants stated that the auditory alert should override the radio. These five participants all experienced the no-muting test condition where the auditory alert played over top of the radio. The auditory alert sound was reported by 92 percent (86 of 93, one participant did not respond) as appropriate. Similar to the visual alert, a number of participants commented that the auditory alert should continue playing until the TTC is greater than 3 s.

Experiment 1 Discussion

Research Question #1 (Experiment 1): In terms of reaction time, is there a benefit to muting secondary audio sources during an imminent collision warning (ICW) alert?

Experiment 1 was conducted to study the auditory component of an ICW for a rear-end event. An ICW was designed following Campbell et al. (2007) guidelines. A scenario was developed where CMV drivers were following a lead vehicle and, as they became distracted with a secondary task, the lead vehicle started to decelerate to trigger the ICW. The test conditions of interest for this experiment were:

- Immediate muting
- Preemptive muting

- No muting
- No alert (i.e., baseline)

The results for this research effort consider three aspects in the evaluation of an ICW: (1) first response, (2) reaction time, and (3) subjective assessment.

First Response

An aspect that was considered important for this evaluation was the response that the ICW elicits. The first response to the ICW alert was categorized in one of three ways: (1) look to the forward roadway, (2) look to the visual alert/IP, or (3) lift foot from the throttle. It should be noted that the initial DAS did not include a camera on top of the display (subsequent experiments included this camera). Therefore, any glance toward the IP was counted as a look to the visual display.

After the ICW alert was presented, looking towards the roadway was the first response for the majority (79 percent) of the participants. That reaction was followed by lifting the foot from the throttle (86 percent) as their second most common response. Almost half the participants (50%) looked at the IP at some point during the braking event. See Figure 29 for more details about responses.

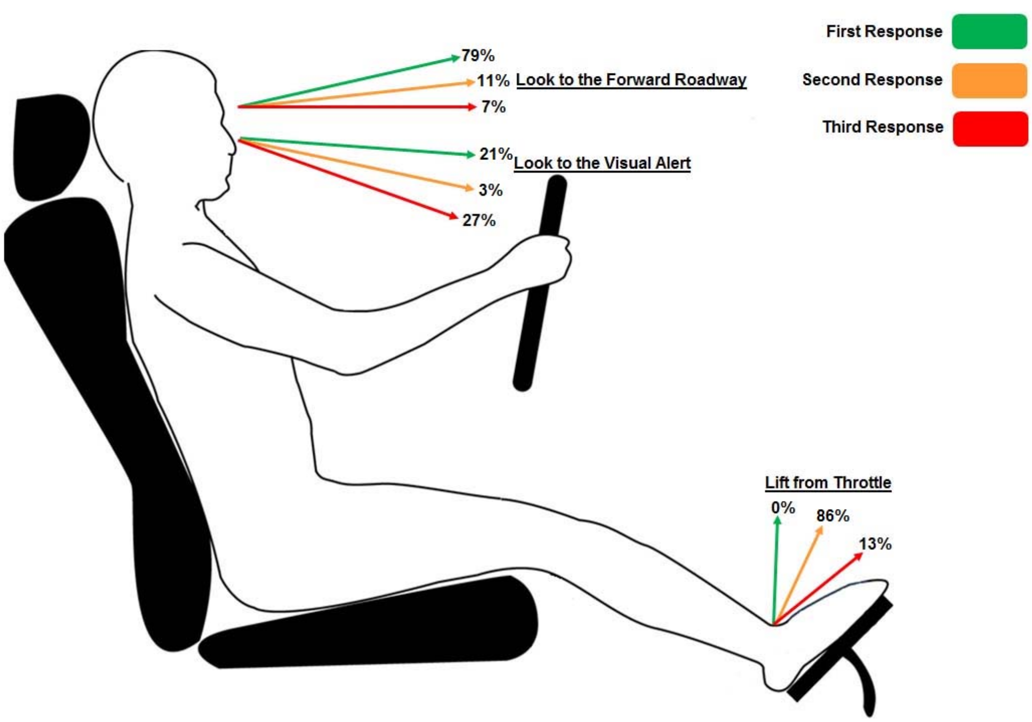

Figure 29. Percentage of Participant Responses per Location

Reaction Time

As previously discussed, an ICW could elicit multiple reactions (e.g., look forward). In addition to the type of reaction, the timing for the reaction is of interest. This study looked at three different reaction times: (1) Look Forward, (2) Throttle Release, and (3) Depress Brake. The first reaction of most of the drivers (79 percent) was looking to the forward roadway. This was done on average within 0.19 s of the point in time when ICW was presented when taking into consideration and removing the five participants that looked to the visual alert as their first response. However, when the ICW was presented without muting the music (loud enough where masking is not an issue, but not too loud to startle the participant) the shortest mean reaction time (0.10 s) was observed. One of the findings in this portion of the analysis is that when other audio sources are muted, in some instances, it tends to attract the participant's attention away from the forward roadway. It could be hypothesized that the driver might think something is happening with the vehicle and try to look towards the IP or radio console areas to check for potential reasons why the audio source could have stopped.

Drivers that were presented with an ICW during the potential rear-end event were able to start releasing the throttle, on average, 0.37 s (43 percent) quicker than the drivers that did not receive an alert. In particular, drivers during the preemptive muting and no-muting test conditions were able to react quicker than when no alert was presented, with reaction times of 0.38 s (56 percent quicker) and 0.45 s (48 percent quicker), respectively. On average, once the ICW was presented, drivers started braking within 1.52 s. However, this was not statistically different from the no alert condition (1.72 s). As part of the Integrated Vehicle-Based Safety System (IVBSS) FOT, Bao et al. (2012) observed very similar brake reaction times (1.62 s) for CMV drivers receiving an ICW alert. However, their reaction time was statistically different from the no alert condition for CMV drivers (1.88 s). Potentially, the higher reaction times during the no alert for Bao et al. could be due to other external factors that the drivers were taking into consideration as they evaluated the rear-end events that were evolving (e.g., weather, roadway type, trailer load, perceived urgency). Moreover, it is known that alert drivers overestimate their headway (Taieb-Maimon and Shinar, 2001). Depending on the conditions, drivers might have believed they had more time to brake, whereas in the current research effort it was evident that immediate action was required once they glanced back to the roadway. Bao et al. (2012) do not describe the throttle response in order to compare the time the CMV drivers noticed the potential threat and when they decided to start reacting. If drivers were engaged in more distracting tasks, that could potentially account for the increased reaction time. For the current study, the distraction tasks were moderate.

Subjective Assessment

Overall, all drivers that experienced an ICW during the study provided a positive assessment. The ICW was considered attention-getting. The auditory component of the alert was the portion of the alert that was rated with the highest impact on capturing the driver's attention. However, the visual component was indicated to be important by 70 percent of the drivers. An auditory alert of a 1.10-s duration and 87 dB (15 dB above the cabin noise plus music level) were deemed fitting for the condition tested. In terms of the ICW's timing, the ICW at 3-s TTC was deemed appropriate. An overwhelming majority supported the use of a red background to elicit a high-urgency mental model in the context in which it was evaluated (e.g., stop, danger). In addition, the selected icon, with an image size of 47.625 mm × 47.625 mm, and the level of contrast were deemed appropriate by the majority of the participants.

Experiment 1 Conclusion

This first experiment suggests that an ICW will enhance reaction time. The first initial response to the alert was to look forward, which is the desired effect in the case of a distracted driver that is about to encounter a potential rear-end event. The second most prevalent response was to release the throttle. When evaluating the effect of the ICW during that period of time (i.e., from event time until the throttle is released), the drivers that had an ICW were able to enhance their reaction time by over 40 percent. Drivers had an overwhelmingly positive response to the alert. However, contrary to what would have been expected, muting other audio sources did not significantly enhance reaction time. On the contrary, in some instances muting delayed the reaction times of interest due to the driver looking at the IP area before looking forward. Therefore, if a simpler implementation of the auditory component of the alert is feasible, there is no need to mute other sources of noise. This statement assumes that a 15-dbA difference is maintained between the noise source and the ICW. Subsequent experiments will implement the ICW without muting the additional audio sources (i.e., music).

This research effort evaluated only driver performance and subjective assessment when the ICW was presented during a real rear-end potential conflict (i.e., no false alarms). If the false alarm rate increases, this could potentially impact the drivers' subjective assessment as well as their reaction times.

CHAPTER 4. EFFECT OF AN IN-CAB VISUAL DISPLAY OF AN ICW ALERT

OVERVIEW

The purpose of this experiment was to examine two aspects relating to the visual component of an ICW alert. The first aspect examined the effect of display complexity. Processing visual information takes time; therefore, presenting a crash warning message in the most parsimonious manner possible could lead to greater performance of the human-machine system. The second aspect examined an ICW alert that presented only an auditory warning (i.e., no visual alert). Similar to examining a simple visual alert versus one displaying more complex information, the no visual alert (i.e., auditory alert only) was examined to determine if this could lead to greater performance of the human-machine system when compared to those who received the visual alert along with the auditory alert. The findings of this study inform the benefit (or lack thereof) of recommending no visual alert, a simpler visual ICW display, or a more complex ICW display that provides additional information to the driver.

Research Question #2 (Experiment 2): In terms of reaction time, is there a benefit to providing drivers a simpler visual ICW alert (providing minimal information) over a more complex ICW alert (providing more in-depth information), or is having no visual alert the most effective method?

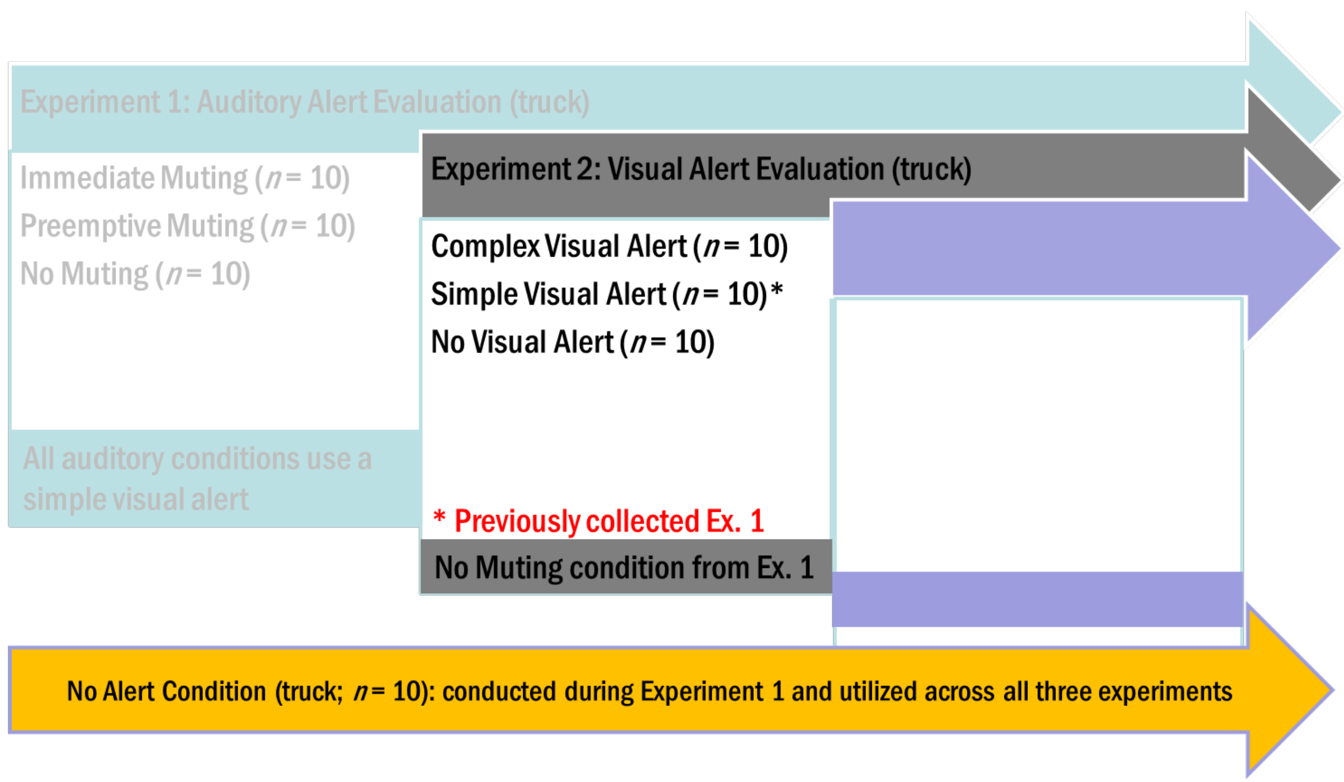

Figure 30. Experiment 2 Design Focus

EXPERIMENTAL METHOD

Participants

A total of 20 participants with valid test trials were needed to complete testing in Experiment 2. This experiment also used data collected previously in Experiment 1. The screening and eligibility requirements were identical to Experiment 1 (see Chapter 3).

Apparatus

2007 Freightliner Cascadia & Utility Trailer

A 2007 Freightliner Cascadia pulling a 2007 Utility 4000D-X 53-ft. dry van trailer (described in Experiment 1, Chapter 3) was used for this experiment. The vehicle configuration was identical to the configuration in Experiment 1.

Data Acquisition System

The DAS configuration and installation from Experiment 1 was used for Experiment 2. Additional modifications to the DAS were needed to add a sixth camera view (Figure 31) to allow more in-depth eye-glance analysis of the drivers' response to the visual alert.

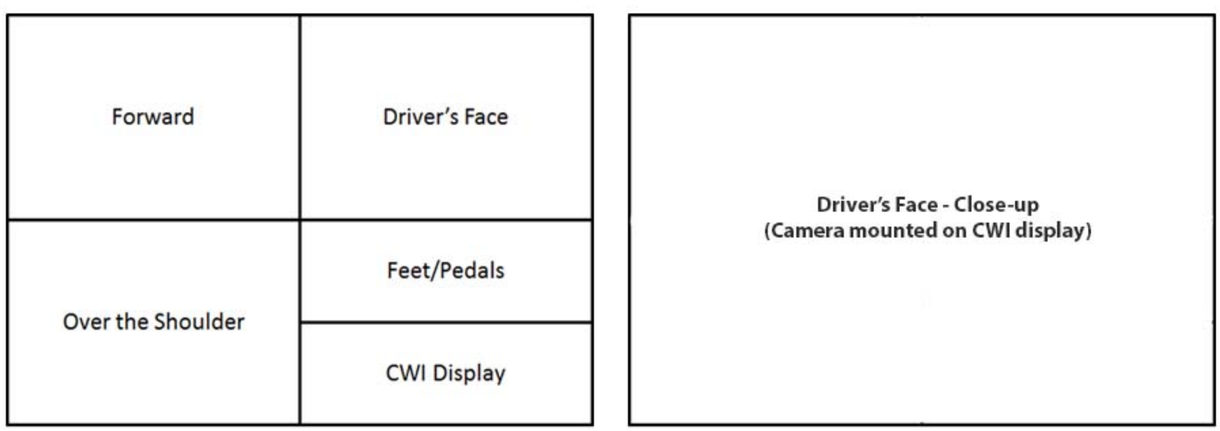

Figure 31. Video Layout as Recorded by the DAS for Experiment 2

Collision Warning Interface

The same experimental CWI developed for Experiment 1 was used for this experiment. Just as in Experiment 1, the CWI in Experiment 2 triggered an auditory alert. However, Experiment 2 examined the visual aspect of the alert rather than the auditory aspect. Experiment 2 displayed a more complex visual alert (Figure 32) simultaneously with the auditory alert and provided more visual information, or no visual alert at all (only auditory alert). Note that the secondary audio (i.e., music) used in Experiment 1 was presented during this experiment at the same levels. Based on the results from Experiment 1, the secondary audio (i.e., music) was not muted when the three ICW alert conditions were presented during Experiment 2 human performance testing (i.e., auditory component of the alert played at 15 dB over cabin noise level and only the visual component was varied). The participants experiencing the simple visual alert were obtained during Experiment 1 testing. Therefore, there was no need to rerun this condition. The data from that between-subjects portion of the previous study were used again for the current experiment.

Figure 32. ICW Visual Alert for Experiment 2 (Image to Scale)

Experimental Conditions

All experimental scenarios occurred on the Virginia Smart Road, as described in Experiment 1. For these scenarios, only the subject vehicle and relevant confederate vehicles were present on the test track.

Four different test conditions were used for this experiment, with each participant experiencing only one test condition (i.e., between-subjects design). These test conditions assessed the effect of display complexity or no visual display at all on reaction time to an ICW alert. Test condition C was the condition with a simple visual display alert while test condition E provided a more complex visual display alert. Test condition F did not present a visual alert (i.e., auditory-only alert) while test condition D was the no alert condition containing neither an auditory nor visual alert. Table 18 provides a description of each test condition.

Table 18. Experiment 2 Test Conditions

Condition	Visual Alert	Alert Definition
D	No Alert*	No alert presented
C	Simple*	Simple visual with auditory alert, cabin sound not muted
E	Complex	More complex visual with auditory alert, cabin sound not muted
F	No Visual Alert	No visual, only auditory alert, cabin sound not muted

* Obtained from Experiment 1

Experimental Design

Similar to Experiment 1, Experiment 2 was a between-subjects design with a single-exposure surprise event. All participants experienced the same six test trials as in Experiment 1. These test trials were the same across all test conditions and were always conducted in the same order. Each test trial was one full length of the test track. A full description of the six test trials is provided in Table 6.

Experimental Procedure

The procedures for this experiment were identical to the procedures in Experiment 1.

Dependent Variables

Objective

The objective DVs for this experiment are the participants' first response when the ICW is activated and the participants' reaction times at three distinct points in time. The first response DV is analyzed through video reduction and eye-glance analysis, while the reaction times are calculated based on the timing of the ICW alert activation and the participant's first look to the forward roadway, the participant's foot first lifting from the throttle, and the participant first depressing the brake pedal. For the purposes of the objective dependent variables, only participants with valid test trials were analyzed.

Subjective

Participants' subjective feedback on task performance and the ICW alert were also assessed via questionnaires. Participants provided ratings using a 7-point Likert-type scale. Additionally, several questions gathered "yes/no" responses. Open-ended responses were also collected with regard to the auditory and visual components of the ICW alert. The subjective feedback was collected from all participants regardless of whether they had valid or invalid test trials.

EXPERIMENT 2 RESULTS

Overview

The following sections present the results for Experiment 2. Results, including participant demographics, are presented along with a brief discussion.

As noted in Chapter 2, three research questions were developed to address the scope of this study. Experiment 2 addressed Research Question #2.

Research Question #2 (Experiment 2): In terms of reaction time, is there a benefit to providing drivers a simpler visual ICW alert (providing minimal information) over a more complex ICW alert (providing more in-depth information), or is having no visual alert the most effective method?

Experiment 2 evaluated the visual alert component of an ICW of an HV-CWI using a Class-8 truck-trailer combination unit. This experiment focused on the effects of visual display complexity, or lack thereof, on driver performance when responding to an ICW and assessed the difference in reaction times, if any, of an ICW visual alert of an HV-CWI.

Experimental Test Trials

Forty-one participants were needed to obtain the 20 valid (react to the alert) test trials required to complete Experiment 2 (i.e., distracted while the event of interest evolved and depressing the throttle). This accounts for the 49% rate of valid test trials, which is consistent with the results encountered during Experiment 1. As described previously in the Experiment 1 results chapter, while the finalized testing protocol was designed to maximize the number of valid test trials, a high number of invalid (react before the alert) test trials (51%) still occurred throughout testing. A detailed explanation for this occurrence was provided earlier in Chapter 3.

Human Performance Testing

Overview

Similar to Experiment 1, data recorded by the DAS installed in the test vehicle were analyzed in a manner allowing for simultaneous and time-synchronized viewing of the vehicle and experimental apparatus data along with the video stream. Two primary measures of interest were analyzed for each participant during test trial 6 (this event contained the FCW event). It is important to understand that all participants were naïve to this study (i.e., did not know an FCW system was installed in the subject vehicle) and received no prior training on either the visual alert or auditory alert. This was to ensure all participants would remain unbiased and not assume the lead vehicle was going to perform a hard-braking maneuver. Also, this is representative of fleets randomly assigning drivers to their fleet vehicles without informing the driver that the vehicle is equipped with a CWS or providing any training on CWSs.

The first measure of interest was DV #1 (first response). The first response to the ICW alert was categorized in one of three ways: (1) look to the forward roadway, (2) look to the visual alert, or (3) lift foot from the throttle. An additional camera was added to the DAS for Experiment 2 and Experiment 3 to allow for more exact eye-glance analysis (i.e., to determine if participant looked to the visual component of the alert).

The second measure of interest was DV #2 (reaction times). Data collected from four different points in time for each participant were used during the current analyses. The first point in time recorded was when the ICW alert was triggered. Note that participants in the no alert condition (no alert) did not receive the ICW alert. Therefore, the 3.0-s TTC was used as the trigger. The second point in time recorded was when the participant first glanced to the forward roadway. The third point in time recorded was when the participant first lifted his/her foot off the throttle. The fourth point in time recorded was when the participant depressed the brake pedal.

Similar to Experiment 1, Experiment 2 used the same four recorded points in time and three different reaction times in the analyses. Refer to Figure 13 for these four recorded points in time and three reaction times.

Demographics

Demographics were collected and compiled for all participants tested in Experiment 2. These demographics also include the simple and no alert conditions collected previously in Experiment 1. For the objective data results, only demographics of those participants with valid test trials (i.e., participants that reacted to the alert) are presented in the tables below. Table 19 presents demographics (per test condition) of the 40 completed participants with valid test data. Across all participants, the mean age was 49 years. Thirty-nine participants were male while one participant was female. All participants had a valid CDL (34 from the state of Virginia, 5 from the state of West Virginia, and 1 from the state of North Carolina), a valid DOT medical card, and no DOT-reportable crashes within the past year.

Table 19. Participant Demographics per Test Condition

Condition	*n*	Male	Female	Mean Age (years)	SD Age (years)	Minimum Age (years)	Maximum Age (years)
Simple Visual	10	10	0	46.3	15.0	21	62
Complex Visual	10	10	0	52.1	10.6	33	72
No Visual Alert	10	9	1	50.1	13.7	27	74
No Alert	10	10	0	48.8	13.1	29	67

During Experiment 2, additional driving and employment demographics were collected from each participant. Driving demographics include years of CMV driving experience, average mileage driven per week, and million-miler status. Employment demographics include the type of fleet operation and distance classification. Operational definitions were provided previously in the Chapter 3 demographics section. Table 20, Table 21, and Table 22 provide these demographics for participants with valid test trials.

Table 20. Participant Driving Demographics

Condition	*n*	Mean Experience (years)	SD Experience (years)	Miles/Week	Million Miler (*n*)
Simple Visual	10	22.5	12.1	1,579	6
Complex Visual	10	25.1	11.3	1,656	8
No Visual Alert	10	14.5	15.7	1,705	4
No Alert	10	23.8	17.4	2,244	6

Table 21. Number of Participants per Fleet Operation Classification

Condition	*n*	For-hire Truckload	For-hire LTL	Private
Simple Visual	10	1	3	6
Complex Visual	10	2	1	7
No Visual Alert	10	3	2	5
No Alert	10	3	2	5

Table 22. Number of Participants per Distance Classification

Condition	*n*	Long Haul	Short Haul	Local
Simple Visual	10	4	3	3
Complex Visual	10	2	8	0
No Visual Alert	10	2	4	4
No Alert	10	5	4	1

Diagnostic Assessment

Diagnostic assessments were again performed with Experiment 2 to determine the normality of the data, determine if any outliers were present, and if so, how those outliers affect the reaction times. The same process was applied as used in Experiment 1 and subsequent analyses were based on these results.

First Response to Alert

Video reduction was performed on the Experiment 2 data set to assess each participant's first response to the ICW alert being activated. It should be noted that this analysis only includes those participants that received the visual alert component in addition to the auditory alert component (i.e., simple and complex conditions). A separate assessment was conducted on the no visual alert (i.e., auditory-only alert) to determine if any of these participants glanced to the IP during ICW alert activation. Again, keep in mind that the response of looking to the visual alert may not sum to 100 percent due to some participants not looking to the visual alert component.

The majority (17 of 20; 85%) of the participants' first response was to look to the forward roadway when the ICW alert was presented. Additionally, the second and third response of each participant were also assessed. Following the participants' first response to the ICW alert activation, the majority of participants (19 of 20; 95%) then lifted their foot from the throttle as their second response. The eye glance of the one participant who did not lift his/her foot from the throttle as the second response went from the ICW visual alert to the forward roadway. Additionally, 40 percent (8 of 20) of the participants did look at the IP at some point during the braking event (i.e., first, second, or third response). Note that not all participants performed a third response (i.e., 12 participants did not glance to the visual alert during the ICW alert presentation).

Additionally, video reduction was also performed on the no visual alert condition to confirm if any participants glanced to the IP during the ICW alert activation. No participants glanced to the IP as their first, second, or third response. All participants (10 of 10; 100%) glanced to the forward roadway as their first response and lifted their foot from the throttle as their second response.

Reaction Time #1 – Look Forward

Two analyses were performed on the data for this reaction time. The initial analysis that was performed combined all data from the three different alert conditions (i.e., no visual, simple, and complex) and compared this combined value against the results for the no alert condition. This comparison assists with the process of identifying if ICW alerts (in general) produce a quicker reaction than conditions with no alert. The second analysis that was performed compared the data between test conditions.

RT #1: Combined Visual Conditions

This analysis was performed with the data from each of the three auditory alert conditions combined. The combined data created a two-sample comparison (combined auditory alert conditions, *n* = 30; no alert, *n* = 10). Figure 33 provides the mean reaction times for RT #1.

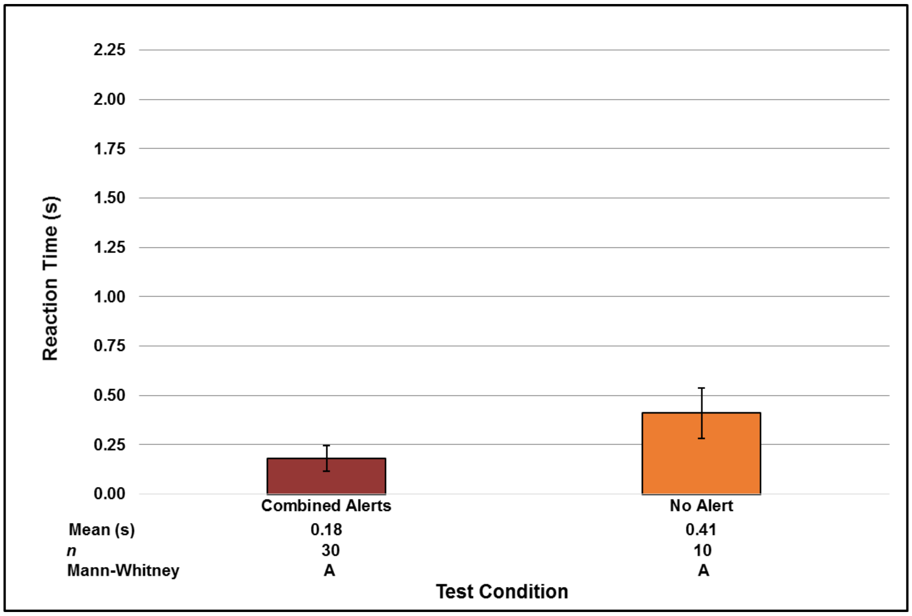

Figure 33. Mean Reaction Times (with Standard Error Bars) from ICW Alert Activation to First Glance to the Forward Roadway (RT #1 – Look Forward) for all Visual Alert Conditions Combined Versus the No Alert Condition

The Mann-Whitney-Wilcoxon test for RT #1 found a significant effect between the no alert condition (M = 0.41, SD = 0.40) and the three visual alert conditions combined (M = 0.18, SD = 0.35); W = 533.5, *p* = .007. This finding indicates that participants receiving an ICW alert had a significantly quicker reaction time looking forward than participants that did not receive an ICW alert. It is important to note that this reaction time is directly linked to the participant's first response (i.e., look to the forward roadway, look to the visual display, or lift foot from the throttle). Looking back, we see that RT #1 in Experiment 1 contained six participants that looked to the visual alert as their first response, while in Experiment 2 only three participants looked to the visual alert as their first response. However, one of the three test conditions receiving the ICW alert was the no visual condition (i.e., did not contain a visual alert component). This results in the lower RT #1 in Experiment 2.

RT #1: Between All Test Conditions

Further analysis was conducted between test conditions with participants that looked to the visual alert as their first response removed. Figure 34 provides these mean reaction times.

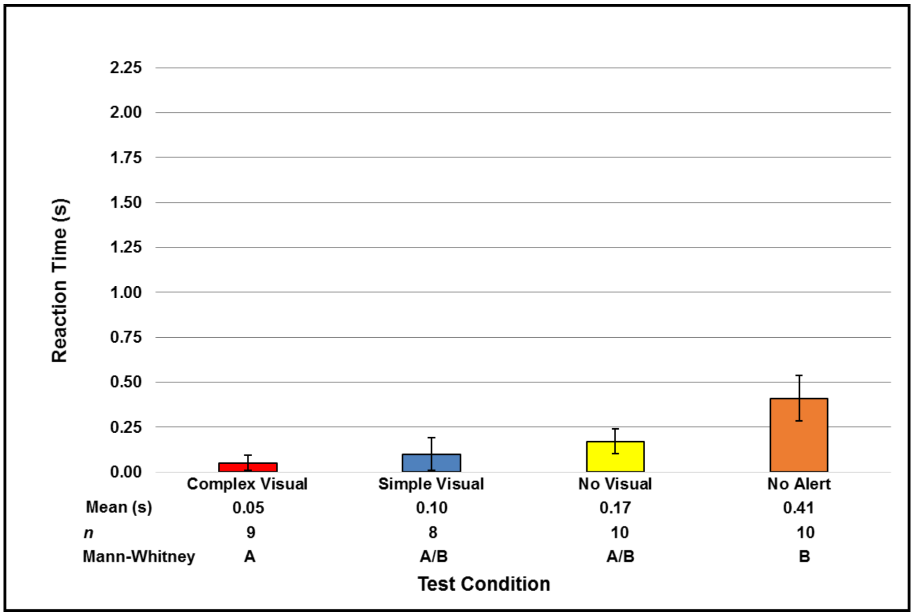

Figure 34. Mean Reaction Times (with Standard Error Bars) for RT #1

The Kruskal-Wallis test was significant for RT #1; H(3) = 13.82, $p = .003$. A post hoc analysis using Mann-Whitney-Wilcoxon tests with a Bonferroni correction comparing each of the alert conditions individually to the no alert condition was then performed. The Bonferroni correction adjusted the significance level to .017. Significant effects were found between the simple visual alert and the no alert condition as well as between the complex visual alert and no alert condition. These findings indicate that both the simple and complex visual alert conditions produced a significantly quicker look forward reaction than the no alert condition. However, it is important to remember that these reaction times rely on the participant's first response to the ICW alert (combined auditory and visual alerts), which can influence their look forward reaction time. Additionally, no significant difference was found between the three alert conditions. Table 23 provides the results of the post hoc analysis.

Table 23. Post Hoc Analysis

Test Condition	Significance Test
Complex Visual versus No Alert	W = 55.0, $p = .003$*
Simple Visual versus No Alert	W = 57.5, $p = .007$*
No Visual versus No Alert	W = 83.0, $p = .102$

* significant, $p \leq 0.017$

Reaction Time #2 – Throttle Release

Similar to RT #1, analyses of both the combined data and between each of three visual alert conditions were also performed on RT #2.

RT #2: Combined Visual Conditions

This analysis was performed with the data from each of the three visual alert conditions combined. The combined data created a two-sample comparison (combined visual alert conditions, *n* = 30; no alert, *n* = 10). Figure 35 provides the mean reaction times for RT #2.

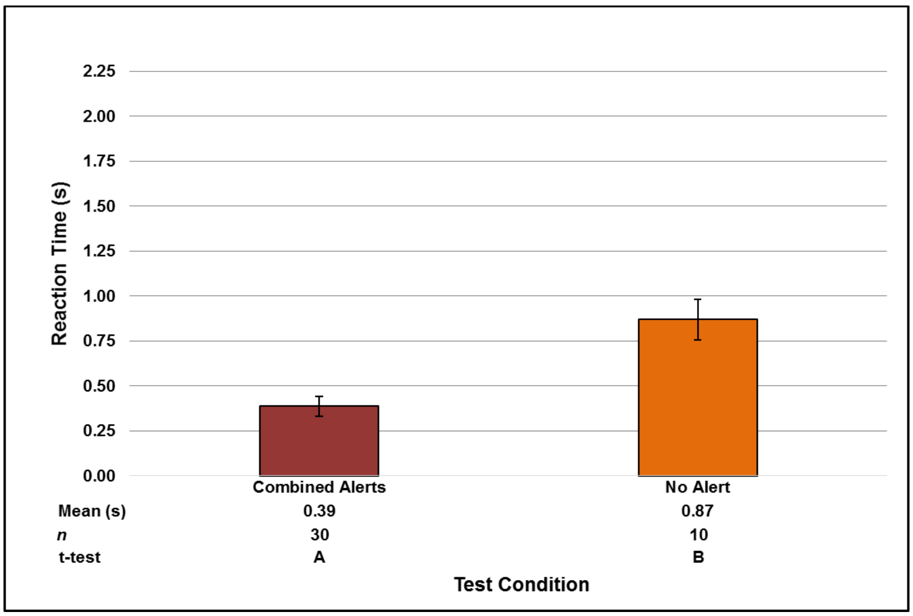

Figure 35. Mean Reaction Times (with Standard Error Bars) from ICW Alert Activation to Initial Deceleration (RT #2 – Throttle Release) for all Visual Conditions Combined Versus the No Alert Condition

This *t*-test for RT #2 found a significant effect between the no alert condition (M = 0.87, SD = 0.36) and the three visual conditions (M = 0.39, SD = 0.30); $t(13) = 3.83$, $p = .002$; d = 1.46. These findings indicate that an ICW alert produces a quicker reaction time when first lifting the foot from the throttle.

RT #2: Between All Test Conditions
After examining the data in a combined manner, the data were then analyzed by test condition using an ANOVA. Figure 36 provides these mean reaction times.

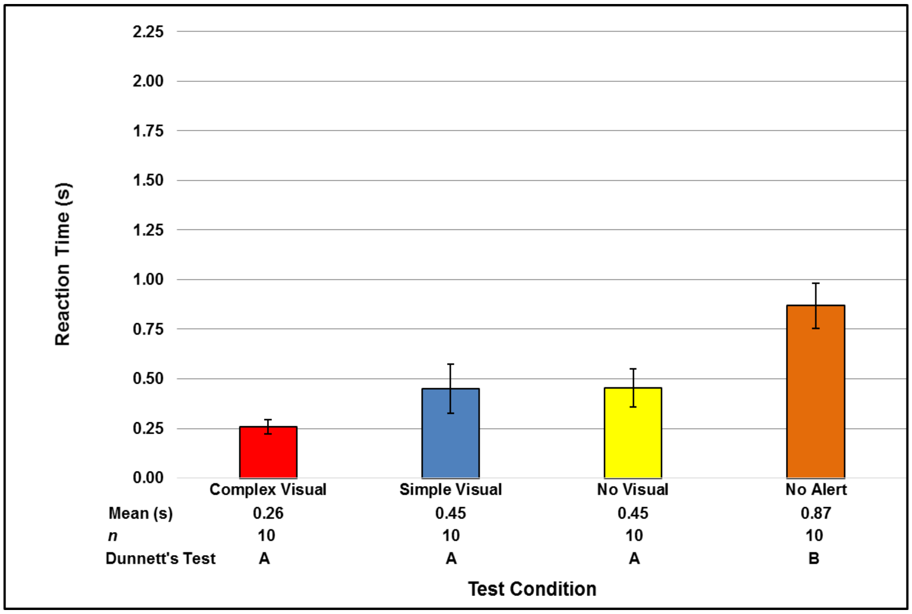

Figure 36. Mean Reaction Times (with Standard Error Bars) for RT #2 – Throttle Release

The ANOVA for RT #2 found a significant effect between test conditions; $F(3, 39) = 6.87$, $p = .001$, $\eta^2 = .36$. Planned comparisons were then performed using Dunnett's method. This comparison method was used because it takes into consideration a control group (i.e., no alert condition). The planned comparisons indicated a significant effect between each of the three visual alert conditions when compared to the no alert condition. Further, Fisher's method planned comparisons were performed and no significant effects were found between any of the visual alert conditions. These findings indicate that each of the three different visual alert conditions during the ICW produces a quicker reaction time for first lifting the foot from the throttle compared to no ICW alert; however, no major difference in reaction times between the three different visual alert conditions were observed.

Reaction Time #3 – Depress Brake

Similar analyses of both the combined data and between each of three visual alert conditions were also performed on RT #3.

RT #2: Combined Visual Conditions

Figure 37 provides the mean reaction times for RT #3 with the combined visual alert conditions.

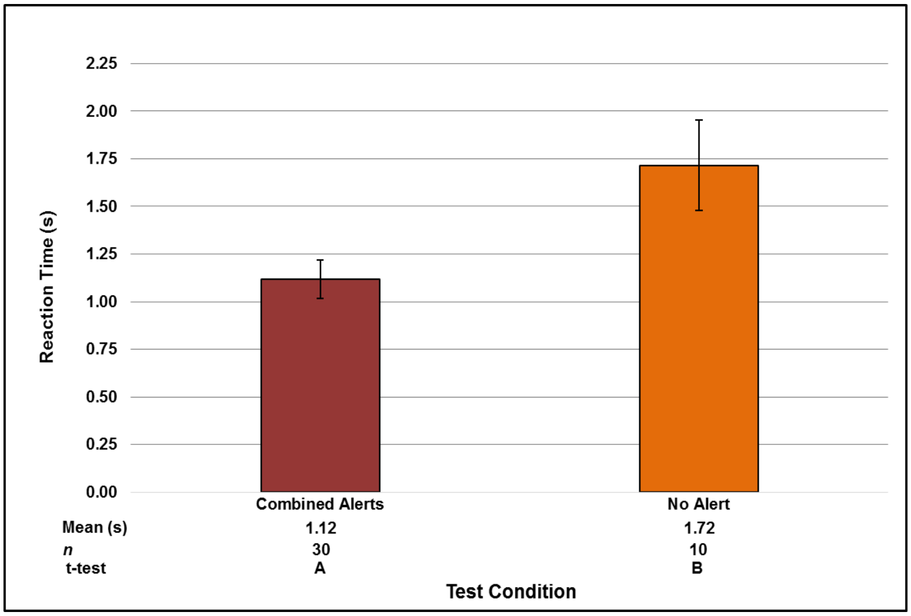

Figure 37. Mean Reaction Times (with Standard Error Bars) from ICW Alert Activation to Initial Deceleration (RT #3 – Depress Brake) for all Visual Conditions Combined Versus the No Alert Condition

Similar to RT #2, RT #3 was also analyzed using a *t*-test. The *t*-test for RT #3 found a significant effect between the no alert condition (M = 1.72, SD = 0.75) and the three visual alert conditions combined (M = 1.12, SD = 0.55); $t(12) = 2.31$, $p = .039$; d = .91. This finding indicates participants receiving an ICW alert had a significantly quicker reaction when depressing the brake when compared against participants that did not receive an ICW alert.

RT #3: Between All Test Conditions

Also similar to RT #2, after examining the data in a combined manner, the data were then analyzed by test condition using an ANOVA. Figure 38 provides these mean reaction times.

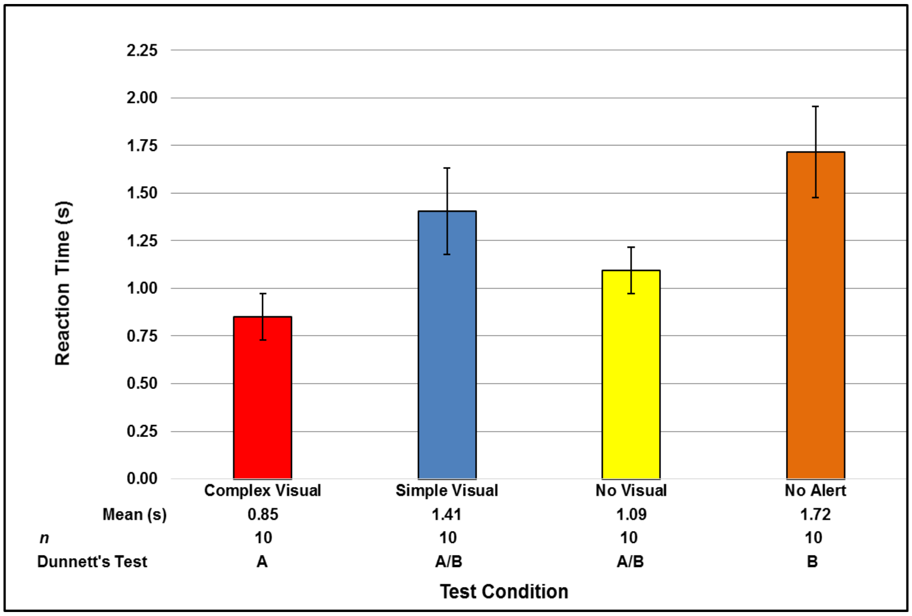

Figure 38. Mean Reaction Times (with Standard Error Bars) for RT #3 – Depress Brake

The ANOVA for RT #3 found a significant effect between test conditions; $F(3, 39) = 4.09$, $p = .013$, $\eta^2 = .25$. As in RT #2, planned comparisons were then performed using Dunnett's method to account for a control group. The planned comparisons indicated that the complex visual condition had a significant effect when compared to the no alert condition; however, the simple visual condition and no visual condition were not statistically different from the no alert condition. Fisher's method was also performed and no significant effects were found between the three alert conditions. It is important to note that 70 percent of the participants in the complex visual condition indicated not even seeing the visual alert component. Further inspection revealed the participants of the complex visual condition had an older mean age, greater mean years of experience, and more million milers, which is a potential trend accounting for their reaction time. However, the sample size was not large enough to take into account these covariates.

Subjective Assessment

Overview

Subjective data were also collected for each participant on the test trial of interest (braking event). Upon completion of the test trial of interest, the participant was asked to park the truck and complete the secondary consent process before proceeding with the subjective questionnaire (Appendix A). Participants in all test conditions were asked a series of questions. These questions are the same questions that were asked in Experiment 1 and addressed different aspects of the ICW:

- Attention-getting qualities of the alert
- Timing of the alert
- Situational awareness
- Need for the visual alert
- Previous FCW exposure
- Open-ended comments

It should be noted that an analysis of the subjective data included all participants that completed testing. This includes participants who reacted to the alert (i.e., valid test trial used for objective data analysis) and participants who reacted before the alert (i.e., invalid test trials not used for the objective data analysis). The participants that reacted before the alert could still provide a useful assessment with regard to the alert. Moreover, they might represent drivers that could potentially experience an ICW alert as they would react in real life and treat the event as a "nuisance" alert. There are compelling reasons for using this other group of participants that might not have conformed to the operational definition for a valid test trial; therefore, the reader is provided with both sets of results (i.e., reacted to alert, reacted before the alert). Note that no alert participants (i.e., did not receive alert)—and, in some instances, participants in the visual alert conditions that reacted before the alert and did not receive the warning—are omitted from questions 1 through 3 given that they did not experience the alert during the event of interest.

Demographics

As mentioned previously, demographics were collected and compiled for all participants (n = 91) who completed testing in Experiment 2. The subjective data demographics represent all 91 participants. Across all participants, the mean age was 49 years. Eighty-eight participants were male, while three participants were female. All participants had a valid CDL (83 from the state of Virginia, 7 from the state of West Virginia, and 1 from the state of North Carolina), a valid DOT medical card, and no DOT-reportable accidents within the past year. Table 24 presents demographics for the 91 participants who completed testing while Table 25, Table 26, and Table 27 provide driving and employment demographics.

Table 24. Participant Demographics per Test Condition

Condition	*n*	Male	Female	Mean Age (years)	SD Age (years)	Minimum Age (years)	Maximum Age (years)
Complex Visual	23	22	1	48.9	10.8	32	72
Simple Visual	30	30	0	48.5	11.6	21	70
No Visual	17	15	2	50.1	12.79	27	74
No Alert	21	21	0	49.0	12.27	29	72

Table 25. Participant Driving Demographics

Condition	*n*	Mean Experience (years)	SD Experience (years)	Miles/Week	Million Miler (*n*)
Complex Visual	23	22.8	12.0	1,671	17
Simple Visual	30	21.9	11.2	1,593	19
No Visual	17	18.7	16.52	1,456	8
No Alert	21	23.3	15.80	1,665	13

Table 26. Number of Participants per Fleet Operation Classification

Condition	*n*	For-hire Truckload	For-hire LTL	Private
Complex Visual	23	3	1	19
Simple Visual	30	7	6	17
No Visual	17	5	3	9
No Alert	21	6	3	12

Table 27. Number of Participants per Distance Classification

Condition	*n*	Long Haul	Short Haul	Local
Complex Visual	23	5	15	3
Simple Visual	30	12	11	7
No Visual	17	5	7	5
No Alert	21	9	8	4

Attention-getting Qualities of the Alert

The first two questions gathered participant input about the attention-getting effects of the auditory alert and the visual display.

1. How attention-getting is the auditory alert?
2. How attention-getting is the visual alert?

These two questions were answered using a 7-point Likert-type scale (Figure 39) and addressed all test conditions receiving the ICW (i.e., simple visual, complex visual, and auditory-only).

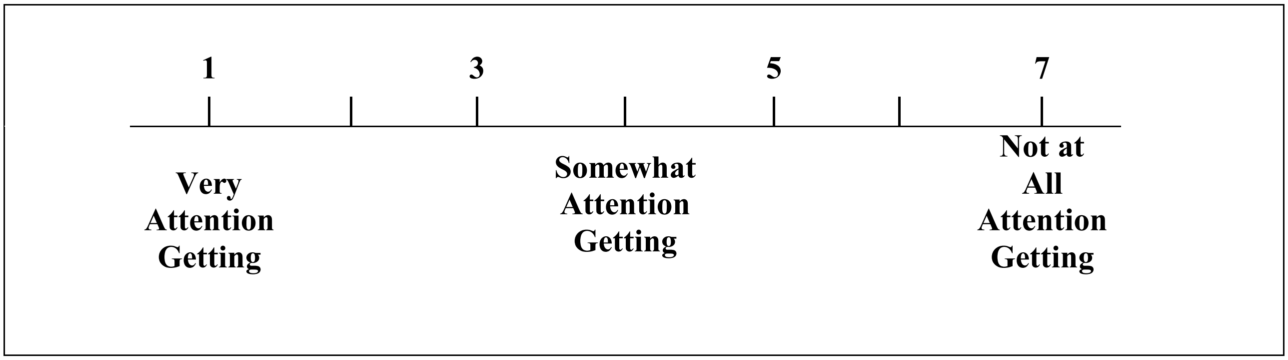

Figure 39. Scale Used to Determine the Attention-getting Quality of the Auditory and Visual ICW Alert

Figure 40 displays the mean participant ratings of the attention-getting effects of both the auditory and visual aspects of the ICW alert. Note that participants from all three visual alert conditions were combined. Also note that the no visual alert (auditory-only) condition does not include the visual alert as part of the ICW and was omitted from question 2.

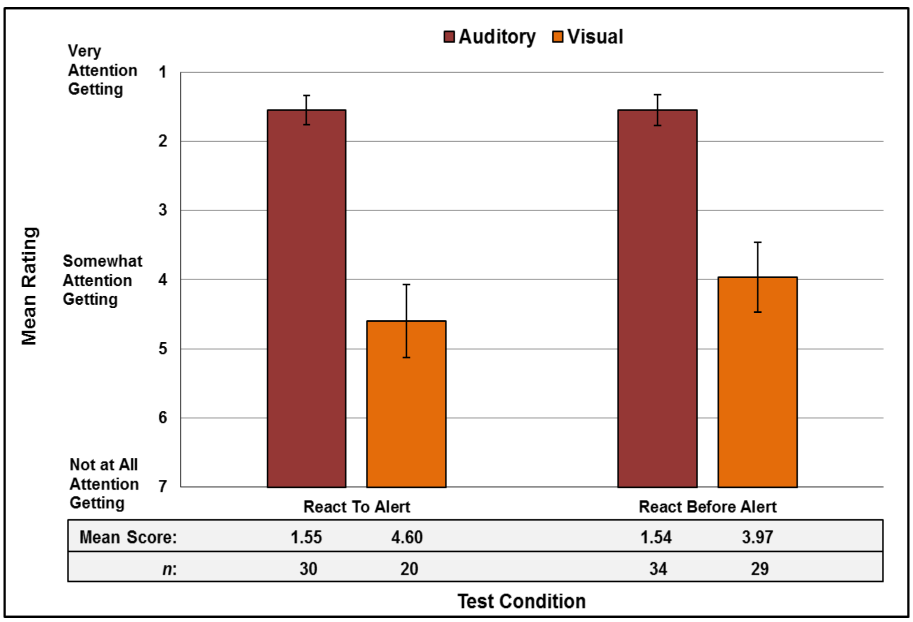

Figure 40. Participant Ratings (with Standard Error Bars) of the Attention-getting Qualities of the ICW Auditory and Visual Alerts (Combined Visual Alert Conditions)

Participants that reacted to the alert and those that reacted before the alert gave the attention-getting qualities of both the auditory alert and the visual alert similar ratings. Participants that reacted to the alert had a mean rating of 1.55 ("very" attention-getting) for the auditory alert and a mean rating of 4.60 (in the range of "somewhat" attention-getting) for the visual alert. Likewise, participants that reacted before the alert provided mean ratings of 1.54 ("very" attention-getting) for the auditory alert and 3.97 ("somewhat" attention-getting) for the visual alert. To assess if there were any differences in attention-getting ratings between participants that reacted to the alert and participants that reacted before the alert, a *t*-test was conducted. No significant effects were found between participants that reacted to the alert and participants that reacted before the alert in either the auditory attention-getting qualities, $t(60) = -0.03$, $p = .979$; d = .01, or the visual attention-getting qualities, $t(42) = -0.82$, $p = .418$; $\eta^2 = .24$.

A further analysis was performed using an ANOVA to assess if there were any differences in participant ratings between each of the three visual alert conditions. Since no significant effects were found in the previous analysis assessing the attention-getting qualities between participants that reacted to the alert and participants that reacted before the alert, this subsequent analysis combined both groups of participants. Figure 41 provides the mean ratings of the auditory and visual attention-getting qualities across the three visual alert conditions.

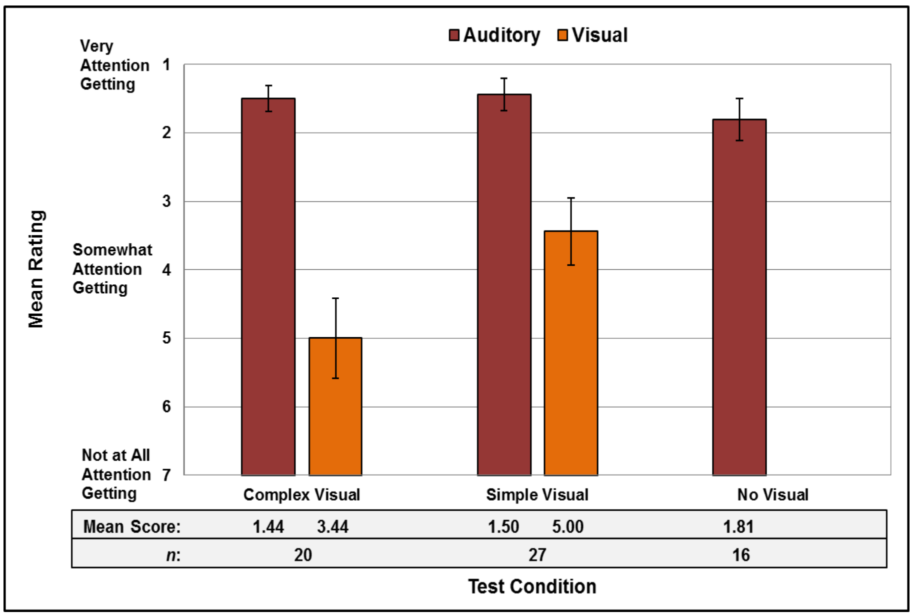

Figure 41. Participant Ratings (with Standard Error Bars) of the Attention-getting Qualities of the ICW Auditory and Visual Alerts (between Visual Alert Conditions)

The ANOVA did not find any significant effect in participant ratings between the three visual alert conditions for the auditory alert attention-getting qualities, $F(3, 62) = 0.59$, $p = .557$; $\eta^2 = .02$. However, the ANOVA did find a slightly significant effect between the simple and complex visual alert conditions for visual alert attention-getting qualities, $F(1, 46) = 4.13$, $p = .048$; $\eta^2 = .08$. The simple visual alert condition received a higher rating, meaning it was perceived as more attention-getting than the complex visual alert. It is important to point out that 6 of the 10 participants in the simple visual alert condition glanced to the IP at some point during the braking event while only 2 of the 10 participants in the complex visual alert condition glanced to the IP.

Timing of the Alert

The third question gathered participant input on the timing of the ICW alert.

3. How appropriate is the timing of the alert?

This question was answered using a 7-point Likert-type scale (Figure 42) and addressed all test conditions receiving the ICW (i.e., simple visual, complex visual, and auditory-only). Participants in the no alert condition and those who did not experience the ICW alert were omitted from this analysis.

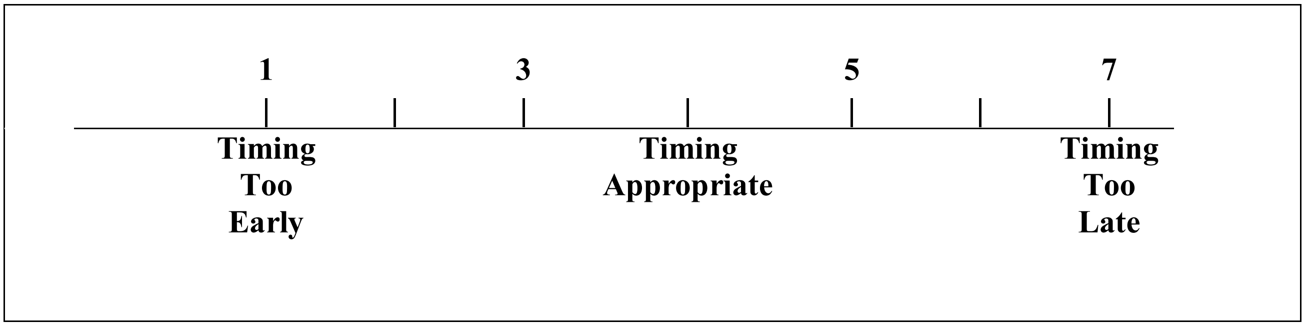

Figure 42. Scale used to Determine Appropriateness of the ICW Alert Timing

Figure 43 displays the mean participant ratings of the appropriateness of the timing of the ICW alert.

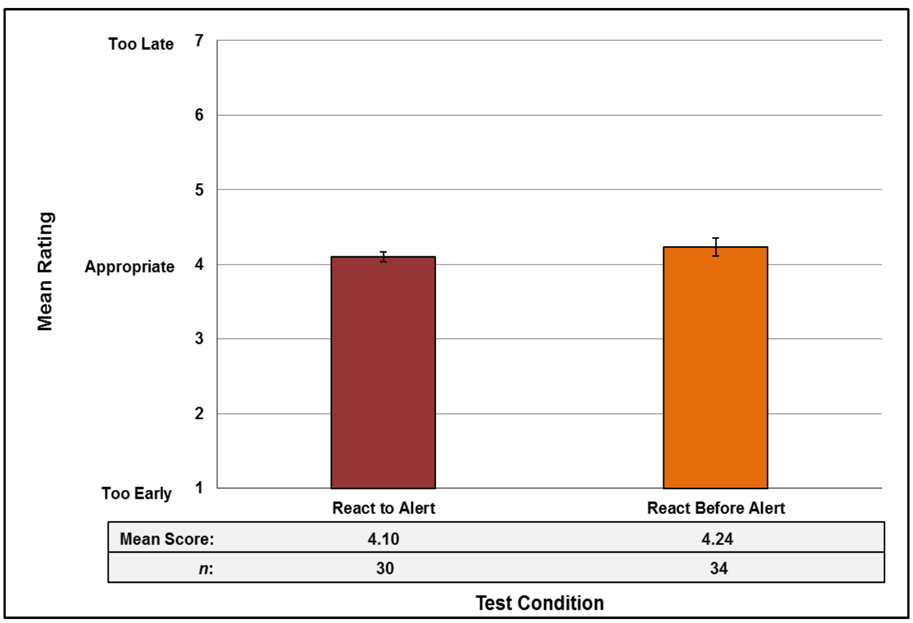

Figure 43. Participant Mean Ratings (with Standard Error Bars) for the Appropriateness of the Timing of the ICW Alert

Similar mean ratings are seen between participants that reacted to the alert (M = 4.10, SE = 0.06) and participants that reacted before the alert (M = 4.24, SE = 0.12). These mean ratings indicate that the timing of the ICW alert is "appropriate." A *t*-test was performed, $t(48) = 0.05$, $p = .301$, d = .26, and no significant effects before participants that reacted before the alert and those that reacted after the alert were found.

Situational Awareness

The fourth and fifth questions gathered participant input on their situational awareness while they were performing the secondary task and during ICW alert activation.

4. Did you see the lead vehicle braking?

5. How quickly did you become aware of what was happening in the event?

Question 4 was answered with a "yes or no" response, while question 5 was answered using a 7-point Likert-type scale (Figure 44). All participants, including the no alert condition participants, provided feedback for these two questions.

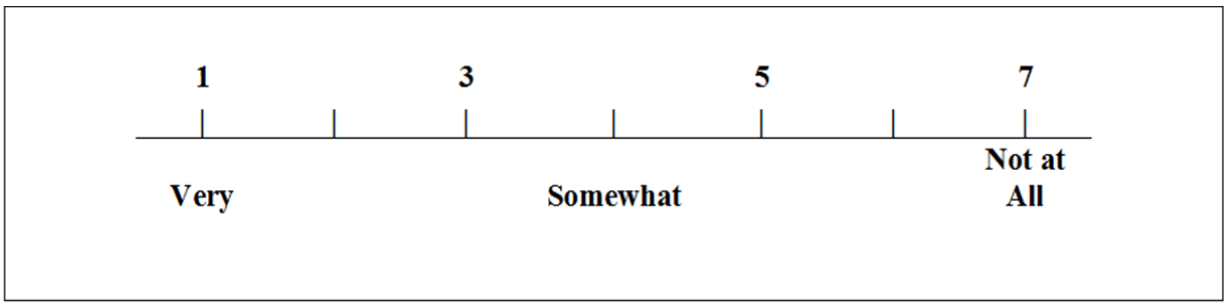

Figure 44. Scale used to Determine how Quickly the Participant Became Aware of What Was Happening in the Event

For question 4, of the participants that reacted to the alert, 73 percent (22 of 30) did not see the brake lights of the lead vehicle, while only 25 percent (10 of 40) of participants that reacted before the alert did not see the brake lights. It is important to understand that the brake lights of the lead vehicle did not remain on for the duration of this event. The brakes were applied only until the lead vehicle slowed to the desired speed (32 km/h). This braking maneuver lasted approximately 1 s. The lead vehicle then continued at 32 km/h for the remainder of the event.

For question 5, Figure 45 provides the mean ratings with regard to how quickly the participants became aware of what was happening in the event.

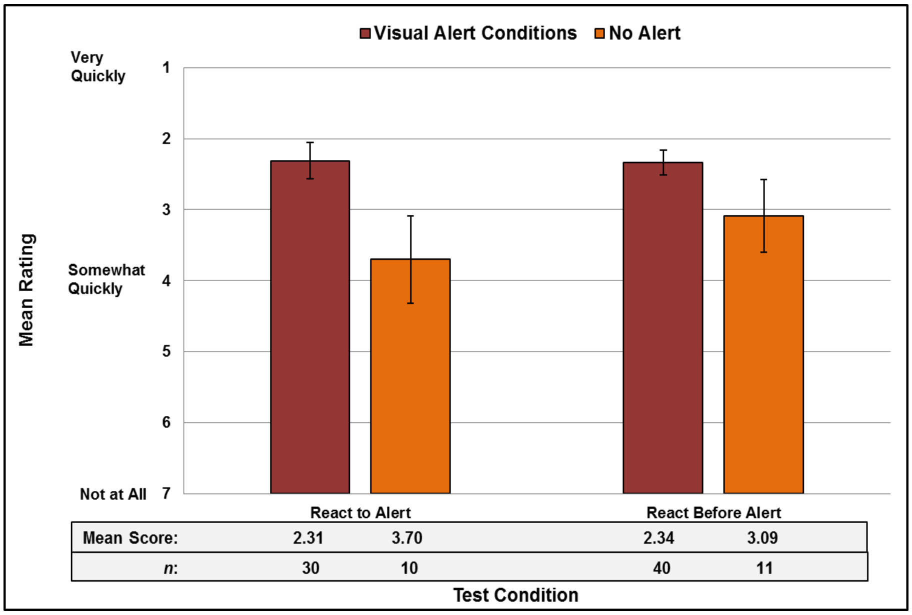

Figure 45. Participant Mean Ratings (with Standard Error Bars) of How Quickly the Participant Became Aware of What Was Happening in the Event

Participants in the three visual alert conditions that reacted to the alert (M = 2.31, SE = 0.26) and reacted before the alert (M = 2.34, SE = 0.18) provided similar ratings. Note that these participants are compared against the no alert condition in Figure 45. Likewise, participants in the no alert condition who reacted after the 3-s TTC (M = 3.70, SE = 0.62) and reacted before the 3-s TTC (M = 3.09, SE = 0.51) also provided similar ratings. A *t*-test was performed to assess if any significance was found between the visual alert conditions and the no alert condition.

- Reacted to the alert versus no alert (after 3-s TTC): $t(12) = 2.08$, $p = .06$; d= .81
- Reacted before the alert versus no alert (before 3-s TTC): $t(12) = 1.38$, $p = .194$; d = .51

No significant effects were found between participants who experienced the ICW alert and the no alert condition (i.e., did not receive an ICW alert). This holds true for participants that reacted to the alert (no alert = after 3-s TTC) and those that reacted before the alert (no alert = before 3-s TTC).

Need for a Visual Alert

The sixth question gathered participant input on the need for the visual aspect of the ICW alert.

6. Do you feel that a visual alert is needed?

This question was answered with a "yes or no" response. Note that participants in the no alert condition are omitted from this question as they did not experience the alert.

Of the participants that reacted to the alert, 47 percent (14 of 30) felt that a visual alert is necessary. Similarly, of the participants that reacted before the alert, 53 percent (21 of 40) also felt that a visual alert is necessary.

Prior FCW Exposure

The seventh question gathered participant input on any prior experience with an FCW in a heavy vehicle.

7. Have you previously driven a heavy vehicle equipped with a forward collision warning system?

This question was answered with a "yes or no" response. Participants responding with a "yes" then provided the name of the system. In some cases, participants could not remember the brand of FCW system they had previously experienced. Note that participants in the no alert condition are omitted.

Nine out of the 30 (30%) participants who reacted to the alert had previously experienced an FCW system in a heavy vehicle, while 9 out of the 40 (23%) participants that reacted before the alert had previously experienced an FCW system in a heavy vehicle.

Open-ended Comments

Participants were shown the visual alert and listened to the auditory alert again while the truck was parked. Participants were then given the opportunity to provide open-ended comments about the different aspects of the visual alert and the auditory alert, such as:

- Size of the visual image
- Background color
- Text color
- Car/truck image color
- Loudness of the auditory alert
- Duration of the auditory alert
- Type of sound used

Participant responses were categorized and then descriptive statistics were calculated. Note that this includes all participants.

When responding about the visual alert, 72 percent (49 of 68) felt the size of the visual image was appropriate. However, 17 participants (25%) stated that the size of the visual alert was too small, while two participants stated that it was too big. Interestingly, several of these participants mentioned it should be the size of the entire display. When it comes to the background color, 88 percent (60 of 68) felt the background color of red was the correct color to use. Comparable to Experiment 1, a number of these participants stated that red means stop, danger, and/or warning. Similarly, 92 percent (60 of 65, three participants did not respond) felt the text color of white was good as it contrasts very well with the red background. Also, 86 percent (56 of 65, three participants did not respond) felt the black color used for the images of the car and truck was appropriate. Several additional comments of interest were provided by more than one participant: (1) make the visual alert flash and (2) move the visual alert to a different location (responses ranged from A-pillar to center stack).

When responding about the auditory alert, 76 percent (52 of 68) felt the duration of the auditory alert was sufficient. However, 13 participants felt the duration of the auditory alert was too short, while three participants felt it was too long. As for the loudness of the auditory alert, 82 percent (56 of 68) felt it was appropriate. Nine participants did, however, state that it was not loud enough, while one participant stated it was too loud (startling effect). Interestingly, five participants stated that the auditory alert should override the radio. These five participants all experienced the no-muting test condition where the auditory alert played over top of the radio. The auditory alert sound was reported by 92 percent (86 of 93, one participant did not respond) as appropriate. Similar to the visual alert, a number of participants commented that it should last until the TTC is greater than 3 s.

Experiment 2 Discussion

Research Question #2 (Experiment 2): In terms of reaction time, is there a benefit to providing drivers a simpler visual ICW alert (providing minimal information) over a more complex ICW alert (providing more in-depth information), or is having no visual alert the most effective method?

Experiment 2 was conducted to study the visual component of an ICW for a rear-end event. The ICW was designed following guidelines from Campbell et al. (2014). The same scenario used in Experiment 1 was also used for this experiment. The test conditions of interest for this experiment were:

- No visual alert (i.e., auditory component of the alert only)
- Simple visual alert
- More complex visual alert (i.e., displaying more information)
- No alert (i.e., baseline)

The results for this research effort consider three aspects in the evaluation of an ICW: (1) first response, (2) reaction time, and (3) subjective assessment.

First Response

Similar to Experiment 1, the first response to the ICW alert was categorized in one of three ways: (1) look to the forward roadway, (2) look to the visual alert, or (3) lift foot from the throttle. It should be noted that the DAS included a camera mounted on the bottom of the display in order to clearly identify when the participant was looking at the visual display.

After the ICW alert was presented, looking towards the roadway was the first response for the majority (85 percent) of the participants. That reaction was followed by lifting the foot from the throttle (95 percent) as the second most common response. For Experiment 2 the proportion of participants looking at the display/IP area was greatly reduced. A potential reason for this is the fact that the exposure to a visual alert component for the ICW is reduced by having a condition with no visual alert. This could potentially suggest that the visual component of the ICW should be delayed in order to ensure the appropriate response order (i.e., for this particular set of experiments look forward and then release the throttle for this experiment). If the visual component of the ICW is presented in the IP, it should only be informational (i.e., provide a confirmation of the event and why an alert was provided). It should not be emphasized (e.g., shown at the same time the auditory component is presented) if it deters from the goal of eliciting the driver to look to the forward roadway as the first response. See Figure 46 for more details about responses.

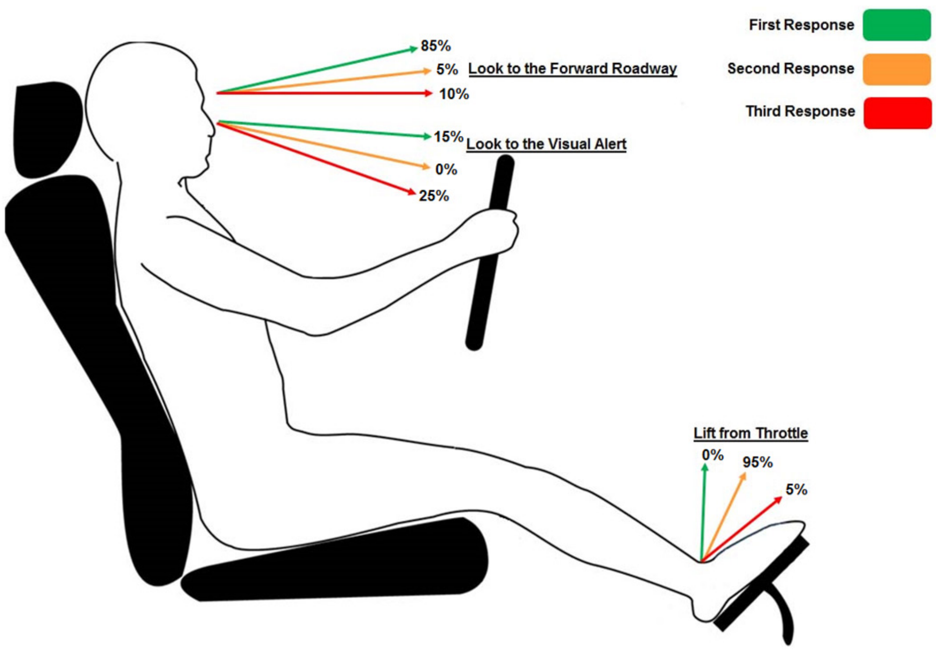

Figure 46. Percentage of Participant Responses per Location

Reaction Time

As previously discussed, an ICW can elicit multiple reactions (e.g., look forward). The goal of an ICW should be to elicit the driver to look towards the forward roadway and stop accelerating (and potentially increase deceleration if the event merits that action). In addition, the timing of the reaction is of interest. Similar to Experiment 1, this study looked at three different reaction times: (1) Look Forward, (2) Throttle Release, and (3) Depress Brake. Most of the drivers' (85 percent) first reaction was looking to the forward roadway. For Experiment 1 there was greater variance in terms of reaction time between the ICW test conditions; however, that was not the case for Experiment 2. All ICW conditions that presented an alert were able to elicit very timely responses, including the alert without a visual component. All mean reaction times for the reaction of looking to the forward roadway were under 0.17 s. A 0.10-s reaction time (no muting condition) for "look ahead" was the best mean reaction time obtained during Experiment 1 for an ICW, and again was near the quickest reaction time for Experiment 2. This process helps confirm that the no muting condition from Experiment 1 continues to excel even when other components of the alert are varied. Another finding of interest in this portion of the analysis is that not having a visual component as part of the ICW (as tested in this study) did not present any unintended consequences or increase the reaction times of interest. However, this might not be the case for a real-world application when nuisance alerts and false alerts are present (i.e., a visual component might help the driver understand why the auditory component was presented). Therefore, the visual display component is suggested as an informational component of the alert and not as a time-sensitive one (i.e., not needed simultaneously when the auditory component is presented).

Drivers that were presented with an ICW during the potential rear-end event were able to start releasing the throttle, on average, 0.48 s (55 percent) quicker than the drivers that did not receive an alert. The participants that experienced the complex visual condition reacted quicker than the ones with a simple or no visual display; however, the difference was not statistically significant. The complex visual condition was able to release the throttle within 0.26 s (70 percent quicker) than when no alert was presented. The participants that were presented with the other two alerts released the throttle within 0.45 s (48 percent quicker than no alert).

On average, once the ICW was presented, drivers started braking within 1.12 s. This was statistically different from the no alert condition (1.72 s). As mentioned in Experiment 1, other external factors that the drivers were taking into consideration as they evaluated the rear-end events that were evolving (e.g., weather, roadway type, trailer load, perceived urgency) should be taken into consideration when these results are compared against other studies.

Subjective Assessment

Very similar to Experiment 1, all drivers that experienced an ICW during the study provided a positive assessment. The ICW was considered attention-getting. The auditory component of the alert was the portion of the alert that was rated with the highest impact on capturing the driver's attention. Moreover, the participants with the complex visual alert did not deem the visual component as important as the ones with a simple visual display. An auditory alert of a 1.10-s duration and 87 dB (15 dB above the cabin noise plus music level) was deemed fitting for the condition tested. In terms of the ICW's timing, the ICW at 3-s TTC was deemed appropriate. Similar to Experiment 1, only half the participants thought the visual alert component was necessary. An overwhelming majority supported the use of a red background to elicit a high-urgency mental model in the context in which it was evaluated (e.g., stop, danger). In addition, the selected icon, with an image size of 47.625 mm × 47.625 mm, and the level of contrast were deemed appropriate by the majority of the participants as well.

Experiment 2 Conclusion

Experiment 2 reiterated that an ICW will enhance reaction time. It continued to point out that the first initial response to the alert was to look forward, which is the desired effect in the case of a distracted driver that is about to encounter a potential rear-end event. The second most prevalent response was to release the throttle. When evaluating the effect of the ICW during that period of time (i.e., from event time until the throttle was released), the drivers that had an ICW were able to enhance their reaction time when compared to the drivers that were not presented with an alert. Drivers had an overwhelmingly positive response to the alert. A very interesting finding for this experiment was the fact that there is no difference in terms of reaction time when the ICW includes a visual component versus when it is suppressed during the rear-end event onset. Not having a visual display did not present any unintended consequences or increase the reaction times of interest. Experiment 1 showed the potential for increased reaction times due to the driver looking at the IP area before looking forward. It is not suggested that all visual components be eliminated. The information they provide is very important to the driver's mental model (to ensure the driver understands why the auditory alert was presented). Moreover, suppressing the visual/informational component might not be the best case for a real-world application when nuisance alerts and false alerts are present (i.e., a visual component might help the driver understand why the auditory component was presented and avoid unnecessary search). Therefore, the visual display component is suggested as an informational component of the alert and not as a time-sensitive one (i.e., not needed simultaneously when the auditory component is presented). It could be hypothesized that delaying the visual component of the ICW should improve reaction times given the first response schema presented above will change to 100 percent of the participants looking forward and quickly recognizing the evolving rear-end event instead of looking at the visual display first.

However, manipulating delays for the visual alert portion was not part of the scope of this research effort, and current design principles suggest including a visual component. Therefore, if a simpler implementation of the ICW is feasible, that combination should always be selected. The details of the suggested ICW entail the auditory component of the alert not needing to mute other sources of noise in the vehicle cabin (from Experiment 1). This statement assumes that a 15-dB difference is maintained between the noise source and the ICW. From the current study we learned that a simple visual display should suffice. Therefore, subsequent experiments will implement the ICW without muting the additional audio sources (i.e., music) and with a simple visual alert.

As noted in Experiment 1, this research effort evaluated only driver performance and subjective assessment when the ICW was presented during a real rear-end potential conflict (i.e., no false alarms). If the false alarm rate increases, this could potentially impact the drivers' subjective assessment and their reaction time.

CHAPTER 5. EFFECT OF FINAL DESIGN IN-CAB AUDITORY & VISUAL ICW ALERT IN A TRUCK-TRAILER COMBINATION AND MOTORCOACH

OVERVIEW

This experiment compares the auditory and visual ICW characteristics previously studied, in terms of reaction time, when presented to truck-trailer combination drivers versus drivers in a motorcoach environment. The findings of this study should demonstrate if an alert that has been utilized in a truck-trailer combination unit environment could elicit similar results in a different heavy-vehicle environment in order to be able to generalize these results as potential benefits for heavy-vehicle CWI design principles. Additionally, this experiment served as a summary of the research program findings.

Research Question #3 (Experiment 3): Based on the findings of Research Questions 1 and 2, is there a benefit in terms of reaction time, to the final design ICW alert over a no alert condition? Are the results obtained for Class 8 truck drivers applicable to motorcoach drivers?

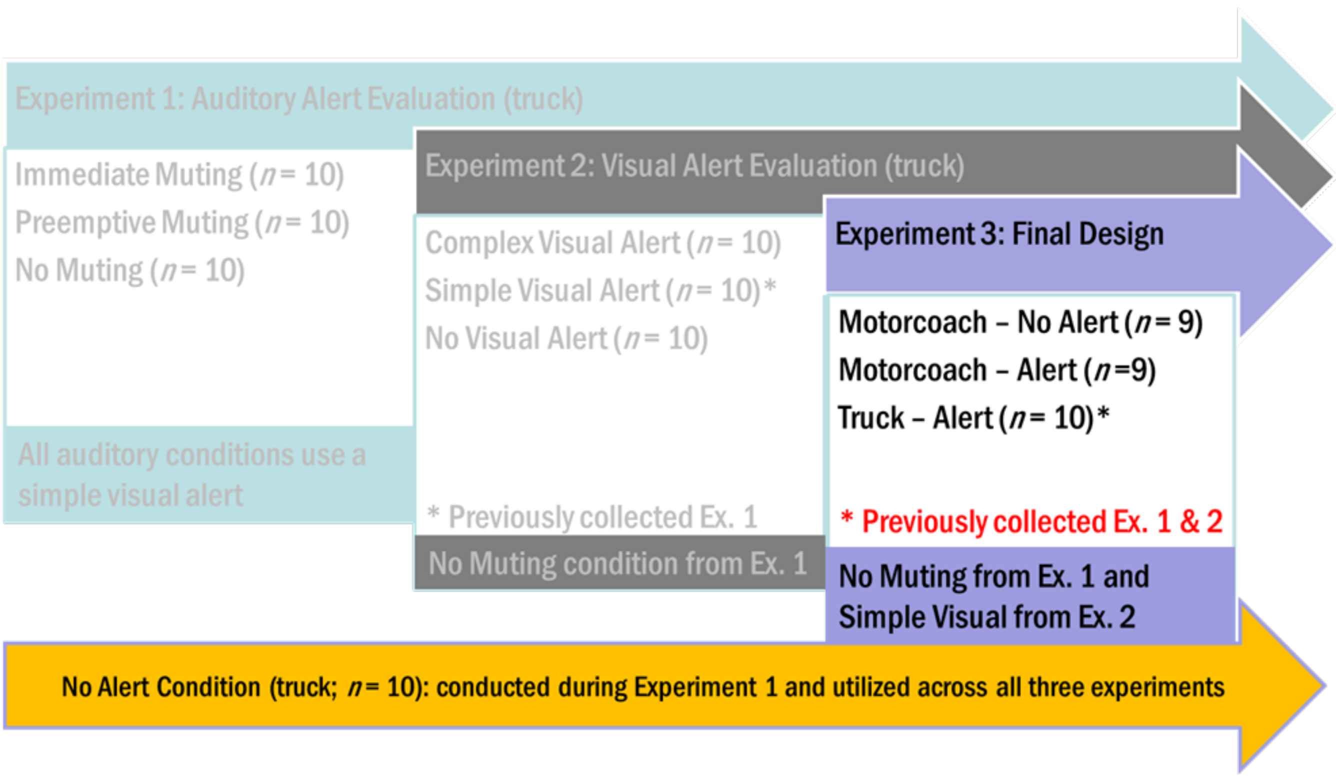

Figure 47. Experiment 3 Design Focus

EXPERIMENTAL METHOD

Participants

A total of 18 participants with valid test trials were tested in Experiment 3. These participants were motorcoach drivers. This experiment also used data collected previously in Experiment 1 and Experiment 2. Screening and eligibility requirements were identical to those used in Experiment 1 and Experiment 2 (see Chapter 3).

Apparatus

2003 MCI Motorcoach

The motorcoach used in this study was a 2003 MCI model E4500 (Figure 48; Figure 49). The E4500 is approximately 14-m long with an approximate gross vehicle weight of 24,500 kg. The motorcoach is equipped with an automatic transmission, an air brake system, ESC, traction control, switchable steerable tag axle, and an ABS.

Figure 48. MCI E4500 Motorcoach

Figure 49. Driver's Area of the MCI E4500 Motorcoach

Data Acquisition System

The DAS installation was identical to the equipment used in Experiment 1 and Experiment 2. The same six camera views were used as in Experiment 2 (see Chapter 4).

Collision Warning Interface

The no muting auditory condition from Experiment 1 and the simple visual condition from Experiment 2 were applied to the CWI in Experiment 3. In the motorcoach application of the CWI, this resulted in the truck image being changed to a motorcoach image (Figure 50).

Figure 50. ICW Visual Alert for Experiment 3 (Image to Scale)

Experimental Conditions

All experimental scenarios occurred on the Virginia Smart Road, as described in Experiment 1. For these scenarios, only the subject vehicle and relevant confederate vehicles were present on the test track.

Four different test conditions were used for this experiment, with each participant experiencing only one test condition. These test conditions assessed the final design auditory and visual alert conditions on reaction time to an ICW alert. Test condition C was a combination of the no muting auditory and the simple visual alert conditions in the tractor-trailer, while test condition D was the no alert condition in the truck-trailer combination unit. Test condition G was the no muting auditory and simple visual alert conditions applied to the motorcoach, while test condition H was the no alert condition in the motorcoach. Table 28 provides a description of the test conditions.

Table 28. Experiment 3 Test Conditions

Condition	Alert Type	Alert Definition
C	Alert – Truck**	Simple visual with auditory alert, cabin sounds not muted
D	No Alert – Truck*	No alert presented (baseline)
G	Alert – Motorcoach	Simple visual with auditory alert, cabin sounds not muted
H	No Alert – Motorcoach	No alert presented (baseline)

* Obtained from Experiment 1
**Obtained from Experiment 2

Experimental Design

Similar to Experiment 1 and Experiment 2, Experiment 3 was a between-subjects design with a single-exposure surprise event. All participants experienced the same six test trials as in the previous two experiments. These test trials were the same across all test conditions and were always conducted in the same order. Each test trial was one full length of the test track. A full description of the six test trials was previously provided in Table 6.

Experimental Procedure

The procedures for this experiment were identical to the procedures for Experiments 1 and 2 (see Chapter 3).

Dependent Variables

Objective

The same objective DVs for this experiment were collected and assessed as in Experiment 1 and Experiment 2. As in the previous experiments, only participants with valid test trials were analyzed.

Subjective

Participants' subjective feedback on task performance and the ICW alert were also assessed via questionnaires. This was the same questionnaire that was administered during Experiment 1 and Experiment 2 (see Appendix A).

EXPERIMENT 3 RESULTS

Overview

The following sections present the results for Experiment 3. Results, including participant demographics, are presented along with a brief discussion.

As noted in Chapter 2, three research questions were developed to address the scope of this study. Experiment 3 addressed Research Question #3.

Research Question #3 (Experiment 3): Based on the findings of Research Questions 1 and 2, is there a benefit in terms of reaction time, to the final design ICW alert over a no alert condition? Are the results obtained for Class 8 truck drivers applicable to motorcoach drivers?

Experiment 3 evaluated the best-performing auditory alert condition from Experiment 1 combined with the best-performing visual alert condition from Experiment 2 using both a Class-8 truck-trailer combination unit and a full-size motorcoach.

Experimental Test Trials

Thirty participants were needed in order to obtain the 18 valid (react to the alert) test trials required to complete Experiment 3 (i.e., distracted while the event of interest evolved and depressing the throttle). This accounts for a 60% rate of valid test trials. As described previously, while the finalized testing protocol was designed to maximize the number of valid test trials, a high number of invalid (react before the alert) test trials (40%) still occurred throughout testing. A detailed explanation for this occurrence was provided earlier in Chapter 3.

Human Performance Testing

Overview

Similar to Experiment 1 and Experiment 2, data recorded by the DAS installed in the test vehicle were analyzed in a manner allowing for simultaneous and time-synchronized viewing of the vehicle and experimental apparatus data along with the video stream. Two primary measures of interest were analyzed for each participant during test trial 6 (this event contained the FCW event). It is important to understand that all participants were naïve to this study (i.e., did not know an FCW system was installed in the subject vehicle) and received no prior training on either the visual alert or auditory alert. This was to ensure that all participants would remain unbiased and not assume the lead vehicle was going to perform a hard-braking maneuver. Also, this is representative of fleets randomly assigning drivers to fleet vehicles without informing the driver that the vehicle is equipped with a CWS or providing any training on CWSs.

The first measure of interest was DV #1 (first response). The first response to the ICW alert was categorized in one of three ways: (1) look to the forward roadway, (2) look to the visual alert, or (3) lift foot from the throttle. An additional camera was added to the DAS for Experiment 2 and Experiment 3 to allow for more exact eye-glance analysis (to determine if the participant looked to the visual component of the alert).

The second measure of interest was DV #2 (reaction times). Data collected from four different points in time for each participant were used during the current analyses. The first point in time recorded was when the ICW alert was triggered. Note that participants in the no alert condition (no alert) did not receive the ICW alert. Therefore, the 3.0-s TTC was used as the trigger. The second point in time recorded was when the participant first glanced to the forward roadway. The third point in time recorded was when the participant first lifted his/her foot off the throttle. The fourth point in time recorded was when the participant depressed the brake pedal.

Similar to Experiment 1 and Experiment 2, the same four recorded points in time and three reaction times have been analyzed (see Figure 13).

Demographics

Demographics were collected and compiled for all participants tested in Experiment 3. These demographics also include the simple visual alert with auditory alert (i.e., cabin sounds not muted) and no alert conditions collected previously in Experiment 1 and Experiment 2. For the objective data results, only demographics of those participants with valid test trials (i.e., participants that reacted to the alert) are presented in the tables below.

Table 29 presents demographics (per test condition) of the 38 completed participants with valid test data. Across all participants, the mean age was 47.6 years. Thirty-six participants were male, while two participants were female. All participants had a valid CDL from the state of Virginia, a valid DOT medical card, and no DOT-reportable crashes within the past year.

Table 29. Participant Demographics per Test Condition

Condition	*n*	Male	Female	Mean Age (years)	SD Age (years)	Minimum Age (years)	Maximum Age (years)
Alert – Truck	10	10	0	46.3	15.0	21	62
No Alert – Truck	10	10	0	48.8	13.1	29	67
Alert – Motorcoach	9	9	0	56.6	12.2	32	71
No Alert – Motorcoach	9	7	2	38.6	16.0	24	71

During Experiment 3, additional driving demographics, including years of CMV driving experience, average mileage driven per week, and million-miler status, were collected. Table 30 provides these demographics.

Table 30. Participant Driving Demographics

Condition	*n*	Mean Experience (years)	SD Experience (years)	Miles/Week	Million Miler (*n*)
Alert – Truck	10	22.5	12.1	1,579	6
No Alert – Truck	10	23.8	17.4	2,244	6
Alert – Motorcoach	9	10.3	9.8	383	2
No Alert – Motorcoach	9	5.9	5.9	444	1

Diagnostic Assessment

Similar to the previous two experiments, diagnostic assessments were performed to determine the normality of the data, determine if any outliers were present, and if so, determine how those outliers affect the reaction times. This diagnostic assessment proceeded in order starting with RT #1, and subsequent data analyses were conducted based on these results.

First Response to Alert

Video reduction was again performed on the Experiment 3 data set to assess each participant's first response to the ICW alert being activated. It should be noted that this analysis does not include the no alert condition as those participants did not experience the ICW alert during the braking event.

The majority (17 of 19; 89%) of the participants' first response was to look to the forward roadway when the ICW alert was presented. When assessing the first response by vehicle type, 80 percent (8 of 10) of the participants that drove the truck-trailer combination unit looked to the forward roadway, while 100 percent (9 of 9) of the participants that drove the motorcoach looked to the forward roadway. The first response for the two participants driving the truck-trailer combination unit that did not look first to the forward roadway was instead looking first at the visual alert component. Additionally, the second and third response of each participant were also assessed. Following the participants' first response to the ICW alert activation, the majority of participants (18 of 19; 95%) then lifted their foot from the throttle as their second response. Broken down by vehicle type, this is 90 percent (9 of 10) for the truck-trailer combination unit and 100 percent (9 of 9) for the motorcoach. The one participant who did not lift his/her foot from the throttle as the second response was driving the truck-trailer combination unit and looked to the forward roadway. Additionally, 42 percent (8 of 19; 6 truck, 2 motorcoach) of the participants looked at the IP at some point during the braking event (i.e., first, second, or third response). Note that not all participants performed a third response (i.e., 11 participants did not glance to the visual alert during the ICW alert presentation).

Reaction Time #1 – Look Forward

Due to the non-normal distribution of reaction times found in RT #1, a non-parametric assessment was conducted. Figure 51 provides the mean reaction times per test condition and vehicle type for RT #1.

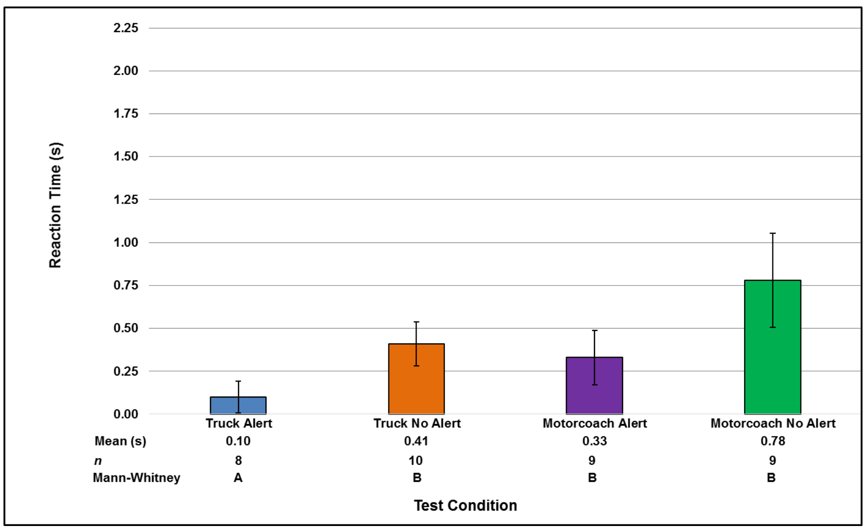

Figure 51. Mean Reaction Times (with Standard Error Bars) for RT #1 – Look Forward

The Kruskal-Wallis test fell just above the significance of .05; H(3) = 6.86, $p = .076$. A post hoc analysis using Mann-Whitney-Wilcoxon tests with a Bonferroni correction comparing each of the ICW alert conditions individually to the no alert conditions was then performed. The Bonferroni correction adjusted the significance level to .017. Significant effects were found between the alert – truck condition and the no alert – truck condition, with the alert – truck condition indicating a quicker reaction time than no alert. However, no significant effects were found between the alert – motorcoach condition and the no alert – motorcoach condition.

Table 31. Post Hoc Analysis for RT #1

Test Condition	Significance Test
Alert – Truck versus No Alert – Truck	W = 57.5, $p = .007$*
Alert – Motorcoach versus No Alert – Motorcoach	W = 76.0, $p = .403$

* significant, $p \leq 0.017$

Reaction Time #2 – Throttle Release

The data for this reaction time followed a normal distribution; therefore, a general linear model was applied to account for the different levels (i.e., ICW alert, no alert, truck-trailer combination unit, motorcoach) in RT #2. Figure 52 provides the mean reaction times per test condition and vehicle type for RT #2.

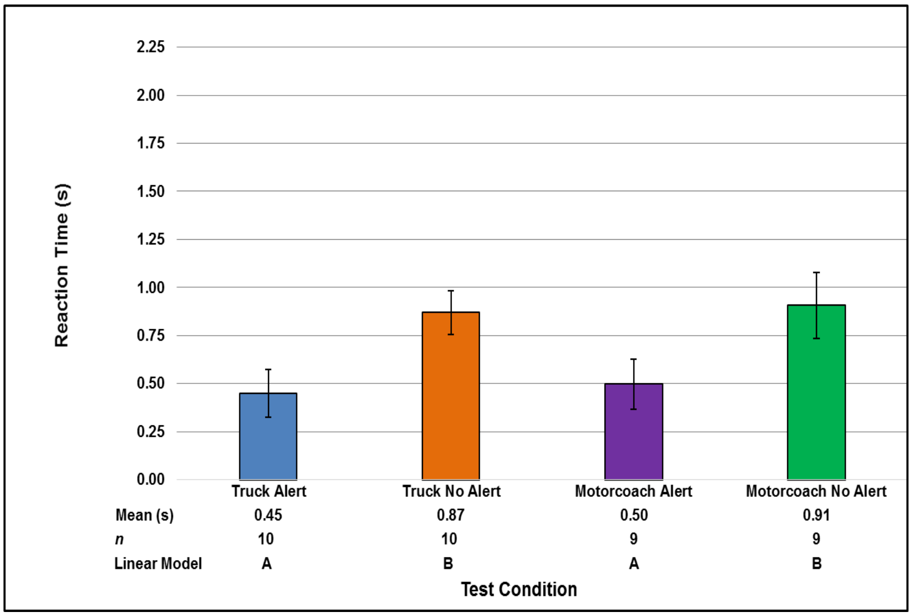

Figure 52. Mean Reaction Times (with Standard Error Bars) for RT #2 – Throttle Release

The general linear model found a significant effect between the ICW alert and no alert; $F(3, 37) = 9.73$, $p = .004$, $\eta^2 = .22$. Further, no significant effects were found between vehicle type; $F(3, 37) = 0.00$, $p = .996$, $\eta^2 = .00$. These findings indicate that an ICW alert produces a significantly quicker reaction than no alert in both the truck-trailer combination unit and the motorcoach.

Reaction Time #3 – Depress Brake

Similar to RT #2, a general linear model was applied to account for the different levels (i.e., ICW alert, no alert, truck-trailer combination unit, motorcoach) in RT #3. Figure 53 provides the mean reaction times per test condition and vehicle type for RT #3.

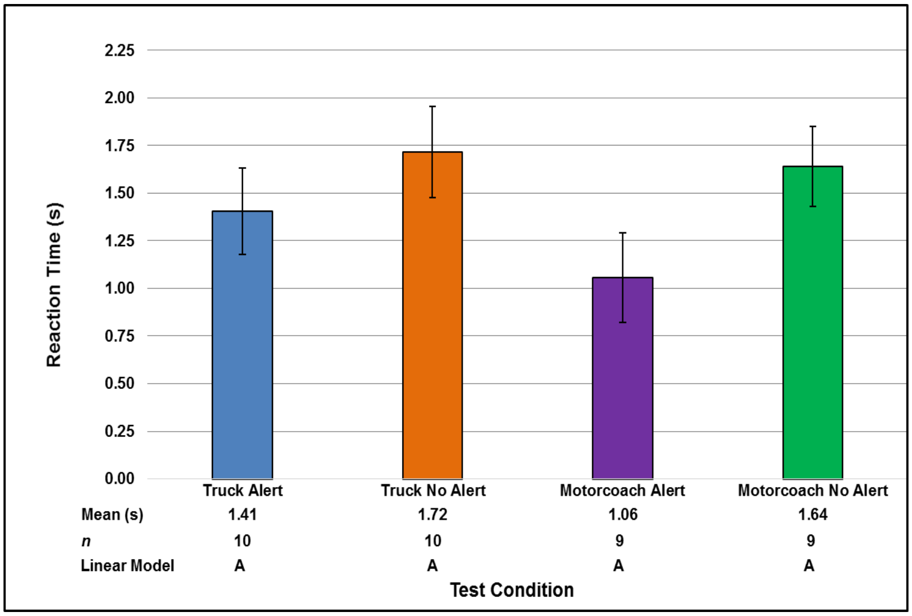

Figure 53. Mean Reaction Times (with Standard Error Bars) for RT #3 – Depress Brake

The general linear model did not find a significant effect between the ICW alert and no alert; $F(3, 37) = 3.82$, $p = .060$, $\eta^2 = .10$. Further, no significant effects were found between vehicle type; $F(3, 37) = 0.36$, $p = .552$, $\eta^2 = .01$. These findings indicate that when braking drivers of the motorcoach react similarly to drivers of the truck-trailer combination. When the participant choses to view the visual alert, as well as how participants interpret the unfolding potential rear-end crash scenario, could be a potential cause for the hesitation between RT #2 and RT #3.

Subjective Assessment

Overview

Subjective data were also collected for each participant on the test trial of interest (braking event) in Experiment 3. The same procedures as the previous two experiments were followed when collecting this subjective data. The same series of questions (including the Likert-type scales) that were asked in Experiment 1 and Experiment 2 were again used and addressed different aspects of the ICW:

- Attention-getting qualities of the alert
- Timing of the alert
- Situational awareness

- Need for the visual alert
- Previous FCW exposure
- Open-ended comments

It is important to again note that an analysis of the subjective data included all participants that completed testing. This includes participants who reacted to the alert (i.e., valid test trial used for objective data analysis) and participants who reacted before the alert (i.e., invalid test trials not used for the objective data analysis). The participants that reacted before the alert could still provide a useful assessment with regard to the alert. Moreover, they might represent drivers that could potentially experience an ICW alert as they would react in real life and treat the event as a "nuisance" alert. There are compelling reasons for using this other group of participants that might not have conformed to the operational definition for a valid test trial; therefore, the reader is provided with both sets of results (i.e., reacted to alert, reacted before the alert). Note that no alert (i.e., did not receive alert) participants—and, in some instances, participants in the visual alert conditions that reacted before the alert and did not receive the warning—are omitted from questions 1 through 3 given that they did not experience the alert during the event of interest.

Demographics

As mentioned in the previous section, demographics were collected and compiled for all participants (*n* = 81) who completed testing in Experiment 3. The subjective data demographics represent all 81 participants. Across all participants, the mean age was 48.7 years (motorcoach = 48.3 years; truck-trailer = 48.7 years). Seventy-nine participants were male, while two participants were female. All participants had a valid CDL from the state of Virginia, a valid DOT medical card, and no DOT-reportable accidents within the past year. Table 32 presents demographics for the 81 participants who completed testing, while Table 33 provides driving demographics.

Table 32. Participant Demographics per Test Condition

Condition	*n*	Male	Female	Mean Age (years)	SD Age (years)	Minimum Age (years)	Maximum Age (years)
Alert – Truck	30	30	0	48.5	11.6	21	70
No Alert – Truck	21	21	0	49.0	12.3	29	72
Alert – Motorcoach	16	16	0	50.9	17.5	22	73
No Alert – Motorcoach	14	12	2	45.4	18.7	24	73

Table 33. Participant Driving Demographics

Condition	*n*	Mean Experience (years)	SD Experience (years)	Miles/Week	Million Miler (*n*)
Alert – Truck	30	21.9	11.2	1,593	19
No Alert – Truck	21	23.3	15.8	1,665	13
Alert – Motorcoach	16	11.1	11.4	360	3
No Alert – Motorcoach	14	10.3	10.7	477	2

Attention-getting Qualities of the Alert

The first two questions gathered participant input about the attention-getting effects of the auditory alert and the visual display. Only participants receiving the ICW alert (i.e., Alert – Truck, Alert – Motorcoach) provided these ratings.

1. How attention-getting is the auditory alert?
2. How attention-getting is the visual alert?

Figure 54 displays the mean participant ratings of the attention-getting effects the auditory aspect of the ICW alert.

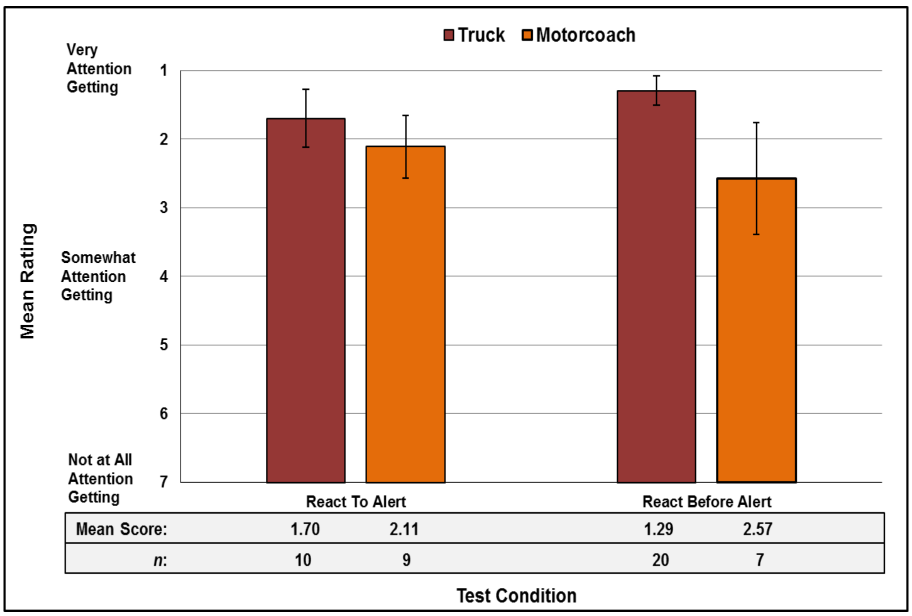

Figure 54. Participant Ratings (with Standard Error Bars) of the Attention-getting Qualities of the ICW Auditory Alert by Vehicle Type

Both truck-trailer combination unit and motorcoach participants that reacted to the alert and those that reacted before the alert gave the attention-getting qualities of the auditory alert similar scores. Participants that reacted to the alert had a mean rating of 1.70 (truck-trailer) and 2.11 (motorcoach), which is approaching "very attention getting." Likewise, participants that reacted before the alert provided mean ratings of 1.29 (truck-trailer) and 2.57 (motorcoach), which is also approaching "very attention getting." To assess if there were any differences in attention-getting ratings by vehicle type and between participants that reacted to the alert and participants that reacted before the alert, a general linear model was applied. No significant effects were found between participants that reacted to the alert and participants that reacted before the alert in the auditory alert attention-getting quality, $F(1, 45) = 0.00$, $p = .954$, $\eta^2 = .00$, or between vehicle type, $F(1, 45) = 0.86$, $p = .359$, $\eta^2 = .02$.

Figure 55 displays the mean participant ratings of the attention-getting effects of the visual aspect of the ICW alert.

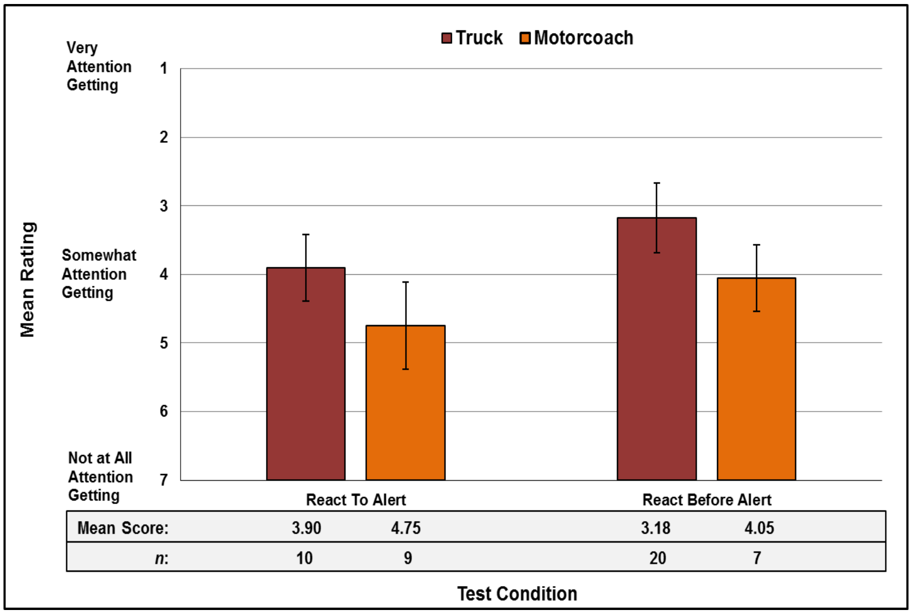

Figure 55. Participant Ratings (with Standard Error Bars) of the Attention-getting Qualities of the ICW Visual Alert by Vehicle Type

Both truck-trailer combination unit and motorcoach participants that reacted to the alert and those that reacted before the alert gave the attention-getting qualities of the auditory alert similar ratings. Participants that reacted to the alert had a mean rating of 3.90 (truck-trailer) and 4.75 (motorcoach), which is in the range of "somewhat attention getting." Likewise, participants that reacted before the alert provided mean ratings of 3.18 (truck-trailer) and 4.05 (motorcoach), which is also in the range of "somewhat attention getting." To assess if there were any differences in attention-getting ratings by vehicle type and between participants that reacted to the alert and participants that reacted before the alert, a general linear model was applied. Although no significant effects were found between participants that reacted to the alert and participants that reacted before the alert in the visual alert attention-getting quality as a whole, $F(1, 45) = 1.31$, $p = .259$, $\eta^2 = .03$, significant effects were found between vehicle types; $F(1, 45) = 7.72$, $p = .008$, $\eta^2 = .26$. Planned comparisons using Tukey's method that were conducted as part of the general linear model indicated a significant effect between motorcoach participants reacting to the alert and truck-trailer combination unit participants reacting before the alert. However, within vehicle type no significant effect was indicated between participants reacting to the alert and those reacting before the alert.

Timing of the Alert

The third question gathered participant input on the timing of the ICW alert.

3. How appropriate is the timing of the alert?

Participants in the no alert condition and those who did not experience the ICW alert were omitted from this analysis.

Figure 56 displays the mean participant ratings of the appropriateness of the timing of the ICW alert by vehicle type.

Figure 56. Participant Mean Ratings (with Standard Error Bars) for the Appropriateness of the Timing of the ICW Alert by Vehicle Type

Similar mean ratings are seen between participants that reacted to the alert (truck [M = 4.00, SE = 0.00]; motorcoach [M = 4.44, SE = 0.34]) and participants that reacted before the alert (truck [M = 4.12, SE = 0.08]; motorcoach [M = 4.33, SE = 0.33]). A general linear model was applied to assess this data and no significant effects were found between participants that reacted to alert and those that reacted before the alert, $F(1, 41) = 0.00$, $p = .987$, $\eta^2 = .00$ or between vehicle type, $F(1, 41) = 0.34$, $p = .562$, $\eta^2 = .01$. These mean ratings and findings indicate that the participants of both the truck-trailer combination unit and the motorcoach deem the timing of the ICW alert as "appropriate."

Situational Awareness

The fourth and fifth questions gathered participant input on their situational awareness while they were performing the secondary task and during the ICW alert activation.

4. Did you see the lead vehicle braking?

5. How quickly did you become aware of what was happening in the event?

Question 4 was answered with a "yes or no" response, while question 5 was answered using a 7-point Likert-type scale (see Figure 44). All participants, including the no alert condition participants, provided feedback for these two questions.

For question 4, of the participants driving the truck-trailer combination that reacted to the alert, 55 percent (11 of 20) did not see the brake lights of the lead vehicle, while only 45 percent (14 of 31) of participants that reacted before the alert did not see the brake lights. Of the participants driving the motorcoach that reacted to the alert, 83 percent (15 of 18) did not see the lights of the lead vehicle, while only 25 percent (3 of 12) of participants that reacted before the alert did not see the brake lights. It is important to understand that the brake lights of the lead vehicle did not remain on for the duration of this event. The brakes were applied only until the lead vehicle slowed to the desired speed (32 km/h). This braking maneuver lasted approximately 1 s. The lead vehicle then continued at 32 km/h for the remainder of the event.

For question 5, Figure 57 provides the mean ratings with regard to how quickly the participants became aware of what was happening in the event in the truck-trailer combination unit.

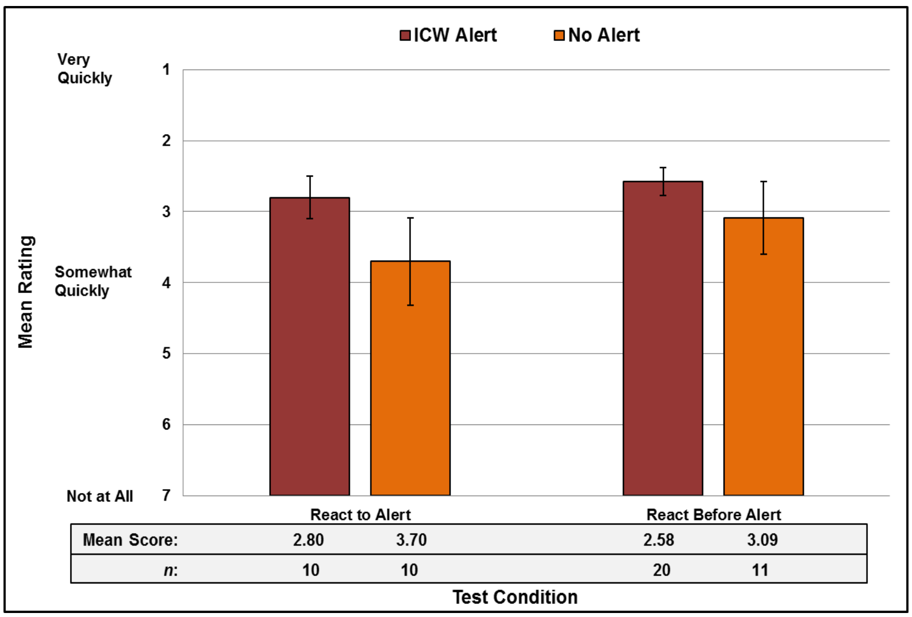

Figure 57. Participant Mean Ratings (with Standard Error Bars) of How Quickly the Participant Became Aware of What Was Happening in the Event (Truck-trailer)

Participants receiving the ICW alert in the truck-trailer combination that reacted to the alert (M = 2.80, SE = 0.30) and reacted before the alert (M = 2.58, SE = 0.19) provided similar ratings. Note that these participants are compared against the no alert condition in Figure 45. Likewise, participants in the no alert condition who reacted after the 3-s TTC (M = 3.70, SE = 0.62) and reacted before the 3-s TTC (M = 3.09, SE = 0.51) also provided similar ratings. A *t*-test was performed to assess if any significance was found between the ICW alert condition and the no alert condition.

- Reacted to the alert versus no alert (after 3-s TTC): $t(17) = -1.12$, $p = .277$, d= .50
- Reacted before the alert versus no alert (before 3-s TTC): $t(16) = -0.87$, $p = .395$, d = .34

No significant effects were found between participants who experienced the ICW alert in the truck-trailer combination unit and the no alert condition (i.e., did not receive an ICW alert). This holds true for participants that reacted to the alert (no alert = after 3-s TTC) and those that reacted before the alert (no alert = before 3-s TTC).

Figure 58 provides the mean ratings with regard to how quickly the participants became aware of what was happening in the event in the truck-trailer combination unit.

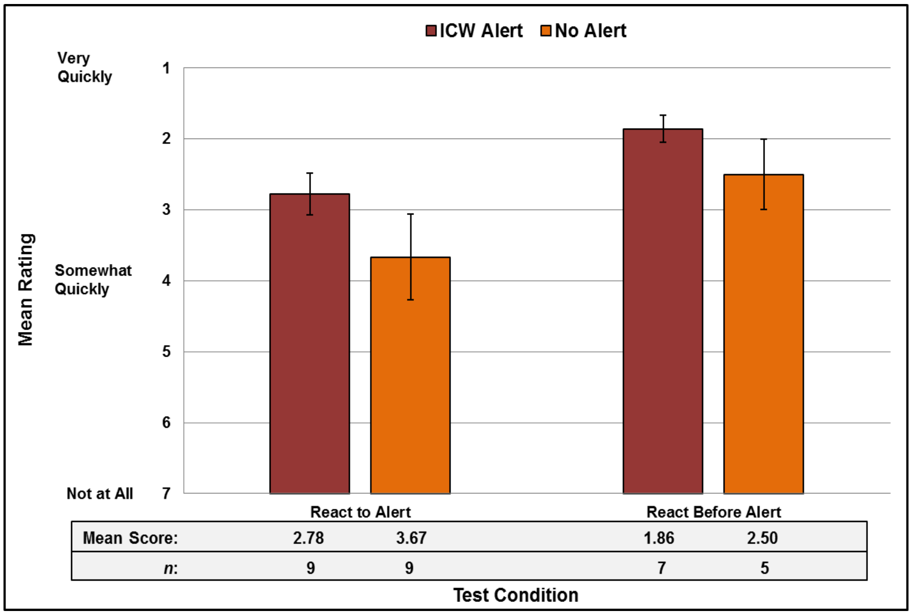

Figure 58. Participant Mean Ratings (with Standard Error Bars) of how Quickly the Participant Became Aware of What Was Happening in the Event (Motorcoach)

Conversely, participants receiving the ICW alert in the motorcoach that reacted to the alert (M = 2.78, SE = 0.49) and reacted before the alert (M = 1.86, SE = 0.26) provided dissimilar ratings. Note that these participants are compared against the no alert condition in Figure 58. Likewise, participants in the no alert condition who reacted after the 3-s TTC (M = 3.67, SE = 0.61) and reacted before the 3-s TTC (M = 2.50, SE = 0.50) also provided similar ratings. A *t*-test was performed to assess if any significance was found between the ICW alert condition and the no alert condition.

- Reacted to the alert versus no alert (after 3-s TTC): $t(15) = -1.14$, $p = .274$, d= .83
- Reacted before the alert versus no alert (before 3-s TTC): $t(6) = -1.14$, $p = .298$, d = .98

No significant effects were found between participants who experienced the ICW alert in the motorcoach and the no alert condition (i.e., did not receive an ICW alert). This holds true for participants that reacted to the alert (no alert = after 3-s TTC) and those that reacted before the alert (no alert = before 3-s TTC).

Need for a Visual Alert

The sixth question gathered participant input on the need for the visual aspect of the ICW alert.

6. Do you feel that a visual alert is needed?

This question was answered with a “yes or no” response. Note that participants in the no alert condition are omitted from this question as they did not experience the alert.

Overall, 65 percent of the participants felt a visual alert is necessary. Table 34 provides a breakdown between reaction and vehicle type.

Table 34. Participant Responses by Reaction and Vehicle Type for Visual Alert Necessity

Condition	*n*	Visual Alert Needed	No Visual Alert
React to the Alert – Truck	10*	6 (75%)	2 (25%)
React Before the Alert – Truck	20*	11 (61%)	7 (39%)
React to the Alert – Motorcoach	9	5 (55%)	4 (45%)
React Before the Alert – Motorcoach	7	5 (71%)	2 (29%)

*** Note that four participants were unsure and did not answer this question.**

Prior FCW Exposure

The seventh question gathered participant input on any prior experience with an FCW in a heavy vehicle.

7. Have you previously driven a heavy vehicle equipped with a forward collision warning system?

This question was answered with a “yes or no” response. Participants responding with a “yes” then provided the name of the system. In some cases, participants could not remember the brand of FCW system they had previously experienced. Note that participants in the no alert condition are omitted.

No participants driving the motorcoach had ever previously experienced an FCW in a heavy vehicle. For participants driving the truck-trailer combination unit, 3 of the 10 (30%) participants who reacted to the alert had previously experienced an FCW system in a heavy vehicle, while 5 of the 20 (25%) participants that reacted before the alert had previously experienced an FCW system in a heavy vehicle.

Open-ended Comments

Participants were shown the visual alert and listened to the auditory alert again while the truck was parked. Participants were then given the opportunity to provide open-ended comments about the different aspects of the visual alert and the auditory alert, such as:

- Size of the visual image
- Background color
- Text color
- Car/truck or bus image color
- Loudness of the auditory alert

- Duration of the auditory alert
- Type of sound used

Participant responses were categorized and then descriptive statistics were calculated. Note that this includes all participants.

When responding about the visual alert, 77 percent (23 of 30) of the motorcoach participants and 77 percent (37 of 48) of the truck-trailer combination unit participants felt the size of the visual image was appropriate. When it comes to the background color, 97 percent (29 of 30) of the motorcoach participants and 92 percent (44 of 48) of the truck-trailer combination unit participants felt the background color of red was the correct color to use. Comparable to Experiment 1 and Experiment 2, a number of these participants stated that red means stop, danger, and/or warning. Similarly, 90 percent (27 of 30) of the motorcoach participants and 98 percent (47 of 48) of the truck-trailer combination unit participants felt the text color of white was good as it contrasts very well with the red background. Only 47 percent (14 of 30) of motorcoach participants felt the black color used for the images of the car and bus was appropriate, while 85 percent (41 of 48) of truck-trailer combination unit participants felt it was appropriate. Similar to the other experiments, several additional comments of interest were provided by more than one participant: (1) make the visual alert flash, (2) make the visual alert last until the foot is on the brake, and (3) move the visual alert to a different location (responses ranged from A-pillar to center stack).

When responding about the auditory alert, 63 percent (19 of 30) of motorcoach participants and 79 percent (38 of 48) of truck-trailer combination unit participants felt the duration of the auditory alert was sufficient. As for the loudness of the auditory alert, 83 percent (25 of 30) of motorcoach participants and 79 percent (38 of 48) of truck-trailer combination unit participants felt it was appropriate. As was seen in Experiment 1, five participants stated that the auditory alert should override the radio. The auditory alert sound was reported by 97 percent (29 of 30) of motorcoach participants and 96 percent of (46 of 48) truck-trailer combination unit participants as appropriate. Similar to the visual alert, a number of participants commented that the audio alert should last until the TTC is greater than 3 s.

Experiment 3 Discussion

Research Question #3 (Experiment 3): Based on the findings of Research Questions 1 and 2, is there a benefit in terms of reaction time, to the final design ICW alert over a no alert condition? Are the results obtained for Class 8 truck drivers applicable to motorcoach drivers?

Experiment 3 was conducted to study the final design visual and auditory components of an ICW for a rear-end event (as identified in Experiment 1 and Experiment 2) in a motorcoach. Motorcoaches present a unique set of challenges when compared to a truck-trailer combination unit. Driver reaction due to passenger transport conditions may be different in terms of responses to the alert based on the type of vehicle as well. Therefore, it was important to study both types of platforms in order to be able to generalize the results obtained under Experiments 1 and 2 to the motorcoach driving environment. Additionally, the driver's area in a motorcoach has some notable differences (e.g., much larger windshield area) which could also influence responses and reaction times. The ICW was designed following guidelines from Campbell et al. (2014). However, it is important to understand that while to visual alert component was mounted as high as possible (i.e., above the speedometer and tachometer) on the IP in the motorcoach similar to current OEMs, it did not fall within the 15 degree vertical and horizontal line of sight for the driver. The same scenarios used in Experiment 1 and Experiment 2 were also used for this experiment. The test conditions of interest for this experiment were:

- Final design ICW alert from previous experiments in a truck
- No alert (i.e., baseline) in a truck
- Final design ICW alert from previous experiments now presented in a motorcoach
- No alert (i.e., baseline) in a motorcoach

The results for this research effort consider three aspects in the evaluation of an ICW: (1) first response, (2) reaction time, and (3) subjective assessment.

First Response

Similar to the first two experiments, the first response to the ICW alert was categorized in one of three ways: (1) look to the forward roadway, (2) look to the visual alert, or (3) lift foot from the throttle.

After the ICW alert was presented, looking towards the roadway was the first response for the majority (89 percent) of the participants. That reaction was followed by lifting the foot from the throttle (95 percent) as the second most common response. For Experiment 3 the proportion of participants looking at the display/IP area as their first response was 11 percent; however, participants driving the truck-trailer combination unit account for this total as no participants driving the motorcoach glanced to the display/IP area as their first response. This could potentially suggest (for the experimental tasks performed in this study) that the larger windshield area and more windows in general allow the driver to see a greater forward field-of-view more quickly. On the motorcoach the windshield area is bigger and the display/IP sits lower (greater than 15 degrees) than where the display/IP would be located in the truck-trailer combination. Another potential is the increase in light within the driver's area that may reduce the perceived luminance of the visual alert, especially on clear, sunny days. Further, one other possible explanation is the perceived increase in risk when transporting passengers. It is important to note, though, that two of the motorcoach participants looked at the visual display as their third response.

The results of Experiment 3 further suggest that the visual component of the ICW should be delayed in order to ensure the appropriate response order (i.e., for this particular set of experiments looking forward and then releasing the throttle). Accordingly, if the visual component of the ICW is presented in the IP, it should only provide a confirmation of the event and why an alert was provided. Figure 59 provides a breakdown of percentages of first, second, and third responses when first reacting to the ICW alert.

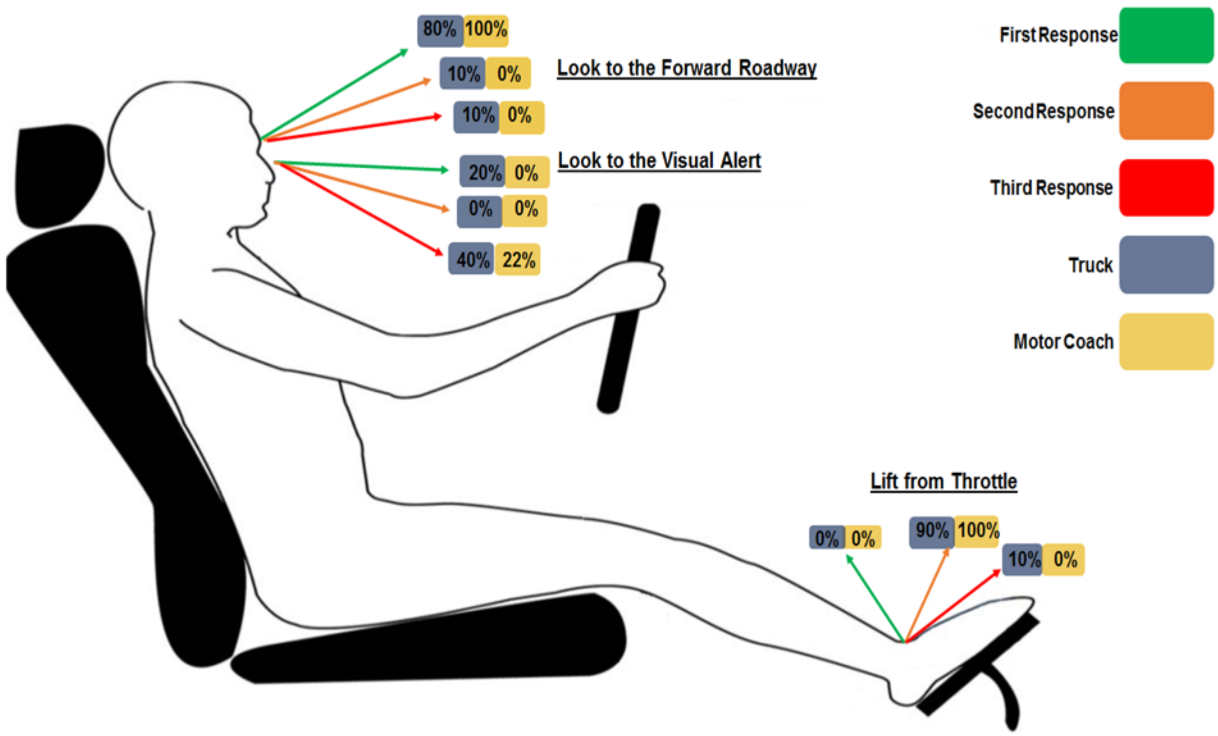

Figure 59. Percentage of Participant Responses per Location

Reaction Time

As previously mentioned, an ICW can elicit multiple reactions, but the main goal should be to draw the driver's attention to the forward roadway and potentially begin decelerating depending on the event unfolding in front of them. Similar to the previous experiments conducted in this study, Experiment 3 looked at three different reaction times: (1) Look Forward, (2) Throttle Release, and (3) Depress Brake. While somewhat unsurprising, no significant differences in driver reaction time were found between vehicle type (i.e., motorcoach and truck-trailer combination unit). Most of the drivers' (89 percent) first reaction was looking to the forward roadway, which occurred within 0.33 s of the point in time when the ICW was presented. Drivers of the truck-trailer combination unit as a whole had a quicker look-forward reaction of 0.10 s versus drivers of the motorcoach with a 0.33 s reaction; however, this difference is not statistically significant.

Overall, drivers that were presented with an ICW during the potential rear-end event were able to start releasing the throttle, on average, 0.42 s (47 percent) quicker than the drivers that did not receive an alert. Participants of both the motorcoach (0.50 s; 46 percent quicker) and truck-trailer combination unit (0.45 s; 48 percent quicker) were able to release the throttle significantly quicker than participants who did receive an ICW alert.

For the braking reaction time, once the ICW was presented, drivers began braking within 1.24 s. This was not statistically different from the no alert condition (1.68 s). As previously mentioned in the first two experiments, other external factors that the drivers were taking into consideration as they evaluated the rear-end events that were evolving (e.g., weather, roadway type, trailer load, perceived urgency) should be taken into consideration when these results are compared against other studies.

Subjective Assessment

The subjective assessment in Experiment 3 provided very similar results to the first two experiments. Both motorcoach and truck-trailer combination unit drivers experiencing the best-performing auditory and visual ICW alert during the study provided a positive assessment. The ICW was considered attention-getting. The auditory component of the alert was the portion of the alert that was rated as having the highest impact on capturing the driver's attention. Moreover, the motorcoach drivers provided assessments on par with drivers of the truck-trailer combination unit. An auditory alert of a 1.10-s duration and 87 dB (15 dB above the cabin noise plus music level) was deemed fitting for the condition tested. In terms of the ICW's timing, the ICW at 3-s TTC was deemed appropriate. Similar to Experiment 1 and Experiment 2, just over half the participants thought the visual alert component was necessary. An overwhelming majority supported the use of a red background to elicit a high-urgency mental model in the context in which it was evaluated (e.g., stop, danger). In addition, the selected icon, with an image size of 47.625 mm × 47.625 mm, and the level of contrast were deemed appropriate by the majority of the participants.

Experiment 3 Conclusion

Experiment 3 used the earlier findings of this study in a truck-trailer combination unit in identifying the final design auditory component and visual component of an ICW alert and then applied those findings to a motorcoach platform. Experiment 1 examined three different auditory muting conditions (immediate, preemptive, and none). While the preemptive and no muting auditory muting conditions produced quicker reaction times than no ICW alert, there was no significant difference in reaction time between the three auditory muting conditions. Therefore, considering the implementation process and practicality from an OEM standpoint, the no muting condition was deemed the appropriate auditory condition as this would be the simplest and least expensive to implement. Experiment 2 examined three visual alert conditions (simple, complex, and none). Just as with the auditory component of the ICW, all three visual alert conditions produced quicker reaction times than no ICW alert; however, there was no significant difference in reaction times between the three visual alert conditions. Following the current design principles that suggest a visual component should be included as part of an ICW alert and keeping in line with the auditory component regarding ease and cost of implementation, the simple visual alert was carried into the current experiment. Thus, an ICW alert consisting of a simple visual alert combined with an auditory alert that does not mute any cabin sounds was utilized in the motorcoach. The motorcoach reaction times were cross-analyzed with truck-trailer combination unit reaction times to determine if any effects are evident based on vehicle type.

Driver response and reaction times in the motorcoach followed similar trends that were found in the truck-trailer combination unit. These trends continued to confirm that an ICW will enhance reaction. The first initial response of drivers in the motorcoach and truck-trailer combination was to look to the forward roadway, which is the primary goal of an ICW alert. No motorcoach driver looked to the visual alert or released the throttle as their first response, while two drivers in the truck-trailer combination did look to the visual alert as the first response to the ICW alert. Overall, the majority of drivers performed the optimal first response of looking to the forward roadway. However, the goal is to redirect all drivers' attention from the task they were performing back to the forward roadway in order to assess and mitigate any rear-end potential conflict. One potential means to ensure that the driver's first response is looking to the forward roadway is to present the visual component in a delayed manner with respect to the auditory component. It is important to note that the Experiment 2 condition in which drivers did not receive a visual alert did not have any negative consequences or increase the reaction times of interest. The second most common response was to release the throttle. When assessing the reaction time of releasing the throttle, drivers were able to shorten their reaction time by 47 percent compared to drivers that were not presented with an ICW alert. Drivers of both the motorcoach and truck-trailer combination unit had an overall positive response to the alert. Another important finding is that vehicle type did not affect driver response or reaction times. While the driver's area of a motorcoach has a different layout and ergonomic design compared to a truck-trailer combination unit and the inherent work responsibilities differ, these findings indicate that an ICW alert elicits enhanced reaction time to a potential rear-end event regardless of vehicle type (as tested in this study).

As noted in the previous two experiments, this research effort evaluated driver performance and subjective assessment only when the ICW was presented during a real rear-end potential conflict (i.e., no false alarms). If the false alarm rate increases, this could potentially impact the drivers' subjective assessment and their reaction time.

CHAPTER 6. CONCLUSIONS

RESEARCH OVERVIEW

The goal of this research effort was to evaluate HV-CWIs in both heavy trucks and motorcoaches. The scope of this effort examined the visual and auditory alerts of an ICW. In order to evaluate ICWs, three separate experiments were designed that explored the two different alert components (visual and auditory) as well as two different vehicle types. Auditory and visual alerts represent unique components of an HV-CWI. The results from this research effort inform design principles as well as OEMs and product engineers that seek to implement these systems into current and future heavy vehicles.

Three different experiments were performed with each experiment addressing a single research question. Experiment 1 was an evaluation of the auditory alert component of an ICW alert using a Class-8 truck-trailer combination unit. This experiment focused on the effects of muting (or not muting) secondary audio sources on driver performance during an ICW. Experiment 2 was an evaluation of the visual alert component on driver performance during an ICW in a Class-8 truck-trailer combination unit, with the best-performing auditory condition identified in Experiment 1 used as the auditory component of the alert presented. This experiment focused on the effects of visual alert complexity and any consequences of not having a visual alert. Experiment 3 was an examination of the best-performing conditions from Experiment 1 and Experiment 2 in a Class-8 truck-trailer combination unit and a motorcoach. Figure 60 provides of flow chart of this experimental design.

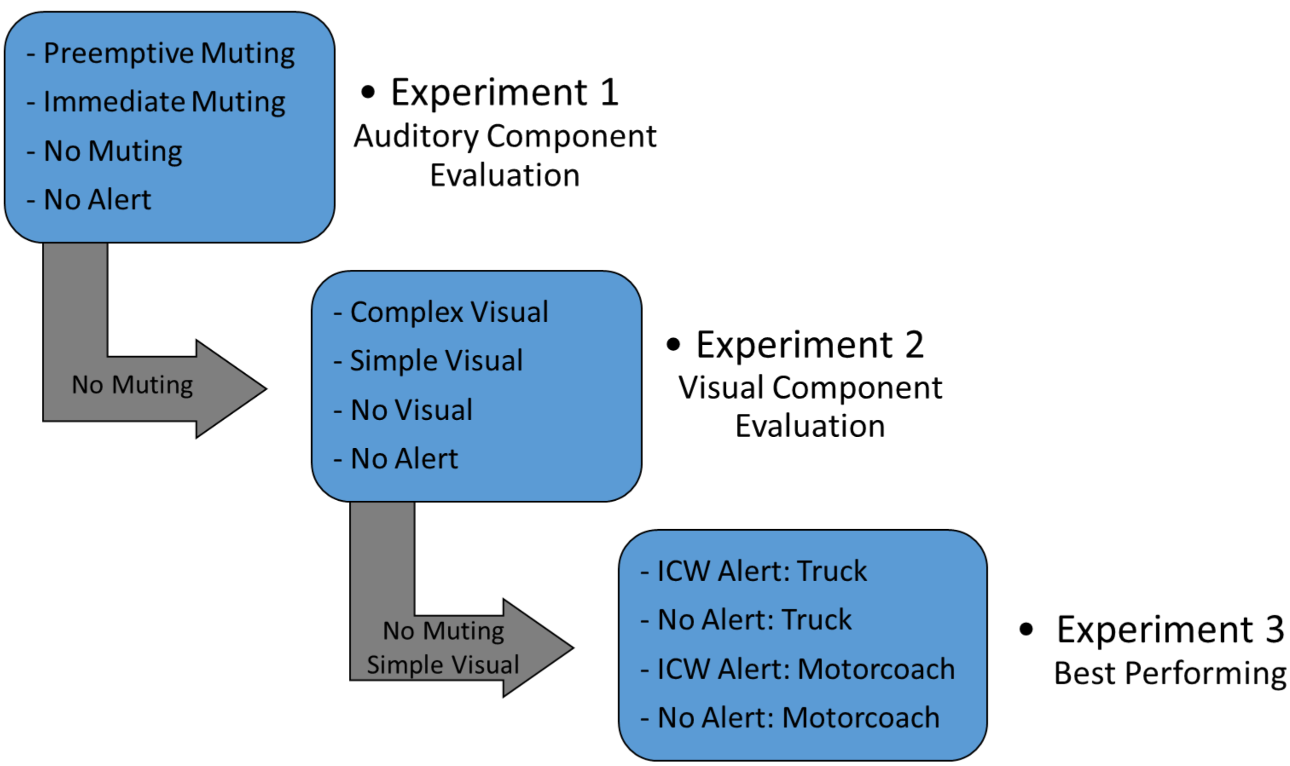

Figure 60. Flow Chart of the HV-CWI Project Experimental Design

Each experiment assessed two primary measures of interest. The first measure of interest was the driver's response to the ICW alert. The driver's first, second, and third responses were categorized in one of three ways.

- Look to the forward roadway
- Look to the IP/visual alert
- Lift foot from the throttle

The second measure of interest was the driver's reaction times to the ICW alert. Data were collected from four different points in time and used to calculate three reaction times. The first point in time recorded was when the ICW alert was triggered. Note that participants in the no alert condition (no alert) did not receive the ICW alert. Therefore, the 3.0-s TTC was used as the trigger. The second point in time recorded was when the participant first glanced to the forward roadway. The third point in time recorded was when the participant first lifted his/her foot off the throttle. The fourth point in time recorded was when the participant depressed the brake pedal.

Using the four recorded points in time, three different reaction times have been analyzed:

- RT #1 – Look Forward: The first reaction time was the length of time from when the ICW alert was triggered to when the participant first glanced to the forward roadway.
- RT #2 – Throttle Release: The second reaction time was the length of time from when the ICW alert was triggered to when the participant first lifted his/her foot from the throttle (i.e., the point of initial deceleration).
- RT #3 – Depress Brake: The third reaction time observed was the length of time from when the ICW alert was triggered to when the participant first depressed the brake pedal.

Figure 13 (provided previously in Chapter 3) depicts the four recorded points in time and the three reaction times measured.

RESEARCH QUESTIONS

The following research questions were developed to address the focus of this research effort and include a summary of the findings.

Research Question #1

Research Question #1 (Experiment 1): In terms of reaction time, is there a benefit to muting secondary audio sources during an imminent collision warning (ICW) alert?

This first experiment indicates that an ICW will enhance reaction time for releasing the throttle, which is the first action to begin slowing the vehicle. Overall, the first initial response to the alert was to look forward for the majority of drivers. This is a critical response with regard to understanding a potential conflict as quickly as possible and acting accordingly. The second most prevalent response was to release the throttle. While these two responses are the desired effect, respectively, some instances existed where the driver's first response was to look at the IP/visual alert. This creates the potential for a delayed reaction time as the driver comprehends what the visual alert is conveying before looking forward and then taking the necessary action.

When evaluating the reaction time of drivers releasing the throttle (RT #2), enhanced reaction times by over 40 percent were seen compared to drivers that did not receive an ICW alert. This even includes the drivers that looked to the IP/visual alert first; however, taking that into consideration and removing the drivers that looked to the IP/visual alert first, the enhanced reaction times would be 56 percent quicker compared to drivers that did not receive the ICW alert. Drivers had an overwhelmingly positive response to the alert. The auditory component of the alert was a replication of CAMP sound #8 that contains an alternating fundamental frequency of 309 Hz and a peak frequency of 2,513 Hz. The auditory alert has a loudness of 87 dBA, duration of 1.10 s, and is provided through two overhead speakers. However, contrary to what would have been expected, muting other audio sources did not significantly enhance reaction time. On the contrary, in some instances muting delayed the reaction times of interest due to the driver looking at the IP area before looking forward. Therefore, if a simpler implementation of the auditory component of the alert is feasible, there is no need to mute other sources of noise. This statement assumes that a 15-dB difference is maintained between the noise source and the ICW. Subsequent experiments implemented the ICW without muting the additional audio sources (i.e., music).

Research Question #2

Research Question #2 (Experiment 2): In terms of reaction time, is there a benefit to providing drivers a simpler visual ICW alert (providing minimal information) over a more complex ICW alert (providing more in-depth information), or is having no visual alert the most effective method?

Experiment 2 continued to confirm that an ICW will enhance reaction time for releasing the throttle. Just as in Experiment 1, the majority of drivers' first initial response to the alert was to look forward, which is the desired effect in the case of a distracted driver that is about to encounter a potential rear-end event. The second most prevalent response was again to release the throttle. The potential exists for increased reaction times due to drivers looking to the IP/visual alert as their first response, as was seen in Experiment 1. This occurred again in Experiment 2 at close to the same rate.

When evaluating the effect of the ICW during that period of time (i.e., from event time until the throttle was released), the drivers that had an ICW were able to enhance their reaction time by 55 percent when compared to the drivers that were not presented with an alert. When removing the drivers that looked to the IP/visual alert, enhanced reaction time increased by 59 percent when compared to drivers that did not receive an ICW alert. Drivers continued to have an overwhelmingly positive response to the alert. The visual component of the alert consisted of a red background, a black vehicle-crash icon, and white text stating "Brake Now." The visual alert was 47.625 mm × 47.625 mm in size and located within 15 degrees of both the vertical and horizontal line-of-sight of the driver. These visual characteristics conform to the SAE J2400 standard, which states a red background should be used for an imminent warning. A very interesting finding for this experiment was the fact that there is no difference in terms of reaction time when the ICW includes a visual component versus when it is suppressed during the rear-end event onset. Not having a visual display did not present any unintended consequences or increase the reaction times of interest. It is not suggested that all visual components be eliminated. The information they provide is very important to the driver's mental model (to ensure they understand why the CWS was presented). Moreover, suppressing the visual/informational component might not be the best case for a real-world application when nuisance alerts and false alerts are present (i.e., a visual component might help the driver understand why the auditory component was presented and avoid unnecessary search). Therefore, the visual display component is suggested as an informational component of the alert and not as a time-sensitive one (i.e., not needed simultaneously when the auditory component is presented). It could be hypothesized that delaying the visual component of the ICW should improve reaction times given that the first response schema presented above will change to 100 percent of the participants looking forward and quickly recognizing the evolving rear-end event instead of looking at the visual display.

However, manipulating delays for the visual alert portion was not part of the scope of this research effort, and current design principles suggest including a visual component. Therefore, if a simpler implementation of the ICW is feasible, that combination should always be selected. From the current experiment, we learned that a simple visual display should suffice. Therefore, subsequent experiments implemented the ICW auditory alert without muting the additional audio sources (i.e., music) and used a simple visual alert as the final design ICW condition.

Research Question #3

Research Question #3 (Experiment 3): Based on the findings of Research Questions 1 and 2, in terms of reaction time, is there a benefit to the final design ICW alert over a no alert condition? Are the results obtained for Class 8 truck drivers applicable to motorcoach drivers?

Experiment 3 used the earlier findings of Experiment 1 and Experiment 2 and applied them in a motorcoach setting. Therefore, an ICW auditory alert without muting additional audio sources (i.e., music) and a simple visual alert were implemented for this experiment. Results were compared to the ones previously obtained from the truck-trailer combination unit to determine if vehicle type influences driver response and reaction times to the presentation of an ICW alert or the lack thereof.

All motorcoach drivers looked to the forward roadway as their first response to the ICW alert. Further, all motorcoach drivers then lifted their foot from the throttle as their second response. Only two motorcoach drivers looked to the IP/visual alert as their third response.

When assessing the reaction time of releasing the throttle, motorcoach drivers were able to shorten their reaction time by 46 percent compared to drivers that were not presented with an ICW alert. Drivers of the motorcoach had an overall positive response to the alert similar to drivers of the truck-trailer combination unit. Another important finding is that vehicle type did not affect driver response or reaction times. While the driver's area of a motorcoach has a different layout and ergonomic design compared to a truck-trailer combination unit and the inherent work responsibilities differ, these findings indicate that an ICW alert elicits similar enhanced reaction times to a potential rear-end event regardless of vehicle type (as tested in this study).

DESIGN IMPLICATIONS

In summary, the following characteristics represent the simplest version of an effective FCW for an imminent crash warning condition based on the research this effort's research findings:

- Visual Component (simple visual alert; Figure 61 [prototype visual icon used in this study])
- Auditory Component (auditory alert, cabin sounds not muted, presented 15 dB above ambient sound level)

Figure 61. Simple Visual Alert

All experiments suggest that the presence of an FCW during a crash imminent condition could improve their reaction time (throttle release) up to 59 percent. This is a key finding given that is the first reaction that will actually impact the vehicle's trajectory and assist in preventing an evolving rear-end event. It is important to note that this improvement does not include cases where the participants looked at the visual/informational display first and the natural chain of events (i.e., look at forward roadway and then release throttle) is delayed. If drivers look up but do not release the throttle quickly, the start of the vehicle's deceleration will be delayed, potentially increasing the likelihood of a safety-critical event. The brake reaction time could potentially be impacted by how the driver perceives the vehicle is reacting (i.e., if enough deceleration is attained by just releasing the throttle). As conducted in this study, no statistical difference in brake response times was observed between drivers that received an ICW alert and drivers that did not, although throttle release reaction times were significantly quicker for those receiving an ICW alert. Results from the configurations studied herein suggest brake reaction times were comparable to those obtained in field operational tests. The reader is encouraged to compare these results based on the testing conditions implicated under the circumstances that rear-end events occur.

As part of the Integrated Vehicle-Based Safety System (IVBSS) FOT, Bao et al. (2012) observed very similar brake reaction times (1.62 seconds) for CMV drivers receiving an ICW alert. However, their reaction time was statistically different from the no alert condition for CMV drivers (1.88 s). Potentially, the higher reaction times during the no alert for Bao et al. could be due to other external factors that the drivers were taking into consideration as they evaluated the rear-end events that were evolving (e.g., weather, roadway type, trailer load, perceived urgency). Moreover, it is known that alert drivers overestimate their headway (Taieb-Maimon and Shinar, 2001). Depending on the conditions, drivers might have believed they had more time to brake, whereas in the current research effort it was evident that immediate action was required once they glanced back to the roadway. Bao et al. (2012) does not describe the throttle response in order to compare the time the CMV drivers noticed the potential threat and when they decided to start reacting. If drivers were engaged in more distracting tasks, that could potentially account for the increased reaction time. For the current study, the distraction tasks were moderate.

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APPENDIX A. PARTICIPANT QUESTIONNAIRE

Virginia Tech Transportation Institute
HV-CWI Questionnaire

General Information:

Date: ____________
Gender: ____________
Age: ____________
CDL Expiration: ____________
State of Issuance: ____________
Medical Card Expiration: ____________

Driving History:

1. How many years have you been a commercial motor vehicle operator?
   ____

2. Are you a million mile driver? **YES** or **NO**

3. How many at-fault accidents have you had while driving a commercial motor vehicle?
   ____

4. Please circle any of the endorsements that are currently valid on your CDL:

   Doubles/Triples
   Tanker
   Hazardous
   Passenger
   School Bus

5. Please describe the following:

   a. Hours driven per week: ____________________________

   b. Miles driven per week: ____________________________

6. Please classify your current or most recent employment driving a commercial motor vehicle:

   a. Vehicle type:
      i. Class 8 truck with trailer

ii. Motorcoach bus
iii. Transit bus
iv. School bus

b. Distance:
   i. Long-haul/national (over 500 miles per trip)
   ii. Short-haul/regional (between 50 and 499 miles per trip)
   iii. Local/delivery (less than 50 miles per trip)

c. Type of operation (select one):
   i. For Hire Truckload
      (Company hired to haul other company's goods, e.g. Schneider)
   ii. For Hire Less-Than-Truckload (LTL)
      (Company hired to haul other company's goods that are generally 10,000lbs or less, e.g. Old Dominion)
   iii. Private fleet
      (Company that hauls own goods, e.g. Wal-Mart)
   iv. Line-haul
      (Travels from terminal to terminal, no pick-up/delivery, e.g. Pitt Ohio)
   v. Passenger transport

7. Have you ever been employed at a trucking or bus company in a position other than driver?
   YES or **NO**

   If yes, please describe:____

Trial 3

Please answer each question by selecting a number on the scale that best reflects your response. Half numbers, such as 4.5, are also acceptable.

1. How common is it for you to experience a distraction such as you just experienced in your normal driving?

1		3		5		7
Very Common			Occasional			Very Rare

2. Do you feel your driving performance was changed while performing this task?

1		3		5		7
Very			Somewhat			Not at All

3. How likely would you be to perform this task while driving in normal traffic?

1		3		5		7
Very			Somewhat			Not at All

Trial 4

Please answer each question by selecting a number on the scale that best reflects your response. Half numbers, such as 4.5, are also acceptable.

1. How common is it for you to experience a distraction such as you just experienced in your normal driving?

1		3		5		7
Very Common			Occasional			Very Rare

2. Do you feel your driving performance was changed while performing this task?

1		3		5		7
Very			Somewhat			Not at All

3. How likely would you be to perform this task while driving in normal traffic?

1		3		5		7
Very			Somewhat			Not at All

Trial 5

Please answer each question by selecting a number on the scale that best reflects your response. Half numbers, such as 4.5, are also acceptable.

4. How common is it for you to experience a distraction such as you just experienced in your normal driving?

1		3		5		7
|	|	|	|	|	|	|
Very Common			**Occasional**			**Very Rare**

5. Do you feel your driving performance was changed while performing this task?

1		3		5		7
|	|	|	|	|	|	|
Very			**Somewhat**			**Not at All**

6. How likely would you be to perform this task while driving in normal traffic?

1		3		5		7
|	|	|	|	|	|	|
Very			**Somewhat**			**Not at All**

Trial 6

Please answer each question by selecting a number on the scale that best reflects your response. Half numbers, such as 4.5, are also acceptable. **(If this is the no alert condition skip questions 1, 2, & 3)**

1. How attention-getting was the sound of the alert?

1		3		5		7
Very			Somewhat			Not at All

2. How attention-getting was the visual display for the alert?

1		3		5		7
Very			Somewhat			Not at All

3. How appropriate was the timing of the alert?

1		3		5		7
Too Early			Appropriate			Too Late

4. Were you aware of the lead vehicle braking?

Yes / No

5. How quickly did you become aware of what was happening in the event?

1		3		5		7
Very			**Somewhat**			**Not at All**

6. Where was the side vehicle when the lead vehicle was braking?

Response:

7. Do you feel the visual alert was needed?

Yes / No

8. Have you previously driven a heavy vehicle equipped with a forward collision warning system?

Yes / No

If yes, please describe the name of system and the type of alert(s) issued:

9. We would like your input on the visual alert icons you may have encountered during the study (Hand participant sheet with alert icons). Please take your time and provide input on the following:

Size:

Background color:

Text color:

Image color:

Additional comments:

10. We would also like your input on the auditory alert you may have encountered during the study (Play the auditory alert). Please take your time and provide input on the following:

Duration of alert:

Loudness of alert:

Sound of alert:

Additional comments:

11. I am going to name and describe different alert types that could occur. For each, please let me know if it could be the same alert as the forward collision warning, or should be different from the forward collision warning alert.

a. **Blind spot warning, which warn a driver when they try to change lanes if there is a car in the blind spot.**

Visual: Same as FCW Alert / Unique Alert

Auditory: Same as FCW Alert / Unique Alert

b. **Electronic emergency brake lights, which notify a driver when a vehicle ahead of them is braking hard.**

Visual: Same as FCW Alert / Unique Alert

Auditory: Same as FCW Alert / Unique Alert

c. **Do not pass, which warn drivers if they attempt to change lanes and pass when there is a vehicle in the opposing lane within the passing zone.**

Visual: Same as FCW Alert / Unique Alert

Auditory: Same as FCW Alert / Unique Alert

d. **Lane departure assist, which warn a driver when the vehicle begins to move out of its lane unless a turn signal is on in that direction.**

Visual: Same as FCW Alert / Unique Alert

Auditory: Same as FCW Alert / Unique Alert

e. **Control loss warning, which warns drivers when they are about to lose control of the vehicle.**

Visual: Same as FCW Alert / Unique Alert

Auditory: Same as FCW Alert / Unique Alert

f. **Intersection movement assist, which warns the driver when it is not safe to enter an intersection, for example, when something is blocking a driver's view of opposing traffic.**

Visual: Same as FCW Alert / Unique Alert

Auditory: Same as FCW Alert / Unique Alert

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