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Deborah L. Bakowski
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REACTION TIME AND GLANCE BEHAVIOR OF VISUALLY DISTRACTED
DRIVERS TO AN IMMINENT FORWARD COLLISION AS A FUNCTION
OF AUDITORY WARNING, FORWARD COLLISION WARNING
SYSTEM TRAINING, AND GENDER

Thesis

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The Degree

Master of Arts in Psychology

by

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May 2010

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ABSTRACT

REACTION TIME AND GLANCE BEHAVIOR OF VISUALLY DISTRACTED DRIVERS TO AN IMMINENT FORWARD COLLISION AS A FUNCTION OF AUDITORY WARNING, FORWARD COLLISION WARNING SYSTEM TRAINING, AND GENDER

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Advisor: Dr. Susan Davis

Rear-end collisions accounted for approximately 1.8 million, or 30%, of all police-reported crashes in 2006. Using forward-looking radar, Forward Collision Warning (FCW) systems can mitigate rear-end collisions by alerting drivers to an imminent forward collision. Because visual distraction is a primary contributing factor in rear-end crashes, the FCW system must be optimized to alert drivers who are inattentive to the forward scene. Based on auditory warning research, the present research hypothesized that the effectiveness of the tonal alert can be improved with increased perceived-urgency and an auditory icon. Evidence from anti-lock brake systems (ABS) suggests that interaction with vehicle technology also improves with system knowledge. The present

study examined the effect of, (a) FCW training, (b) auditory warning type, and (c) gender, on a visually distracted driver's response to an unexpected, forward collision threat, in a driving simulator. Through an increase in eyes-forward-time and an understanding of the FCW alerts, training produced dramatic improvements in glance behavior, reaction times (RT), and collision statistics, with 47% fewer glances-back to the console and 68% fewer collisions. Gender by training interactions suggest that women may benefit more from training than men. While the car horn warning produced similarly robust glance, RT, and collision benefits, it was the highest-urgency warning which resulted in the fastest initial glance to the forward scene. The car horn and highest-urgency warnings increased ratings of *understandability* and *safety*. Glances-back resulted in longer RTs, a shorter minimum time to collision (minTTC), a 63% increase in collisions, and a fourfold increase in collision velocity. Results suggest that even brief training can aid interaction with an FCW system, glance behavior and RTs can improve with the use of an auditory icon as the auditory warning, and that uninterrupted forward attention during a collision threat is imperative for an effective collision avoidance response. In addition to on-road testing, whether the car horn will continue to outperform the highest-urgency warning when the forward threat is immediately visible requires further investigation.

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LIST OF ACRONYMS

- ACC – Adaptive Cruise Control.
- ART – Accelerator Release Time; difference between lead-vehicle braking and accelerator release.
- BRT – Brake Reaction Time; difference between the lead-vehicle braking and the participants' initial contact with brake pedal.
- BRT50% – difference between the lead-vehicle braking and the participant depressing the brake pedal 50% of its total distance of travel.
- Collision Velocity (m/s) –
- 1) velocity of following (striking) vehicle at the moment of collision with lead (struck) vehicle, or
 - 2) velocity of following (striking) vehicle at the moment of collision with lead (struck) vehicle, had the host not steered around the lead-vehicle.
- CWS – Collision Warning System.
- DOT – Department of Transportation.
- FCW – Forward Collision Warning.

- GRT – Glance Reaction Time; elapsed time between the lead-vehicle braking and the driver's first forward glance.
- HUD – Head-up display. A virtual image with an approximate focal point above the front bumper.
- IIHS – Insurance Institute for Highway Safety.
- LVM – Lead-Vehicle Moving.
- LVS – Lead-Vehicle Stationary.
- NCSA – National Center for Statistics and Analysis.
- NHTSA – National Highway Traffic Safety Administration.
- NCS – National Safety Council.
- OEM – Original Equipment Manufacturer.
- PTT – Pedal Transition Time; the difference between ART and BRT.
- TH – Time Headway (= Range/Host Vehicle Speed).
- TTC – Time to Collision, the time before the moment of collision, or impact if conditions remain unchanged:
- $$= ((v^2 + 2Ad)^{1/2} - v_1) / A, \text{ where}$$
- d = distance to lead-vehicle
- v = relative velocity of the vehicle ahead
- A = deceleration of vehicle ahead.

CHAPTER 1

INTRODUCTION

For more than two decades, engineers and researchers in government agencies, the automotive industry, and academia have contributed to the research and development of Collision Warning Systems (CWS) in an effort to mitigate the fatalities, injuries, and property damage associated with the most common types of vehicle accidents. One of the most frequent types of accidents, rear-end collisions, occurs when a following-vehicle collides with the rear of a lead-vehicle traveling in the same lane and direction (Singh, 2003). Forward Collision Warning (FCW) systems, one type of CWS, are intended to alert drivers in the following-vehicle to the imminent forward collision threat, so that the frequency and severity of rear-end collisions may be reduced and injury and property damage for occupants of both vehicles can be mitigated.

Because visual distraction has been shown to be a critical contributing factor in these types of accidents (Knipling, Wang, & Yin, 1993; Knipling, Mironer, et al., 1993; Summala, Lamble, & Laakso, 1998; Hancock, Lesch, & Simmons, 2003; Tijerina, Barickman, & Mazzae, 2004; Dingus et al., 2006; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006) an FCW alert must be designed to capture a visually distracted driver's

attention the moment the alert is presented to them and help redirect their attention to the forward roadway. As Ljung et al. (2007) state, "Since the effectiveness of interactive systems is dependent on how well they interact with the users, Human-Machine-Interface development and testing becomes a central tenet of interactive safety systems" (p. 2).

Using Human Factors research to optimize the auditory component of the warning system and to understand how training influences drivers' reaction times is fundamental to furthering the effectiveness of FCW systems. Without the optimization of these two components, the success of FCW systems will be compromised.

FCW system development efforts are warranted, not only to reduce the current rate of rear-end collisions, but also as a proactive approach toward reducing the likely increase of these collisions. As the number of drivers and vehicles steadily climbs each year, the use of electronic devices within the vehicle also continues to increase rapidly, potentially increasing the frequency of visual distraction, and consequently, the risk of rear-end collisions.

U.S. Driving Statistics

An overview of U.S. driving statistics reveals a consistent increase in the number of people on U.S. roadways. An examination of national driving statistics in the U.S. over the past 10 years (see Figures 1, 2, and 3) shows a consistent increase in the number of licensed drivers, registered vehicles, and miles traveled (National Center for Statistics and Analysis [NCSA], 2006).

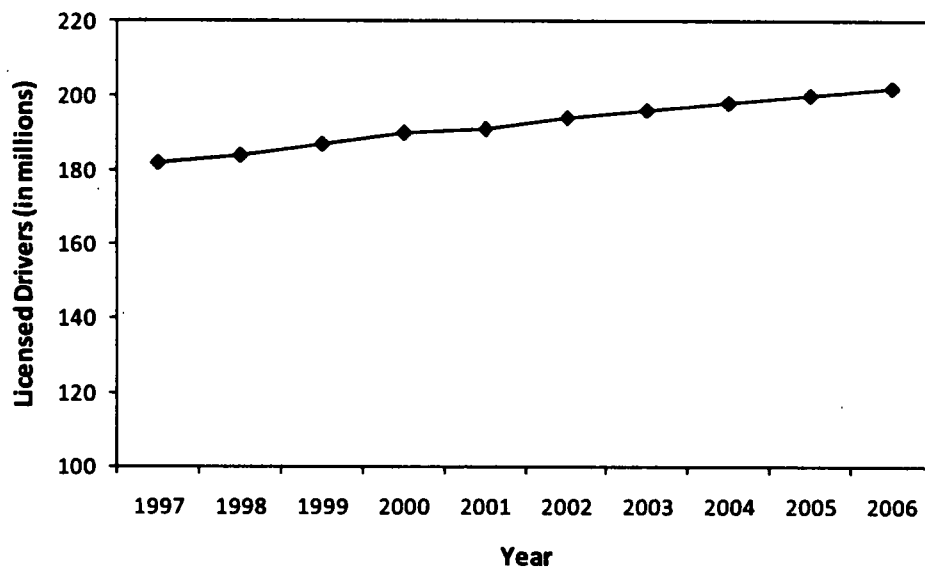


Figure 1. Number of licensed drivers (in millions) in the U.S. between 1997 – 2006.
Data from: National Center for Statistics and Analysis. (2006). Fatality Analysis Reporting System.

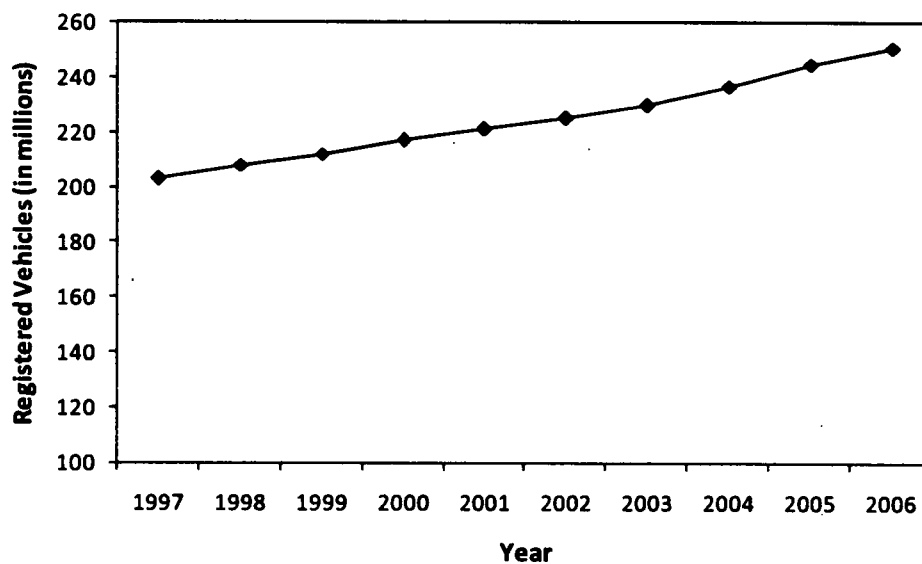


Figure 2. Number of registered vehicles (in millions) in the U.S. between 1997 – 2006.
Data from: National Center for Statistics and Analysis. (2008). Fatality Analysis Reporting System.

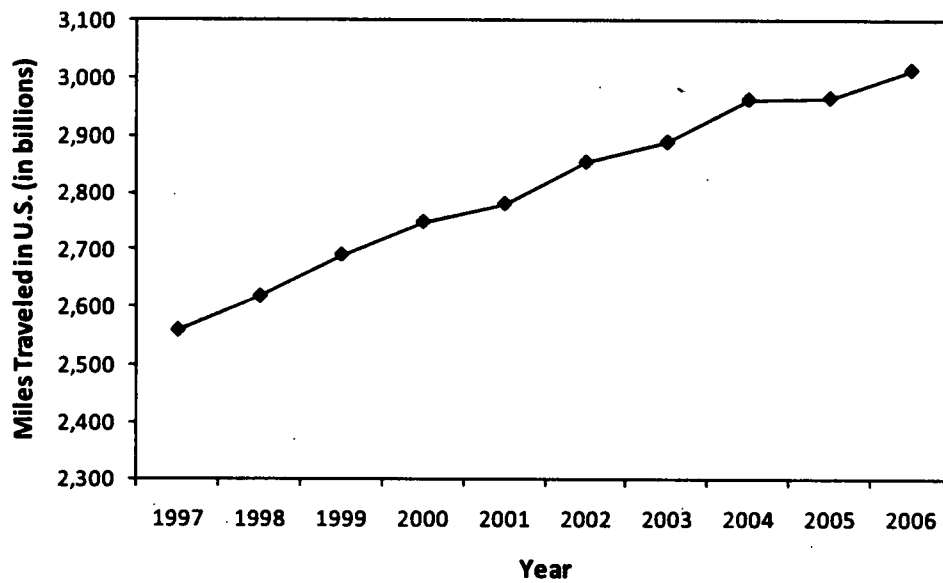


Figure 3. Number of vehicle miles traveled (in billions) in the U.S between 1997 – 2006.
Data from: National Center for Statistics and Analysis. (2008). Fatality Analysis Reporting System.

Rear-End Collisions

An unfortunate and sometimes tragic aspect of the proliferation of automobile use are accidents. Rear-end collisions, which regularly account for a large portion of crashes, include two subtypes, lead-vehicle stationary (LVS) and lead-vehicle moving (LVM; Knippling, Wang, & Yin, 1993). As shown in Table 1, since 1996, rear-end collisions have accounted for between 27.9% and 30.5% of all police-reported, motor vehicle crashes (National Highway Traffic Safety Administration [NHTSA], 1996, 1997, 1998b, 1999, 2000c, 2001, 2002, 2003, 2004, 2005 & 2006).

Table 1

Police-Reported Rear-End Crashes^a

Year	Fatalities		Injuries		Total ^b	
	Number	%	Number	%	Number	%
1996	1,835	4.9%	653,000	29.0%	1,907,000	27.9%
1997	1,833	4.9%	629,000	28.8%	1,921,000	28.4%
1998	1,896	5.1%	608,000	30.0%	1,872,000	29.6%
1999	1,923	5.2%	618,000	30.1%	1,859,000	29.6%
2000	2,007	5.4%	622,000	30.0%	1,897,000	29.7%
2001	1,963	5.2%	600,000	30.0%	1,880,000	29.7%
2002	1,987	5.2%	570,000	29.6%	1,900,000	30.1%
2003	2,076	5.4%	569,000	29.6%	1,871,000	29.6%
2004	2,083	5.4%	555,000	29.8%	1,886,000	30.5%
2005	2,118	5.4%	513,000	28.2%	1,824,000	29.6%
2006	2,102	5.4%	503,000	28.8%	1,818,000	30.4%

Note. From *Traffic Safety Facts: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*. National Highway Traffic Safety Administration (1996, 1997, 1998b, 1999, 2000c, 2001, 2002, 2003, 2004, 2005 & 2006).

^aPercent as a proportion of all police-reported, motor vehicle crashes for respective category, per year.

^bTotal includes rear-end crashes resulting in fatality, non-fatal injury, and property damage only.

Over an 11-year period, the proportion of all types of crashes that rear-end collisions represent (fatal, non-fatal injury, and property damage only) has increased from 27.9% to 30.4%. Similarly, the proportion of all crashes that fatal rear-end collisions account for has also increased over the past decade from 4.9% to 5.4%. While the actual number of rear-end collisions is less than was reported 11 years ago, the total number of police-reported rear-end collisions for 2006 still remains at over 1.8 million.

The actual number of property-damage-only rear-end collisions is likely higher given minor crashes that go unreported to the police. Knipling and colleagues (1993) offered an estimate of 1.76 million non-police reported rear-end collisions per year, an estimate inclusive of all vehicle types (i.e., passenger vehicles and combination-unit trucks). Estimates from the Virginia Tech Transportation Institute 100-Car Study suggest that in urban and suburban settings the actual crash rate for all types of passenger-vehicle collisions may actually be up to five times higher than the police-reported rate (Dingus et al., 2006).

Cost estimates for these types of collisions vary. A NHTSA (2000b) document suggests that the economic cost of rear-end collisions for passenger vehicles is \$18.3 billion per year. Another measure of the economic effect of rear-end collisions that might be considered is the cost of whiplash injuries. For example, NHTSA (2000a) estimates that 740,000 whiplash injuries occur annually in rear-end and other types of collisions, with an estimated cost of \$4.5 billion per year. NHTSA (1998a) reported that more than 25% of all rear-impacts lead to neck injuries.

In addition to the overwhelming human and monetary costs, rear-end collisions can also impact drivers who were not directly involved in a collision. It is reported that rear-end collisions cause between 144 million (1993 estimate) and 157 million (1996 estimate) vehicle-hours of delay annually (Knipling, Wang, & Yin, 1993; National Safety Council, 1996).

While it is evident that rear-end collisions take a significant toll on people and vehicles, as with many types of collisions, accident reports generally fail to capture a

complete picture of the contributing factors. Conclusive evidence about the causal factors, such as the driver's state and actions just before an accident, may not be disclosed by the driver of the striking vehicle or apparent to accident investigators. Moreover, it is unlikely that every driver correctly recalls or discerns the role of each contributing factor, leaving a less-than-ideal record of the causal factors. To further compound this problem, most accident reports typically lack the detail that might provide more precise data about the events leading up to a crash. Statistics are often based on accident reports in which distraction or inattention is deemed a factor only when an observation is made by an eyewitness, or when admissions are made by the drivers themselves (Klauer et al., 2006).

Researchers have collected and reviewed accident reports in an effort to gain insight into the causal factors associated with forward collisions. According to a review of the 1990 General Estimates System, which included an examination of accident reports by Knipling and colleagues (1993), most rear-end collisions, including both LVS and LVM, did *not* happen during poor visibility or bad weather conditions. Ninety percent of LVS and LVM crashes in this sample occurred while drivers were traveling a straight road, most occurred on roadways with level profiles, and 72% happened on dry surface conditions. The authors also report that impairment was rarely a contributing factor. Of drivers in this sample, only 3% received a citation for drugs or alcohol, and approximately 53% of drivers were not cited for a violation (Knipling, Wang, & Yin, 1993).

An examination of the 1979 Indiana Tri-Level study, conducted by Knipling, Mironer, et al. (1993), which included 57 rear-end collisions, suggested that the crashes were the result of recognition errors caused by inattention and distraction. According to the authors, driver inattention away from the forward scene was identified as a contributing factor in over 60% of rear-end crashes, a statistic often-cited and commonly-accepted in the literature. Despite an historically incomplete picture of driver behavior in the moments prior to rear-end collisions, these samples of accident data suggest that inclement weather, road type, and impairment make relatively small contributions to rear-end collisions. Further, they imply that other factors, such as a driver's behavior and attention level, have a greater impact, thereby demanding a deeper investigation of driver distraction in order to understand the relationship between visual distraction and rear-end collisions (Knipling, Mironer, et al.).

Visual Distraction

Driver distraction has been classified by NHTSA as any activity that takes an operator's attention away from driving (Ranney, Mazzae, Garrott, & Goodman, 2000). The extent of distraction can be influenced by the nature of the task, as well as a driver's level of engagement with the task (Ranney et al.). These authors explain that, by definition, there are four categories of distraction: visual, auditory, biomechanical, and cognitive. A single task can be dynamic and ultimately incorporate more than one type of distraction, for example, looking down (visual) to reach for (biomechanical) a ringing (auditory) cell phone (Ranney et al.). Theoretically, the cause of the distraction may be related (controlling wipers, headlights) or secondary (playing music, eating) to the

primary task of driving. Furthermore, the source of distraction can range from traditional, (e.g., interaction with passengers), to newer technology (e.g., dialing a cell phone or texting), and can be considered a distraction regardless of whether the operator's attention is directed toward the interior or exterior of the vehicle.

As the analysis of the 1979 Indiana Tri-Level study by Knippling, Mironer, et al. (1993) suggests, driver inattention away from the forward scene has been identified, and long-accepted, as a primary causal factor in rear-end collisions. Evidence from a number of studies (e.g., Hancock et al., 2003; Summala et al., 1998; Tijerina et al., 2004) corroborate this conclusion.

Summala and colleagues investigated drivers' ability to detect the brake lights on a lead-vehicle while engaged with a secondary task which required their visual attention (1998). The researchers argue that, even for experienced drivers, in-vehicle tasks can impair a driver's ability to respond to the brake lights of a lead-vehicle. The study examined the effects of visual distraction, as well as, driving experience and variations in following distance, and required participants to drive on a public road, which had not yet been opened to public traffic, while accompanied by a driving instructor. Drivers were asked to perform a visual search task on three digital display locations: just above the steering wheel, at the speedometer, and on the console, near the radio. As compared with attentive participants, visually distracted drivers had longer brake reaction times (BRTs) in response to the activation of brake lights of the lead-vehicle, which increased in accordance with the location of the visual distraction (Summala et al.). The further away from the forward scene the driver was asked to look (i.e., console display in comparison

with just above the steering wheel), the longer their brake reaction time was in response to the brake lights of the lead-vehicle.

In another test track study, drivers were asked to engage in a secondary task, which placed visual and cognitive demands on them, as they drove toward a traffic light (Hancock et al., 2003). Participants were shown a 7-digit number prior to their drive and, when prompted by an auditory cue, compared it to a number displayed on a cell phone as they neared a lighted-intersection. On one-third of the trials, as drivers neared the intersection the traffic light changed from green to red, requiring participants to stop as quickly as possible. Each secondary task event was complete when drivers pressed one of two buttons on a simulated cell phone indicating whether or not the two 7-digit numbers were identical. Hancock and colleagues reported that participants demonstrated significantly slower BRTs in response to the change in the traffic signal while engaged with the secondary task. Participants who were distracted by the secondary task also had significantly shorter stopping times which are indicative of less-gradual, more intense braking. Distracted participants also demonstrated shorter stopping distances relative to the intersection, which meant that when drivers were not engaged with the cell phone task they were able to bring their vehicle to a stop further away from the intersection than those who were distracted, a result of detecting and responding to the traffic light earlier (Hancock et al.). The authors also report that in the presence of distraction, the compliance rate with the traffic control device dropped significantly. The simulated task of looking down at a cell phone and making an entry had a clear impact on drivers' ability to respond to a stopping event, causing the authors to conclude that distraction can

decrease the inherent safety margin that fully attentive drivers have (Hancock et al.). In the context of this study, visual distraction, in conjunction with a memory task and phone interaction, delayed participants' initiation of the braking response.

Tijerina and colleagues (2004) investigated when and how drivers make the decision to look away from the forward roadway by conducting a naturalistic study of eye glance behavior in which participants drove vehicles for 3 hr, unaccompanied, on public roads. Participants were told to drive as they normally would, were given no time constraints, and were given no indication that the purpose of the study was to examine eye glance behavior. An examination of participants' behavior while following a lead-vehicle suggested that drivers tend to make an assumption about the behavior of a lead-vehicle and, generally, do not expect the lead-vehicle to brake abruptly. Tijerina and colleagues explain that drivers relied on this assumption when making decisions to look away from the forward scene and often did so at a following distance that would have been unsafe, had the lead-vehicle actually begun to brake suddenly. In addition, the authors suggested that the demand characteristics of secondary activities, which were not reported in this study, may have played a role in the duration of drivers' eye glances away from the forward scene. Tijerina and colleagues concluded that drivers' eye glance behavior is often directed by unsafe assumptions about other traffic and possibly the demands of secondary tasks, rather than objective metrics such as distance or speed.

The Virginia Tech Transportation Institute's 100-Car Naturalistic Study (100-Car Study; Dingus et al., 2006) offers some of the most recent and compelling evidence, recorded outside of a simulated or controlled driving environment, about the role that

visual distraction plays in rear-end collisions. Data were collected for 109 primary drivers, totaling approximately 2 million miles of driving and 43,000 hrs of video. Vehicles were fitted with unobtrusive cameras and recording equipment, participants were given no special instructions, and were never accompanied by a researcher. A total of 69 actual crashes and 761 near-crashes were captured on video during the course of the study. Crashes were defined as contact with another vehicle or object and near-crashes involved the driver making a severe, rapid evasive maneuver to avoid contact with another vehicle or object. The strength of this naturalistic study is that, as opposed to relying solely on accident reports, driver behavior and eye glances in the seconds just before the occurrence of actual crashes and near-crashes was recorded and can be analyzed (Dingus et al.).

Dingus and colleagues (2006) concluded that driver inattention from the forward roadway was a contributing factor in 78% of all crashes and 65% of all near-crashes. For rear-end collisions specifically, driver inattention from the forward roadway was a contributing factor in 93% (14 out of 15) crashes, and 68% of near-crashes. The authors reported that drivers who were looking away from the forward scene when the lead-vehicle began braking had longer brake reaction times than those who were looking forward. These results indicate that inattention from the forward roadway plays a much larger role than previously reported in the literature and clearly demonstrate that visual inattention can severely compromise a driver's ability to respond to events, increasing the likelihood of a crash.

In an additional analysis of the 100-Car Study data (Klauer et al., 2006), researchers further examined the effect of inattention on overall crash and near-crash rates for all types of collisions that had been observed in the study. Klauer and colleagues report that as the length of eye glances away from the forward scene increases the odds of being in any type of crash or near-crash also increase. Glances away from the forward roadway which last longer than 2 s significantly increase the risk of a crash or near-crash (Klauer et al.).

These studies (Knipling, Mironer, et al., 1993; Knipling, Wang, & Yin, 1993; Summala et al., 1998; Hancock et al., 2003; Dingus et al., 2006; Klauer et al., 2006) present a compelling picture of the relationship between visual distraction and rear-end collisions. The evidence strongly suggests that non-driving related visual distraction is the foremost causal factor of rear-end collisions, in that, when a driver's attention is directed away from the forward scene, the detection of imminent collision threat is delayed, likewise delaying or preventing the braking response required to avoid the conflict. Further compounding the problem is that drivers who engage in visually demanding secondary tasks generally fail to allow for a greater distance between their vehicle and the lead- vehicle (Tijerina et al., 2004), a precaution that might help to compensate for delayed detection and reaction times.

Sources of Visual Distraction

A discussion of visual distraction raises questions about its sources and causes. The visual distraction that non-driving-related, secondary tasks creates for drivers, outside of controlled, simulated environments, is dependent on a number of factors, some

of which are difficult to anticipate or to quantify. The level of visual distraction may depend on the demand characteristics of the secondary task (Tijerina et al., 2004), the driver's level of engagement with the task (Ranney et al., 2000), the location of the distraction (Summala et al., 1998), and the driver's own ability to manage divided attention. Furthermore, the likelihood of an instance of visual distraction leading to an actual collision can also be dependent on the behavior of other drivers and current traffic conditions.

Sources of visual distraction within the vehicle range from traditional, such as the behavior of children and others passengers and driver's eating, to new nomadic and in-vehicle technology. Nomadic, or handheld wireless devices, include products such as cell phones, mp3 players, PDAs, and pagers, the use of all of which continues to become more widespread. There has also been an increase in enhanced electronics integrated into the vehicle itself (e.g., navigation systems, displays, touch screens, and an ever-expanding list of vehicle features).

While completely escaping the burden of traditional distracters, such as passenger interaction, is clearly impractical, it is particularly troublesome that the use of nomadic and in-vehicle devices, which typically require visual attention to operate, has become so common. One example of the increasing use of nomadic devices is that of cell phones.

The National Occupant Protection Use Survey (NOPUS) obtains a measure of cell phone use in the U.S. from probability samples and statistical data editing (NCSA, 2005). Drivers of passenger vehicles are observed from 1200 roadside sites by trained observers, while stopped at intersections, during daylight hours. The study concluded that in 2005,

at any time of the day, 6% of drivers were holding a cell phone to their ear, as compared with 5% in 2004. The Insurance Institute for Highway Safety (IIHS; 2006) explains that this percentage of drivers actually doubled from 3% in the 2000 NOPUS, demonstrating a consistent rise in hand-held cell phone use over the 5-year period. Furthermore, NOPUS reported that the number of drivers age 16-24 that were holding a cell phone to their ear at any given time rose from 8% in 2004 to 10% in 2005.

Automotive market research suggests that by 2013, more than 30 million new cars will be made with factory-installed telematics instrumentation (Telematics Update, 2008). While not all of these in-vehicle systems will require visual attention to operate, this is further evidence of the increase in demand for access to information from within the vehicle.

As evidenced by these examples, the use of nomadic and in-vehicle electronic devices is likely to continue to rise, increasing the opportunity for visual distraction and, as a result, forward collisions.

Forward Collision Warning Systems

With conclusive evidence that visual distraction can impede a driver's conflict avoidance response (Knipling, Mironer, et al., 1993; Knipling, Wang, & Yin, 1993; Summala et al., 1998; Hancock et al., 2003; Dingus et al., 2006; and Klauer et al., 2006), and that driver interaction with visually distracting nomadic devices and in-vehicle displays is becoming more common, one approach to mitigating all types of vehicle crashes caused by distraction, including rear-end collisions, has been to regulate which secondary tasks drivers are permitted to engage in or to lock-out complex, in-vehicle

functions while driving. For example, standard OEM navigation systems prevent visually-intensive tasks, such as destination entry while driving, and a number of states have passed laws prohibiting the use of handheld phones. As of July 2008, five states plus the District of Columbia (DC) ban talking on handheld cell phones while driving, 17 states and DC ban all cell phones for *novice* drivers, and four states ban texting, or written messages sent via cell phone, for all drivers. Furthermore, 25 countries have laws which restrict or prohibit handheld cell phones in cars (Governors Highway Safety Association, 2008).

A second approach, however, aims to mitigate the frequency and severity of rear-end collisions by monitoring the vehicle's environment. In a 2001 report, the National Transportation Safety Board (NTSB) stated that there are two types of vehicle-based warning systems, also called headway detection systems (Knipling, Wang, & Yin, 1993), intended to reduce rear-end collisions. The first is Adaptive Cruise Control (ACC) which uses engine control and brake application to slow the following vehicle; the second type, CWSs, are generally intended to aid drivers by providing a visual or audible alert to warn of an imminent forward collision (NTSB, 2001). Thus, forward-looking radar technology can be used to actively track other vehicles and identify imminent forward collision threats, situations where, based on the speed and velocity of the host- and lead-vehicles, the driver must respond immediately in order to avoid causing a rear-end collision. Lee, Ries, McGehee, and Brown (2000) reported that Japanese, European, and U.S. automobile manufacturers, as well as research efforts by the National Highway Traffic

Safety Administration, have focused on the development of rear-end collision warning systems.

The ability of FCW systems to reduce rear-end collisions in simulated environments and their potential on-road safety benefit has been documented in the literature. In one example, Lee et al. demonstrated that FCW systems do have the potential to reduce accidents (2000). Drivers, who were visually distracted when the lead-vehicle applied its brakes, experienced two imminent forward collision threats, but only received an FCW alert in one of those instances. Results showed a significant decrease in collisions and collision velocity when drivers received forward collision warnings, indicating a clear safety benefit.

Kiefer, Cassar, Flannagan, Jerome, and Palmer also found support for FCW systems in a test track study (2005). Participants drove in a real car, on a closed course, behind a surrogate target (a mock rear half of a vehicle constructed to absorb low-speed collisions without permanent damage attached to a collapsible telescoping tow beam). Participants experienced a surprise braking event when the lead-vehicle began to decelerate or suddenly change lanes to reveal a parked vehicle after the participants had been prompted to engage in either a visually or cognitively distracting task. As a primary dependent measure, researchers examined how many times the accompanying researcher was forced to intervene, that is, assist the participant in making a collision avoidance response. Significantly more interventions were required in trials where drivers were not exposed to the FCW alert, demonstrating the overall safety benefit of the FCW system (Kiefer et al.). That is, participants who received an FCW alert were able to react with the

appropriate collision avoidance maneuver, and thus, did not require intervention from the accompanying driver.

This discussion assumes the viability, continued development, and availability of radar and eye-tracking technologies, which are beyond the scope of any single study. However, a smaller part of this picture is the effort to optimize the warning that can be generated for visually distracted drivers when an imminent forward collision threat is detected by optimizing the auditory component of the FCW alert. The greatest gain of an FCW system will be its ability to capture the attention of visually distracted drivers, prompting them to redirect their attention to the forward roadway, facilitating detection of the forward collision threat, and offering the best opportunity to mitigate the severity and frequency of rear-end collisions. While the ability of an auditory warning to capture a visually distracted driver's attention will be one of the greatest assets of an FCW system, it also becomes one of the warning system's greatest design challenges.

Auditory Warning

Broadly stated, the visual and auditory components of an FCW system work together to alert a driver to the threat of an imminent forward collision. Depending on the eccentricity of the glance angle from the forward scene, however, a visually distracted driver may have little or no view of a visual warning presented on the HUD or instrument cluster, limiting its effectiveness and creating a considerable burden for the auditory warning. In the case of a visually distracted driver, the auditory component becomes primarily responsible for capturing drivers' attention and prompting them to redirect their focus to the location of the threat, the forward roadway. Drivers who redirect their focus

to a rear-view mirror, nomadic device, or in-vehicle display will further delay the detection of the imminent forward collision threat.

Adding to the challenge of selecting an auditory warning which immediately captures a visually distracted driver's attention and helps to redirect focus to the forward threat, are the issue of false alarms produced by the FCW system. Although true detections by radar algorithm, drivers often perceive alerts triggered by out-of-path stationary objects (e.g., guardrails, road signs, overpasses), or by in-path moving objects which pose little threat (e.g., the lead-vehicle in a passing maneuver or a lead-vehicle turning out-of-path) as false alarms, or nuisance alerts. High false alarms rates can increase annoyance, making the driver more likely to ignore the warnings or to disable the FCW system altogether (NHTSA, 2007; Knippling, Mironer, et al., 1993). FCW systems must also balance attention capture with excessive startle so as not to inhibit a required braking reaction or to provoke unnecessary responses such as unsafe steering. Finally, the design of the FCW alert ought to reduce ambiguity during infrequent or first-time exposure. FCW alerts will likely incorporate some combination of auditory, visual, and, possibly, even haptic components that are intended to work simultaneously.

Perceived-Urgency

One area of focus in the design of non-verbal auditory warnings is the perceived, psychoacoustic, urgency of a sound. As explained by Hellier and Edworthy (1999), while perceived-urgency is one of many characteristics of a sound, it is one that is particularly relevant in the selection of auditory warnings. A warning's perceived-urgency is a function of its acoustic parameters. A mismatch between these parameters and the

situation or message that the warning is intended to represent can reduce the effectiveness of the warning (Edworthy, Loxley, & Dennis, 1991). A warning which is correctly mapped to the criticality of its situation is one that can be more informative and better facilitate an appropriate response from the user (Hellier & Edworthy, 1999).

A considerable amount of research has been conducted to identify which acoustic parameters have a significant effect on perceived-urgency and what their relative contribution is. For example, Edworthy et al. (1991) investigated the variation of sounds across several acoustic parameters. Participants were asked to rank the most urgent sound from groupings of sounds, as well as rate each sound individually. The authors reported that an increase in perceived-urgency was achieved using parameters such as high fundamental frequency, an inharmonic series, the absence of delayed harmonics, and a standard amplitude envelope, as well as, fast speed, regular rhythm, large pitch range, random pitch contour, and an atonal pitch pattern (Edworthy et al.).

Hellier, Edworthy, and Dennis (1993) explored the power of the relationship between four parameters (speed defined as pulse rate, fundamental frequency, the number of times a sound is repeated, and inharmonicity) and perceived-urgency. Results showed that while all four variables increased perceived-urgency, speed and repetition were the most practical variables to increase. That is, it took smaller changes in speed and repetition rate than in fundamental frequency to increased perceived-urgency.

Edworthy, Hellier, and Hards (1995) examined to what extent meanings change with different levels of acoustic parameters in the context of a helicopter cockpit environment. Participants rated sounds, which varied across four acoustic properties on

42 different adjectives. As part of the study's conclusions, the authors reported that increased ratings of 'urgency' and 'danger' were associated with increased pitch, speed, and inharmonicity of a sound. These results were further supported by Guillaume, Pellieux, Chastres, and Drake (2003) who asked participants to listen to pairs of sounds and identify the more urgent of each pair. Sound sequences which were fast, had a high pitch, had irregular harmonics, and fast onset and offset ramps were judged by participants to be more urgent.

This sample of studies (Edworthy et al., 1991; Hellier et al., 1993; Edworthy et al., 1995; Guillaume et al., 2003) demonstrates that perceived-urgency can be reliably increased by manipulating a variety of acoustic parameters. NHTSA guidelines for crash warning system interfaces state that auditory warnings should convey a level of urgency that matches the potential crash conflict they represent (NHTSA, 2007). It stands to reason, then, that the efficiency of an FCW alert could be improved by increasing its perceived-urgency to match the urgency of the situation it represents, an imminent forward collision. Guillaume et al. (2003) noted that increased warning efficiency is represented by an increase in appropriate reaction to the warnings, which usually correlates with decreased reaction times. In terms of an FCW alert, this would result in a decreased accelerator release time (ART) and BRT, consequently resulting in a decrease in collision rates and velocities. In an investigation of the perceived-urgency of collision warnings and email alerts, Wiese and Lee found that high-urgency auditory warnings had the positive effect of reducing ARTs (2004). However, the authors also reported that the high-urgency warning was rated as significantly more annoying. Despite the apparent

benefits of increasing urgency, a warning delivered at too high of an intensity or frequency, for example, will also raise startle and annoyance beyond acceptable levels.

A second, similar experiment by Guillaume et al. (2003), also found that acoustic characteristics were predictive of urgency ranking, with the exception of two alarms. Although unintended, the authors explained that both alarms were similar to common sounds. The alarm which was rated as more urgent than its acoustic properties would have predicted, sounded similar to a sequence which alternated between two tones, like that of a warning signal. They suggested that the alarm's urgency rating was actually based on the mental representation it created, that of a warning signal. In contrast, an alarm with a high pitch and fast rate received a lower-than-expected rating of urgency because it sounded like a bicycle bell, a sound the authors suggested was associated with little threat and possibly even relaxation. These findings suggest that the *learned* meaning of a sound may supersede the information conveyed by its acoustic parameters.

Auditory Icons

Gaver (1986) reported that an auditory icon is a caricature of a naturally occurring sound, the advantage of which is that the listener uses information about the source that generated the sound rather than sound properties like frequency. Gaver examined their use in the context of computer interfaces and suggested that if mapping between the meaning and the sound source could be achieved, the sound would be more easily learned and remembered. For example, if the sound of a piece of paper hitting metal represents an email arriving, the sound of a large object hitting metal should represent a *large* email

arriving. In this example, the magnitude of the email is conveyed through the source of the sound. Gaver offered that auditory icons provide an intuitive way to represent data.

Belz, Robinson, and Casali found support for the use of auditory icons as forward and side collision warnings in a commercial vehicle driving simulator (1999).

Participants, who were licensed commercial truck drivers, were presented with two types of collision threats as part of a repeated measures design. In the first scenario, participants encountered forward roadway hazards (a person or vehicle) and received either a conventional high-urgency warning or an auditory icon (skidding tires). In the second scenario, drivers encountered a side collision threat (i.e., vehicles positioned alongside the host truck during lane change scenarios) and received either another conventional high-urgency warning or an auditory icon (long horn honk).

In both collision scenarios, the auditory icons (skidding tires and long horn honk) elicited more positive results than the conventional high-urgency warnings. The skidding tires produced significantly faster response times (accelerator release and brake reaction) to the forward threats, while the long horn honk resulted in significantly fewer side collisions. Belz et al. concluded that these results confirm the potential usefulness of representational sounds, such as auditory icons, for in-vehicle warnings (1999).

Graham (1999) hypothesized that because listeners respond to the object or event that caused or created the sound, auditory icons are capable of conveying information because they are analogous to easily recognized events, unlike abstract sounds. The challenge, however, of using auditory icons is that many warning messages lack a direct correspondence to an auditory representation (Graham). An imminent forward collision

threat, for example, has no direct sound representation. Graham conducted a comparison of four FCW alerts: a non-speech warning (a computer-generated beep), a speech warning ('ahead!'), and two auditory icons (skidding tires and car horn) as part of a driving simulator experiment. The results revealed that both auditory icons (skidding tires and car horn) produced faster BRTs than the speech warning ('ahead!'). Furthermore, one of the auditory icons, the car horn, produced a faster BRT than the non-speech, computer-generated beep. The results of this experiment further support the use of auditory icons as FCW alerts for improving reaction times. Therefore, there is a need to compare the relative gain of auditory icons with that of increased perceived-urgency.

FCW System Knowledge

Although FCW systems must deliver an auditory warning which drivers respond to quickly, the FCW alert will be completely unfamiliar to some users. These first-time, or infrequent exposures, present a unique design challenge. System knowledge, or training, can potentially affect users' ability to respond quickly and appropriately. Therefore, there is a need to examine how a driver's knowledge of an FCW system can affect their response to an FCW alert during an imminent forward collision event.

As applied in the context of driving, training has been shown to have an effect on driver's interaction with vehicle technology in two anti-lock brake system (ABS) studies. Mollenhauer, Dingus, Carney, Hankey, and Jahns studied the effect of training on drivers' braking responses in an ABS-equipped vehicle (1997). The authors reported that the introduction of ABS into the mainstream automotive market produced a unique set of problems. According to surveys, most drivers appreciated the safety benefit that anti-lock

brakes provided, but did not receive training on their correct use. As a result, in hard braking situations, drivers often continued to pump their brakes instead of applying constant, increasing pressure, thus rendering ABS ineffective. Without ABS, tires can skid and drivers lose the ability to steer the vehicle. When accident data failed to show the benefits of anti-lock brakes on vehicles equipped with ABS, researchers pointed to a lack of proper training as one explanation. As part of a closed course study, participants were asked to brake on icy road conditions on both a straightaway and in a curve. Drivers were also exposed to a surprise braking event on a straightaway, where a large piece of Styrofoam was used to obstruct their path. Results showed that drivers who had received ABS training were more likely to use the appropriate braking method (i.e., continuous force) in all three situations (Mollenhauer et al.).

Mazzae, Barickman, Baldwin, and Forkenbrock also examined driver behavior in cars equipped with ABS (1999). The authors investigated whether an incorrect driver response can reduce the effectiveness of ABS. Of the participants who drove ABS-equipped vehicles, half viewed videos instructing them that in order to correctly use the system the driver must *not* pump the brake pedal in an emergency braking situation. In dry conditions, drivers who had received the instructions had significantly longer brake application durations than those who did not see the video, indicating that they had kept more consistent pressure on the brake pedal as was instructed in the video. That is, drivers who received ABS training were more likely to use the correct braking method.

However, even drivers who owned ABS-equipped vehicles were not aware of the proper braking method. In an analysis comparing crash and fatality rates before and after

the inclusion of ABS on production vehicles, Farmer, Lund, Trempel, and Braver state that drivers were initially unaware of how to properly use the braking system (1997). The authors explained that, as reported in Williams and Wells (1994), a North Carolina and Wisconsin study revealed that more than 40% of responders with ABS-equipped vehicles thought that pumping the brakes was the proper technique.

The Insurance Institute for Highway Safety (IIHS) reported that, surprisingly, when initially introduced, vehicles with anti-lock brakes were involved in fatal-to-their-own-occupant, single-vehicle, run-off-the-road crashes at a higher rate than prior to the introduction of ABS (2000). A follow-up analysis of crash data between 1996-1998 revealed that the over-involvement of ABS-equipped vehicles in these types of crashes had disappeared and returned to levels similar to those prior to the introduction of ABS.

Unable to provide an explanation for the exceedingly poor early performance and later improvement to these crash numbers, the IIHS suggested that exposure to information about ABS might have brought about a change in driver behavior, helping drivers learn how to use the brakes more effectively (2000). This hypothesis is based on the belief that system knowledge and training can play a role in helping drivers to understand the technology in their vehicle and interact with it more effectively and safely.

In an investigation of FCW system awareness, Ljung et al. (2007) found that experience with prior warnings can affect a driver's response to a surprise FCW event. Participants in two studies were led to believe that the purpose of their drive was to evaluate other types of warning systems, rather than to study their response to an FCW event. They were given no information about the FCW event prior to the start of their

drives. Each participant was also presented with a secondary task which required them to read back a sequence of random numbers presented on a display located near the lower center console and armrest of the vehicle, as they drove. This visual distraction was intended to model that of handheld nomadic devices and only visually distracted drivers were included in the study. In the first experiment, drivers received only information about an Adaptive Cruise Control (ACC) system which was used as a means to control headway between the host vehicle and lead-vehicle. In a second experiment, drivers received training, including a demonstration, about a Lane Departure Warning (LDW) system and then experienced 36 LDW events during their drive, which included three different types of warnings. Drives in both experiments ended with a surprise FCW event. The same three FCW alerts were used for the surprise event in both experiments, an abstract audio and visual presentation, an abstract haptic warning, and a verbal warning with visual and audio presentation. Experiment 2 also included a no-warning condition.

Ljung et al. (2007) examined two primary dependent variables, interpretation of the warning and BRT, measured from the start of the FCW to the brake onset, or the time the host vehicle began to slow. In the first experiment (ACC), only 27 of 38 (71%) drivers responded to the warning by looking up before the completion of the secondary task, and furthermore, only 17 of those drivers braked, while the other 10 *glanced-back down* to complete the secondary task. This is compared with the 45 out of 48 (93.7%) drivers who looked up before the end of the secondary task *and* braked in the second experiment, where drivers had been exposed to LDW alerts throughout the drive.

Ljung and colleagues (2007) acknowledge that a shorter headway in Experiment 2 likely improved the braking responses of those who did look up because the shorter headway made the collision appear more imminent and made up for a lack of salient brake lights in a simulated environment. However, more participants looked forward in response to the FCW alert in the second experiment; glancing forward was a variable which was uninfluenced by headway which changed the appearance of the proximity of the lead-vehicle. The authors concluded that the exposure to the LDW alerts, during Experiment 2, made drivers aware that the vehicle could provide situation warnings and trained them how to respond appropriately to the warnings (Ljung et al., 2007).

Together, these findings (Mollenhauer et al., 1997; Mazzae et al., 1999; IIHS, 2000; Farmer et al., 1997; Ljung et al., 2007), demonstrate that the benefit of safety-enhancing technology can be severely diminished by a lack of driver training about how to properly interact with the technology. In terms of FCW systems, training and system knowledge, even in the form of exposure to warnings generated by *another* collision warning system, have the potential to improve a driver's glance behavior by returning their focus to the forward scene more quickly and keeping it focused there, facilitating a decrease in reaction times and, likewise, collision rates and velocity.

Kiefer et al. (2005) addressed the issue of training specifically for an FCW system. In a closed course study, participants were asked to follow a lead-vehicle while accompanied by a researcher. If a driver came too close to colliding with the lead-vehicle, the researcher was able to intervene and make a collision avoidance maneuver. Analysis revealed that visually distracted drivers who required interventions by the accompanying

test driver in order to avoid rear-ending the lead-vehicle, had longer alert onset-look up times. Alert onset-look up time was defined as the duration of time between the issue of the alert and the participant's direction of focus toward the forward scene. The researchers suggested that the alert onset-look up time could be reduced with further training or experience, increasing the effectiveness of the FCW system (Kiefer et al., 2005).

Expectation of the Braking Event

In terms of an experimental protocol, the introduction of FCW training inevitably raises concerns about how knowledge of the system will effect participants' expectation of the lead-vehicle braking. The argument could be made that, for participants who are recipients of training, any improvement observed in glance behavior, reaction times, or collision rates may not be solely attributable to training, but rather to driver's *expectation* of the braking event, or of "something" that will happen.

Van Der Hulst, Meijman, and Rothengatter investigated the effect of cues in the driving environment on brake reaction times in a simulator study (1999). While following a lead-vehicle, drivers received either (a) no cues that the lead-vehicle was about to brake, or (b) they saw a vehicle pull out in front of the lead-vehicle from a side road. Participants had the opportunity to see, well in advance, that the lead-vehicle would need to slow in order to give way to the vehicle that had just pulled out. Researchers found that drivers who observed the car pull out from the side road decreased their own speed and increased time headway in anticipation of the lead-vehicle slowing or braking, while drivers who were not exposed to the car pulling out showed no change in speed. It was

also found that the time it took participants to release the accelerator was shorter for drivers who expected the lead-vehicle to brake as a result of seeing a vehicle pull out from a side road, than for drivers who were not exposed to the second vehicle. Therefore, it was concluded that drivers will make anticipatory responses based on expectation in a scenario which involves a potential collision (van Der Hulst et al.). If the same holds true for FCW system training, it is conceivable that drivers who are told that a warning system is in place to issue imminent collision alerts will, as a result, be more likely to expect the lead-vehicle to brake suddenly.

In a second study, Hancock et al. (2003) exposed drivers to two blocks of trials, each consisting of 24 trials. Each block included combinations of the distracter task and the stopping task, which required drivers to respond quickly to a changing traffic light. The authors reported that, in the second block, drivers had a faster Stopping Time; that is, the time between brake activation and the car coming to a complete stop was shorter. Hancock et al. attribute this faster reaction time to a learning effect, as drivers had received exposure to the distraction and stopping tasks as part of the first block of trials. The authors suggested that, despite the random, infrequent activation of the stop light, drivers began to prepare themselves for the braking event (Hancock et al.).

The issue of expectation also extends to FCW systems, as well. In one example, visually distracted drivers began a simulator experiment with a practice drive where they were told to respond when the lead-vehicle braked suddenly (Lee et al., 2000). As a means of reducing anticipation of the imminent collision scenario, the researchers exposed drivers to several lead-vehicles that did not brake during the test drive. Lead-

vehicles which did not stop were included to help reduce the predictability of the imminent braking event. This study demonstrates the importance of addressing the issue of expectation in studies conducted in an FCW environment and taking measures to counteract its effects. Exploring alternate methods of reducing the driver's anticipation of a braking event is a worthwhile effort, where expectation will be a function of training.

An investigation was conducted of supplementary brake lights, that is, additional brake lights located adjacent to the traditional brake lights, which warn the following driver when the lead-vehicle is braking heavily and decelerating rapidly, (Wierwille, Lee, & DeHart, 2005). Drivers were instructed to follow a surrogate lead-vehicle, which was equipped with the supplemental brake lights, on a closed course. During their drive, participants in the following vehicle were exposed to two heavy braking events during which the lead-vehicle's supplemental brake lights were activated by its heavy braking and rapid deceleration. Whereas the first braking event came as a surprise to the participants, just prior to the second braking event drivers received an explanation of the purpose of the supplemental lights, were told which of the two additional brake light conditions they were in, and to expect the lead-vehicle to brake for a second time. Wierwille and colleagues report that, as expected, a strong learning effect was revealed. With prior exposure and system knowledge participants demonstrated faster accelerator release times and reduced times-to-full-stop as part of the second braking event. This example suggests that only the first, unexpected, exposure to a braking event reliably reflects a surprise scenario and that drivers' reactions to subsequent exposures are significantly different due, in part, to their expectation of the event.

When all participants of a single study are exposed to the same instructions or driving experiences, the relative comparison of accelerator release and brake reaction times are not compromised. However, reducing expectation even further by presenting the braking event at an unlikely time during the drive, using a between-subjects design to expose participants to only one event, is a worthwhile goal that may serve two purposes. First, it provides the opportunity to better emulate real-world, imminent collision events where a forward collision threat takes drivers by surprise. Second, it can provide an opportunity to examine what effect the overwhelming surprise of that situation has on glance behavior and subjective evaluations of an FCW system, measures which have far more variability than reaction times. A challenge is to vary FCW system training, while controlling for expectation.

Gender

In addition to auditory warning type and FCW training, gender is also important to consider. Hancock and colleagues (2003) examined the effect of gender in their study of distracted drivers' reaction times to the activation of a traffic light in the intersection of a closed course and reported an effect of gender on Stopping Distance. They found that female drivers stopped closer to the line which marked the boundary of the intersection than male drivers. Hancock et al. suggested that the differences between the sexes in the brake pressure that they can apply may account for the longer Stopping Distance of female drivers. The authors also reported a significant interaction between Stopping Accuracy, defined as compliance with stopping at the red light, and the distraction task. Upon introduction of the distraction task, the decrease in Stopping Accuracy for men was

relatively small while women showed a significant decrease in accuracy. While non-distracted female drivers had a higher compliance rate with the red light than men, they had a significantly lower compliance rate when the in-vehicle distracter task was introduced. According to Hancock et al. the presence of distraction can disadvantage, to a greater extent, women more than men.

The role of gender in FCW studies has also been addressed, Kiefer and colleagues (2005) asked drivers to follow a surrogate lead-vehicle, which braked suddenly while participants were engaged in cognitively and visually distracting tasks. If the participant came too close to actually colliding with the lead-vehicle, the accompanying researcher intervened and made an evasive maneuver in order to avoid the collision. The frequency of these researcher interventions became a dependent variable. The authors summarized gender effects by explaining that when the FCW system was inactive and drivers received no alert, women had higher researcher-intervention rates than men. However, when the FCW system was active, there was no difference between the male and female driver intervention rates. Kiefer et al. suggested that the presence of an FCW alert may equalize drivers' abilities to respond to threatening situations.

However, as the following examples demonstrate, the effect of gender is not consistent across studies. As part of the research program, Crash Avoidance Metrics Partnership (CAMP; Kiefer, LeBlanc et al., 1999) investigated many aspects of the FCW systems, including minimum functional requirements and the objective test procedures for evaluating them. The human factors portion of the investigation examined two variables associated with driver behavior, BRT and driver deceleration behavior (i.e.,

how hard the driver brakes in response to an alert). In a test protocol referred to as "last-second" braking behavior, drivers were asked to wait to brake until the last possible moment in order to avoid a collision while following a surrogate lead-vehicle on a test track. Kiefer et al. reported that braking behavior was uninfluenced by gender.

In an on-road naturalistic study of eye glance behavior, Tijerina et al. (2004) concluded that the number of glances away from the forward scene and location of glances away (e.g., to the center mirror, over left shoulder, over right shoulder) were also independent of gender. Furthermore, gender differences were not observed in an investigation of ABS. Mazzae et al. (1999) found no reliable difference between men and women in brake pedal force or BRT in response on either wet or dry pavement.

PRESENT RESEARCH

The purpose of the present study is to examine the effects of three variables, (a) FCW system training, (b) auditory warning, and (c) gender on a visually distracted drivers' response to an unexpected, imminent forward collision event in a simulated driving environment. First, the effect of FCW system training was studied by providing only half of the participants with a brief description of the FCW system which included a demonstration of the respective auditory warning. Second, the effect of auditory warning was investigated by comparing four different auditory warning conditions: no-auditory warning (baseline), *average*-urgency tonal warning, *highest*-urgency tonal warning, and an auditory icon, a *car horn*. Each auditory warning was combined with the same FCW visual icon and presented on the screen of the driving simulator, as an approximation of a

HUD image (see Appendix A for the FCW icon). Third, the effect of gender was examined. As was determined prior to the study, eight dependent variables recorded in the simulator were to measure the effects of training, auditory warning, and gender. They included seven quantitative variables: GRT, ART, pedal transition time, BRT, BRT50%, minimum TTC, collision velocity, and one categorical dependent variable, collision rate.

Pilot Study

A Pilot Study was conducted to narrow the initial selection of five auditory warnings (i.e., *average-urgency* tonal warning, *higher-urgency* tonal warning, *highest-urgency* tonal warning, *screeching tires*, and a *car horn*) to the three that were to be used in the present study (see Appendix B for complete description of the Pilot Study; see also Bakowski, 2009, for internet link to auditory warning sounds). The final selection of auditory warnings for the present study was based entirely on the subjective ratings collected from the Pilot Study questionnaire (see Appendix C for Pilot Study questionnaire). Two primary conclusions were drawn from these results: (a) the highest-urgency tonal warning was most often associated with the correct meaning of the FCW alert, while also providing the greatest contrast to the average-urgency warning on the subjective measures and, (b) the car horn was more frequently associated with the moments just before a forward collision becomes imminent than the skidding tires (see Appendix D for all Pilot Study Results). Based on trends observed in the subjective ratings, the *average-urgency* tonal warning, the *highest-urgency* tonal warning, and the *car horn* were selected for use in the present study.

Hypotheses

As shown in Table 2, results were expected to reveal faster GRT, ART, pedal transition time, BRT, BRT50%, lower collision velocities, higher minimum TTC, and lower collision rates for drivers who received training, as compared with untrained drivers. Training was to benefit drivers by providing them with an awareness of the FCW system, understanding of the meaning of the FCW alert, and knowledge of the appropriate response (e.g., braking). The same positive effects were expected for drivers receiving either the highest-urgency warning or the car horn as compared to the average-urgency warning, due to the benefits of increased perceived-urgency (i.e., facilitated attention capture, representation of higher threat-severity) and of the auditory icon (i.e., a recognizable sound, drawing attention outside of the vehicle, related to the threat itself), respectively. Furthermore, all three audible alerts (i.e., average-urgency, highest-urgency, and car horn) were expected to outperform the baseline condition, no-auditory warning, because return to the forward scene, and thus, recognition of the threat, would be delayed in the absence of an auditory cue. Although little *quantitative* difference between highest-urgency and car horn was forecasted prior to the experiment, the study provided an opportunity to explore any differences.

In contrast to training and auditory warning, the effect of gender was less predictable in light of the wide range and inconsistency of gender effects reported in previous driving studies. Prior to the present study, it was recognized that reaction times, such as BRT and BRT50%, would provide evidence for the effect of gender if women were to transition more slowly from the accelerator to the brake pedal and apply less

force once contact with the pedal was made. Furthermore, should distraction have a greater negative effect on female than male drivers, the effect would be evidenced through a longer GRT and higher collision rate for women. Interactions between the training, auditory warning, and gender warning variables were not expected at the outset of this experiment.

Table 2

Quantitative Hypotheses

Independent Variable	When Compared To	Hypotheses
FCW System Training <i>i.e., Awareness of System and Knowledge of Appropriate Response to Warning</i>	No-FCW System Training	Faster GRT Faster ART, BRT, BRT50% Faster PTT Larger minTTC Slower Collision Velocity Fewer Collisions
Higher Perceived-Urgency <i>i.e., Highest-Urgency Tonal Warning</i>	Average-Urgency Tonal Warning	Faster GRT Faster ART, BRT, BRT50% Faster PTT Larger minTTC Slower Collision Velocity Fewer Collisions
Auditory Icon <i>i.e., Car Horn Warning</i>	Average-Urgency Tonal Warning	Faster GRT Faster ART, BRT, BRT50% Faster PTT Larger minTTC Slower Collision Velocity Fewer Collisions
Audible <i>i.e., Average-Urgency, Highest-Urgency, and Car Horn Warnings</i>	No-Auditory Warning	Faster GRT Faster ART, BRT, BRT50% Faster PTT Larger minTTC Slower Collision Velocity Fewer Collisions

The purpose of the FCW questionnaire (see Appendix K), which was administered to each participant immediately following the presentation of the debriefing on the console monitor, was threefold. A summary of the qualitative hypotheses are shown in Table 3.

Table 3

Qualitative Hypotheses

Independent Variable	When Compared To	Hypotheses
FCW System Training <i>i.e., Awareness of System and Knowledge of Appropriate Response to Warning</i>	No-FCW System Training	Does <i>not</i> Increase Expectation Does <i>not</i> Reduce Surprise
Higher Perceived-Urgency <i>i.e., Highest-Urgency Tonal Warning</i>	Auditory Icon <i>i.e., Car Horn Warning</i>	Improves Attention Capture Helps Avoid a Collision Reduces Collision Severity
Auditory Icon <i>i.e., Car Horn Warning</i>	Higher Perceived-Urgency <i>i.e., Highest-Urgency</i>	Less Startling Less Annoying More Understandable

First, the questionnaire was used to validate the training methods employed in the study. Because of the deception created in the instructions regarding the number and purpose of drives, it was anticipated that both untrained *and* trained participants would be sufficiently misled to believe that the second drive was only practice and did not contain a braking event. Therefore, it was anticipated that both conditions would be as likely to disagree that they *expected* the lead-vehicle to brake, creating an imminent forward

collision during "Practice Drive #2". Furthermore, all participants, regardless of training, were expected to agree that they were *surprised* by the braking event, a result also attributable to the deception. Similar self-report measurements of expectation and surprise across both levels of training would lend support to the conclusion that any observed improvement in reaction times was attributable to knowledge and understanding of the FCW system, rather than anticipation of the braking event inadvertently created by the training, one of the foremost challenges this study.

Second, the questionnaire was to serve as a comparison of the attributes of the three auditory warnings, including attention capture, startle, annoyance, understandability, usefulness in enhancing safety, usefulness on real roadways, and ability to reduce collision severity or helpfulness in avoiding the collision. Specifically, it was anticipated that these analyses would highlight the *qualitative* differences between the highest-urgency and car horn warnings. In accordance with trends observed in the Pilot Study, the car horn warning was expected to set itself apart from the highest-urgency warning on attributes, such as, annoyance, startle, and understandability, while respondents would likely agree that the highest-urgency warning excelled at attention capture and the ability to reduce the severity of collisions or avoid them altogether. The third purpose of the questionnaire was to examine whether training or auditory warning type influence drivers' likelihood of recommending the FCW system, as a whole.

CHAPTER 2

METHOD

Participants

Eighty employees (40 women and 40 men) at Delphi Electronics and Safety Systems in Kokomo, Indiana, participated in the study. Employees were informed about the opportunity to participate through emails distributed using a random selection process (see Appendix E for text of email). Those who expressed interest in participating were asked to complete a screening questionnaire (Appendix F) to confirm that they met predetermined criteria. Participants were randomly assigned to one of the 8 conditions (5 men and 5 women in each condition) formed by the crossing of the two FCW training conditions and the four auditory warning types (no-training with no-auditory, average-urgency, highest-urgency, or car horn and training with no-auditory, average-urgency, highest-urgency, or car horn).

Participants were required to be between 35 and 55 years of age, have at least 10 years of driving experience, not be prone to motion sickness, vertigo, dizziness, headaches, claustrophobia, or migraines, and women could not be pregnant. They were required to drive an average of at least 5,000 miles (19,312,128 m) per year, have a valid

U.S. driver's license, and have normal or corrected-to-normal vision (see Appendix G for the actual mean [SD] of age, years of driving experience, and miles driven per year by condition). Volunteers could not have participated in similar previous experiments and had to agree not to take driving-impairing drugs at least 4 hr before their scheduled study. Volunteers who did not meet these requirements were notified by email and were not invited to participate.

Volunteers who met the requirements were paid for their participation with a \$30 Best Buy gift certificate. Informed consent for both University of Dayton (Appendix H) and Delphi (Appendix I) were obtained upon their arrival at the study. Informed consent forms included permission to videotape head movement. Although all participants were explicitly informed on both Informed Consent forms that they would be recorded on video, and all agreed to give permission to be recorded before proceeding with the study, every effort was made to more broadly and generally state that the purpose of the recording was to capture head movement, rather than to specifically analyze the direction and duration of drivers' eye glances. It was thought that making drivers aware of the intent of the recording, specifically eye glance analysis, might make some participants more self-aware and either intentionally or inadvertently alter their behavior.

Design

As shown in Figure 4, a 2 (FCW system training) x 4 (auditory warning) x 2 (gender) between-subjects design was implemented for the present study. Prior to the start of their drive, 40 of the 80 participants received FCW system training (training), which served as the first independent variable. The FCW training provided a brief

overview of the FCW concept, radar technology, and the respective auditory warning, if applicable. The remaining 40 participants (no-training) did not receive information about the FCW system, the radar technology, or exposure to their respective auditory warning. Serving as the second independent variable during the surprise, imminent braking event was auditory warning type. All 80 participants were exposed to one of four levels of the auditory warning independent variable: 20 participants received the average-urgency tone, 20 received the highest-urgency tone, 20 received the car horn, and 20 received no-auditory warning. The audible alert which participants in the FCW training condition were exposed to was dependent on their respective auditory warning condition (average-urgency, highest-urgency, or car horn).

		HUD + No- Auditory Warning	HUD + Average- Urgency Warning	HUD + Highest- Urgency Warning	HUD + Car Horn
Women	No-FCW Training	n = 5	n = 5	n = 5	n = 5
	FCW Training	n = 5	n = 5	n = 5	n = 5
		HUD + No- Auditory Warning	HUD + Average- Urgency Warning	HUD + Highest- Urgency Warning	HUD + Car Horn
Men	No-FCW Training	n = 5	n = 5	n = 5	n = 5
	FCW Training	n = 5	n = 5	n = 5	n = 5

Figure 4. Experimental design, 2 (FCW training) x 4 (auditory warning) x 2 (gender).

Quantitative dependent variables included GRT (measured in s), ART, pedal transition time, BRT, BRT50%, minimum TTC, and collision velocity (m/s). Collision rate was examined as a categorical dependent variable. Dependent subjective measures obtained from the post-drive FCW questionnaire included ratings for expectancy, surprise, understandability, usefulness, attention capture, startle, annoyance, helpfulness of the auditory warning in avoiding or reducing the severity of the collision, and likelihood to recommend (see Appendix K for FCW questionnaire). Video coding was done following the experiment to examine glance behavior.

Equipment and Materials

Equipment used in this experiment included a fixed-base driving simulator at Delphi Electronics and Safety Systems in Kokomo, Indiana. The simulator was powered by Global Sim, Inc.'s DriveSafety™ Research Simulator, a fully integrated, high-performance driving simulation system. The HyperDrive™ Authoring Suite was used to create the driving scenarios and was hosted on a Dell computer. The simulator included a rear projection screen, 64 m by 85 m, manufactured by Sharp, and an in-vehicle console display screen measuring 30.48 cm x 15.42 cm, (see Appendix J for photographs of the driving simulator, rear projection screen, and in-vehicle display screen). The simulator projected a 1024 x 768-pixel 50-deg-vertical forward field-of-view image located in front of the vehicle. Steering feedback was presented with a force-feedback torque motor, to reproduce the feel of the road. The vehicle cab consisted of the front half of a 1995 Pontiac Bonneville exterior (with doors and roof removed), with a 1996 Buick Park Avenue instrument cluster and dashboard. The simulator included a speaker which produced the auditory warning sounds, which was located directly in front of the driver on the dashboard. The simulator also included speakers, located just behind the driver's seat, which produced ambient sounds for engine noise and passing vehicles, located directly behind the driver and passenger seats. The simulator also included one video camera, mounted above the cluster, facing the driver.

Procedure

Upon their arrival at the driving simulator at Delphi Electronics and Safety, participants signed the University of Dayton and Delphi informed consent forms,

received a \$30 Best Buy gift certificate, and were asked to take a seat in the driving simulator. After participants were shown how to adjust the seat and steering wheel positions in the simulator, the overhead room lights were dimmed to enable better viewing of the projection screen. The researcher reminded participants that if they felt any discomfort, in particular nausea or sweating, during the experiment they should stop driving and alert the researcher immediately. Participants were also reminded that they could communicate any concerns or questions to the researcher during their drive via a one-way intercom.

Participants were then asked to press the brake pedal once, which prompted an instruction slide to appear on the rear-projection screen in front of them. As shown in Figure 5, the instruction slides consisted of the Experiment Agenda, information regarding the purpose of the study, as well as FCW training information for participants in the training condition. Note that participants experienced an abbreviated Drive 2 and did not experience Drives 3 or 4, which were presented on the instruction slides to encourage drivers anticipate a longer experiment than they would actually experience.

No-FCW System Training Slide

Experiment Agenda:

Drive 1: Practice Drive 1 (Acclimatization) 7 min
Drive 2: Practice Drive 2 (Navigation Emphasis) 15 min
Drive 3: Forward Collision Warning System A 15 min
Drive 4: Forward Collision Warning System B 15 min

Experiment Overview:

Purpose: Investigate how roadside and in-vehicle information affect driver's driving performance.

FCW System Training Slide

Experiment Agenda:

Drive 1: Practice Drive 1 (Acclimatization) 7 min
Drive 2: Practice Drive 2 (Navigation Emphasis) 15 min
Drive 3: Forward Collision Warning System A 15 min
Drive 4: Forward Collision Warning System B 15 min

Experiment Overview:

Purpose: Investigate how Forward Collision Warning (FCW) may be designed to reduce the effects of driver distraction.

FCW: A radar mounted near the front bumper measures the range and closure rate of the vehicle in front and calculates the threat of imminent collision (you need to brake immediately to avoid colliding with the lead-vehicle).

Figure 5. Instruction slides, displayed prior to the start of each drive.

Every participant saw the same experimental agenda, regardless of training or auditory warning condition, which indicated that there would be a total of four drives lasting 7 min, 15 min, 15 min, and 15 min, respectively, with the first two drives being considered practice. In actuality however, each participant would drive one, 10-min drive and a second drive which would conclude after approximately 5 min with the imminent forward collision event, as shown in Table 4.

Table 4

Comparison of Actual and Perceived Experimental Agendas

		Experimental Agenda	
		Instruction Slide	Actual
Drive 1	Practice 1 (Acclimatization)	7 min	10 min
Drive 2	Practice 2 (Navigation Emphasis)	15 min	~ 5 min ^a
Drive 3	FCW System A	15 min	
Drive 4	FCW System B	15 min	

^aDrivers experienced the imminent forward collision event at approximately 5 min into the second drive. The host-vehicle safely coming to a stop or colliding with the lead-vehicle marked the conclusion of the imminent forward collision event and the driving portion of the experiment.

This deception in the experimental agenda was critical to the design of the present study, and was incorporated for several reasons. First, inherent to almost every real-world rear-end collision is the unexpected braking or stopping of the lead-vehicle. In order to achieve the most realistic, worst-case scenario, given the constraints of a simulated environment, it was essential to attempt to make the forward collision event as *unexpected* as possible in the present study. If drivers anticipated the location or timing of a forward collision threat, they would be less likely to comply with the visual distraction, maintain the appropriate speed, or follow the lead-vehicle closely enough. Second, it was important to counter any indication of imminent forward collision created for participants as part of the training condition. Creating an experimental agenda with four continuous drives and labeling the first two segments as *practice* drives, helped to create the perception for every participant that if an event were to take place, it was unlikely to

occur before the third drive, which was not scheduled to begin until more than 20 min into the experiment. By presenting all participants with an imminent forward collision event at approximately 5 min into the second "Practice" drive, the lead-vehicle's braking was unexpected and took participants by surprise, as much like a real-world imminent forward collision event as possible in a simulated environment.

Participants in the FCW training condition saw a slide on the screen that indicated that the purpose of the study was to "Investigate how FCW systems may be designed to reduce the effects of driver distraction". The slide indicated that an FCW system works by mounting a forward-looking radar on the front of the vehicle which "measures the range and closure rate of the vehicle in front and calculates the threat of imminent collision" and if a threat is detected that drivers need to "brake immediately to avoid colliding with the lead-vehicle". The researcher also read the agenda, purpose of the study, and FCW explanation aloud, as participants viewed the text on the screen. Participants in the training condition were then instructed to press the brake pedal once, which activated the auditory warning, if applicable to their particular condition (i.e., average-urgency warning, highest-urgency warning, or the car horn warning). The visual FCW alert was also presented when participants pressed the accelerator pedal. The FCW icon appeared in the center of the screen, as a simulated HUD, just above the hood of the driving simulator vehicle (see Appendix A for FCW icon as shown on a simulated HUD). The icon consisted of a red outline of a car and an amber 'crash' symbol on a black background.

Participants in the no-training condition were presented with a slide on the screen which indicated that the purpose of the study was to “investigate how roadside and in-vehicle information affect driver’s driving performance.” No indication or explanation of the FCW system was given in the no-training condition. The researcher also read the agenda and purpose aloud. Participants in this condition were then instructed to press the brake pedal one time. In this way, participants in both conditions had identical experience operating the brake pedal. However, drivers in the no-training condition were not exposed to the visual or auditory FCW alerts warnings when they engaged the pedals.

Next, the researcher pointed out the console screen to all participants and briefly explained that scrolling text would appear along the bottom of the screen to offer navigation instructions and speed instructions (see Appendix L for messages). The purpose of presenting scrolling text messages on the console monitor was to both effectively and consistently deliver navigation and speed instructions, as well as to create visual distraction during the braking event. Because drivers became accustomed to receiving instructions from the console monitor, the message presented just before the braking event – that is, the message explicitly used to create visual distraction – did not seem out of the ordinary to participants. Therefore, participants were willing to look away from the forward scene without suspicion that the lead-vehicle would brake at that precise moment.

Participants in both training conditions were then instructed to press the accelerator pedal once to begin Drive 1. The researcher left the room at this time. As participants drove, in-vehicle text messages presented information about the appropriate

speed to travel at, which highway exits to take, what turns to make, and which vehicle to follow (see Appendix L).

At the completion of Drive 1, the scrolling text indicated to drivers that, "Drive 1 is complete. The next drive is also practice but will have a greater emphasis on navigation, so pay close attention for important instructions. Like the last practice, you will also start by following the white sedan". All participants were told that Drive 2 would end when they "park next to the red SUV". In actuality, the duration of Drive 2 was approximately 5 min, instead of 15 min as the Experimental Agenda indicated. Participants were presented with the console monitor message, "When you get to the next intersection, take the west (2nd) highway EXIT." to create visual distraction .5 s before the lead-vehicle braked and decelerated to a stop at a rate of -5 m/s^2 , creating an imminent forward collision threat for the participant. In order to maintain consistency, the lead-vehicle was programmed to brake when there was approximately a 2 s Time Headway (TH) between it and the host vehicle.

In response to the imminent braking situation, the FCW system presented participants in each of the four conditions with the same FCW icon on the simulated HUD. In addition to the visual icon, participants received one of four auditory warnings: the average-urgency tone, the highest-urgency tone, the car horn, or no-auditory warning. The warnings occurred .5 s after the event to simulate the lag in detecting deceleration. The conclusion of the imminent forward collision event represented the end of the drive, and was marked by the host vehicle safely coming to a stop behind or beside the lead-vehicle, or colliding with the lead-vehicle in a rear-end collision.

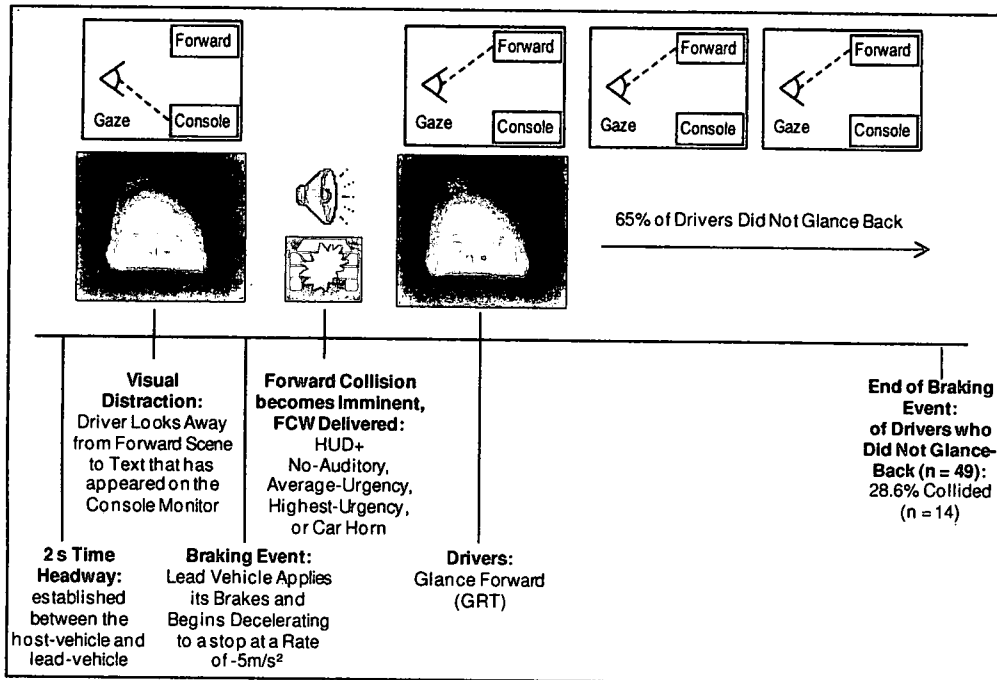
Immediately following the conclusion of the drive, the in-vehicle scrolling text presented a short debriefing on the console monitor.

"Don't worry if you crashed-- many people do. The last drive was not just practice. We told you it was to try to manage your expectations because in FCW experiments in driving simulators, people often expect braking events. Please don't tell anyone else about the braking event at the end in case they may run in a similar experiment. The previous drive was actually the final drive. When you complete the questionnaire, it will complete this experiment."

The purpose of this debriefing was twofold. It quickly offered an explanation for why the drive ended in such an abrupt and arresting manner, revealing the deception in the experimental agenda, and reassured drivers that they were not at fault if they had collided with the lead-vehicle. Following the presentation of the debriefing, the researcher immediately returned to the room to discuss any questions or concerns expressed by participants. Finally, the FCW questionnaire (see Appendix K) was administered by the researcher to participants immediately following the debriefing and was used to measure (a) participants' expectation of the braking event, (b) attributes of the auditory warning, and (c) participants' "likelihood to recommend" to the FCW system. As a precaution, participants were reminded not to reveal the purpose or outcome of the experiment to others, so as to preserve the surprise of the braking event. After participants had completed the questionnaire, the researcher answered any remaining questions. A University of Dayton debriefing form (see Appendix M) was also provided to participants at the completion of the study.

Prior to the start of the experiment an examination of video, which had been recorded in the simulator and provided views of the forward driving scene and the driver as captured from a camera mounted above the instrument cluster, was planned in order to measure GRT (i.e., the duration of time between the lead-vehicle braking and the driver's first forward glance). It was expected that once participants looked from the console to the forward scene the first time, the forward collision threat would be understood, and, as a result, their gaze would not leave the forward roadway and an avoidance response (i.e., braking) to the imminent forward collision threat would be initiated. However, examination of the video revealed an unexpected glance behavior, which, to be properly accounted for, ultimately required an additional analysis. After looking forward for the first time, 35% of drivers actually *glanced-back* to the console monitor, before again looking forward and initiating their response to the imminent forward collision threat, as shown in Figure 6. As a result, duration of console gaze was added as an eighth quantitative dependent variable to measure total gaze-on-console time between the lead-vehicle braking and BRT. Glance-back was also added as a second categorical dependent variable.

No Glance-Back



Glance-Back

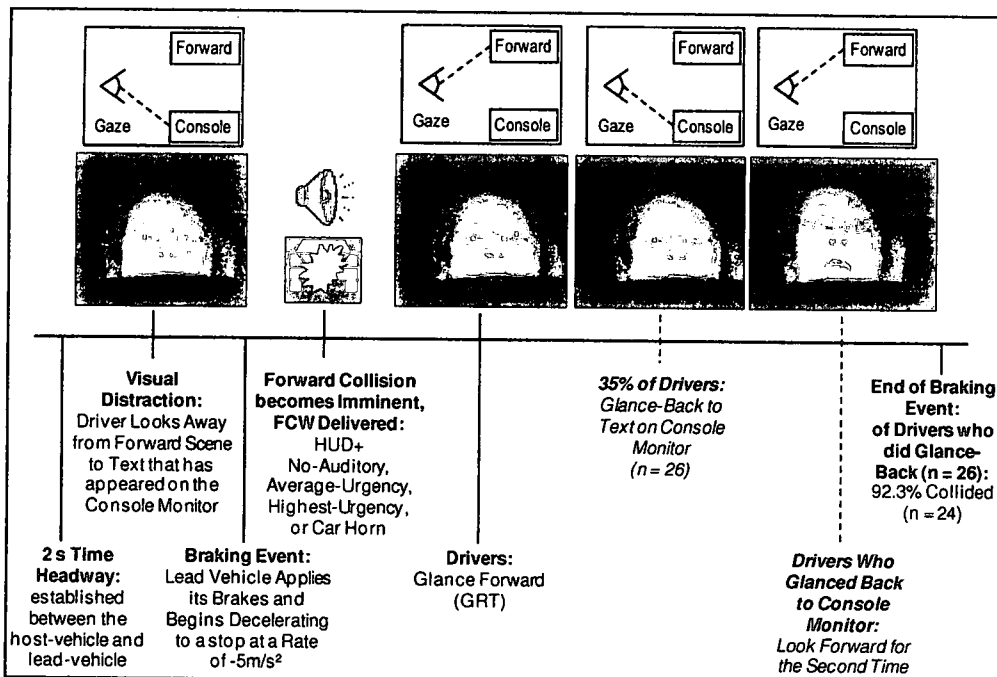


Figure 6. Comparison of glance behavior, 65% of drivers did not glance-back, 35% did glance-back.

A representation of the eight quantitative simulator dependent variables (GRT, duration of console gaze, ART, pedal transition time, BRT, BRT50%, minimum TTC, and collision velocity) is shown in Figure 7, and reflects a timeline adjusted to include drivers' glances-back to the console monitor.

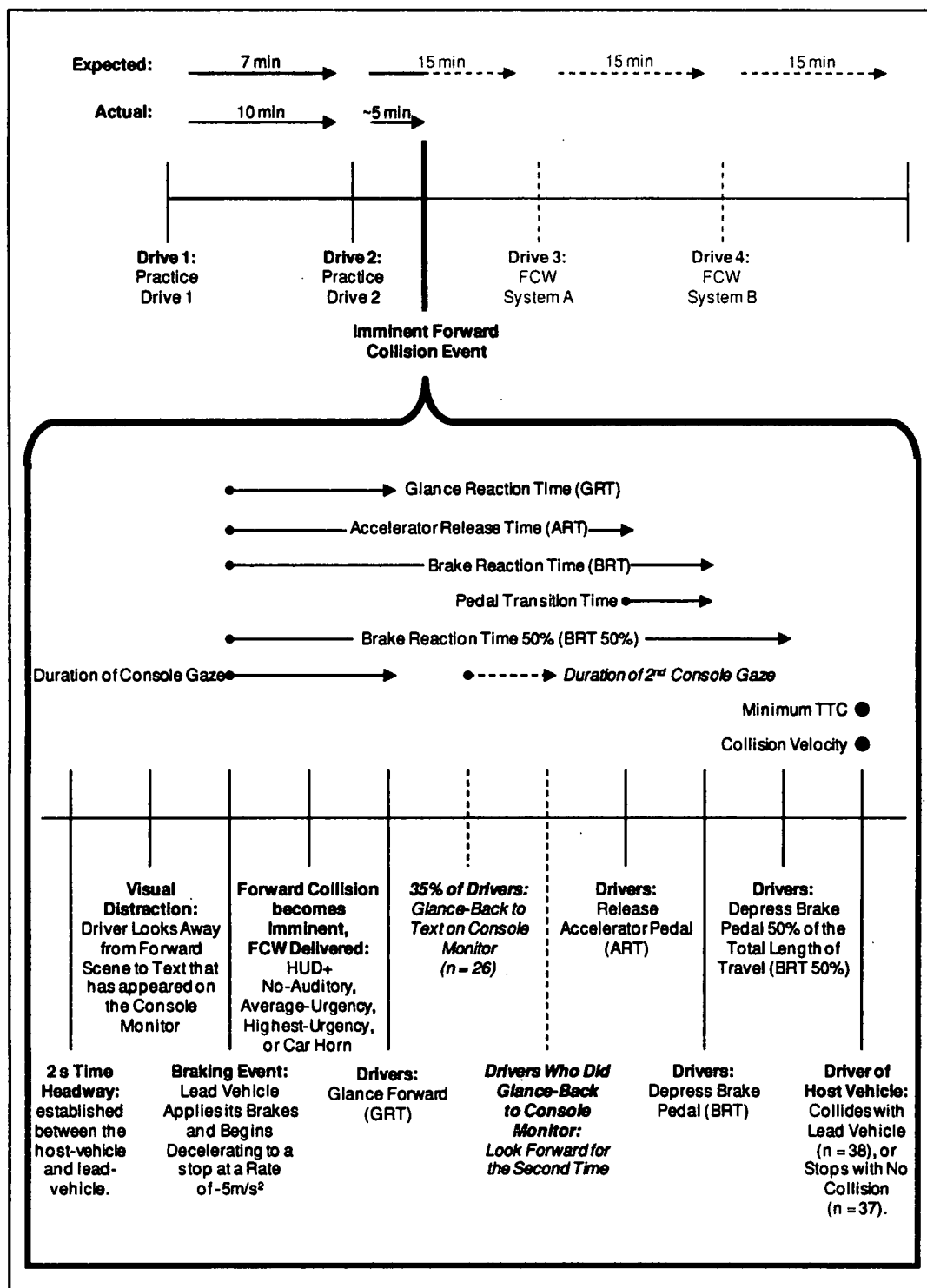


Figure 7. Timeline of dependent variables surrounding the imminent FCW event.

CHAPTER 3

RESULTS

The following describes the number of participants replaced during the course of the experiment, the number of outliers removed, and the final number of participants in each condition prior to data analysis.

Participants Replaced

Twenty-eight participants were replaced during the course of the study (see Table 5). Of those 28 participants, 8.5% of men ($n = 4$) and 19.6% of women ($n = 11$) experienced simulator sickness and voluntarily withdrew before completing the entire drive. The remaining 13 participants were replaced because of failure to follow simulator-operating instructions, failure to depress the accelerator or brake pedals (resulting in no RT measure), failure to look at the console monitor at the beginning of the imminent braking event (resulting in no GRT measure), or failure to drive below the instructed speed limit (see Appendix N for details).

Table 5

Number of Participants Replaced per Condition

Auditory Warning	FCW System Training		<i>Total</i>
	No-Training	Training	
HUD + No-Auditory Warning	2	3	5
HUD + Average-Urgency Warning	1	5	6
HUD + Highest-Urgency Warning	3	4	7
HUD + Car Horn Warning	2	8	10
<i>Total</i>	8	20	28

Removal of Outliers

Following the completion of data collection, analysis revealed five outliers which were removed without replacement (see Table 6). Further analysis confirmed that the number of outlying data points were relatively well-represented across the two FCW training conditions, the four auditory warning conditions, and sex of participant. It was decided a priori that outliers greater than and less than 2 SDs would be removed due to the variability of the single-event, between subjects design. With respect to the direction of the reaction times however, the two reaction times which were greater than 2 SDs above (slower) than the mean were recipients of the FCW training, while the three outliers which fell more than 2 SDs below (faster) than the mean were in the no-training condition. This trend is counterintuitive to the effect that FCW training was expected to

have – that drivers who received training would be more likely to demonstrate faster reaction times.

Table 6

Outliers Removed: More than 2 SD Below (Faster) or Above (Slower) than Condition Mean

Auditory Warning	FCW System Training	
	No-Training	Training
HUD + No-Auditory Warning		ART slower (1 Man)
HUD + Average-Urgency	BRT faster (1 Man)	
HUD + Highest-Urgency	BRT faster (1 Woman)	ART and BRT slower (1 Man)
HUD + Car Horn		ART and BRT slower (1 Woman)

The final number of participants in each condition after the removal of outliers is shown in Table 7.

Table 7

Number of Participants included in Final Analysis after Removal of Outliers

	FCW System Training				<i>Total</i>
	No-Training		Training		
Auditory Warning	Male	Female	Male	Female	
HUD + No-Auditory Warning	6	4	4	5	19
HUD + Average-Urgency Warning	4	5	5	5	19
HUD + Highest-Urgency Warning	5	4	3	6	18
HUD + Car Horn Warning	5	5	5	4	19
<i>Total</i>	20	18	17	20	75

Training, Auditory Warning, and Gender Analyses

The present research hypothesized that FCW training would improve glance behavior, reaction times, and collision statistics. The same positive effects were expected for drivers who received either the highest-urgency warning or the car horn as compared to the average-urgency warning.

Individual analyses of the eight quantitative dependent variables (GRT, duration of console gaze, ART, pedal transition time, BRT, BRT50%, minTTC, and collision velocity) as a function of FCW training, auditory warning, and gender are reported in Table 8. Of these eight dependent variables, the 2 x 4 x 2 between subjects Analysis of Variance (ANOVA) revealed a significant interaction between training and gender for

three variables, a main effect of training for seven variables, and a main effect of auditory warning for seven variables. The examination of the data revealed no main effect of gender, and no interactions between training, auditory warning, and gender, between training and auditory warning, or between gender and auditory warning.

Table 8

Mean (SD) Dependent Variables as a Function of Training, Warning, and Gender

DV	FCW System Training		Auditory Warning				Gender	Interactions
	No- Training	Training	No- Auditory	Average- Urgency	Highest- Urgency	Car Horn	Male Female	Gender x Training
GRT (s)								
Male	1.24 (.37)	1.16 (.44)	1.47 (.37)	1.33 (.47)	.99 (.33)	.98 (.16)	1.20 (.40)	
Female	1.19 (.48)	1.04 (.30)	1.12 (.37)	1.30 (.49)	.92 (.24)	1.12 (.41)	1.11 (.39)	
All	1.22 (.42)	1.10 (.37)	1.30 (.40)	1.31 (.47)	.95 (.28)***	1.05 (.31)	1.16 (.40)	
Gaze (s)								
Male	1.72 (.50)	1.28 (.50)	1.70 (.39)	1.82 (.60)	1.48 (.53)	1.08 (.35)	1.52 (.54)	
Female	1.79 (.38)	1.08 (.35)	1.42 (.46)	1.51 (.53)	1.37 (.56)	1.32 (.55)	1.40 (.51)	
All	1.75 (.45)	1.17 (.43)*****	1.57 (.43)	1.67 (.58)	1.42 (.53)	1.20 (.46)***	1.46 (.53)	
ART (s)								
Male	2.69 (.91)	1.99 (.69)	2.61 (.67)	2.94 (.74)	2.26 (.98)	1.68 (.71)	2.38 (.88)	
Female	2.88 (1.04)	1.55 (.54)	2.72 (.96)	2.11 (.88)	1.88 (1.01)	1.96 (1.23)	2.16 (1.04)	
All	2.77 (.96)	1.75 (.64)*****	2.66 (.80)	2.55 (.89)	2.05 (.99)	1.81 (.97)***	2.27 (.96)	
PTT (s)								
Male	.73 (.63)	.43 (.22)	.59 (.50)	.44 (.40)	.60 (.43)	.74 (.68)	.59 (.51)	
Female	.85 (.88)	.59 (.26)	.64 (.66)	.81 (.69)	.69 (.64)	.70 (.64)	.71 (.63)	
All	.78 (.75)	.52 (.25)*	.62 (.56)	.62 (.57)	.65 (.54)	.72 (.64)	.65 (.57)	
BRT (s)								
Male	3.42 (.61)	2.42 (.68)	3.20 (.64)	3.38 (.76)	2.86 (.85)	2.42 (.75)	2.97 (.81)	
Female	3.73 (.71)	2.14 (.63)	3.37 (.83)	2.92 (1.01)	2.57 (1.10)	2.66 (1.14)	2.87 (1.04)	
All	3.55 (.66)	2.27 (.66)*****	3.28 (.72)	3.16 (.89)	2.70 (.98)	2.53 (.94)****	2.92 (.92)	$p = .039$
BRT50% (s)								
Male	3.75 (.54)	2.88 (.77)	3.52 (.63)	3.69 (.77)	3.54 (.61)	2.73 (.76)	3.36 (.78)	
Female	4.00 (.58)	2.61 (.71)	3.71 (.76)	3.19 (1.02)	3.02 (1.09)	3.08 (.90)	3.25 (.95)	
All	3.86 (.56)	2.74 (.74)*****	3.61 (.68)	3.45 (.91)	3.25 (.92)	2.90 (.82)***	3.30 (.86)	$p = .037$
minTTC (s)								
Male	.47 (.99)	2.46 (2.47)	.63 (.71)	.65 (1.52)	.82 (1.63)	3.22 (2.66)	1.36 (2.04)	
Female	.34 (1.41)	3.98 (2.28)	1.05 (1.31)	2.20 (2.91)	3.22 (3.20)	2.65 (2.59)	2.31 (2.64)*	
All	.41 (1.18)	3.28 (2.45)*****	.83 (1.03)	1.39 (2.35)	2.15 (2.84)	2.95 (2.57)****	1.83 (2.39)	$p = .020$
Velocity (m/s)								
Male	10.74 (6.85)	2.33 (5.25)	6.33 (7.91)	11.16 (7.98)	7.35 (7.01)	3.15 (5.17)	6.98 (7.44)	
Female	14.68 (4.97)	1.50 (4.64)	9.74 (9.55)	8.03 (7.85)	6.20 (8.04)	6.42 (8.07)	7.56 (8.16)	
All	12.51 (6.33)	1.89 (4.88)*****	7.95 (8.65)	9.68 (7.86)	6.71 (7.40)	4.70 (6.71)**	7.27 (7.76)	$p = .059$

*Approached significance $p < .06$; ** $p < .05$; *** $p \leq .01$; **** $p \leq .001$; ***** $p \leq .000001$

Glance Reaction Time. GRT, the difference in time between the lead-vehicle braking and the driver's first forward glance, was examined in a 2 (FCW training) x 4 (auditory warning) x 2 (gender), between-subjects Multivariate Analysis of Variance. As shown in Figure 8, the main effect for auditory warning was significant, $F(3, 59) = 4.391$, $MSE = .139$, $p = .007$, $\eta^2 = .183$. A post hoc Tukey HSD revealed that the GRT for highest-urgency ($M = .95$, $SD = .28$) was significantly faster than the no-auditory ($M = 1.30$, $SD = .40$) and average-urgency ($M = 1.31$, $SD = .47$) warning conditions. However, there was no difference between the no-auditory, average-urgency, and car horn ($M = 1.05$, $SD = .31$) warning conditions. (Note, error bars in Figure 8 and all other figures presented throughout these Results represent 1 SD less than and greater than the mean for each particular condition). The main effects for gender and training were not significant. The interactions between training and warning and gender, training and auditory warning, training and gender, and warning and gender were not significant at $p > .05$, the level of significance used throughout these analyses.

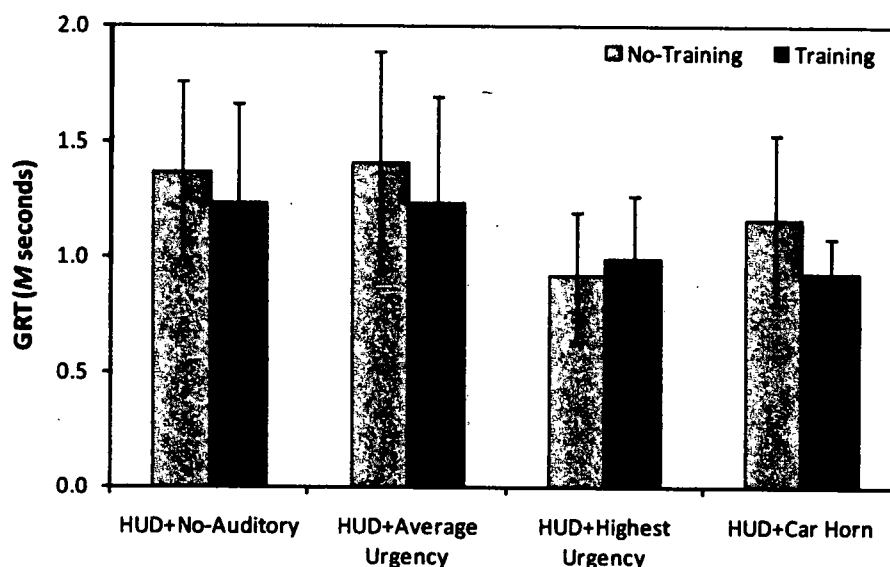


Figure 8. Mean GRT as a function of FCW system training and auditory warning.

Duration of Console Gaze. The duration of console gaze measured the total time that drivers spent looking at the console monitor between the time the lead-vehicle began braking and when the driver initiated braking in the host vehicle. The duration of console gaze was examined in a $2 \times 4 \times 2$, between-subjects MANOVA. As shown in Figure 9, a significant main effect was revealed for training, $F(1, 59) = 35.015$, $MSE = .168$, $p < .0001$, $\eta^2 = .372$. There was also a significant main effect for auditory warning $F(3, 59) = 4.947$, $MSE = .168$, $p = .004$, $\eta^2 = .201$. A post hoc Tukey HSD revealed that the duration of console gaze was significantly shorter for car horn ($M = 1.20$, $SD = .46$) than for no-auditory ($M = 1.57$, $SD = .43$) and average-urgency ($M = 1.67$, $SD = .58$). However, there was no difference between the no-auditory, average-urgency, and highest-urgency ($M = 1.42$, $SD = .53$) warning conditions. The main effect for gender

was not significant. The interactions between training, warning and gender, training and auditory warning, training and gender, and warning and gender were not significant.

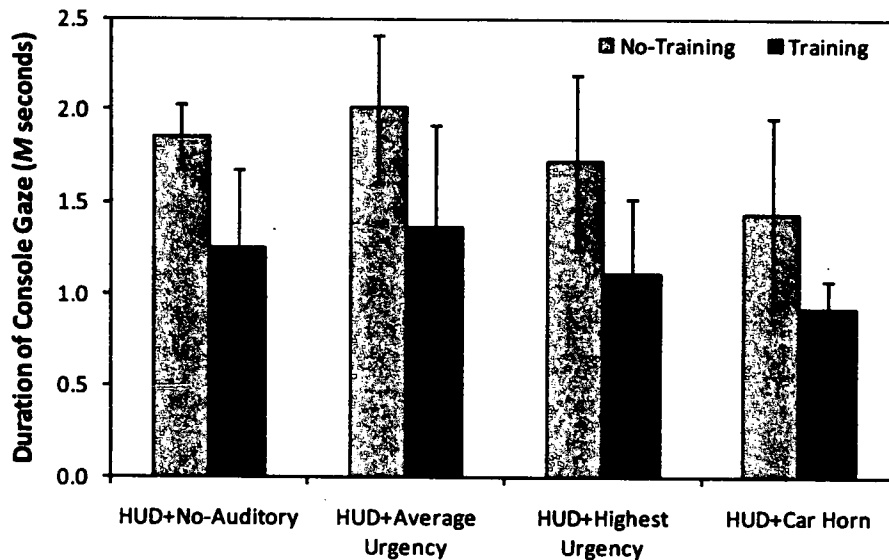


Figure 9. Mean duration of console gaze as a function of FCW system training and auditory warning.

Accelerator Release Time. ART, the difference in time between the lead-vehicle braking and the driver lifting their foot from the accelerator pedal, was examined in a 2 x 4 x 2, between-subjects MANOVA. As shown in Figure 10, the main effect for training was significant, $F(1, 59) = 36.015$, $MSE = .550$, $p < .0001$, $\eta^2 = .379$. The main effect for auditory warning was significant, $F(3, 59) = 5.924$, $MSE = .550$, $p = .001$, $\eta^2 = .231$. A post hoc Tukey HSD revealed that the ART for car horn ($M = 1.81$, $SD = .97$) was significantly faster than no-auditory ($M = 2.66$, $SD = .801$) and average-urgency ($M = 2.55$, $SD = .89$). However, there was no difference between the no-auditory, average-urgency, and highest-urgency ($M = 2.05$, $SD = .99$) warning conditions. The main effect for gender was not significant. The interactions between training, warning and gender,

training and auditory warning, training and gender, and warning and gender were not significant.

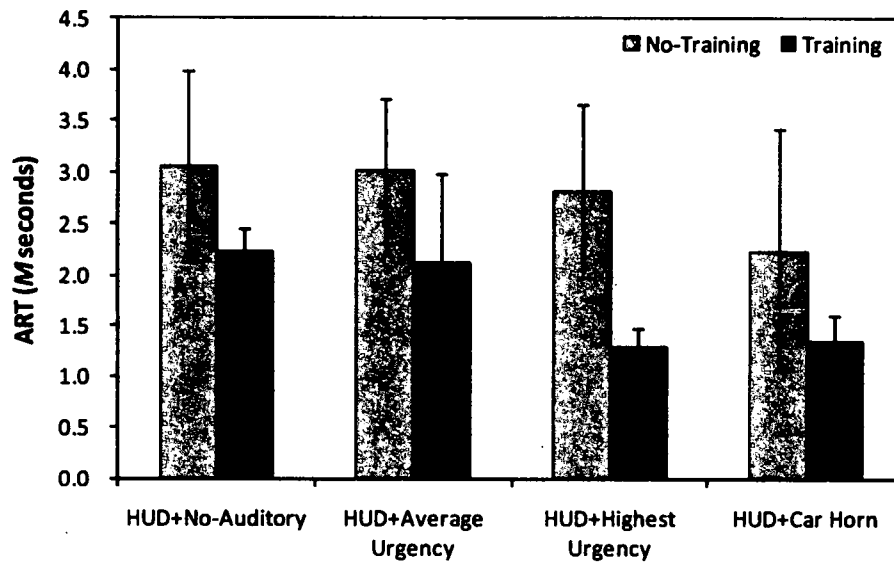


Figure 10. Mean ART as a function of FCW system training and auditory warning.

Pedal Transition Time. Pedal transition time, the difference in time between the driver releasing the accelerator pedal and depressing the brake pedal, was examined in a $2 \times 4 \times 2$, between-subjects MANOVA. As shown in Figure 11, the main effect of training approached significance, $F(1, 59) = 3.696$, $MSE = .362$, $p = .059$, $\eta^2 = .059$. The main effects for auditory warning and gender were not significant. The interactions between training, warning and gender, training and auditory warning, training and gender, and warning and gender were not significant.

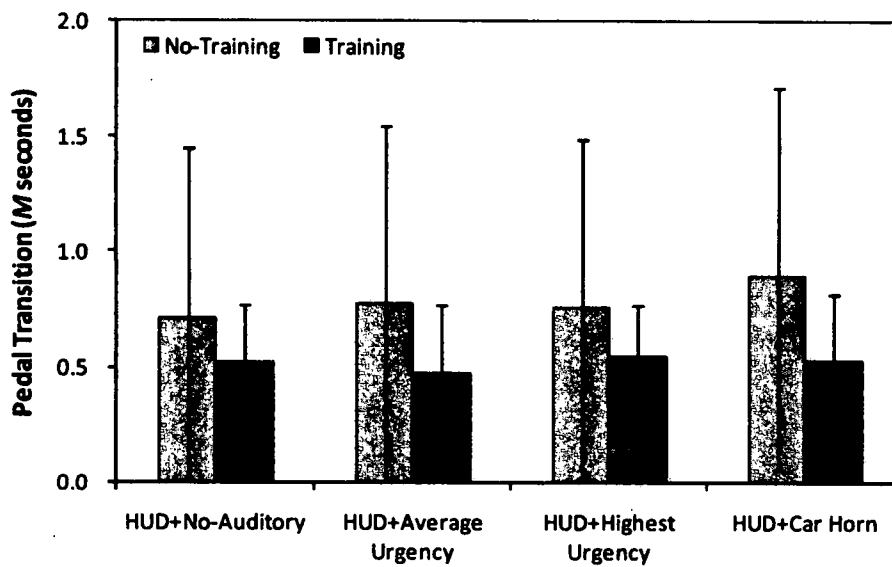


Figure 11. Mean pedal transition time as a function of FCW system training and auditory warning.

Brake Reaction Time. BRT, the measure of time between the lead-vehicle braking and the driver depressing the brake pedal, was examined in a $2 \times 4 \times 2$, between-subjects MANOVA. As can be seen in Figure 12, there appears to be an interaction between gender and training. Although women ($M = 3.73$, $SD = .71$) were slower than men ($M = 3.42$, $SD = .61$) to press the brake in the no-training condition, women ($M = 2.14$, $SD = .63$) were faster than men ($M = 2.42$, $SD = .68$) to respond when they had received training. Overall, the effect of training appears to be great for both men and women. Analysis verified the observation that the interaction between training and gender was significant, $F(1, 59) = 4.472$, $MSE = .338$, $p = .039$, $\eta^2 = .070$. In addition, the main effect of training was significant and very strong, $F(1, 59) = 93.014$, $MSE = .338$, $p < .0001$, $\eta^2 = .612$. Follow-up paired comparisons looking at the differences between men and women at each level of FCW training produced no significant differences, $t(73) = -$

0.92 and 0.83, for the no-training and training conditions, respectively, $p > .05$. However, as expected, paired comparisons t -tests revealed significant differences between no-training and training, $t(73) = 3.00$ and 4.70 , for men and women, respectively, $p < .05$. That women responded somewhat better than men to training is believed to account for the interaction. As can be seen in Figure 13, the main effect for auditory warning was also significant $F(3, 59) = 7.753$, $MSE = .338$ $p = .0002$, $\eta^2 = .283$. A post hoc Tukey HSD revealed that the BRT for car horn ($M = 2.53$, $SD = .94$) and highest-urgency ($M = 2.70$, $SD = .98$) were significantly faster than for the no-auditory ($M = 3.28$, $SD = .72$) warning. The car horn was also significantly faster than average-urgency ($M = 3.16$, $SD = .89$). However, there was no difference between no-auditory and average-urgency, highest-urgency and average-urgency, or highest-urgency and car horn. The main effect of gender was not significant. The interactions between training, warning and gender, training and auditory warning, and warning and gender were not significant.

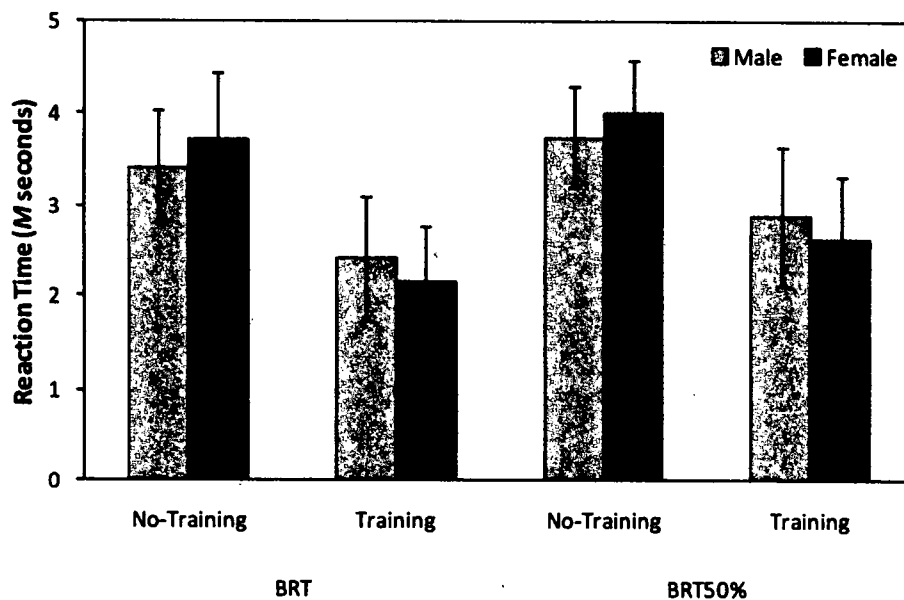


Figure 12. FCW system training by gender interaction for BRT and BRT50%.

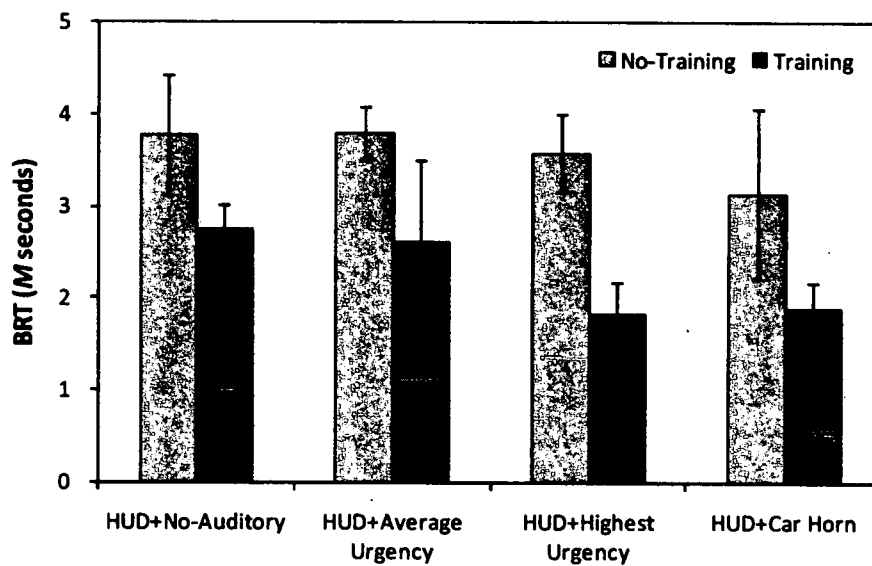


Figure 13. Mean BRT as a function of FCW system training and auditory warning.

BRT50%. BRT50% which represents the difference in time between when the lead-vehicle applied its brakes and when the driver depressed the brake pedal 50% of the

pedal's total length of travel, was examined in a $2 \times 4 \times 2$ between-subjects MANOVA. As can be seen in Figure 12, there appears to be an interaction between gender and training. Although women ($M = 4.00$, $SD = .58$) were slower than men ($M = 3.75$, $SD = .54$) to press the brake pedal 50% of the way in the no-training condition, women ($M = 2.61$, $SD = .71$) were faster than men ($M = 2.88$, $SD = .77$) to respond when they had received training. Overall, the effect of FCW training appears to be great for both men and women. Analysis verified the observation that the interaction between training and gender was significant, $F(1, 59) = 4.554$, $MSE = .347$, $p = .037$, $\eta^2 = .072$. In addition, the main effect of training was significant and very strong, $F(1, 59) = 64.219$, $MSE = .347$, $p < .0001$, $\eta^2 = .521$. Follow-up paired comparisons looking at the differences between men and women at each level of FCW training produced no significant differences, $t(73) = -0.72$ and 0.78 , for the no-training and training conditions, respectively, $p > .05$. However, as expected, paired comparisons t -tests revealed significant differences between no-training and training, $t(73) = 2.51$ and 11.84 , for men and women, respectively, $p < .01$. That women responded somewhat better than men to training is believed to account for the interaction. As can be seen in Figure 14, the main effect for auditory warning was also significant $F(3, 59) = 5.520$, $MSE = .347$, $p = .002$, $\eta^2 = .219$. A post hoc Tukey HSD revealed that the BRT50% for car horn ($M = 2.53$, $SD = .94$) was significantly faster than for no-auditory ($M = 3.28$, $SD = .72$) and average-urgency ($M = 3.16$, $SD = .89$). However, there was no difference between the no-auditory, average-urgency, and the highest-urgency ($M = 2.70$, $SD = .98$). The main

effect of gender was not significant. The interactions between training, warning and gender, training and auditory warning, and warning and gender were not significant.

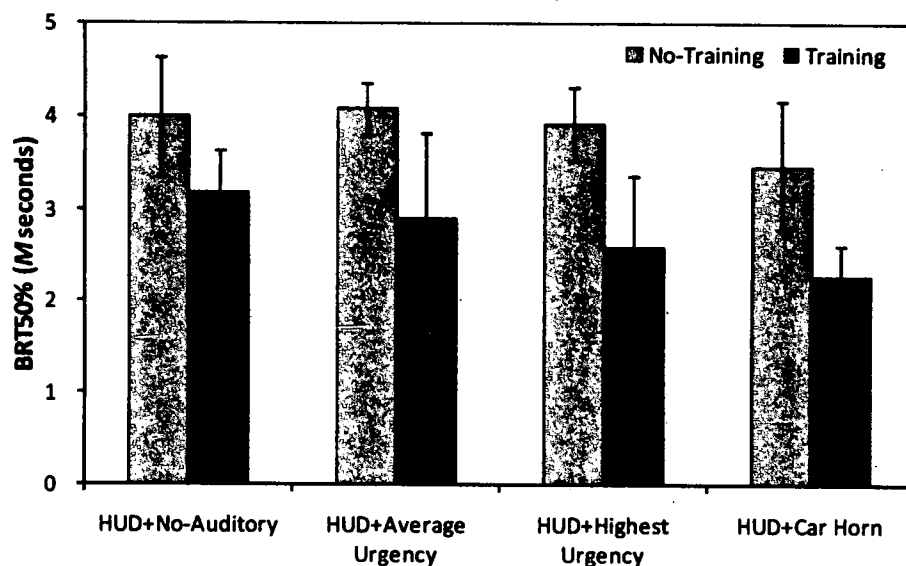


Figure 14. Mean BRT50% as a function of FCW system training and auditory warning.

Minimum Time to Collision. MinTTC, a measure of the closest distance between the host vehicle and lead-vehicle given velocity and distance, was examined a 2 x 4 x 2 between-subjects MANOVA. For drivers who collided with the lead-vehicle, minTTC was recorded as zero. As can be seen in the Figure 15, there appears to be an interaction between gender and training. Although women ($M = .34$, $SD = 1.41$) had a smaller minimum TTC than men ($M = .47$, $SD = .99$) in the no-training condition, women ($M = 3.98$, $SD = 2.27$) had a larger minimum TTC than men ($M = 2.46$, $SD = 2.47$) when they had received training. Overall, the effect of training appears to be great for both men and women. Analysis verified the observation that the interaction between training and

gender was significant, $F(1, 59) = 5.765$, $MSE = 2.512$, $p = .02$, $\eta^2 = .089$. In addition, the main effect of training was significant and very strong, $F(1, 59) = 54.749$, $MSE = 2.512$, $p < .0001$, $\eta^2 = .481$. The main effect of gender approached significance, $F(1, 59) = 3.729$, $MSE = 2.512$, $p = .058$, $\eta^2 = .059$. Follow-up paired comparisons looking at the differences between men and women at each level of training produced no significant differences, $t(73) = .05$ and $-.61$, for the no-training and training conditions, respectively, $p > .05$. Paired comparisons t -tests revealed significant differences between no-training and training, $t(73) = -.79$ and -1.45 , for men and women, respectively, $p < .05$. That women responded somewhat better than men to training is believed to account for the interaction. As can be seen in Figure 16, the main effect for auditory warning was also significant $F(3, 59) = 6.731$, $MSE = 2.512$, $p = .0006$, $\eta^2 = .255$. A post hoc Tukey HSD revealed that the minTTC for car horn ($M = 2.95$, $SD = 2.57$) was significantly greater than for no-auditory ($M = .83$, $SD = 1.03$) and average-urgency ($M = 1.39$, $SD = 2.35$). However, there was no difference between no-auditory, average-urgency, and highest-urgency ($M = 2.15$, $SD = 2.84$). The interactions between training, warning and gender, training and auditory warning, and warning and gender were not significant.

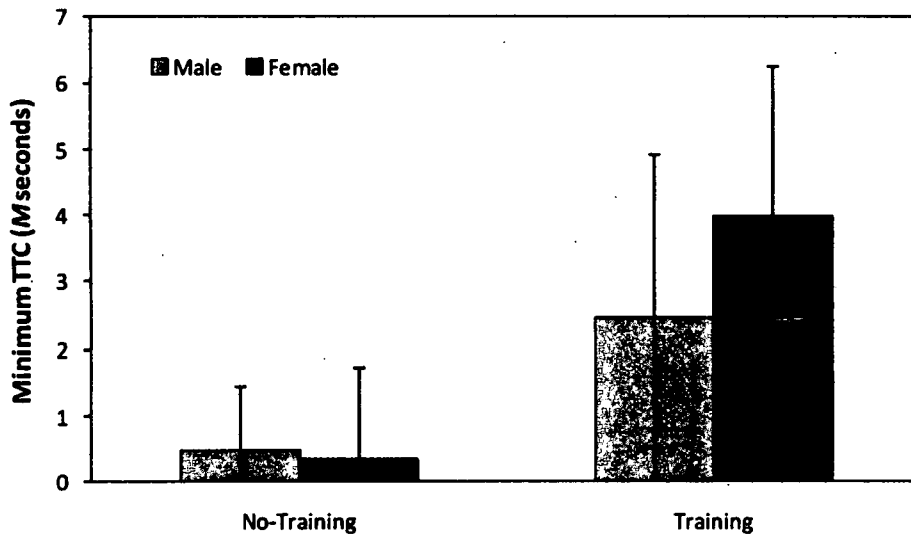


Figure 15. FCW system training by gender interaction for minimum TTC.

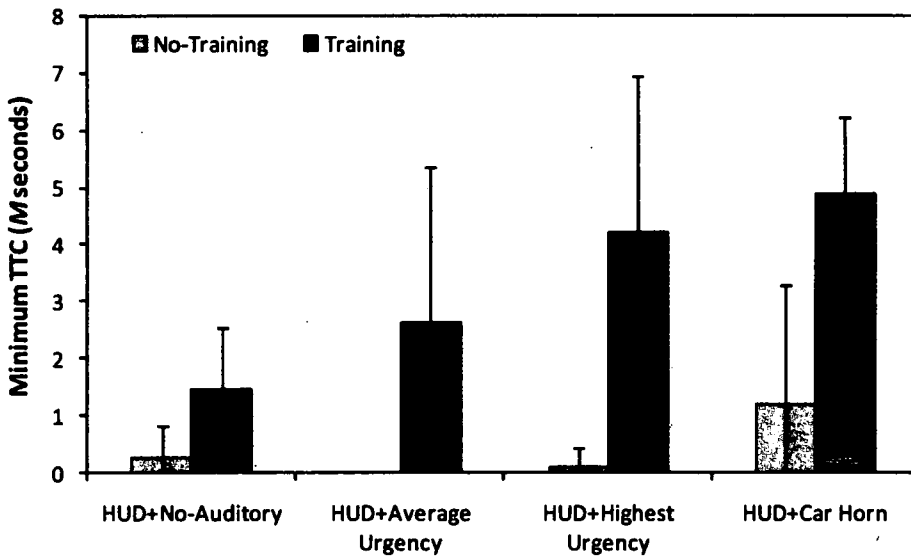


Figure 16. Mean minimum TTC as a function of FCW system training and auditory warning.

Collision Velocity. The velocity (m/s) at the moment (a) the following-vehicle impacted the lead-vehicle, or (b) the following-vehicle passed the lead-vehicle's rear

bumper if the driver steered around, was examined in a $2 \times 4 \times 2$, between-subjects MANOVA. For drivers who did not collide with the lead-vehicle, collision velocity was recorded as 0 m/s. As shown in Figure 17, a significant main effect was revealed for training, $F(1, 59) = 76.687$, $MSE = 28.517$, $p < .0001$, $\eta^2 = .565$. There was also a significant main effect for auditory warning, $F(3, 59) = 3.379$, $MSE = 28.517$, $p = .024$, $\eta^2 = .147$. A post hoc Tukey HSD revealed that collision velocity was significantly lower for car horn ($M = 4.70$, $SD = 6.71$) than for average-urgency ($M = 9.68$, $SD = 7.86$). However, there was no difference between car horn, highest-urgency ($M = 6.71$, $SD = 7.40$), and no-auditory ($M = 7.95$, $SD = 8.65$). The main effect for gender was not significant. The interactions between training, warning and gender, training and auditory warning, training and gender, and warning and gender were not significant.

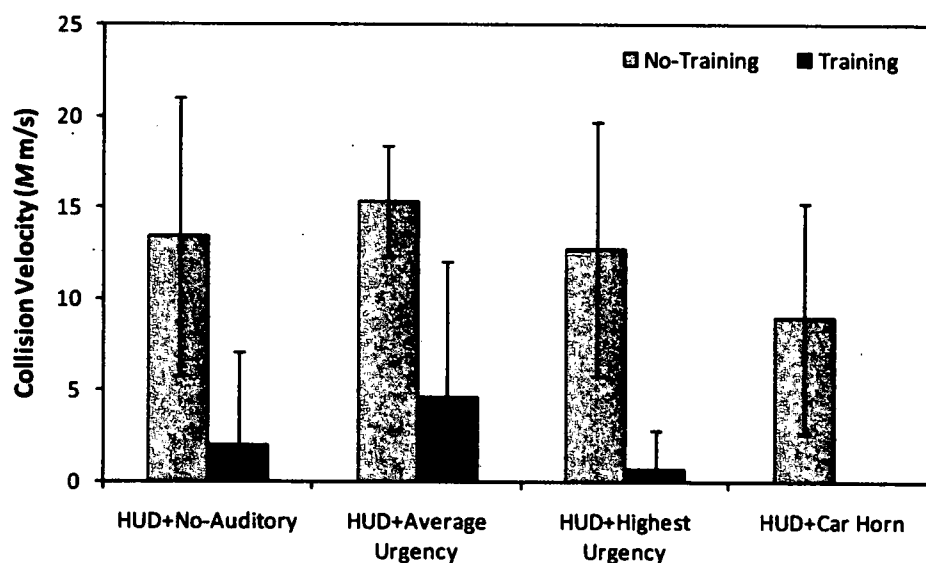


Figure 17. Mean collision velocity as a function of FCW system training and auditory warning.

Glance-Back Analyses

A second analysis provided an opportunity to examine the effect of glancing back, an unexpected and unplanned for behavior, but one which warranted examination. In this analysis, glancing back is treated an independent variable and its effect on the eight quantitative dependent variables is examined. As can be seen in Table 9, analysis revealed a main effect of glancing back to the console for seven of the eight quantitative dependent variables. Thus, when drivers glanced-back, duration of console gaze, ART, PTT, BRT, BRT50%, minTTC, and collision velocity are significantly longer. However, drivers who glanced-back also had a significantly earlier GRT. Following Table 9, results for each of the eight, independent, one-way analyses of variance (ANOVA) are given.

Table 9

Mean (SD) Dependent Variables as a Function of Glances-Back

DV	Glance-Back to Console	
	No Glance-Back	Glance-Back
GRT (s)		
Male	1.26 (.45)	1.11 (.28)
Female	1.18 (.45)	.95 (.18)
All	1.22 (.45)	1.03 (.25)***
Gaze (s)		
Male	1.26 (.45)	1.97 (.36)
Female	1.18 (.45)	1.86 (.27)
All	1.22 (.45)*****	1.92 (.32)
ART (s)		
Male	2.08 (.74)	2.89 (.90)
Female	1.85 (.87)	2.81 (1.09)
All	1.96 (.81)****	2.85 (.97)
PTT (s)		
Male	.53 (.33)	.70 (.72)
Female	.54 (.27)	1.06 (.98)
All	.54 (.30)**	.86 (.85)
BRT (s)		
Male	2.61 (.69)	3.59 (.60)
Female	2.39 (.84)	3.87 (.59)
All	2.50 (.77)*****	3.72 (.60)
BRT50% (s)		
Male	3.00 (.74)	3.98 (.31)
Female	2.81 (.81)	4.16 (.44)
All	2.90 (.77)*****	4.07 (.38)
minTTC (s)		
Male	2.11 (2.25)	.06 (.23)
Female	3.30 (2.64)	.23 (.79)
All	2.72 (2.51)****	.14 (.55)
Velocity (m/s)		
Male	3.12 (5.65)	13.60 (5.12)
Female	3.77 (6.31)	15.46 (5.51)
All	3.45 (5.94)*****	14.46 (5.28)

** $p < .05$; *** $p \leq .01$; **** $p \leq .001$; ***** $p \leq .000001$

The next set of effects was all significant for the effect of Glance-Back at console. All were examined in a between-subjects Analysis of Variance.

GRT: A main effect for glance-back was significant, $F(1, 73) = 3.912$, $MSE = .152$, $p = .003$, $\eta^2 = .052$ (see Figure 18).

Duration of Console Gaze: A main effect for glance-back was significant, $F(1, 73) = 50.261$, $MSE = .166$, $p < .00001$, $\eta^2 = .408$ (see Figure 18).

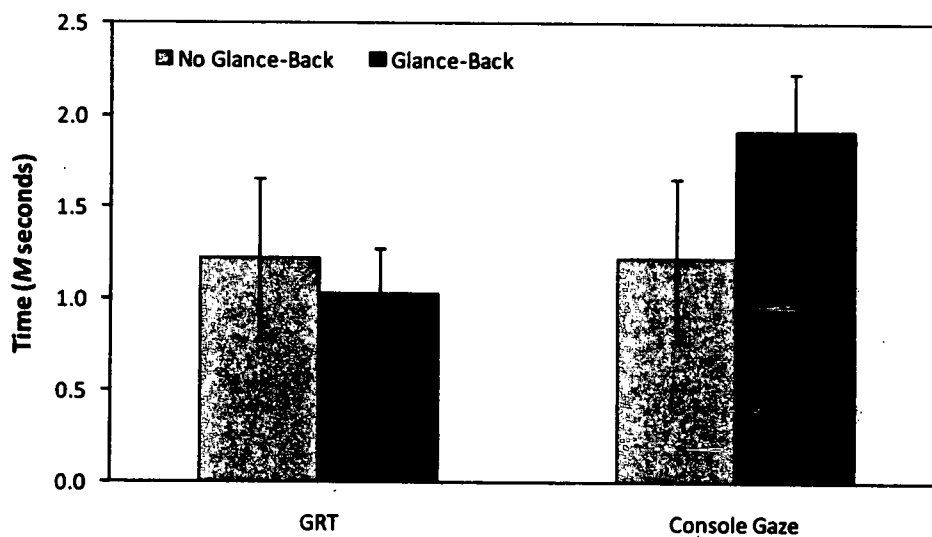


Figure 18. Mean GRT and console-gaze duration as a function of glance.

ART: A main effect for glance-back was significant, $F(1, 73) = 17.872$, $MSE = .756$, $p < .0001$, $\eta^2 = .197$ (see Figure 19).

Pedal Transition Time: A main effect for glance-back was significant, $F(1, 73) = 5.991$, $MSE = .306$, $p = .017$, $\eta^2 = .076$ (see Figure 19).

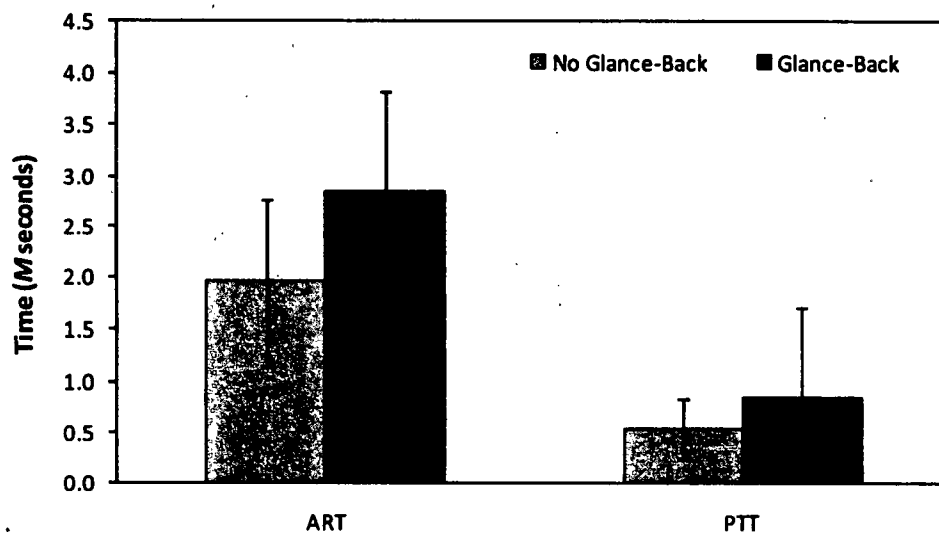


Figure 19. Mean ART and PTT as a function of glance.

BRT: A main effect for glance-back was significant, $F(1, 73) = 49.027$, $MSE = .402$, $p < .00001$, $\eta^2 = .402$ (see Figure 20).

BRT50%: A main effect for glance-back was significant, $F(1, 73) = 52.355$, $MSE = .441$, $p < .00001$, $\eta^2 = .418$ (Figure 20).

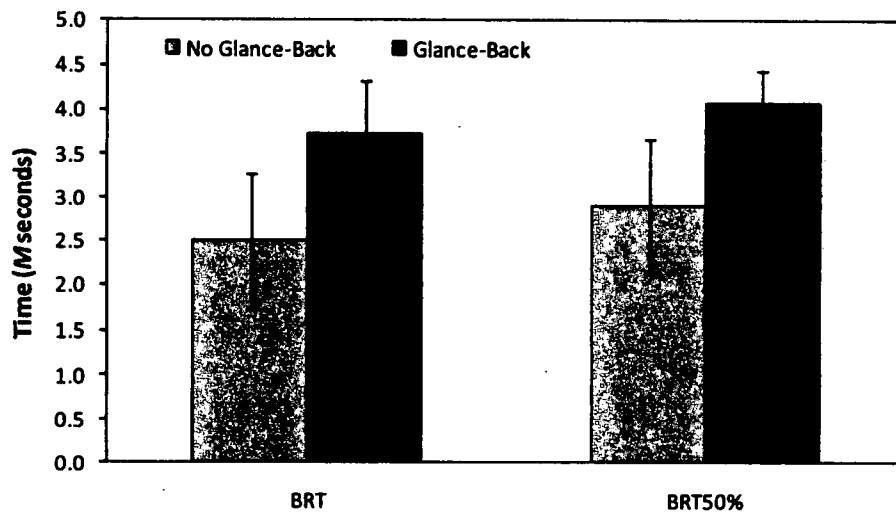


Figure 20. Mean BRT and BRT50% as a function glance.

Minimum TTC: A main effect for glance-back was significant, $F(1, 73) = 26.765$, $MSE = 4.237$, $p < .00001$, $\eta^2 = .268$ (see Figure 21).

Collision Velocity: The main effect for glance-back was significant, $F(1, 73) = 62.804$, $MSE = 32.784$, $p < .00001$, $\eta^2 = .462$ (see Figure 21).

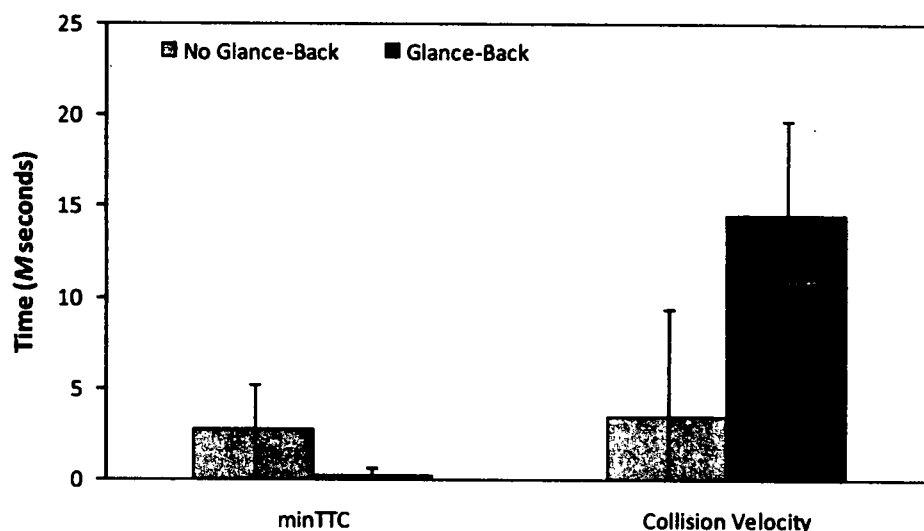


Figure 21. Mean minTTC and collision velocity as a function of glance-back.

Correlational Analyses

A series of Pearson Product-Moment Correlation analyses in the no-training condition evaluated the relationships between the eight dependent variables, collapsed across gender, auditory warning, and glance-back. As shown in Table 10, significant positive correlations were revealed between console gaze and GRT, ART, BRT, BRT50%, and collision velocity; between ART and BRT, BRT50%, and collision velocity; between BRT and BRT50% and collision velocity; and between BRT50% and collision velocity; $r(n = 38) \geq .322, p \leq .049$. Negative correlations were significant for ART and pedal transition, minTTC and GRT, minTTC and console gaze, minTTC and ART, minTTC and BRT, minTTC and BRT50%, minTTC and collision velocity, $r(n = 37) \leq -.329, p \leq .044$. With the exception of the cells outlined in Table 10, significance is the same between no-training and training.

As shown in Table 11, a series of Pearson Product-Moment Correlation analyses in the training condition evaluated the relationships between the eight dependent variables, collapsed across gender, auditory warning, and glance. Significant positive correlations were revealed between GRT and console gaze, ART, BRT, BRT50%, and collision velocity; between console gaze and ART, BRT, BRT50% and collision velocity; between ART and BRT, BRT50%, and collision velocity; between pedal transition and BRT50%; between BRT and BRT50% and collision velocity; and between BRT50% and collision velocity; $r (n = 37) \geq .356, p \leq .030$. Negative correlations were significant between minTTC and GRT, console gaze, ART, BRT, BRT50%, and collision velocity; $r (n = 37) \leq -.511, p \leq .001$.

Table 10

Correlation Matrix of Quantitative Dependent Variables: No-Training Condition (N = 38)^a

	Collision Velocity	min TTC	BRT50%	BRT	Pedal Transition	ART	Console Gaze	GRT
GRT	-.005	-.137	-.038	.020	-.329*	.269	.322*	1.000
Gaze	.670***	-.553***	.641***	.657***	-.008	.460**	1.000	
ART	.671***	-.541***	.648***	.634***	-.724****	1.000		
Pedal	-.046	-.046	.020	.074	1.000			
BRT	.919****	-.834****	.959****	1.000				
BRT50%	.948****	-.796****	1.000					
min TTC	-.705****	1.000						
Velocity	1.000							

□ Outline indicates correlations whose significance level is different from that of the training condition.

^aCollapsed across auditory warning, gender, and glance.

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .000001$

Table 11

Correlation Matrix of Quantitative Dependent Variables: Training Condition (N = 37)^a

	Collision Velocity	min TTC	BRT50%	BRT	Pedal Transition	ART	Console Gaze	GRT
GRT	.496**	-.511**	.519***	.614***	.172	.561***	.826****	1.000
Gaze	.648***	-.636***	.681***	.674***	.097	.651***	1.000	
ART	.625***	-.798****	.745****	.924****	-.137	1.000		
Pedal	.285	-.186	.356*	.252	1.000			
BRT	.721****	-.851****	.866****	1.000				
BRT50%	.733****	-.923****	1.000					
min TTC	-.531***	1.000						
Velocity	1.000							

□ Outline indicates correlations whose significance level is different from that of the no-training condition.

^aCollapsed across auditory warning, gender, and glance.

* $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .000001$

Qualitative Analyses

Qualitative analyses using chi-square tests were used to examine glances-back to console (treated as a dependent variable), collision rate, and results from the FCW questionnaire. Because of the limitations of chi-square tests of independence analysis, only two variables can be entered into the same analysis concurrently. In order to accomplish a complete analysis, each variable required several sets of chi-square tests.

Collision and Glance-Back Chi-Square Analyses

For the glanced-back and collision variables, six separate sets of chi-square comparisons were necessary to evaluate all possible interactions and effects for each variable. As shown in Figure 22, the chi-square analyses of categorical variables obtained in the driving simulator was composed of the following comparisons:

- (1) no glance-back (or no collision) by glanced-back (or collided);
- (2) levels of training by levels of glance-back (or collision);
- (3) levels of auditory warning by levels of glance-back (or collision);
- (4) male by female for glanced-back (or collided) *only*;
- (5) levels of training by levels of gender for glanced-back (or collided) *only*;
- (6) levels of auditory warning by levels of gender for glanced-back (or collided) *only*;

A summary of chi-square test results for the glance-back and collision analyses is shown in Table 12.

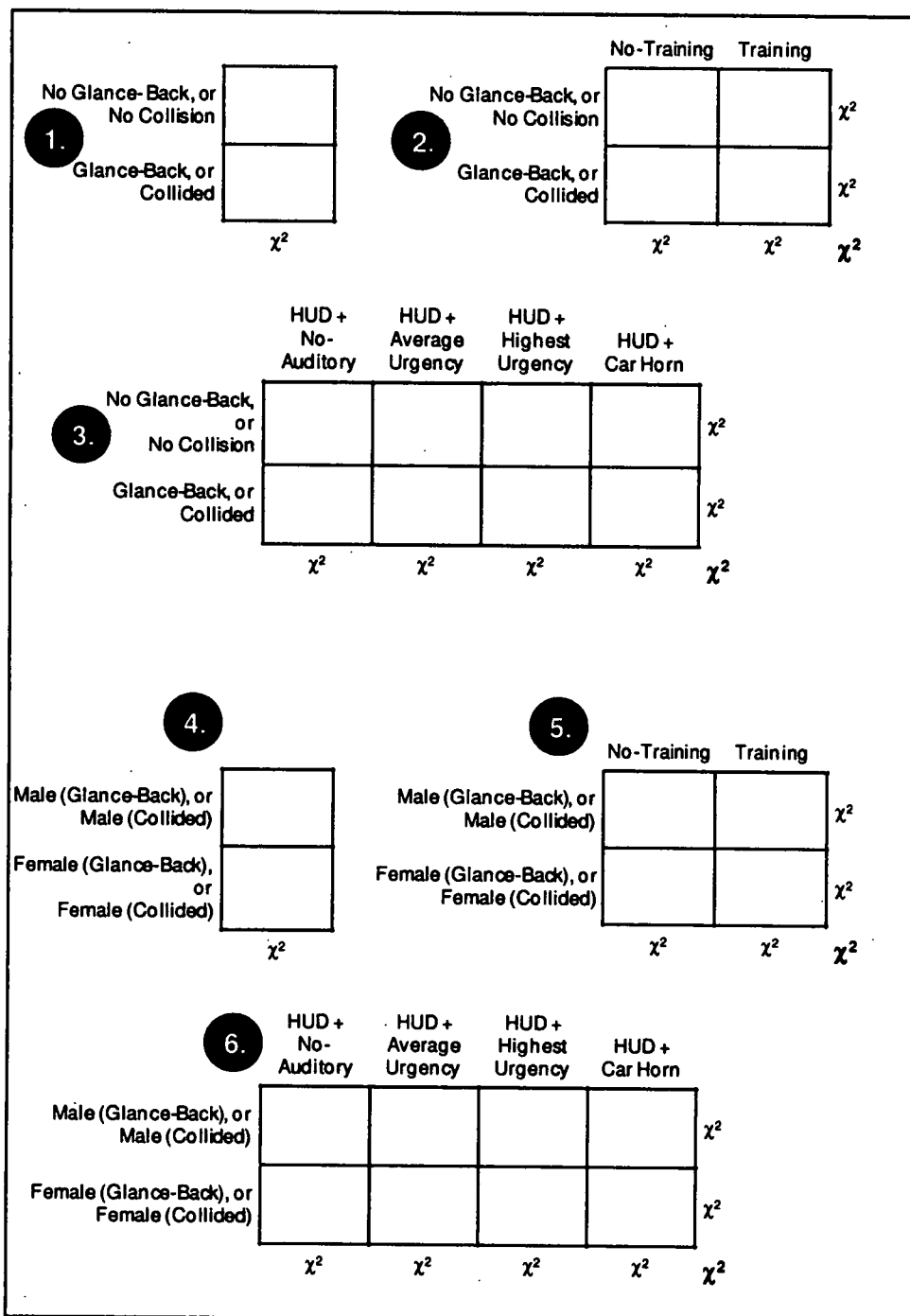


Figure 22. Overview of simulator chi-square analyses.
 χ^2 : goodness-of-fit test. χ^2 : test of independence.

Table 12						
Summary of Simulator Chi-Square Analyses						
Comp. #					Glances	Collisions
1.	G	No Glance-Back or No Collision	by	Glanced-Back or Collided	**	NS
2.	I	No-Training and Training	by	Levels of Glance or Levels of Collision	**	**
	G	No-Training	by	Levels of Glance or Levels of Collision	NS	**
	G	Training	by	Levels of Glance or Levels of Collision	**	**
	G	No-Training and Training	by	No Glance-Back or No Collision	**	**
	G	No-Training and Training	by	Glanced-Back or Collided	**	**
3.	I	HUD+No-Auditory HUD+Average-Urgency HUD+Highest-Urgency HUD+Car Horn	by	Levels of Glance or Levels of Collision	NS	NS
	G	HUD+No-Auditory HUD+Average-Urgency HUD+Highest-Urgency HUD+Car Horn	by	No Glance or No Collision	NS	NS
	G	HUD+No-Auditory HUD+Average-Urgency HUD+Highest-Urgency HUD+Car Horn	by	Glanced-Back or Collided	NS	NS
	G	HUD+No-Auditory	by	Levels of Glance or Collision	NS	NS
	G	HUD+Average-Urgency	by	Levels of Glance or Collision	NS	NS
	G	HUD+Highest-Urgency	by	Levels of Glance or Collision	NS	NS
	G	HUD+Car Horn	by	Levels of Glance or Collision	**	NS
Glanced-Back (only) and Collided (only)						
4.	G	Male	by	Female	NS	NS
5.	I	No-Training and Training	by	Male and Female	NS	NS
	G	No-Training	by	Male and Female	NS	NS
	G	Training	by	Male and Female	NS	NS
	G	No-Training and Training	by	Male	**	**
	G	No-Training and Training	by	Female	**	**
6.	I	HUD+No-Auditory HUD+Average-Urgency HUD+Highest-Urgency HUD+Car Horn	by	Male and Female	--	--
	G	HUD+No-Auditory HUD+Average-Urgency HUD+Highest-Urgency HUD+Car Horn	by	Male	--	NS
	G	HUD+No-Auditory HUD+Average-Urgency HUD+Highest-Urgency HUD+Car Horn	by	Female	--	--
	G	HUD+No-Auditory	by	Male and Female	--	NS
	G	HUD+Average-Urgency	by	Male and Female	--	NS
	G	HUD+Highest-Urgency	by	Male and Female	--	--
	G	HUD+Car Horn	by	Male and Female	--	--

Note. I: chi-square test of independence. G: chi-square goodness-of-fit test.

** $p \leq .05$; NS: $p > .05$.

--: chi-square test criteria for minimum n not met.

Comp. #: Comparison number, as shown in Figure 22.

Glances-Back to Console. A comparison was made of participants in the no-training and training conditions according to their glance behavior, that is, glanced-back or no glance. A chi-square test of independence showed that glance was not independent of training, $\chi^2(1, N = 75) = 18.35, p < .0001$, as can be seen in Table 13.

Table 13

Percent Glances-Back as a Function of Training, Auditory Warning, and Glances-Back (N = 75)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Did Not Glance <i>n</i> = 16	Glanced-Back <i>n</i> = 22	Did Not Glance <i>n</i> = 33	Glanced-Back <i>n</i> = 4
HUD + No-Auditory Warning	5.3	8	10.7	1.3
HUD + Average-Urgency	5.3	6.7	10.7	2.7
HUD + Highest-Urgency	1.3	10.7	10.7	1.3
HUD + Car Horn	9.3	4	12	--

More participants did not glance-back (65%) than glanced-back (35%). However, using modified Bonferroni adjusted alpha levels, fewer trained participants glanced-back, $\chi^2(1, n = 37) = 22.73, p < .0001$. The difference between glance behavior was not significant for drivers who received no-training. Furthermore, of the drivers who did glance-back, more did not receive training, $\chi^2(1, n = 26) = 12.46, p = .0004$. Of the

drivers who did not glance-back, more had been trained, $\chi^2(1, n = 49) = 5.89, p = .015$. Thus, when drivers glance-back they are more likely to have received no-training, but when they do not glance-back, they are more likely to have received training. Finally, trained participants are less likely to glance-back.

A second chi-square test of independence, ignoring training, showed that glance behavior was independent of auditory warning, $\chi^2(3, N = 75) = 4.94, p = .176$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the four auditory warning types revealed that for the car horn warning condition, fewer drivers glanced-back, $\chi^2(1, n = 19) = 8.90, p = .003$. Glance behavior did not differ significantly in the no-auditory, average-urgency, and highest-urgency warning conditions. Thus, the car horn warning significantly reduced glances-back to console.

Too few participants glanced-back ($N = 26$) to perform a gender by auditory warning analysis. That is, there were too few participants to perform a 2 (gender) by 4 (auditory warning) chi-square test of independence with 8 conditions and maintain reliability.

Glanced-Back (only). Of only the participants who glanced-back, a comparison was made of training according to each gender. A chi-square test of independence showed that gender was independent of training, $\chi^2(1, N = 26) = .028, p = .867$, as can be seen in Table 14.

Table 14

Percent Glances-Back as a Function of Training, Auditory Warning, and Gender (N = 26)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Male <i>n</i> = 12	Female <i>n</i> = 10	Male <i>n</i> = 2	Female <i>n</i> = 2
HUD + No-Auditory Warning	11.5	11.5	--	3.8
HUD + Average-Urgency	15.4	3.8	3.8	3.8
HUD + Highest-Urgency	15.4	15.4	3.8	--
HUD + Car Horn	3.8	7.7	--	--

Regardless of gender, more participants who glanced-back had received no-training (85%) than training (15%), $\chi^2(1) \geq 5.33$, $p \leq .021$. Thus, with training, both men and women made fewer glances-back to the console.

Too few participants glanced-back ($N = 26$) to perform the gender by auditory warning analysis. That is, there were too few participants to perform a 2 (gender) by 4 (auditory warning) chi-square test of independence with 8 conditions and maintain reliability.

Collisions. A comparison was made of participants in the no-training and training conditions according to collision with the lead-vehicle. A chi-square test of independence showed that collision was not independent of training, $\chi^2(1, N = 75) = 34.67$, $p < .0001$, as can be seen in Table 15.

Table 15

Percent Collisions as a Function of Training, Auditory Warning, and Gender (N = 75)

Auditory Warning	FCW System Training			
	No-Training		Training	
	No Collision <i>n</i> = 6	Collision <i>n</i> = 32	No Collision <i>n</i> = 31	Collision <i>n</i> = 6
HUD + No-Auditory Warning	2.7	10.7	9.3	2.7
HUD + Average-Urgency	--	12	9.3	4
HUD + Highest-Urgency	1.3	10.7	10.7	1.3
HUD + Car Horn	4	9.3	12	--

Note. Collisions operationally defined as the host vehicle being unable to stop in time and, as a result, (a) colliding with (rear-ending) the lead-vehicle, or (b) steering around and past the rear bumper of the lead-vehicle as part of an avoidance maneuver.

More participants collided (51%) than did not collide (49%). However, using modified Bonferroni adjusted alpha levels, untrained participants had more collisions, $\chi^2(1, n = 38) = 17.79, p < .0001$. Of trained drivers, more had no collision, $\chi^2(1, n = 37) = 16.89, p < .0001$. Furthermore, of the drivers who did not collide, more had received training, $\chi^2(1, n = 37) = 16.89, p < .0001$, while more drivers who collided had not received training, $\chi^2(1, n = 38) = 17.79, p < .0001$. Thus, training significantly reduced collisions, while untrained drivers were more likely to collide. Furthermore, drivers who

avoided a collision were more likely to have received training, while drivers involved in a collision were more likely to have been untrained.

A second chi-square test of independence showed that collision was independent of auditory warning, $\chi^2(3, N = 75) = 2.67, p = .445$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the four auditory warning types revealed that regardless of auditory warning, there was no difference in collisions, $\chi^2(1) \leq 1.32, p \geq .251$. That is, likelihood of a collision with the lead-vehicle did not differ according to auditory warning.

Collided (only). Of *only* the participants who collided with lead-vehicle, a comparison was made for each gender according to training. A chi-square test of independence showed that gender was independent of training in affecting collision, $\chi^2(1, N = 38) = .563, p = .453$, as can be seen in Table 16.

Table 16

Percent Collided as a Function of Training, Auditory Warning, and Gender (N = 38)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Male <i>n</i> = 16	Female <i>n</i> = 16	Male <i>n</i> = 4	Female <i>n</i> = 2
HUD + No-Auditory Warning	10.5	10.5	2.6	2.6
HUD + Average-Urgency	13.2	10.5	5.3	2.6
HUD + Highest-Urgency	10.5	10.5	2.6	--
HUD + Car Horn	7.9	10.5	--	--

Note. Collisions are operationally defined as the host vehicle being unable to stop in time and, as a result, (a) colliding with (rear-ending) the lead-vehicle, or (b) steering around and past the rear bumper of the lead-vehicle as part of an avoidance maneuver.

Regardless of gender, more participants who collided had not received training (76%) than had training (24%), $\chi^2(1) \geq 7.20, p \leq .007$. Thus, with training, fewer men and women collided when they had been the recipients of training.

A second chi-square test of independence showed that gender was independent of auditory warning, $\chi^2(3, N = 38) = .483, p = .923$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the four auditory warning conditions revealed that, as a function of auditory warning, there was no difference between men and women for collisions, $\chi^2(1) \leq .333, p \geq .564$. Separate chi-square goodness-of-fit tests for each gender revealed that, regardless of gender, there was no difference in collisions across the four levels of auditory warnings, $\chi^2(1) \leq 1.60, p \geq$

.659. That is, collisions did not differ as a function of gender at each level of the auditory warning or differ as a function of auditory warning for either men or women.

FCW Questionnaire Chi-Square Analyses

Before conducting the qualitative analysis for each question from the FCW questionnaire, responses were combined into two categories. The FCW questionnaire asked participants to choose one of four options in response to each statement: strongly disagree, somewhat disagree, somewhat agree, strongly agree. For data analysis, responses were grouped into two levels of agreement, agree (strongly agree and somewhat agree) and disagree (strongly disagree and somewhat disagree) in order to allow chi-square tests to be conducted. Items from the FCW questionnaire are divided into three sections: training method validation, auditory warning attributes, and likelihood of recommending the FCW system. Descriptive statistics for all data collected from the FCW questionnaire appear in Appendix O.

For the qualitative analysis of the questionnaire variables, four separate sets of chi-square comparisons were necessary to evaluate all possible interactions and effects for each variable. As shown in Figure 23, the chi-square analyses of qualitative variables obtained through the FCW questionnaire was composed of the following comparisons:

- (1) agree by disagree;
- (2) levels agreement by levels training;
- (3) levels of agreement by levels of auditory warning;

(4) levels of training by levels of auditory warning for:

(4a) agree *only*;

(4b) disagree *only*.

A summary of chi-square test results for the FCW questionnaire analyses are shown in Tables 17 and 18.

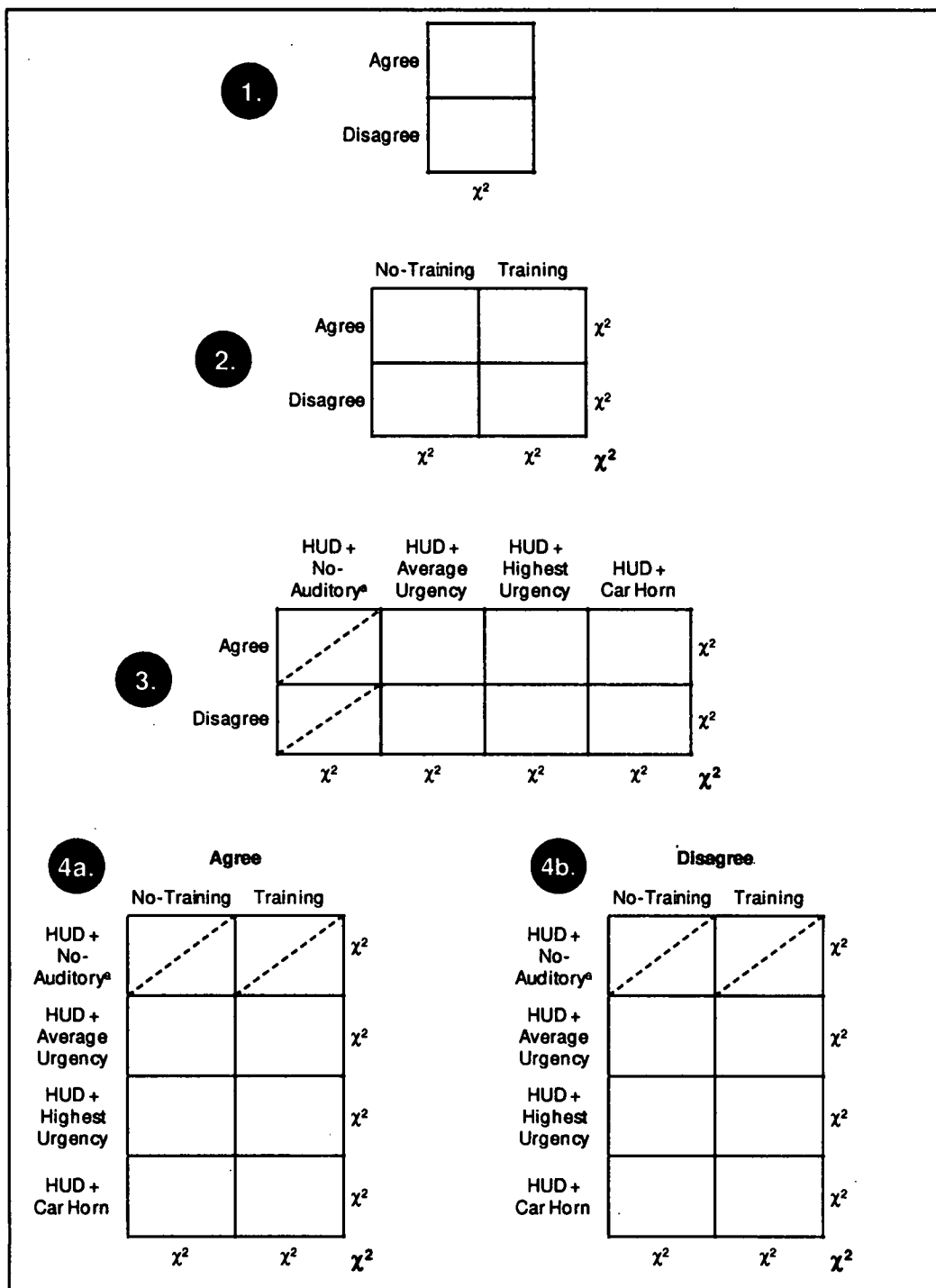


Figure 23. Overview of FCW questionnaire chi-square analyses.

χ^2 : goodness-of-fit test. χ^2 : test of independence.

^aHUD + No-Auditory included in training method validation analysis only.

Table 17														
FCW Questionnaire Chi-Square Analyses: Agreement by Training and by Warning														
Comparison #:				FCW Questionnaire Statements										
				Training Method Validation		Auditory Warning Attributes								FCW
				Expected Braking	Surprise at Braking	Captured Attention	Startle	Annoying	Understandable	Useful	Useful Real Roads	Reduced Severity	Helped Avoid	Recommend
1.	G	Agree	by Disagree	**	**	**	**	**	NS	**	**	NS	**	**
2.	I	No-Training Training	by Agree Disagree	**	**	NS	*	**	**	NS	NS	NS	NS	*
	G	No-Training	by Agree Disagree	**	**	**	**	**	**	**	**	NS	--	**
	G	Training	by Agree Disagree	NS	**	--	**	**	**	**	27/27	NS	**	27/27
	G	Agree	by No-Training Training	*	NS	NS	NS	NS	**	NS	NS	**	**	NS
	G	Disagree	by No-Training Training	NS	*	2/2	*	**	**	NS	1/1	*	--	3/3
3.	I	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	by Agree Disagree	NS	NS	NS	NS	NS	*	**	NS	NS	NS	NS
	G	HUD+No-Auditory	by Agree Disagree	**	**	/	/	/	/	/	/	/	/	/
	G	HUD+Average	by Agree Disagree	**	**	**	**	**	NS	NS	18/18	NS	*	**
	G	HUD+Highest	by Agree Disagree	**	18/18	17/17	**	**	NS	**	**	NS	9/9	**
	G	Car Horn	by Agree Disagree	**	**	**	**	**	NS	**	17/17	NS	**	16/16
	G	Agree	by (HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	G	Disagree	by (HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	NS	--	--	--	--	NS	--	--	--	--	--

Note. I: Chi-square test of independence. G: chi-square goodness-of-fit test.

NS: $p > .05$

*Approached significance $p < .06$

** $p \leq .05$

--: Chi-square test criteria for minimum n not met.

/: HUD+No-Auditory not included in auditory warning attributes or FCW system analyses.

##: All participants in cell provided the same response.

Comparison. #: Comparison number, as shown in Figure 23.

Table 18														
FCW Questionnaire Chi-Square Analyses: FCW Training by Warning for Levels of Agreement														
Comparison #:					FCW Questionnaire Statements									
					Training Method Validation		Auditory Warning Attributes							
					Expected Braking	Surprise at Braking	Captured Attention	Startle	Annoying	Understandable	Useful	Useful Real Roads	Reduced Severity	Helped Avoid
4a. Agree	I	No-Training Training	by	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	--	NS	NS	NS	NS	NS	NS	NS	--	NS
	G	No-Training	by	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	--	NS	NS	NS	NS	NS	NS	NS	--	NS
	G	Training	by	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	--	NS	NS	NS	NS	NS	NS	NS	--	NS
	G	HUD+No-Auditory	by	No-Training Training	--	NS	/	/	/	/	/	/	/	/
	G	HUD+Average	by	No-Training Training	--	NS	NS	NS	NS	NS	NS	NS	--	NS
	G	HUD+Highest	by	No-Training Training	--	NS	NS	NS	NS	**	NS	NS	--	**
	G	HUD+Car Horn	by	No-Training Training	--	NS	NS	NS	NS	NS	NS	NS	--	NS
4b. Disagree	I	No-Training Training	by	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	NS	--	--	--	--	NS	--	--	--	--
	G	No-Training	by	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	NS	--	--	--	--	NS	--	--	--	--
	G	Training	by	(HUD+No-Auditory) HUD+Average HUD+Highest HUD+Car Horn	NS	--	--	--	--	NS	--	--	--	--
	G	HUD+No-Auditory	by	No-Training Training	NS	--	/	/	/	/	/	/	/	/
	G	HUD+Average	by	No-Training Training	NS	--	--	--	--	NS	--	--	--	--
	G	HUD+Highest	by	No-Training Training	NS	--	--	--	--	6/6	--	--	--	--
	G	HUD+Car Horn	by	No-Training Training	NS	--	--	--	--	--	--	--	--	--

Note. I: Chi-square test of independence. G: Chi-square goodness-of-fit test.

NS: $p > .05$; *Approached significance $p < .06$; **: $p \leq .05$

--: Chi-Square test criteria for minimum n not met.

/: HUD+No-Auditory not included in auditory warning attributes or FCW system analysis.

##: All participants in cell provided the same response.

Comparison. #: Comparison number, as shown in Figure 23.

FCW Questionnaire – Training Method Validation

Questionnaire Item 1: I EXPECTED the vehicle in front of me to brake hard during my last drive. A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 19.

Table 19

Percent of Agreement with the Statement, "I EXPECTED the vehicle in front of me to brake hard during my last drive." as a Function of Training and type of Auditory Warning (N = 75)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 33	Agree <i>n</i> = 5	Disagree <i>n</i> = 24	Agree <i>n</i> = 13
HUD + No-Auditory Warning	12	1.3	6.7	5.3
HUD + Average-Urgency	10.7	1.3	8	5.3
HUD + Highest-Urgency	10.7	1.3	8	4
HUD + Car Horn	10.7	2.7	9.3	2.7

A chi-square test of independence showed that agreement was not independent of training, $\chi^2(1, N = 75) = 4.96, p = .026$. As can be seen in Table 19, more participants disagreed (76%) than agreed (24%) that they expected the lead-vehicle to brake hard during the last drive. However, using modified Bonferroni adjusted alpha levels, the

difference between agreement and disagreement was only significant for participants in the no-training condition, $\chi^2(1, n = 38) = 20.63, p < .0001$. Thus, participants in the training condition were *not* more likely to agree that they expected the lead-vehicle would brake. The difference between training for participants who agreed that they expected the lead-vehicle to brake approached significance, $\chi^2(1, n = 18) = 3.56, p < .059$. That is, agreement was more likely to have been preceded by training than no-training.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(3, N = 75) = .233, p = .972$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the four auditory warning types revealed that, regardless of auditory warning, more disagreed with the statement than agreed, $\chi^2(1) \geq 4.26, p \leq .039$. That is, there was no difference in the type of auditory warning that was used for expectation of the lead-vehicle braking. The differences between auditory warning for those who agreed and disagreed were not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning, when examining disagreement separately, $\chi^2(3) = .369, p = .947$. Neither was there an effect of training nor type of auditory warning when these two variables were entered into this analysis. The number of participants who agreed ($N = 18$) was too small to be included in this analysis.

Questionnaire Item 2: I was SURPRISED when the vehicle in front of me braked hard during my last drive. A comparison was made of participants in the no-training and

training conditions according to their agreement or disagreement with the statement, as shown in Table 20.

Table 20

Percent of Agreement with the Statement, "I was SURPRISED when the vehicle in front of me braked hard during my last drive." as a Function of Training and type of Auditory Warning (N = 75)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 1	Agree <i>n</i> = 37	Disagree <i>n</i> = 6	Agree <i>n</i> = 31
HUD + No-Auditory Warning	--	13.3	2.7	9.3
HUD + Average-Urgency	--	12	2.7	10.7
HUD + Highest-Urgency	--	12	--	12
HUD + Car Horn	1.3	12	2.7	9.3

A chi-square test of independence, showed that agreement was not independent of training, $\chi^2(1, N = 75) = 4.09, p = .043$. As can be seen in Table 20, regardless of training, more participants agreed (91%) than disagreed (9%) that they were surprised when the lead-vehicle braked hard, $\chi^2(1) \geq 16.89, p < .0001$. However, using modified Bonferroni adjusted alpha levels, the difference between those who agreed and those who disagreed was greater in the no-training condition than it was in the training condition. Thus, participants in both training conditions agreed that they were surprised when the

lead-vehicle braked. The difference between training for participants who agreed was not significant.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(3, N = 75) = 2.85, p = .415$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the four auditory warning types revealed that for the no-auditory, average-urgency, and car horn warning conditions, more agreed with the statement than disagreed, $\chi^2(1) \geq 8.90, p \leq .003$. Because all participants in the highest-urgency warning condition agreed ($N = 18$), no chi-square test was performed. That is, there was no difference in the type of auditory warning that was used for surprise at the lead-vehicle braking. The difference between auditory warning for participants who agreed was not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning, when examining agreement, $\chi^2(3, N = 68) = .311, p = .958$. Neither was there an effect of training nor type of auditory warning for agreement when these two variables were entered into the same analysis. The number of participants who disagreed with the statement ($N = 7$) was too small to be considered for analysis.

FCW Questionnaire – Auditory Warning Attributes Analysis

Before being asked to respond to the auditory warning attribute questions, all 52 participants in the three auditory warning conditions (average-urgency, highest-urgency, and car horn) were asked if they had received an auditory warning to ensure that their

responses were based on their recall of the event rather than an obligation to complete the questionnaire (*Questionnaire Item 4*). Four participants who did receive an alert (one average-urgency, one highest-urgency, and two car horn), answered that they had not, and thus, were directed not to respond to the auditory warning attribute questions.

Questionnaire Item 7: The audio warning captured my ATTENTION. A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 21.

Table 21

Percent of Agreement with the Statement, "The audio warning captured my ATTENTION." as a Function of Training and type of Auditory Warning (N = 52)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 2	Agree <i>n</i> = 23	Disagree <i>n</i> = 0	Agree <i>n</i> = 27
HUD + Average-Urgency	1.9	15.4	--	17.3
HUD + Highest-Urgency	--	15.4	--	17.3
HUD + Car Horn	1.9	13.5	--	17.3

A chi-square test of independence showed that agreement was independent of training, $\chi^2(1, N = 52) = 2.246, p = .134$. As can be seen in Table 21, regardless of training, more participants agreed (96%) than disagreed (4%) that the audio warning

captured their attention. More participants in the no-training condition agreed with the statement, $\chi^2(1) = 17.64, p = .00003$. All trained participants ($n = 27$) also agreed. Thus, participants in both training conditions agreed that the audio warning captured their attention. The difference between levels of training for participants who agreed was not significant.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(2, N = 52) = 1.01, p = .603$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the three auditory warning types revealed that for the average-urgency and car horn conditions, more agreed with the statement than disagreed, $\chi^2(1) \geq 13.24, p \leq .0001$. Because all of the participants in the highest-urgency warning condition agreed that the audio warning captured their attention, no chi-square test was performed. That is, there was no difference in the type of auditory warning that was used for attention capture. The difference between auditory warnings for participants who agreed was not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning, when examining agreement separately, $\chi^2(2, N = 50) = .048, p = .976$. Neither was there an effect of training nor type of auditory warning when these two variables were entered into the same analysis. The number of participants who disagreed with the statement ($N = 2$) was too small to be considered for analysis.

Questionnaire Item 8: The audio warning STARTLED me. A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 22.

Table 22

Percent of Agreement with the Statement, "The audio warning STARTLED me." as a Function of Training and type of Auditory Warning (N = 52)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 1	Agree <i>n</i> = 24	Disagree <i>n</i> = 6	Agree <i>n</i> = 21
HUD + Average-Urgency	1.9	15.4	1.9	15.4
HUD + Highest-Urgency	--	15.4	3.9	13.5
HUD + Car Horn	--	15.4	5.8	11.5

A chi-square test of independence, showed that the independence of agreement with training approached significance, $\chi^2(1, N = 52) = 3.70, p = .054$. As can be seen in Table 22, regardless of training, more participants agreed (87%) than disagreed (13%) that the audio warning startled them, $\chi^2(1) \geq 8.33, p \leq .004$. However, the difference between those who agreed and those who disagreed was greater in the no-training condition than it was in the training condition. The difference between training, for participants who agreed, was not significant. Using modified Bonferroni adjusted alpha

levels, of the participants who disagreed that the audio warning was startling, the difference between levels of training approached significance, with more receiving training $\chi^2(1, n = 7) = 3.57, p = .059$. The difference between training for participants who agreed with the statement was not significant. Thus, participants in both training conditions agreed that the audio warning startled them and disagreement was more frequently preceded by training.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(2, N = 52) = .383, p = .826$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the three warning types revealed that, regardless of auditory warning, more agreed that the audio warning startled them than disagreed, $\chi^2(1) \geq 7.12, p \leq .008$. That is, ratings of startle did not differ across auditory warning. The difference between auditory warning for participants who agreed was not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning when examining agreement separately, $\chi^2(2, N = 44) = .153, p = .926$. Neither was there an effect of training nor type of auditory warning when these two variables were entered into the same analysis. The number of participants who disagreed with the statement ($N = 7$) was too small to be considered for analysis.

Questionnaire Item 14: The audio warning is likely to be ANNOYING on real roadways if I experience it several times a week and it often does not correspond to a real threat in the environment. A comparison was made of participants in the no-training

and training conditions according to their agreement or disagreement with the statement, as shown in Table 23.

Table 23

Percent of Agreement with the Statement, "The audio warning is likely to be ANNOYING on real roadways if I experience it several times a week and it often does not correspond to a real threat in the environment." as a Function of Training and type of Auditory Warning (N = 52)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 1	Agree <i>n</i> = 24	Disagree <i>n</i> = 8	Agree <i>n</i> = 19
HUD + Average-Urgency	--	17.3	5.8	11.5
HUD + Highest-Urgency	1.9	13.5	1.9	15.4
HUD + Car Horn	--	15.4	7.7	9.6

A chi-square test of independence showed that agreement was not independent of training, $\chi^2(1, N = 52) = 5.96, p = .015$. As can be seen in Table 23, regardless of training, more participants agreed (83%) than disagreed (17%) that the audio warning would likely be annoying if it did not correspond to a real threat, $\chi^2(1) \geq 4.48, p \leq .034$. However, using modified Bonferroni adjusted alpha levels, the difference between those who agreed and those who disagreed was greater in the no-training condition than it was in the training condition. Of the participants who disagreed, more had received training,

$\chi^2(1, n = 9) = 5.44, p = .020$. The difference between training for participants who agreed with the statement was not significant. Thus, participants in both training conditions agreed that the audio warning is likely to be annoying on real roadways if they experienced it several times a week and it often does not correspond to a real threat in the environment and disagreement was more likely to have been preceded by training.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(2, N = 52) = .830, p = .660$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the three auditory warning types revealed that, regardless of auditory warning, more agreed with the statement than disagreed, $\chi^2(1) \geq 4.77, p \leq .029$. That is, ratings of annoyance did not differ across type of auditory warning. The difference between auditory warning for participants who agreed with the statement was not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning, when examining agreement separately, $\chi^2(2, N = 43) = .788, p = .674$. Neither was there an effect of training nor type auditory warning when these two variables were entered into the same analysis. The number of participants who disagreed with the statement ($N = 9$) was too small to be considered for analysis.

Questionnaire Item 5: When the car in front of me braked hard during the last drive, the system presented an audio warning that was UNDERSTANDABLE. A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 24.

Table 24

Percent of Agreement with the Statement, "When the car in front of me braked hard during the last drive, the system presented an audio warning that was UNDERSTANDABLE." as a Function of Training and type of Auditory Warning (N = 52)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 18	Agree <i>n</i> = 7	Disagree <i>n</i> = 5	Agree <i>n</i> = 22
HUD + Average-Urgency	15.4	1.9	7.7	9.6
HUD + Highest-Urgency	11.5	3.9	--	17.3
HUD + Car Horn	7.7	7.7	1.9	15.4

A chi-square test of independence revealed that agreement was not independent of training, $\chi^2(1, N = 52) = 15.05, p = .0001$. As can be seen in Table 24, more participants agreed (56%) than disagreed (44%). Using modified Bonferroni adjusted alpha levels, with training, more participants agreed with the statement, $\chi^2(1, N = 27) = 10.70, p = .001$. However, with no-training, more disagreed that the audio warning was understandable, $\chi^2(1, N = 25) = 4.84, p = .028$. Likewise, of those who agreed, more had been trained, $\chi^2(1, N = 29) = 7.76, p = .005$. While, of those who disagreed, more had received no-training $\chi^2(1, N = 27) = 7.35, p = .007$. Thus, with no-training, respondents are more likely to disagree that the auditory warning was understandable, but with training, they are more likely to agree.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, but approached significance, $\chi^2(2, N = 52) = 5.74, p = .057$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the three types of auditory warning revealed that, regardless of auditory warning, there was no significant difference in agreement, $\chi^2(1) \leq 2.88, p \geq .09$ for the understandability of the audio warning. That is, there was no difference in agreement for the type of auditory warning used for understandability. The differences between auditory warning for participants who agreed and disagreed with the statement were not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning, when examining agreement separately, $\chi^2(2, N = 29) = .950, p = .622$. However, using modified Bonferroni adjusted alpha levels, a chi-square goodness-of-fit test of participants in the highest-urgency warning condition who agreed revealed that more had received training, $\chi^2(1, n = 11) = 4.46, p = .035$. That is participants who received training and the highest-urgency warning were more likely to agree with the question regarding auditory warning understandability.

Agreement was more likely to have been preceded by training. The number of participants who disagreed ($N = 23$) was too small to be considered for this analysis.

Questionnaire Item 6: The audio warning was USEFUL for enhancing safety. A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 25.

Table 25

Percent of Agreement with the Statement, "The audio warning was USEFUL for enhancing safety." as a Function of Training and type of Auditory Warning (N = 52)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 6	Agree <i>n</i> = 19	Disagree <i>n</i> = 2	Agree <i>n</i> = 25
HUD + Average-Urgency	7.7	9.6	3.9	13.5
HUD + Highest-Urgency	1.9	13.5	--	17.3
HUD + Car Horn	1.9	13.5	--	17.3

A chi-square test of independence showed that agreement was independent of training, $\chi^2(1, N = 52) = 2.75, p = .098$. As can be seen in Table 25, regardless of training, more participants agreed (85%) than disagreed (15%) that the audio warning was useful for enhancing safety, $\chi^2(1) \geq 6.76, p \leq .009$. Thus, drivers in both FCW training conditions agreed that the audio warning was useful for enhancing safety. The differences between training for agree and disagree were not significant.

A second chi-square test of independence showed that agreement with the statement was not independent of auditory warning, $\chi^2(2, N = 52) = 6.81, p = .033$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the three auditory warning types revealed that, while more participants in the highest-urgency and car horn warning conditions agreed, $\chi^2(1) = 13.24, p = .0002$, the

difference in agreement was not significant for the average-urgency warning. That is, participants who received the highest-urgency and car horn warnings were more likely to agree that the audio warning was useful for enhancing safety than those who received the average-urgency warning.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning for agreement, $\chi^2(2, N = 44) = 0.15, p = .992$. Neither was there an effect of training nor type of auditory warning when these two variables were entered into the same analysis. The number of participants who disagreed with the statement ($N = 8$) was too small for analysis.

Questionnaire Item 12: The audio warning would be USEFUL on real roadways for enhancing safety. A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 26.

Table 26

Percent of Agreement with the Statement, "The audio warning would be USEFUL on real roadways for enhancing safety." as a Function of Training and type of Auditory Warning (N = 52)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 1	Agree <i>n</i> = 24	Disagree <i>n</i> = 0	Agree <i>n</i> = 27
HUD + Average-Urgency	--	17.3	--	17.3
HUD + Highest-Urgency	1.9	13.5	--	17.3
HUD + Car Horn	--	15.4	--	17.3

A chi-square test of independence showed that agreement was independent of training, $\chi^2(1, N = 52) = 1.10, p = .294$. As can be seen in Table 26, more participants agreed (98%) than disagreed (2%) that the audio warning would be useful on real roadways for enhancing safety. The difference between agreement and disagreement was significant for participants in the no-training condition, $\chi^2(1, n = 25) = 21.16, p < .0001$. Because all participants in the training condition agreed ($n = 27$), no chi-square tests for training or disagreement were performed. The difference between training was not significant for drivers who agreed. Thus, drivers in both FCW training conditions agreed that the audio warning would be useful on real roadways for enhancing safety.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(2, N = 52) = 2.10, p = .350$. Using

modified Bonferroni adjusted alpha levels, a chi-square goodness-of-fit test for highest-urgency revealed that more agreed $\chi^2(1, n = 17) = 13.24, p < .0003$. Because all participants in the average-urgency ($n = 18$) and car horn ($n = 17$) conditions agreed, no chi-square tests were performed. That is, there was no difference in the type of auditory warning that was used for usefulness on real roadways. The difference between auditory warning was not significant for drivers who agreed.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning for those who agreed, $\chi^2(2, N = 51) = .133, p = .936$. Neither was there an effect of training nor type of auditory warning when these two variables were entered into the same analysis. The participants who disagreed ($N = 1$) did not require analysis.

Questionnaire Item 10: The audio warning helped me to reduce the SEVERITY of the collision. Whereas 38 drivers collided with the lead-vehicle, only 22 responses to this question are reported. Sixteen participants were directed not to respond to this question: 10 of the drivers who collided were in the no-auditory-warning condition, 3 drivers did not realize they had collided with the lead-vehicle, and three drivers did not recall receiving an auditory warning, presumably because the forward-collision event was so demanding.

A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 27.

Table 27

Percent of Agreement with the Statement, "The audio warning helped me to reduce the SEVERITY of the collision." as a Function of Training and type of Auditory Warning (N = 22)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 6	Agree <i>n</i> = 12	Disagree <i>n</i> = 1	Agree <i>n</i> = 3
HUD + Average-Urgency	13.6	18.2	4.6	9.1
HUD + Highest-Urgency	9.1	22.7	--	4.6
HUD + Car Horn	4.6	13.6	--	--

A chi-square test of independence showed that agreement was independent of training, $\chi^2(1, N = 22) = .105, p = .746$. As can be seen in Table 27, of the participants who collided, more agreed (68%) than disagreed (32%) that the audio warning helped reduce the severity of the collision, however this difference was not significant for either no-training or training. Using modified Bonferroni adjusted alpha levels, of the participants who agreed, more were untrained than trained, $\chi^2(1, n = 15) = 5.40, p = .020$. The difference between levels of training approached significance for drivers who disagreed, $\chi^2(1, n = 7) = 3.57, p = .059$. Thus, when participants agree that the auditory warning helped them to reduce the severity of their collision, they are slightly more likely to be untrained.

Too few participants collided ($N = 22$) to perform an the agreement by auditory warning analysis. A third pair of chi-square tests of independence to examine the interaction between training and warning for agreement ($N = 15$) and disagreement ($N = 7$) were not conducted because the number of participants was too small for each test.

Questionnaire Item 11: The audio warning helped me to AVOID the collision.

Whereas 37 drivers avoided a collision with the lead-vehicle, only 27 responses to this question are reported. Ten participants were directed not to respond to the auditory warning attribute questions and, as a result, did not answer this question: 9 of the drivers who collided were in the no-auditory warning condition and 1 driver did not remember receiving an auditory warning.

A comparison was made of participants in the no-training and training conditions according to their agreement or disagreement with the statement, as shown in Table 28.

Table 28

Percent of Agreement with Statement, "The audio warning helped me to AVOID the collision." as a Function of Training and type of Auditory Warning (N = 27)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 0	Agree <i>n</i> = 4	Disagree <i>n</i> = 1	Agree <i>n</i> = 22
HUD + Average-Urgency	--	--	--	22.2
HUD + Highest-Urgency	--	3.7	--	29.6
HUD + Car Horn	--	11.11	3.7	29.6

A chi-square test of independence showed that agreement was independent of training, $\chi^2(1, N = 27) = .181, p = .671$. As can be seen in Table 28, more participants agreed (96%) than disagreed (4%) that the audio warning helped them to avoid the collision. Using modified Bonferroni adjusted alpha levels, the difference between agreement and disagreement was significant for the training condition, $\chi^2(1, n = 23) = 19.17, p = .00001$. Because all participants in the no-training condition agreed ($N = 4$), no chi-square tests for no-training or disagree were performed. Of the drivers who agreed, more had received training, $\chi^2(1, n = 26) = 12.46, p = .0004$. That is, drivers who received training and did not collide, were more likely to agree that the audio warning helped them avoid a collision. Furthermore, agreement with the statement was more likely to have been preceded by training.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(2, N = 27) = 1.30, p = .523$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests for each of the auditory warning types revealed that for the car horn warning, more participants agreed, $\chi^2(2, n = 12) = 8.33, p = .004$. Because all participants in the average-urgency and highest-urgency warning conditions agreed, no chi-square tests were performed. There was no difference between auditory warning for those who agreed.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning, when examining agreement separately, $\chi^2(2, N = 26) = 2.41, p = .299$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests revealed that of participants who agreed in the highest-urgency warning condition, more had been training, $\chi^2(1, n = 9) = 5.44, p = .020$. All participants who received the average-urgency warning and agreed, had received training ($n = 6$). The difference between levels of training for the car horn warning was not significant. Nor were the differences between auditory warning for either level of training. The number of participants who disagreed with the statement ($N = 1$) was too small to be considered for analysis.

FCW Questionnaire – Likelihood to Recommend FCW System

Questionnaire Item 13: If it were priced reasonably, I would recommend a Forward Collision Warning system like this one. A comparison was made of participants

in the no-training and training conditions according to their agreement or disagreement with the statement, as is shown in Table 29.

Table 29

Percent of Agreement with the Statement, "If it were priced reasonably, I would recommend an FCW System like this one." as a Function of Training and type of Auditory Warning (N = 51)

Auditory Warning	FCW System Training			
	No-Training		Training	
	Disagree <i>n</i> = 3	Agree <i>n</i> = 21	Disagree <i>n</i> = 0	Agree <i>n</i> = 27
HUD + Average-Urgency	3.9	13.7	--	17.6
HUD + Highest-Urgency	1.9	13.7	--	17.6
HUD + Car Horn	--	13.7	--	17.6

A chi-square test of independence showed that independence between agreement and training approached significance, $\chi^2(1, N = 51) = 3.59, p = .058$. As can be seen in Table 29, more participants agreed (94%) than disagreed (6%) that they would recommend an FCW system like this one. Using modified Bonferroni adjusted alpha levels, the difference between agreement was significant for participants in both the no-training condition, $\chi^2(1, n = 24) = 13.50, p < .0002$. All participants in training condition agreed with the statement (*n* = 27). The difference between training for those who agreed

was not significant. Thus, participants in both training conditions agreed that they would recommend the FCW system.

A second chi-square test of independence showed that agreement with the statement was independent of auditory warning, $\chi^2(2, N = 51) = 1.89, p = .389$. Using modified Bonferroni adjusted alpha levels, separate chi-square goodness-of-fit tests revealed that for the average- and highest-urgency warning conditions, more agreed that they would recommend the FCW system, $\chi^2(2) \geq 10.89, p \leq .001$. Because all participants who received the car horn agreed that they would recommend the FCW system ($n = 16$), no chi-square test was performed. That is, there was no difference in the type of auditory warning that was used for recommendation of the FCW system. The difference between auditory warning for those who agreed was not significant.

A third pair of chi-square tests of independence indicated that there was no interaction between training and warning for agreement, $\chi^2(2, N = 48) = .000, p = 1.00$. Neither was there an effect of training nor type of auditory warning when these two variables were entered into the same analysis, using modified Bonferroni adjusted alpha levels. The number of participants who disagreed ($N = 3$) was too small to be considered for analysis.

CHAPTER 4

DISCUSSION

The present study examined the effects of FCW training, auditory warning type, and gender on a visually distracted driver's reaction to an unexpected forward collision event. Eight quantitative (GRT, ART, duration of console gaze, pedal transition time, BRT, BRT50%, minTTC, and collision velocity) and two qualitative dependent variables (glances-back and collision rate) were examined to measure the effect of the three independent variables. In addition to the three instances of an interaction between gender and training, the analysis revealed two major outcomes, the consistent benefits of FCW training and the positive effects of the car horn warning.

A second, follow-up, analysis was undertaken to evaluate the main effects of glancing back on the eight dependent variables. Examining glance behavior as an independent variable revealed the severe consequences of eyes-off-road time in the presence of an imminent forward collision threat. Details of the major outcomes and interactions, as well as, their implications and limitations follow.

FCW System Training

Participants in the training condition were given a brief overview of the FCW system which explained that a radar mounted on the front of the vehicle measures the distance and closure rate of in-path vehicles, calculating the threat of an imminent

collision. Drivers were told that in order to avoid a collision, they were to brake immediately when they received an FCW alert. To complete training, all participants received a demonstration of the visual icon and the auditory warning, if applicable to their condition (i.e., average-urgency, highest-urgency, or car horn). This brief explanation and single exposure to the FCW alert(s) led to a robust and consistent effect throughout the analysis. A summary of the main effect of FCW training is shown in Table 30.

Table 30

Main Effect of FCW System Training

Dependent Variable	Mean		<i>p</i>	<i>eta</i> ²
	No-Training	Training		
GRT (s)	1.22	1.10	Not sig.	--
Gaze (s)	1.75	1.17	< .0001	.372
ART (s)	2.77	1.75	< .0001	.379
PTT (s)	.78	.52	.059	.059
BRT (s)	3.55	2.27	< .0001	.612
BRT50% (s)	3.86	2.74	< .0001	.521
minTTC (s)	.41	3.28	< .0001	.481
Velocity (m/s)	12.51	1.89	< .0001	.565
Collisions (χ^2)	84%	16%	< .0001	
Glances (χ^2)	58%	11%	< .0001	

Outline represents a significant main effect of FCW system training.

 Indicates a significantly different, more desirable result (e.g., a faster RT or slower velocity).

 Indicates a significantly different, less desirable result (e.g., a shorter RT or faster velocity).

A summary of the quantitative training results, as they relate to the hypotheses, is reported in Table 31.

Table 31

Results of Quantitative Training Hypotheses

Independent Variable	When Compared To	Hypotheses	Supported
FCW System Training <i>i.e., Awareness of System and Knowledge of Appropriate Response to Warning</i>	No-FCW System Training	Faster GRT	No
		Faster ART, BRT, BRT50%	Yes
		Faster PTT	No
		Larger minTTC	Yes
		Slower Collision Velocity	Yes
		Fewer Collisions	Yes

Leading the list of positive outcomes, was a sharp decline in the number of glances-back to console. Trained drivers made 47% fewer glances-back than untrained participants. As a direct result of the decrease in glance frequency, duration of console gaze was significantly lower (.58 s) for trained drivers.

With the exception of quick, sporadic glances to the rear-mirror image overlaid on the simulator screen or to the instrument cluster to check speed, video analysis confirmed that if drivers were not looking at the forward scene, they were generally gazing at the console monitor, or transitioning between the two. Therefore, with no other in-vehicle displays or external projection screens to direct their gaze to in the simulator, a reduction in console-gaze duration can accurately be categorized as an increase in eyes-on-road time. It is suggested that the benefit of training observed in the subsequent reaction time

metrics, (e.g., ART, BRT, and BRT50%), can, in large part, be credited to this increase in eyes-forward time.

FCW training shortened ART, BRT, and BRT50%, all, by over 1 s each. The value of increased eyes-forward time is the opportunity it provides the driver to visually detect the decelerating lead-vehicle more quickly. The earlier that this threat-detection occurs, the earlier the operator will initiate the threat-mitigating response, that is, release the accelerator and apply pressure to the brake pedal.

The ultimate test of the effectiveness of training, and the product of (a) increased eyes-forward time, (b) an understanding of the alert(s), and (c) faster reaction times, is evidenced in the three collision-related metrics, which marked the conclusion of the braking event. FCW training increased minTTC by 2.87 s, decreased the number of collisions by 68%, and decreased collision velocity by 10.62 m/s. These positive effects of training replicate those found in ABS studies (see Mollenhauer et al., 1997, and Mazzae et al., 1999), as well as, the suggestion by the IIHS (2000) that system training can improve a driver's collision avoidance response.

The dramatic improvement across these eight metrics is likened to a chain reaction of events. An understanding of the FCW system and the meaning of the alert(s) facilitated an increase in eyes-forward time, leading to earlier threat detection and reaction times, which in turn, allowed drivers to maintain greater relative distance from the lead-vehicle during deceleration (minTTC), cause fewer collisions, and realize a drop in collision velocity. It is noteworthy that seven of a possible ten dependent variables

revealed a significant effect of training. Furthermore, for six of those variables, the strength of the effect ranged from $\eta^2 = .23$ to $.61$.

It is proposed that increased eyes-forward time without an understanding of the meaning of the FCW alert(s) would have likely been less effective at reducing ART, BRT, and BRT50%. Likewise, knowledge of the FCW system, without increased attention to the forward roadway to allow detection and visual confirmation of the threat, would also have been far less beneficial. It is evident that eyes-forward-time works in concert with FCW system knowledge to improve the driver's collision avoidance response.

The improvement in reaction times and collision statistics serve as a testament to the importance of increasing eyes-forward time, one of the benefits provided by training, and falls easily in line with the literature that have identified eyes-off-road time as a contributing factor in rear-end collisions (Knipling, Mironer, et al., 1993; Knipling, Wang, & Yin, 1993; Summala et al., 1998; Hancock et al., 2003; Dingus et al., 2006; Klauer et al., 2006).

The main effect of training was qualified by three training by gender interactions, BRT, BRT50%, and minTTC. The first two variables, BRT and BRT50% shared identical interactions. That is, while training produced a significant improvement in reaction times for both men and women, the strength of the effect was greater for female drivers. Unlike BRT and BRT50%, the difference between training and no-training was not reliable for minTTC. However, the trend appeared to follow a similar pattern. That is, without training, the minTTC for women was smaller. However, with training, men came

closer than women to colliding with the lead-vehicle than female drivers. The lack of a significant difference between levels of training for either men or women is likely attributable to a larger error variance, that is, a larger variance in minTTC, as compared with, BRT or BRT50%. MinTTC ranged from a minimum of 0.0 for drivers who collided to a maximum of 8.6 for drivers who stopped safely.

Furthermore, although the following interactions between training and gender were *not* significant, a trend similar to that of BRT, BRT50%, and minTTC was apparent for duration of console gaze, ART, and collision velocity, which did approach significance. The trend for all three of these variables showed that, without training, men slightly outperformed women, but with training, women had a marginally shorter console-gaze duration, faster ART, and slower collision velocity than men.

Rather than tempering the positive effects of training, the training by gender interactions, and to a lesser extent, the trends, reinforce the finding that training provided a significant gain for both men and women. Women, however, showed a greater improvement than men in the length of time it took them to contact the brake (BRT) and the speed of that pedal depression (BRT50%). In addition, the trends suggest that women had larger drops in the length of their glances-back, release of the accelerator (ART), and velocity at time of collision.

The results indicate that the information and exposure to the FCW alert(s) which drivers gained during training had a larger influence on women. With little comparable literature to point to, providing an explanation, however, is far more difficult.

Hancock et al. reported that when not distracted, women had a higher rate of compliance with a changing traffic light (2003). However, when the secondary task was added, women showed a significant decrease in accuracy. The authors suggested that the visually distracting secondary task had a greater negative effect on women than on men. If a similar effect holds true for system knowledge, then *untrained* women would be affected more negatively by a lack of system knowledge, while trained women would be expected to respond more quickly, which may account for the training by gender interactions of the present study.

However, other studies found no effect of gender and do not support the finding of the present research. For example, in an on-road naturalistic study of eye glance behavior, Tijerina et al. (2004) concluded that the number of glances away from the forward scene and location of glances away (e.g., to the center mirror, over left shoulder, over right shoulder) were also independent of gender. Furthermore, gender differences were not observed in an investigation of ABS. Mazzae et al. (1999) found no reliable difference in brake pedal force or BRT in response on either wet or dry pavement.

A number of alternative explanations should be considered. If trained women, who had an understanding of the FCW alert(s) and knew that they represented an imminent collision threat, felt more responsible for creating such a severe circumstance, then they may have tended toward a more aggressive response to mitigate the threat. Per anecdotal evidence gathered by the researcher, unsolicited reactions from participants immediately following conclusion of the experiment indicated that women had a greater tendency than men to express some degree of responsibility, or self-blame, for causing

the sudden braking event. This sentiment was, of course, unfounded because the lead-vehicle's deceleration was triggered independently of participants' actions and was identical across all participants. To pursue this observation, future research might use an experimentally-induced imminent braking scenario coupled with visual distraction, as the present research did, followed by a post-drive questionnaire asking participants to rate to what degree they felt responsible for the imminent braking event.

This finding might also suggest a greater willingness of women to accept the training as more instructional or advisory than men, resulting in the information having greater salience, and creating a stronger influence on their behavior. Desire to maintain longer distances between the lead-vehicle or more concern for avoiding a collision might both play a role here. Future research might examine whether men may be less willing than women to consider a researcher's instructions or training. Subsequent efforts may also explore how the researcher's gender and age influence the value or validity the participants' place on the instructions presented to them. Of course, these suggestions are purely speculative and demand appropriate research before a conclusion can be reached. Furthermore, the result that training had a larger influence on women should not overshadow the strongest and most predominant result of the study, which is that training did help *both* men and women realize a safer collision avoidance response.

Pedal Transition Time

A positive, albeit more moderate, effect of training, which approached significance, was also evidenced in pedal transition time. Because the mean transition time between accelerator release and initial contact with the brake pedal fell well-below 1

s for untrained drivers, the opportunity for improvement was limited, likely a contributing factor in a difference which only approached significance.

As stated in the hypothesis of the present study, trained drivers were expected to demonstrate faster pedal transition times. That is, with an understanding of the FCW alert(s), trained drivers were to move more quickly from the accelerator to the brake, because they were aware of the rapid collision avoidance response that the situation demanded. While limited support for the PTT hypothesis was found in a result that approached significance ($p = .059$), evidence for an additional pattern of results emerged from the correlational analysis.

A comparison of the correlational matrixes reveals a very different relationship between ART and PTT across levels of training. While there is a strong, negative correlation ($r = -.724, p = .0000003$) between ART and PTT for untrained drivers, no significant relationship between the two variables exists in training. That is, the earlier *untrained* drivers released the accelerator, the longer it took them to make the transition to the brake, and likewise, the later untrained drivers released the accelerator, the shorter their transition to the brake was.

Naturally, drivers who take very long to release the accelerator (ART) will find themselves dangerously close to the lead-vehicle and will, inevitably, feel compelled to make a panic-stop, shortening PTT considerably. A panic-stop scenario is one where the operator depresses the brake pedal as quickly and as forcefully as they are physically able to avoid a collision that has been detected too late. These late-braking scenarios complicate data interpretation because they drive down mean PTT (i.e., a *desirable*

result), but do so because the operator was forced to make a panic stop because of late detection (i.e., an *undesirable* circumstance) and therefore do not reflect the positive effect of training.

In contrast, when ART is early, it can be argued that a longer PTT affords the driver the opportunity to make a more controlled transition, a more desirable circumstance. While this holds true when the lead-vehicle slows gradually, drivers in the present study faced a severe forward collision threat, created by a lead-vehicle decelerating to a stop at -5 m/s^2 , at a relatively short time-headway (2 s). Therefore, the present study's finding that ART shares a negative correlation ($r = -.724, p = .0000003$) with PTT, when drivers are *not* knowledgeable of the FCW system, is especially problematic. When *untrained* drivers released the accelerator early, their collision avoidance response suffered. That is, without knowledge of the FCW system or an understanding of the alert(s), movement between the accelerator and brake pedal was essentially interrupted, lengthening PTT, and delaying braking.

That this relationship was, in contrast, *not significant* for drivers who did receive training is telling. In addition to an overall reduction in ART, it suggests that training reduces long delays in collision avoidance responses for drivers who release the accelerator especially early. With an understanding of the FCW system and meaning of the alert(s), it is proposed that trained drivers can detect and recognize the threat earlier, helping them to avoid the costly delay between releasing the accelerator and depressing the brake pedal that some untrained experienced.

The same pattern of results is thought to hold true for the relationship between PTT and GRT. A significant negative correlation exists between the two dependent variables for untrained drivers, but when training is administered there is no reliable difference.

Driving Simulator

It is important to acknowledge that detection of the lead-vehicle was confounded, for all drivers, by its appearance on the simulator screen. The brake lights, in particular, had limited brightness and contrast due to constraints of the simulator's hardware. In an on-road scenario, with normal visibility, a vehicle's brake lights are likely to be more salient to the following driver, aiding in their detection. Although unintentional, this constraint might have actually helped illuminate the benefits of training. By delaying detection of the threat, drivers with an understanding of the FCW system and its warnings had the opportunity to respond more quickly. The advantage of a faster response afforded by training is one that may not have been detected had the simulator presented a high-resolution, high-contrast image.

GRT

Noticeably absent from the discussion of the otherwise positive effects of training, is GRT, which was not a significant metric. It was hypothesized that, with training, drivers would better understand and recognize the auditory warnings, and, as a result, glance forward more quickly when an audio alert was heard as compared to untrained drivers. In stark contrast to this expectation, training failed to produce a reliable

difference in GRT. Furthermore, these results conflict with Kiefer et al. who suggested that with more training the alert onset-look up time (GRT) could be reduced (2005).

A GRT measurement represents the time between the lead-vehicle's brake application and the moment a driver's eyes met the forward scene for the first time. This metric was intentionally designed to capture the total time a driver's eyes were away from the forward scene during the presence of the threat (i.e., while the lead-vehicle was decelerating). However, it is important to acknowledge the placement of the auditory warning in relation to the other metrics. The FCW alert(s) were presented .5 s *after* the lead-vehicle applied its brakes, in an effort to simulate the lag in detecting deceleration. Therefore, the total duration of eyes-off-road time between the moment drivers were first made aware of the threat (i.e., FCW alert(s)) and when their eyes met the forward scene for the first time, is better represented by removing a constant .5 s from the GRT measurement.

Examining the GRT results in this light reveals an important pattern and offers a possible explanation for the lack of difference between levels of training. For untrained drivers, the duration of time between delivery of the FCW alert(s) and first forward gaze is well-under 1 s (i.e., a mean GRT of 1.22 s minus the .5 s prior to the delivery of the alert). It is apparent that, even without training, once alerted, drivers took little time to transition their gaze from the console monitor to their first forward glance, leaving only a small margin for improvement by training.

Upon further examination, 25% of *untrained* participants had a GRT of less than .90 s. Removing the .5 s between brake application and prior to delivery of the FCW

alert(s) reveals that one quarter of *untrained* participants took less than 4/10 of a second to look from the console monitor to the forward scene. Not only does this leave minimal, if any, opportunity for training to improve reaction time, but it also suggests that some drivers may have already, of their own volition, initiated a return to the forward scene out of necessity to manage divided attention in a dual task environment.

That some drivers had likely already initiated a return to the forward scene is not completely unexpected due to the rapid succession of events contained within a 5-second time span (i.e., presentation of the distracter task, deceleration of the lead-vehicle, and delivery of the FCW alert), in combination with the freedom drivers had to manage their own visual focus. In an effort to achieve a more realistic experience, the present study had to forgo control of when and which displays drivers glanced to, resulting in greater variability and less conformity of driver behavior. While the GRT metric is not invalidated by these findings, when studying glance behavior in a simulated environment, the measurement might be made more salient by eliminating the gap between the lead-vehicle's brake application and the delivery of the FCW alert(s), making it less likely that drivers will have already initiated a return to the forward scene as part of their effort to balance both the primary and secondary tasks and better isolating the effect of training. GRT might also better capture the effectiveness of training by reducing variation in initiation of downward glance to the console screen, with a more demanding presentation that draws attention away from the road in a more consistent manner, making it less likely that some drivers will begin their return to the forward scene earlier than others.

Another consideration includes the nature of the FCW training, as it was provided in this study. It is plausible that training failed to have enough influence on the transition time between console gaze and the first forward glance. As Kiefer et al. (2005) suggest, an improvement in GRT might require a richer training experience with more information and, perhaps, more exposure to the auditory warning so as to garner a faster glance response. In the context of this experiment, drivers who are more familiar with the FCW alert, that is, those who find it more recognizable, might more quickly associate it with an event in the forward scene, as opposed to the secondary task, decreasing glance time.

Alternatively, and in a more positive light, this finding can be loosely interpreted as support for the effectiveness of the deception incorporated into this study. That is, a driver who anticipated a forward collision, because of an expectation created during training, might demonstrate shorter glance durations than their untrained counterparts out of concern for an event in the forward scene. That the GRT of trained versus untrained participants was *not* reliably different, indicates a willingness on behalf of all participants, regardless of training, to engage in the secondary task, while apparently expecting the lead-vehicle to maintain its current speed without suddenly stopping.

Glances-Back

One of the most surprising findings that emerged from video analysis was the realization that nearly 35% of drivers glanced-back to the console monitor after looking forward the first time, but prior to initiating a braking response. Glancing back was not only affected by training and auditory warning, but impacted other variables as well. Because over one-third of participants returned their gaze to the secondary task after

experiencing the FCW alert(s), an adjustment to the analyses was warranted in order to examine the impact of those glances. As a result, two variables, duration of console gaze and glancing back were added to the analyses. Duration of console gaze helped to account for time spent looking at the monitor during a glance-back, a measure GRT was not designed to capture. Thus, duration of gaze can be thought of as GRT plus duration of the glance-back, for drivers whose gaze did return. Glancing back was added to the qualitative, chi-square analysis, as well.

First, the issue of why participants glanced-back is addressed. As previously discussed, the low-contrast brake lights on the lead-vehicle lengthened detection time. The earlier that drivers glanced forward, the less likely they were to immediately recognize the threat. An unobvious threat left drivers who glanced forward earlier searching, albeit *momentarily*, for an explanation to the FCW alert(s). Although admittedly unintentional, the low-contrast graphics provided a unique opportunity to understand how drivers might behave if, for any reason, the forward threat was briefly unclear or obscured, as well as how a response that was delayed by glancing to an *incorrect* location (e.g., side-mirror or in-vehicle secondary task) may impact a collision avoidance response. It is likely that when the cause of the FCW alert(s) was not immediately apparent in the forward scene, it was the console monitor that drivers glanced-back to because, in the context of this study, it had served as the sole source of information during the first 12 min of their, drive which they had come to rely upon for driving and navigation instructions. Furthermore, the likelihood that drivers returned their attention to the console monitor, rather than other locations, was greater than normal

because peripheral and side-view images were not provided in the simulator, limiting their point-of-gaze options. Although not entirely unrealistic, drivers in a real-world situation might be less likely to glance-back to a secondary task to identify the cause of a warning, but may in fact, be more likely to redirect their gaze to other, incorrect, external locations (i.e., side-mirrors, or blind spots). While the location might be different in an on-road setting, the present study affords the opportunity to examine the effect that gazing at any location, other than the threat itself, has on collision avoidance responses.

All drivers were not equally likely to glance-back. Remarkably, of the 26 participants who glanced-back, *untrained* drivers accounted for 85% of them. Again, it is thought that an understanding of the FCW system and its alert(s) prompted drivers to keep their attention forward, while also facilitating earlier detection and recognition of the threat.

A comparison of the correlational matrixes reveals an additional pattern thought to be related to glance behavior. Trained drivers demonstrated positive correlations between GRT and: ART, BRT, BRT50% and collision velocity, as well as, a negative correlation with minTTC, all significant at the $p < .01$ level. That is, the earlier drivers looked forward for the first time, the better ART, BRT, BRT50%, minTTC, and collision velocity were. In stark contrast, the same five correlations in the no-training condition are *not* significant. The prevalence of untrained drivers glancing back likely contributes to the absence of relationships between GRT and the other variables, as glancing back interrupts and delays a driver's collision avoidance response. That GRT correlates in a predictable way when drivers are trained (e.g., the faster the glance time, the earlier the

ART) is a result of fewer glances-back, that is, fewer interruptions to the collision avoidance response. That trained drivers were able to execute more consistent collision avoidance responses demonstrates one of the most positive outcomes of training revealed in the present study.

FCW Questionnaire – Training Method Validation

The introduction of FCW training in this study raised concerns that any positive result would be attributable, not only to training, but to the driver's *expectation* of encountering a braking situation. This concern was based, in part, on van Der Hulst et al. (1999) who found that drivers make anticipatory responses based on expectation of a collision and Hancock et al. (2003) who credited a learning effect for the improvement in Stopping Times after multiple exposures to the braking event. Deception, in the form of (a) an erroneously long experimental agenda with two practice sessions instead of one to create a false sense of security, and (b) scrolling text instructions located far from the forward scene on the console monitor to create visual distraction, were incorporated into the study. These measures were intended to keep drivers who had an understanding of the FCW system and its alert(s) from reacting more quickly to the forward threat by preparing for the lead-vehicle to brake. Finally, two items were added to the post-drive FCW Questionnaire to compare self-report measures of drivers' *expectation* and *surprise* of the braking event across training conditions. It was hoped that all drivers would disagree that they *expected* the lead-vehicle to brake, and, likewise, agree that they were *surprised* when it did. A summary of the qualitative training results, as they relate to the hypotheses, is reported in Table 32.

Table 32

Results of Qualitative Training Hypotheses

Independent Variable	When Compared To	Hypotheses	Supported
FCW System Training i.e., Awareness of System and Knowledge of Appropriate Response to Warning	No-FCW System Training	Does <i>not</i> Increase Expectation Does <i>not</i> Reduce Surprise	Partially Yes

Questionnaire Item 1: I EXPECTED the vehicle in front of me to brake hard during my last drive. As hoped, the majority (76%) of respondents agreed with the statement. However, the difference in ratings of expectation was not significantly different across levels of training ($p = .071$). Likewise, in a result that approached significance, more participants who had agreed, had also been recipients of training ($p = .059$).

Questionnaire Item 2: I was SURPRISED when the vehicle in front of me braked hard during my last drive. Again, a majority of participants agreed with the statement (90%). However, more participants, whether recipients of training or not, agreed that they were surprised.

While the *expect* and *surprise* results do not invalidate the positive effects of training, they do suggest that some participants may not have been completely confident that the second of four scheduled drives would be event-free. Of particular concern are the number of *trained* participants who agreed ($n = 13$) that they "*expected* the lead-

vehicle to brake hard during the last drive". Despite that both statements addressed the same event (i.e., the imminent braking event in the second Practice Drive), more drivers reported that they *expected* the lead-vehicle to brake hard during the drive, than reported they were *surprised* by it. These conflicting results reveal that a number of drivers ($n = 15$) may have interpreted the two items differently.

Until just moments prior to the event, drivers had virtually no indication that the lead-vehicle would decelerate to a stop at that *specific* point (i.e., 5 min into the second of four scheduled drives). However, in the context of a simulator experiment and in light of the information provided during training, it is not unreasonable that participants could surmise that "something" may happen before the experiment was over. It is suggested that a number of drivers may have responded to the first statement with these broad expectations in mind (i.e., Did you expect *something* to occur at *some time* during the experiment?). An assessment of expectation may have been better captured through a series of progressive statements, measuring first, their general expectation, and then more specifically, their expectation of a braking event during the second Practice Drive, followed by their expectation for an event one-third of the way through that drive.

Ultimately, the goal of an FCW experiment should be to completely eliminate expectation and surprise all drivers with the braking event. It is proposed that the presence of a vehicle in the passing lane, just moments before the braking event, may have also contributed to why some drivers reported that they were not *surprised* and why even more said they *expected* an event. A bus in the adjacent lane was programmed to approach, but unlike other vehicles during the drive, *not pass* the lead-vehicle, seconds

prior to the braking event. The presence of the bus, just left of the lead-vehicle, was intended to force participants to respond to the forward collision by braking, rather than steering around the threat. Anecdotal evidence suggests that participants noticed the unusual behavior of the bus. Following the debriefing, several participants expressed to the researcher that the behavior of the bus was conspicuous and had piqued their curiosity. It is unlikely that participants related the bus to a sudden braking event or fully appreciated its purpose, as it only approached moments before the event. With its presence, however, drivers may have been more likely to agree that a braking event was *expected* and disagree that they were *surprised* when reflecting, post-drive, on their experience.

Future studies should consider alternative methods (e.g., more left-lane traffic moving at a natural pace or a single lane with no shoulder and opposing traffic) to discourage drivers from steering around the lead-vehicle into an empty lane when faced with an imminent forward collision. To examine whether the actions of the bus altered participant's behavior as a number of participants indicated, mean glance duration to the console in its presence can be compared with the presence of naturally-paced vehicles and with instances when the adjacent lane is clear of other traffic. A heightened awareness and concern for the bus may be reflected in abbreviated glance durations to the scrolling text.

Furthermore, to completely remove all expectation of a lead-vehicle braking event, drivers would need to be thoroughly misled into believing that the purpose of the experiment is something other than an FCW system evaluation and training about the

FCW system could not be provided. Finally, when participants agreed with *expectation* or disagreed with *surprise* on the questionnaire, an open-ended question would provide insight into their response.

Auditory Warning

To compare the effectiveness of an auditory icon and a heightened perceived-urgency warning, the highest-urgency and car horn warnings were compared to an average-urgency alert, which was a tonal-warning used in earlier FCW studies. A fourth condition, no-auditory warning, was added as a baseline. It was hypothesized that the highest-urgency and car horn warnings would outperform the average-urgency warning because of their ability to capture drivers' attention more quickly and to represent a threat external to the host vehicle, respectively. Drivers received the auditory warnings during the braking event, approximately .5 s after the lead-vehicle applied its brakes, before any drivers had returned their focus forward. The 5 participants who were looking forward during the delivery of the auditory warning were eliminated. Like training, the effect of auditory warning was also well-represented, with a significant effect for a total of eight out of a possible ten variables. A summary of the main effect of auditory warning is presented in Table 33.

Table 33

Main Effect of Auditory Warning

Dependent Variable	Mean				<i>p</i>	<i>eta</i> ²
	No Auditory Warning	Average-Urgency Warning	Highest-Urgency Warning	Car Horn Warning		
GRT (s)	1.30	1.31	.95	1.05	.007	.183
Gaze (s)	1.57	1.67	1.42	1.20	.004	.201
ART (s)	2.66	2.55	2.05	1.81	.001	.231
PTT (s)	.62	.62	.65	.72		
BRT (s)	3.28	3.16	2.70	2.53	.0002	.283
	3.28	3.16	2.70	2.53		
BRT50%	3.61	3.45	3.25	2.90	.002	.219
minTTC (s)	.83	1.39	2.15	2.95	.0006	.255
Velocity (m/s)	7.95	9.68	6.71	4.70	.024	.147
Collisions (χ^2)	53%	63%	50%	37%		
Glances (χ^2)	37%	37%	50%	16%		

Outline represents a significant main effect of auditory warning.

 Indicates a significantly different, more desirable result (e.g., a faster RT or longer minTTC).

 Indicates a significantly different, less desirable result (e.g., a slower RT or shorter minTTC).

A summary of the quantitative auditory results, as they relate to the hypotheses, is reported in Table 34.

Table 34

Results of Quantitative Auditory Hypotheses

Independent Variable	When Compared To	Hypotheses	Supported
Higher Perceived-Urgency <i>i.e., Highest-Urgency Tonal Warning</i>	Average-Urgency Tonal Warning	Faster GRT	Yes
		Faster ART, BRT, BRT50%	No
		Faster PTT	No
		Larger minTTC	No
		Slower Collision Velocity	No
		Fewer Collisions	No
Auditory Icon <i>i.e., Car Horn Warning</i>	Average-Urgency Tonal Warning	Faster GRT	No
		Faster ART, BRT, BRT50%	Yes
		Faster PTT	No
		Larger minTTC	Yes
		Slower Collision Velocity	Yes
		Fewer Collisions	No
Audible <i>i.e., Average-Urgency, Highest-Urgency, and Car Horn Warnings</i>	No-Auditory Warning	Faster GRT	Partially
		Faster ART, BRT, BRT50%	Partially
		Faster PTT	None
		Larger minTTC	Partially
		Slower Collision Velocity	None
		Fewer Collisions	None

The highest-urgency warning resulted in faster initial glances forward (GRT) than did the no-auditory and average-urgency conditions. Therefore, a visually distracted driver's attention can easily be captured and brought forward more quickly by increasing the perceived-urgency of a tonal warning. This result is in line with Wiese and Lee, who

also found a benefit to incorporating a higher-urgency warning, which in that particular study reduced ART (2004).

Because the highest-urgency condition produced the fastest initial glances forward (GRT), it would naturally be expected to continue to outperform the other warnings on the remaining variables as well (e.g., ART, BRT). However, the low-contrast simulator image inadvertently created an additional challenge for the warnings. When visual detection of the threat was momentarily delayed for early responders, drivers, and particularly those who did not have the benefit of training, were left searching for an explanation. As a result of the confusion, many drivers glanced-back to the instructions on the console monitor. In the context of the present scenario, the most effective auditory warning is the one which can generate, not only the fastest initial glance forward, but the fewest glances-back and the shortest *overall* duration of console gaze.

The remarkably consistent advantage of the car horn quickly emerges from the data analysis. The car horn warning was the only audible warning to produce a significant decrease in the number of glances-back to console, supporting the hypothesis that as a sound associated with an external source, drivers' attention is more likely to be drawn toward the outside of the vehicle. This also suggests that drivers have a representation of a car horn sound encoded in memory as a cautionary sound. This decrease in glances led to a gain for the car horn in subsequent metrics. The car horn condition outperformed both the no-auditory and average-urgency conditions in duration of console gaze, ART, BRT, BRT50%, and minTTC ($p \leq .004$). In a related finding, drivers receiving the car

horn warning had a lower collision velocity than those in the average-urgency condition. In addition, trends in collision rates also point to the advantage of the car horn. Although, not a reliable difference, the car horn was the *only* auditory warning condition in which more drivers were able to avoid the collision than not. The positive effects of the car horn warning also reflect the results of both Belz et al. (1999) and Graham (1999) who found that auditory icons resulted in faster reaction times to forward collision events.

While the car horn did not produce the fastest return to the forward scene (GRT), the apparent advantage of the car horn, in the present study, was that it helped to keep the driver's attention forward once they had transitioned forward from the secondary task, by reducing the number and duration of glances-back to console. As was observed with training, the increase in eyes-forward time again played an important role in the improvement of the subsequent metrics. More eyes-forward time facilitated detection of the decelerating lead-vehicle, resulting in earlier reaction times (i.e., ART, BRT, BRT50%) and the avoidance or mitigation of collisions (i.e., minTTC and collision velocity). These results demonstrate that an auditory icon, associated with a well-learned sound, whose source is external to the vehicle and related to the nature of threat, can produce a significant improvement in eyes-on-road time, and thus, improve reaction times and collision statistics, reducing the overall number and severity of rear-end collisions.

Finally, similar to the training analysis where pedal transition time (PTT) only approached significance, PTT was not significant for auditory warning. The hypothesis had originally implied that a faster PTT is reflective of a more efficient collision

avoidance response. In contrast to that expectation though, as the prevailing auditory warning, the car horn did not produce a reliable difference in PTT. As was evidenced in the training analysis, PTT can be driven down by panic stops which are indicative of late threat detection, a highly undesirable result. The lower PTTs produced by panic stops, which are associated with no-training, and therefore distributed equally across warnings, are one possible contributing factor in the lack of significant difference between the auditory warning conditions.

In an unexpected result, the average-urgency warning failed to produce a significant benefit over the no-auditory condition. As the average-urgency alert was the tonal warning used in previous studies to evaluate the effectiveness of the warning system, this suggests that the positive effects of an FCW system may have potentially been underestimated, particularly in a simulator environment. In other words, had previous studies examined a car horn, or even the highest-urgency warning, earlier results may have been even more positive.

It is suggested that two factors contributed to the lack of difference between no-auditory and average-urgency. First, in light of the finding that some drivers may have already begun their transition back to forward scene when the auditory warning was delivered, the consequence of the absence of a sound may not have been as noticeable or severe. To restate an earlier conclusion, for the purpose of a simulator test, eliminating the .5 s delay between the application of the lead-vehicle's brakes and the activation of the FCW alerts may provide a better opportunity to study the effect of the presence, or absence, of auditory warnings before drivers naturally initiate movement. With the

elimination of this delay, the difference between the three auditory warning conditions as compared with the no-auditory-warning condition would become more noticeable.

Furthermore, the trend in the data actually shows a higher collision velocity for average-urgency than for the no-auditory condition. These results seem to suggest that the average-urgency tonal alert lacks the attributes or characteristics that can capture attention more quickly, such as the highest-urgency alert, or that can help the driver to associate the warning with other vehicles in the external environment, such as the car horn.

Limitations

Despite the promise of the car horn results, there are several critical limitations that must be acknowledged. First, the earlier that drivers looked forward for the first time, the less salient the decelerating lead-vehicle's image appeared. Because drivers who received the highest-urgency alert looked forward earlier than participants in the other three conditions, they saw the least salient image, which increased their likelihood of glancing back. The scenario presented to drivers in the present study, effectively, tests a situation which represents lowered-visibility or lower-contrast brake lights. However, in real-world, normal visibility conditions, it is thought that the appearance of a lead-vehicle and brake lights can be expected to be somewhat more salient. When the forward scene is not degraded, threat detection is likely to occur earlier, and operators are much less likely to glance away from forward scene in search of an explanation. With the elimination of glances-back to the console, one possibility is that the highest-urgency warning might

continue to outperform the other conditions in subsequent variables, just as it had for GRT.

Therefore, the question that remains unanswered is whether the benefit of the car horn lies solely in its ability to keep attention forward in light of an ambiguous threat and a highly-relevant secondary task, or whether the inherent properties of an auditory icon truly facilitate drivers' recognition and detection of the forward collision threat more effectively than a high-urgency tonal warning. A simulator scenario in which the forward threat is immediately recognizable upon the first forward glance is needed to address this issue, followed by on-road studies to test real-world conditions.

The second notable limitation is direction of gaze, as the forward scene with an embedded rear-mirror image was the only simulator display presented to drivers. When drivers transitioned their gaze away from the secondary task on the console monitor, the only driving information available to them was the *forward* scene. Thus, the opportunity to study drivers' likelihood of glancing elsewhere was limited. With more sources of driving information (e.g., side-view mirrors, peripheral displays, and a more realistic rear-view mirror display), the likelihood of glancing to the wrong location increases and can be more realistically examined. This is an important consideration for production systems because a glance to the wrong location, or effectively, any increase in eyes-away-from-forward, can delay detection of the threat and, consequently, the appropriate collision avoidance response. The car horn's success in an on-road scenario is dependent, not only on keeping attention on the outside scene, but at the *correct* external location, a burden also shared with the visual warning component of the system.

The third limitation of the present study and consideration for future research is the visual warning. To more closely reflect a production system in the present study, each auditory warning condition included a visual alert, shown as a simulated HUD on the forward display. As a result, the present study captured how a change in auditory warning would effect a driver's collision avoidance response when paired with a visual icon, a common FCW visual alert method. Therefore, the positive effects of the car horn are more correctly attributed to both the auditory icon coupled with the presentation of the visual icon. Furthermore, the baseline condition represents a condition with only a visual icon on a simulated HUD, rather than the absence of all warnings. To better isolate the benefits and limitations of auditory warnings, audio alerts should also be examined independently of visual warnings, as well as with the visual warning intended for production to study interaction effects.

In the present study, the highest-urgency alert serves as only one example of a tonal warning which has a higher perceived-urgency than the alert used in previous studies (i.e., the average-urgency warning) and is likely too extreme (i.e., too startling and too high pitched) to be considered for an actual production environment. Given the countless number of variables that contribute to a sound's overall perceived-urgency (Edworthy et al., 1991; Hellier et al., 1993; Edworthy et al., 1995; Guillaume et al., 2003), as well as, the endless number of ways technology can manipulate those variables, there are many opportunities to optimize the perceived-urgency of a tonal warning, while maintaining its suitability for on-road use.

Finally, one of the most important results from the present study may be found in the lessons of both the highest-urgency and car horn warnings, which contributed to significant improvements in responses to the FCW alert(s). The optimal audible warning for an FCW system may be an auditory icon, such as a car horn, with an increased perceived-urgency. In a best case scenario, increasing the perceived-urgency of a car horn may garner faster GRTs, like the highest-urgency warning, while at the same time, also reducing glances to a secondary task or incorrect location, as the car horn warning demonstrated.

Auditory Warning – Sound Analysis

Following completion of the present research, a quantitative sound analysis and comparison of the auditory warning sounds was undertaken. The analysis of the five auditory warnings (i.e., higher-urgency and screeching tires from the pilot study; and average-urgency, highest-urgency, and car horn from the experiment) was conducted by the Physics Department at the University of Dayton (Yakopcic, 2009). A summary of the five auditory warnings is shown in Table 35. As the sound analyses were conducted after the experiment was complete, the findings did not influence which sounds were selected during the pilot study testing. Details and insights provided from the analysis follow. See Appendix P for the waveform and frequency response plots of each of the five warning sounds.

Table 35

Auditory Warning Sound Analysis

Auditory Warning	Amplitude (dB)	Fundamental Tones	Fundamental Frequencies (Hz)	Repeating Harmonics	Musical Dissonance
Average-Urgency	83 – 84	1	727	No	No
Highest-Urgency	96 – 99	2	2500 & 2650	No	Yes
Car Horn	94 – 96	2	375 & 450	750 & 900	Yes
Higher- Urgency	93 – 94	2	2500 & 2650	No	Yes
Screeching Tires	91 – 93	Many	790	No	No

Bold: indicates that sound chosen for use in experiment. (All five sounds were used in pilot study).

Average-Urgency (experiment). According to the analysis conducted by Yakopcic (2009), the average-urgency warning consists of only one frequency (727Hz). The analysis also confirmed that the sound was digitally created, as opposed to being a recording of the sound's playback, as the other warning sounds are (Yakopcic). The finding is consistent with this warning sound having been used in previous FCW studies, as part of the Automotive Collision Avoidance System Field Operational Test program (ACAS FOT). See Appendix P for the waveform and frequency response plots of the average-urgency warning.

Highest-Urgency (experiment). Yakopcic states that, in addition to the pure sinusoidal tones, there are many harmonics present in the highest-urgency warning sound (2009). Further, the second fundamental tone is approximately equal to one half-step above the first fundamental tone, such as two keys on a piano which are directly next to

each other and produce the most dissonant tone that can be created on a piano (Yakopcic). The finding is consistent with this sound being rated as the most *urgent* of the three tonal warnings that were presented to pilot study participants. Yakopcic also notes that this sound is about 18% louder than the Average Urgency signal. See Appendix P for the waveform and frequency response plots of the highest-urgency warning.

Car Horn (experiment). Yakopcic concluded that there are multiple frequencies added together to create the car horn sample. In addition, Yakopcic observed that the second frequency presented in the car horn sample, 450Hz, is almost exactly a minor third away from the first tone, a tone combination that can be considered somewhat dissonant. It is possible then, that the positive effect of the car horn warning can be attributed to both the sound's auditory icon properties, as well as, its musical dissonance. See Appendix P for the waveform and frequency response plots of the car horn warning.

Higher-Urgency (pilot study). The peaks of the fundamental frequencies appear at 2500Hz and 2650Hz, which show the musical dissonance of being one half-step away from each other (Yakopcic). It is important to note that these are the same frequencies that were observed in the highest-urgency sound. See Appendix P for the waveform and frequency response plots of the higher-urgency warning.

Screeching Tires (pilot study). The screeching tires sound was included in the pilot study as a second auditory icon. However, the car horn was selected for the experiment as more participants felt it was better suited to the meaning of the FCW alert. Yakopcic found that there is a great amount of noise in this sound sample, which does

have one strong peak at approximately 790Hz. See Appendix P for the waveform and frequency response plots of the screeching tires warning.

FCW Questionnaire – Auditory Warning Attributes

As a precaution, all participants were asked if they had received an auditory warning. The 52 participants that correctly responded that they had were presented with ten statements pertaining to the attributes of the auditory warning, as well as, their likelihood to recommend the system they had just experienced. A summary of the qualitative auditory warning attribute results, as they relate to the auditory hypotheses, is reported in Table 36.

Table 36

Results of Qualitative Hypotheses

Independent Variable	When Compared To	Hypotheses	Supported
Higher Perceived-Urgency <i>i.e., Highest-Urgency Tonal Warning</i>	Auditory Icon <i>i.e., Car Horn Warning</i>	Improves Attention Capture	No
		Helps Avoid a Collision	No
		Reduces Collision Severity	No
Auditory Icon <i>i.e., Car Horn Warning</i>	Higher Perceived-Urgency <i>i.e., Highest-Urgency</i>	Less Startling	No
		Less Annoying	No
		More Understandable	No

It is clear that single-event methodology did not allow for a sensitive measure of auditory warning attributes. A more naturalistic and prolonged exposure (e.g., on public roadways) is required to better understand drivers' subjective experience with the

audio/visual warning interface. Responses to each of the auditory warning attribute questions are examined below.

Questionnaire Item 7: The audio warning captured my ATTENTION. It was expected that responses to this statement would help to reveal the benefits of the car horn and, especially, the highest-urgency warning over the average-urgency alert. In contrast however, there was nearly identical agreement across all three audible alerts, as well as, both levels of training, that the auditory warning did capture drivers' attention. Only 4% of all operators who received an audible alert disagreed with the statement.

In order to distinguish between auditory warnings, this item is better suited to a repeated-measures design, where participants are exposed to all auditory warnings and can better judge which audible best captured their attention. Furthermore, participants' agreement that the alerts captured their attention is reflective only of a relatively quiet simulator environment rather than an on-road scenario with vehicle, passenger, and radio noise.

Questionnaire Item 8: The audio warning STARTLED me. Like the previous question, agreement that the audio alert startled participants was almost identical across the three auditory warning conditions and both levels of training. However, 13% of drivers did disagree that they were startled. The majority of those who disagreed (six out of seven) were participants who had received training. It appears that FCW system knowledge and demonstration of the auditory warning may work to slightly reduce participants' perception of *startle*. The result suggests that, with training, participants' perception of their experience with the auditory warning is less negative. However, it is

unknown whether it was the knowledge of the warning system or the demonstration of the auditory warning that had a greater impact on this result. Furthermore, the length of time this benefit of training persists and how many more exposures are needed to further reduce startle is unknown. Although ideal, achieving a balance between attention capture and startle may be an unrealistic goal. Again, like the previous statement, had the experiment used a within-subjects design, it is far more likely that a difference in agreement across levels of auditory warning would have been more noticeable.

Questionnaire Item 14: The audio warning is likely to be ANNOYING on real roadways if I experience it several times a week and it often does not correspond to a real threat in the environment. Participants were asked to respond to this question to estimate the impact of nuisance alerts, in a production environment. False alarms in an on-road environment are likely true detections by the radar. However, when a threat is not imminent because of action planned by one of the vehicles (e.g., a lead-vehicle turning out-of-path or a lane change by the host-vehicle) and the driver is aware of the situation, the FCW alert can be perceived as a nuisance alarm. As expected, the majority, 83%, of participants agreed that they would be annoyed. Again, the likelihood of agreeing was almost identical across auditory warning conditions. In contrast, it was expected that the highest-urgency warning would stand out from the others on the attribute of annoyance, as Wiese and Lee found (2004).

However, of the 9 drivers who disagreed that they would be annoyed, 8 had been recipients of training. Like the previous questionnaire item, this result demonstrates that knowledge of the warning system and demonstration of the alert can alter drivers'

opinion of the system. With an understanding of the purpose of the warning system and the added safety it can provide, a small percentage of drivers expect to be more tolerant of false alarms. If a brief overview and general understanding of the FCW system increases tolerance of nuisance alerts, the acceptance of these types of alarms might also be increased with an understanding of what causes specific alerts to occur (e.g., lead-vehicles turning out-of-path or the host-vehicle making a lane change). Having had only one exposure to a forward collision threat and no on-road experience, drivers' ability to judge the annoyance of nuisance alerts is limited.

Questionnaire Item 5: When the car in front of me braked hard during the last drive, the system presented an audio warning that was UNDERSTANDABLE. While only a marginal difference exists between agreement and disagreement (56% and 44%, respectively), training and auditory warning did have an influence on responses. As expected, with training, participants were more likely to judge the auditory warning as *understandable*.

Furthermore, the chi-square Test of Independence for agreement by auditory warning approached significance ($p = .057$), a result of the contrasting trends across warning conditions. When drivers received the average-urgency alert, more disagreed that the auditory warning was *understandable*. The opposite trend was evident for the highest-urgency and car horn warnings, suggesting that when drivers received one of these two warnings, there was a tendency to judge the alert to be more understandable.

Whereas there are commonalities between the attributes of the auditory icon and characteristics of an FCW alert (i.e., both involve another vehicle in the environment

external to the host-vehicle) as a tonal warning, the highest-urgency does not have properties that make it inherently more likely to be *understood* as an FCW alert. Instead, it is more likely that the highest-urgency audible, as a sound with higher perceived-urgency, was more distinct, perhaps more memorable, to drivers than the average-urgency warning. Furthermore, like others, this questionnaire item also lends itself to a repeated-measures design where operators have the opportunity to compare and select the most understandable of the three warnings.

Questionnaire Item 6: The audio warning was USEFUL for enhancing safety.

Eighty-five percent of participants agreed with the statement. Furthermore, drivers were in agreement regardless of training condition. However, the auditory warning analysis revealed one of the most telling results of the questionnaire analysis. When participants received the highest-urgency or car horn warnings, significantly more agreed that the audio warning was useful for enhancing safety. In contrast, agreement was not statistically different for drivers who heard the average-urgency alert. Therefore, increasing the perceived-urgency of a tonal warning or providing drivers with an auditory icon increases ratings of perceived *usefulness for enhancing safety*.

However, it is suggested that this result is heavily influenced by drivers' experience in the simulator taken as a whole, rather than attributed only to the auditory warning. That is, drivers in the highest-urgency and car horn warning conditions had fewer collisions, a tangible metric that may have left a greater impression on them than the audible alert itself. It is likely that drivers responded to this statement with their overall experience in mind, rather than the usefulness of the just the auditory warning

component. It may be unreasonable to expect that drivers who just experienced a forward collision threat, which can be quite overwhelming, to easily parse and evaluate only the auditory component of their experience.

Questionnaire Item 12: The audio warning would be USEFUL on real roadways for enhancing safety. As a follow-up to the previous question, participants were asked to respond to this statement to measure the auditory warning's usefulness in an on-road, production environment. With the exception of 1 participant, all agreed ($n = 51$), regardless of training or warning, that the system would be useful for enhancing safety on real roads. While the responses to this statement provide a clear endorsement of all auditory warnings, it is likely that drivers answered with the concept of the FCW system as a whole in mind, rather than the single auditory warning to which they had been exposed. Again, a repeated-measures design would have likely resulted in greater distinction between the auditory warning conditions.

Questionnaire Item 10: The audio warning helped me to reduce the SEVERITY of the collision. Before they were presented with this statement, drivers were asked if they had collided with the lead-vehicle (*Questionnaire Item 9*). A number of respondents expressed an uncertainty about whether or not they had collided. The confusion is likely attributable to a lack of feedback from the simulator (i.e., no force feedback cues in the fixed-base simulator and no change in the appearance of the lead-vehicle once the host-vehicle had made contact with it).

The earlier quantitative collision velocity analysis revealed that trained drivers and those who received the car horn had significantly lower collision velocities.

Surprisingly though, questionnaire responses do not reflect this finding. The difference between agree and disagree was not significant for levels of training or auditory warning. Contributing to the lack of difference were a small number of responses in total ($n = 22$) and, of the drivers who did collide, far fewer had been trained or had received the car horn warning, making comparisons across training and warning less meaningful. Furthermore, collision velocity, particularly in a fixed-base simulator after only one exposure, is a metric that may be less tangible to drivers. The collision velocity metric is more well-suited for a quantitative analysis.

Questionnaire Item 11: The audio warning helped me to AVOID the collision. In direct contrast to the previous questionnaire item, drivers who were trained or had received the car horn were less likely to collide, and as a result, disproportionately represented in responses to this statement, as well. That said, significantly more drivers who agreed had been trained, suggesting that training increases eyes-on-road time, thereby reducing reaction times and decreasing collision rates. Furthermore, with the exception of one respondent, all participants ($n = 26$), regardless of warning condition, agreed that the auditory warning helped them to avoid the collision.

Questionnaire Item 4: Which meaning does the auditory warning you just heard best reflect? The fourth item on the FCW questionnaire (see Appendix K) was omitted from the analyses. Drivers were asked to select which statement the audible best reflected:

- (1) My vehicle is experiencing mechanical failure;
- (2) There is a vehicle in front of my car;

- (3) I am close to the vehicle in front of my car;
- (4) If I don't respond within the next few seconds, I will collide with the vehicle in front of my car;
- (5) It is too late to avoid a collision with the vehicle in front of my car;
- (6) I have crashed into the vehicle in front of my car.

Preliminary examination showed that the most common answer at nearly every level of training and auditory warning was, "If I don't respond within the next few seconds, I will collide with the vehicle in front of my car" (see Appendix O for results). Although the responses appear overwhelmingly accurate, drivers were clearly reflecting on the FCW event they had just experienced, rather than their interpretation of the auditory warning. It would have been more appropriate to ask this question *prior* to exposing drivers to the forward collision braking event in the simulator.

FCW Questionnaire – Likelihood to Recommend FCW System

Questionnaire Item 13: If it were priced reasonably, I would recommend a Forward Collision Warning system like this one. An overwhelming majority of respondents (94%) agreed with this statement, which was intended to measure the production viability of an FCW system. Participants agreed, regardless of training or auditory warning. All three participants who disagreed with this statement were untrained and collided with the lead-vehicle.

Gender

In addition to the three gender by training interactions described earlier (i.e., BRT, BRT50%, minTTC), the main effect of gender was also examined. Nine of the ten

dependent variables (i.e., GRT, duration of gaze, ART, PTT, BRT, BRT50%, collision velocity, glances back, and collision rate) did not reveal a reliable difference between male and female drivers. However, the main effect of gender did approach significance for minTTC, as female participants maintained a longer minTTC than men. For women, but not for men, training resulted in a larger improvement in time to initial contact with brake (BRT) and time to depress the pedal (BRT50%) than men. Earlier deceleration allowed women to maintain a greater distance from the lead-vehicle at a slower speed, as evidenced in higher minTTCs.

This result appears to contrast with previous studies, such as Hancock et al. (2003), who found that female drivers stopped closer to the boundary of the intersection when responding to the activation of a traffic light. The authors attributed the difference to the finding that men applied more brake pressure than women. However, because the present study did not measure force on the pedal or rate of deceleration the results are not directly comparable.

Gender and Warning

In a cursory examination of the means across four auditory warnings at each level of gender (see Table 8), it is noticeable that the trends in the data, particularly for women, often differ from the main effects reported throughout this discussion. For example, as stated earlier, the car horn resulted in a slower collision velocity than did the average-urgency warning. However, based on the means, this result appears to hold true only for male participants. While no gender by warning interactions are reliable or even approach significance, an additional analysis was performed to investigate these observations.

When examined independently of each other, the main effect of warning appears strikingly different across genders, as shown in Table 37.

For men, the main effect of auditory warning is significant for GRT, console gaze, ART, BRT, BRT50%, minTTC, and collision velocity at $p \leq .030$. For women though, the main effect of auditory warning is significant for only *one* dependent variable, BRT. Furthermore, in the analysis of male drivers, the effect of the car horn is overwhelmingly positive. In the sole reliable result for women, though, the highest-urgency warning produces the fastest BRT.

Table 37

Main Effect of Auditory Warning by Gender

Dependent Variable	Men		Women	
	<i>p</i>	Significant Differences	<i>p</i>	Significant Differences
GRT (s)	.018	Car Horn < No-Auditory Highest-Urg. < No-Auditory		
Gaze (s)	.005	Car Horn < No-Auditory Car Horn < Average-Urg.		
ART (s)	.002	Car Horn < No-Auditory Car Horn < Average-Urg.		
PTT (s)				
BRT (s)	.003	Car Horn < No-Auditory Car Horn < Average-Urg.	.032	Highest-Urg. < No-Auditory
BRT50%	.005	Car Horn < No-Auditory Car Horn < Average-Urg. Car Horn < Highest-Urg.		
minTTC (s)	.0006	Car Horn > No-Auditory Car Horn > Average-Urg. Car Horn > Highest-Urg.		
Velocity (m/s)	.030	Car Horn < Average-Urg.		
Collisions (χ^2)		n = 14		n = 12
Glances (χ^2)		n = 20		n = 18

The contrast between the main effect of auditory warning from men and women is striking. Particularly concerning is that for female drivers auditory warning was significant for only one variable (i.e., BRT). Meaning that, for seven of the eight variables, neither the car horn warning nor the highest-urgency warning showed an improvement over the no-auditory condition. Had the present experiment included only men *or* women, this contrast would have failed to surface.

One explanation is that the visual icon was more helpful to women, than to men, easing the disadvantage of the absence of the audible in the no-auditory condition, and thus, making it more difficult for the car horn to outperform the no-auditory condition. Likewise, the effect of the lower-urgency tonal warning (i.e., average-urgency) may be less for men than for women, creating a better opportunity for the highest-urgency and, especially, the car horn to alert men. A third possibility, is that as in the study by Hancock et al. (2003), women were more negatively affected by the visual distraction than men, making the positive effects of the car horn more difficult to detect. If this is the case, visually-distracted female drivers might benefit from a slightly earlier warning or a more salient visual warning. While the reason for this contrast remains unclear, it can only be suggested that the effect of visual and audible warnings across gender be carefully considered in future studies and their importance not be understated.

Glance-Back Analyses

The unexpected glance behavior revealed during video coding warranted a change in the planned analyses. In addition to the inclusion of console-gaze duration in the MANOVA and the glance-back variable in the chi-square analysis, glances-back were

also identified as an independent variable in a separate MANOVA. Because of the small number of participants, training, auditory warning, and gender could not be included in the same analysis. Although limited in its scope, this additional analysis helps to demonstrate the negative effect that even small increases in eyes-off-road time can have during an FCW event and provides considerations for future studies. That is, future work can examine whether these short, but costly, glances-back to the secondary task are likely to happen in the real world, or were simply an effect of this experimental design, and if so, how to avoid this confound in future experiments. Furthermore, the auditory component of an FCW system optimally needs to be designed to aid in directing the driver's attention to the correct primary task location (i.e., the forward scene), rather than a side- or rear-view mirror, for example.

When drivers glanced-back to the console monitor after looking forward for the first time, duration of gaze increased by an average of .89 s, across training, auditory warning, and gender. This increase in eyes-off-road time also increased reaction times. That is, drivers who glanced-back had a longer ART, BRT, and BRT50% ($p \leq .0001$). The most substantial statistics, however, are the collision metrics. Glances-back to the console, that is, an average eyes-off-road increase of .89 s, resulted in a minTTC that was shorter by 2.58 s and a collision velocity that was more than four times higher than for drivers who did not glance-back. Of the 26 drivers who glanced-back, 92% of them went on to collide with the lead-vehicle, as compared with only 29% of drivers who did not glance-back.

In addition, pedal transition time was longer for participants who glanced-back ($p = .02$). In this instance, a longer PTT appears to be an indication of a delay between ART and the completion of the collision avoidance response. It appears that while many drivers release the accelerator in response to the FCW alert(s), they are generally unwilling to continue their collision avoidance response until they have visual recognition of the threat.

One of the most interesting aspects of the glance-back analysis is GRT. Drivers who eventually glanced-back had initially looked forward .19 s *earlier* than drivers who would go on to maintain their forward gaze ($p = .052$). Although seemingly counterintuitive, as earlier glance reaction times *should* imply a safer collision avoidance response, this result falls directly in line with concerns about the quality of the simulator image. The earlier drivers initially looked forward, the less salient the lead-vehicle's brake lights, and the more likely they were to glance-back in search of an explanation of the FCW alert(s). In the context of this study, drivers who glanced forward the earliest were at a slightly greater disadvantage than those who looked up later.

While it is unlikely that a driver in the real world would feel as compelled as participants in the present study to glance-back to a secondary task display, the likelihood of glancing to another location may actually be considerably higher in a real vehicle. With more mirrors and windows to mistake for the location of the threat and without a strong visual cue to draw attention to the correct forward location, the opportunity for gaze errors increases and can have a dramatic effect on collision avoidance responses. Whether the increase in eyes-off-road time is the result of a longer initial glance or,

instead, a glance to the wrong location (e.g., side-mirrors or secondary tasks), less eyes-on-road time during a forward collision threat allows the host vehicle to come significantly closer to colliding (minTTC) with the lead-vehicle and leads to the striking vehicle having significantly higher velocity during a collision. The results speak to the need for optimized FCW alert(s), both audible and visual, which will not only capture a visually distracted drivers' attention, but pull it to the correct location, without delay or interruption.

Importantly, training was not spread equally across glance behavior. Eighty-five percent of drivers who glanced-back were *untrained*. Therefore, the increase in eyes-off-road time created by glances-back to the console is likely mitigated by FCW system knowledge. In a production environment, training may be equally important for, not only a quick transition to the forward scene, but for maintaining that focus, as well.

Ljung et al. suggested that experience with other warning systems may influence a driver's likelihood of glancing back (2007). That is, when participants were exposed to LDW alerts throughout their drive, fewer glanced-back to the secondary task after looking up for the first time. Although no other warning systems were active during the present study, it is not out of the question that prior experience could have played a marginal role in glancing back. More in-depth screening questions about prior experience may prove useful in future studies. Furthermore, Ljung et al. also found that the appearance of the lead-vehicle, as was determined by time headway, influenced the probability of glancing back. That is, a shorter time headway compensated for a lack of salient brake lights, making the threat more apparent.

Future Studies

One of the foremost concerns and limitations of the present experiment that will be of high priority to address in subsequent studies is the demonstration of the audio warnings during training. By using a between-subjects design and providing participants with exposure to one independent variable (i.e., auditory warning) as part of the second independent variable (i.e., training), drivers were effectively presented with four different training experiences (HUD + no-auditory, HUD + average-urgency, HUD + highest-urgency, and HUD + car horn). The use of different sounds unintentionally created four different training experiences. While the impact of this approach is unknown, the challenge in future studies will be to provide operators with an identical training experience across all levels of auditory warning, so that a difference in priming cannot be called into question. One option is to provide a demonstration of an alternative audio alert, one not used in any of the warning conditions. A second method might be to discuss, but not demonstrate, the audio alert.

Relative to the results of the present experiment, one of the most important future efforts will be to further optimize the auditory warning by exploiting the advantages of both the auditory icon car horn and highest-urgency warning. The next step is to develop a car horn warning with a higher perceived-urgency. If the benefits observed in the present study continue to hold true, a car horn with a higher perceived-urgency may combine the benefits of both audible warnings and generate the fastest GRT, as well as, the fewest glances-back. A second option might be to carefully combine both warnings so that a tonal warning with high perceived-urgency transforms into a car horn, over the

course of the 1 s duration. Of course, successful FCW systems are also dependent on the simultaneous optimization of system training and the auditory component, and of technology (e.g., radar) and other components (e.g., visual alert and timing of the alerts), as well.

Future studies should explore the issue of glancing back, by presenting drivers with a forward threat that is immediately recognizable upon first forward glance. A comparison of warnings, in this scenario, is necessary to identify whether the car horn warning will continue to outperform the others when drivers feel less compelled to glance-back, or whether the highest-urgency alert will replace the car horn as the prevailing auditory warning.

The importance of verifying the results of this and future simulator studies in an actual vehicle on test-tracks and on-road cannot be overstated. While technology advancements continue to make driving simulators more realistic, it is imperative that any result collected in an artificial environment be explored on-road. In the context of an actual vehicle, in an uncontrolled environment, there are countless variables (e.g., an endless combination of road and traffic patterns, multiple secondary tasks, noise, weather, and the interaction of variables) that will impact the effectiveness of an FCW system. Furthermore, the impact of false alarms, or nuisance alerts, needs to be explored.

The length of time that the benefits of training persist is another aspect of these results that needs to be explored. In the present study, participants encountered the forward collision event no more than 30 min after receiving training. If a delay of weeks or months occurs between training and exposure to an FCW alert, the positive effects of

training may be compromised, to the point of ineffectiveness, or at worst, eliminated. The frequency with which drivers will need to be reminded of the FCW system and its alerts needs to be carefully examined. A simulator study where participants receive training but are *not* exposed to a forward collision event would offer an opportunity to examine how long the benefits of training persist. Response to an imminent forward collision event, without the benefit of *retraining*, could be assessed in a second simulator experience, at various time durations (e.g., weeks, months), after the initial training.

Visually distracted drivers facing a forward collision threat have an even better chance of avoiding or reducing the severity of a collision in a vehicle equipped with both an FCW system *and* ABS. In order to take advantage of both systems, drivers must not only brake quickly, but with continuous force, and if necessary, execute an appropriate steering response, a benefit afforded by ABS. Therefore, it will be especially useful to test drivers' responses in a vehicle equipped with both systems and study, not only their initial brake response times, but their braking behavior throughout the duration of the event. Also important is to explore the most effective training methods for vehicles with more than one warning system (e.g., Lane Departure Warning Systems), where multiple audio and visual alarms may conflict.

Conclusions

The present study demonstrated that when visually distracted drivers are presented with an unexpected imminent forward collision threat in a simulated environment, FCW training, along with the use of a tonal warning with higher perceived-urgency and an auditory icon as the auditory warnings, can produce considerable gains in

collision avoidance responses. FCW training provided drivers with an understanding of the alert(s) and worked to facilitate an improvement in glance behavior by increasing eyes-forward time. These two benefits of training led to earlier detection and recognition of the forward collision threat, evidenced by earlier reaction times and far safer collision statistics as compared with drivers who were untrained. From an application standpoint, the unique value of these results lies in the concise nature of the training, which was comprised of a two-sentence explanation of the system and a *single* demonstration of the audio and visual warnings. What remains to be seen, however, is how long the benefit of the brief description and single warning demonstration will persist. The benefit of training might also be lessened when, unlike the present study, the forward threat is instantly visible to drivers.

Whereas the relatively high perceived-urgency of the highest-urgency tonal warning produced the fastest GRT, the auditory icon car horn warning produced fewer and shorter glances-back to the console than the no-auditory and average-urgency warnings. As a result, it was the car horn that facilitated faster reaction times and an improvement in the collision statistics. The sound analysis conducted following the experiment suggests that the benefit of the car horn may be attributable to both its auditory icon properties, as well as, the musical dissonance represented in the sound.

While the car horn results are robust, their interpretation is constrained by the appearance of simulator graphics, which, although only momentary, inhibited drivers' recognition of the lead-vehicle's brake lights. The ambiguity created when the brake lights first became apparent to drivers led to one of the most unexpected results in the

present study, that is, the frequency of drivers glancing back to the console monitor. As the glance-analysis demonstrated, even an increase of eyes-off-road time of less than 1 s during the presence of an imminent forward collision can have dramatic consequences.

If the advantage of the car horn lies solely in its ability to keep the attention of operators who are searching for an explanation forward, toward the lead-vehicle, then eliminating the detection delay may return the advantage to the highest-urgency warning. The question that results from the present study is whether the car horn will continue to prevail when the visibility of the threat (i.e., the lead-vehicle's rapid deceleration and brake-lights) is improved or whether the car horn is only valuable in conditions with less than perfect visibility. Although the highest-urgency alert was an extreme example, it demonstrates that increasing the perceived-urgency of the auditory warning can be an effective method for improving glance behavior. Furthermore, the importance of testing these findings in a real-world, on-road scenario, in the presence of many other variables, is critical.

Overall, the effect of gender paled in comparison to the strength of the training and auditory warning variables. However, there is some evidence that women's braking response benefited more from training than did men. Although an unplanned analysis, the more notable finding is the difference between the effect of the auditory warning when men are examined independently of women. That is, for men, seven out of eight quantitative dependent variables showed a significant effect, while only one (BRT) was significant for women. The absence of a reliable interaction between variables limits the

scope of conclusions from the present study, but does suggest the importance of considering gender effects in future studies.

From an application standpoint, the criteria for the testing and comparison of FCW systems ought to include the ability of the audio and visual alerts to pull a visually distracted driver's attention to the correct, forward location, and to *keep it there* in light of a visually-ambiguous threat. Preventing glances to the wrong location or from returning to a secondary task is critical to the improvement of the collision avoidance response. In terms of a real-world scenario, the present study offers encouraging results that the severity and frequency of rear-end collisions can be further mitigated by optimizing the auditory warning of FCW systems, as well as, the training drivers receive prior to driving a vehicle equipped with an FCW system. If these results continue to hold true on-road, then the reduction in the rate and severity of rear-end collisions will mean a decrease in personal injuries, property damage, monetary costs, and time delays. The importance of training is easily applied to other types of warning systems (e.g., blind spot detection, lane departure), as well as, other technology found on production vehicles (e.g., ABS and Electronic Stability Control). Furthermore, once optimized, the audio and visual alerts ought to be standardized in all FCW systems, across all suppliers and vehicle platforms.

The post-drive questionnaire helped to confirm that a majority of drivers did *not expect* and were *surprised* by the sudden braking event, indicating that the deception was effective. The last-minute presence of a vehicle in the adjacent lane or a very general

anticipation of an event in context of a simulator experiment likely influenced those responses which fell outside the majority.

A number of auditory warning attributes failed to show an effect of training or auditory warning as was hoped (i.e., *capture attention, startle, useful on real roadways for enhancing safety, reduce severity*). Many of these statements are better suited to a repeated-measures design where respondents are exposed to all three auditory warning conditions before evaluating attributes of the sounds. These results also emphasize the importance of using both qualitative and quantitative measures to evaluate auditory warnings.

Training had a marginal, but beneficial effect on several attributes. Training slightly reduced negative characteristics like *startle* and the sentiment that on-road nuisance warnings would be *annoying*. Furthermore, with training, participants rated the audio alert as more *understandable* and more helpful in *avoiding* a collision.

It appears that participants responded to several questionnaire items with the FCW system as a whole in mind, rather than only the audio component. In addition to the car horn, the highest-urgency warning also increased *understandability*. However, it is more likely that a tonal warning with high perceived-urgency is more memorable or distinct than it is necessarily *understandable*. The car horn and highest-urgency warnings also increased ratings of *useful for enhancing safety*, a result likely tied to their collision outcome. In an encouraging result, an overwhelming majority of participants agreed that they would recommend an FCW system like this one, providing evidence for the production viability of warning systems like these.

In short, the present study offers evidence that FCW training and the optimization of the auditory warning, with higher perceived-urgency and an auditory icon, can significantly improve the performance of the warning system. The results also suggest that the method of deception used in the present study is generally effective. Furthermore, training and auditory warning can influence ratings of startle, annoyance, and understandability. These results also add more support to the importance of eyes-on-road time, focused toward the location of the threat, during an FCW event.

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APPENDIX A

FCW Icon

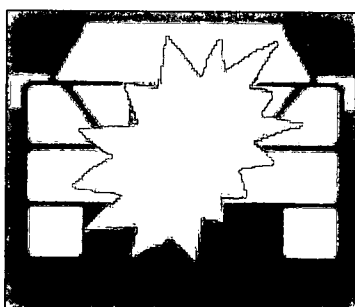


Figure A-1. FCW icon (red car with amber crash symbol).

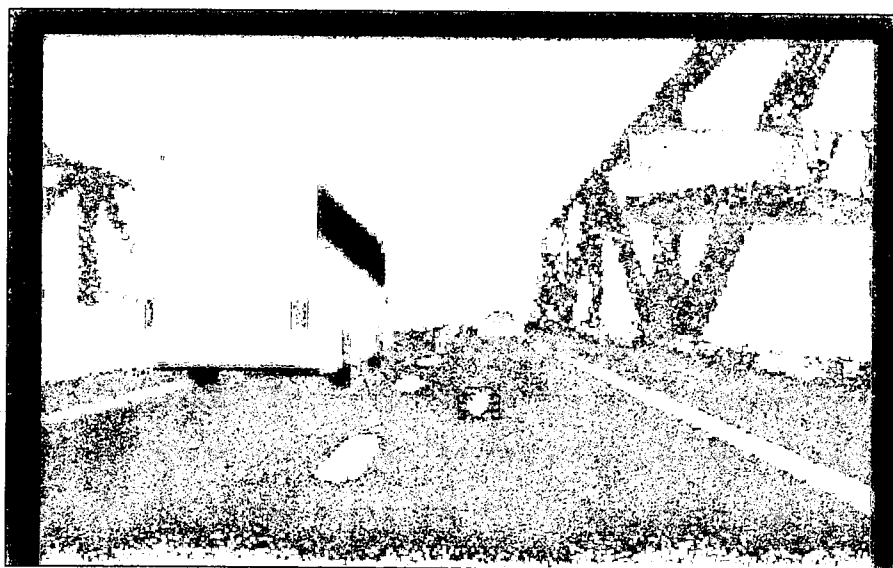


Figure A-2. FCW icon displayed on screen as a simulated HUD, as seen from the host vehicle.

APPENDIX B

PILOT STUDY DESCRIPTION

The Pilot Study was conducted at the University of Dayton, in Dayton, Ohio. A tonal auditory warning which had been used as part of the Automotive Collision Avoidance System Field Operational Test program (ACAS FOT) was the first to be selected for the Pilot Study and was dubbed the *average-urgency* warning. It was believed that including a warning that had been employed in other FCW experiments served as a logical starting point and would allow for useful comparisons.

Included in the Pilot Study for comparison were the *average-urgency* warning, two additional non-verbal auditory warnings, and two auditory icons. Researchers based their selection of the two additional auditory warnings strictly on their estimation of faster speed and higher frequencies. Accordingly, they were labeled as the *higher-* and *highest-urgency* warnings. Also included in the Pilot Study were two auditory icons, a *car horn* and *screeching tires*. The labels were used for data analysis only and participants were not exposed to them. While an objective comparison of warning sounds involves a detailed analysis of many parameters, the comparisons and rankings of warning sounds in the pilot study were based solely on researcher estimates and subjective ratings provided by participants.

The screeching tires and car horn sounds were chosen to serve as the auditory icons for the Pilot Study because, in the context of an on-road driving environment, they are easily recognized, capture a driver's attention quickly, and can prompt drivers to redirect their visual attention forward, toward other vehicles, and away from interior objects, such as nomadic devices, because they are recognized to originate from outside of the driver's vehicle. Furthermore, the use of these two auditory icons has also been reported in the literature. For example, Graham (1999) suggested that skidding tires relate to the action required by the driver (emergency braking) and, although a car horn is not necessarily indicative of a highly dangerous situation, depending on its volume, it can signal the close proximity of another vehicle. Although sirens used by police, ambulance, and fire trucks are also well-learned and recognized as originating outside the vehicle, they were not considered for inclusion in the Pilot Study. These sounds have a dedicated association with emergency vehicles, and the application of another meaning (i.e., for FCW) potentially jeopardizes their effectiveness and increases the chance for confusion. While the sources of screeching tires and car horns are almost unmistakable and quickly capture a driver's attention, unlike emergency sirens, their circumstances can be ambiguous, making them more suitable for the Pilot Study investigation.

Speech warnings were considered unsuitable candidates for the present study. As Graham (1999) summarized, listeners typically need to hear nearly the entire message before it is understood. Furthermore, shortening the message or increasing the rate of presentation can decrease the accuracy of understanding (Graham).

Forty-seven students who were enrolled in an Introductory to Psychology course (23 women and 24 men) participated in the Pilot Study as part of their course requirements. The opportunity to participate in the study was posted on the University of Dayton's Psychology Department's Subject Pool website and included a description of the study, which stated that participants would be asked to evaluate the characteristics of several auditory warning sounds. The median age of participants was 19, with a minimum age of 18 and a maximum age of 45. The median number of years of driving experience reported by participants was 3 years, with a minimum of 1 year and a maximum of 29 years.

The Pilot Study questionnaire was presented to participants in three parts (see Appendix C for complete Pilot Study Questionnaire). In Part 1, participants were presented with the five auditory warnings, the order of which was counterbalanced across five sessions, each session having different participants, but all participants experiencing all five auditory warnings. After hearing each of the five sounds, participants were asked to select which of the following statements each sound best represented:

- (1) My car is experiencing mechanical failure;
- (2) There is a vehicle in front of my car;
- (3) I am close to the vehicle in front of my car;
- (4) If I don't respond within the next few seconds, I will collide with the vehicle in front of my car;
- (5) It is too late to avoid the collision with the vehicle in front of my car;
- (6) I have crashed into the vehicle in front of my vehicle.

Trends in the results (see Appendix D) showed that each of the three tonal warnings was most frequently associated with the statement: "My car is experiencing mechanical failure". Looking at, "There is a vehicle in front of my car", "I am close to the vehicle in front of my car", and "If I don't respond within the next few seconds, I will collide with the vehicle in front of my car", the highest-urgency warning was increasingly associated with those statements which represent coming *closer* to the collision.

Regarding the auditory icons, participants demonstrated a tendency to associate screeching tires with events *following* the moment when the forward collision becomes imminent (i.e., "It is too late to avoid a collision with the vehicle in front of me" and "I have crashed into the vehicle in front of my vehicle"). In contrast, the car horn was associated with events *prior* to the moment when the forward collision becomes imminent (i.e., "There is a vehicle in front of my car" and "I am close to the vehicle in front of my car").

In Part 2 of the questionnaire, participants were asked to rank the five sounds on each of three attributes: annoyance, startle, and attention capture ability. Questionnaire responses revealed a similar trend across all three attributes. Overall, the highest-urgency warning was ranked most annoying, most startling, and the best at attention capture. Of the three tonal warnings, the average-urgency warning received the lowest mean ranking, making it the least annoying, least startling, and least able to capture attention. It appeared then, based at least on the trends in the data, that participants' ratings were consistent with researchers' initial categorization of the non-verbal, tonal warnings: the warning with the highest perceived-urgency (as ranked by the researchers) was the one

ranked most annoying, most startling, and best at attention capture (by Pilot Study participants). Furthermore, the opposite held true for the average-urgency warning.

Unlike the tonal warnings, there was little difference between the two auditory icons in Part 2. The screeching tires were ranked only slightly higher than the car horn on all three attributes, indicating that participants perceived the tires as only slightly more annoying, more startling, and better at capturing attention than the car horn.

Part 3 of the Pilot Study questionnaire asked participants to choose the sound that would best answer each of three questions

(1) "Imagine you are driving and you've taken your eyes off the road, to look down at your radio, for example. As you are looking down, the car in front of you unexpectedly slams on their brakes. Which sound do you feel would best alert you?";

(2) "Imagine that you hear this sound several times a week in your vehicle and many times it does not appear to correspond with any real collision threat (false alarms). Which sound would least annoy you?";

(3) "Which sound, do you feel, would be *best* for alerting drivers to the threat of potential collisions, but not be too annoying during false alarms (situations with no potential collision threat)".

Responses revealed that, across all five sounds, the highest-urgency tone was rated best for attention capture, while the average-urgency tone was the most preferred warning sound for false alarms, again confirming the rankings established by researchers.

Pilot Study participants most frequently chose the car horn as the best at providing a balance between both attributes.

The five warning sounds presented to participants in the Pilot Study were ultimately narrowed to three for the present experiment. Selection was based only on trends and patterns observed in the data, rather than statistical analysis and significance. First, in addition to being the auditory warning used in previous FCW studies, the average-urgency tone represented the lower range of perceived-urgency because it was consistently rated the least annoying, the least startling, and the worst at attention capture. The highest-urgency tone was selected because it provided the greatest contrast to the average-urgency warning. Of all five warning sounds evaluated, it was the one most often matched with the intended meaning of the FCW alert: "If I don't respond within the next few seconds, I will collide with the vehicle in front of my car". The highest-urgency tone also represented the higher range of perceived-urgency because it was consistently rated the most annoying, most startling, and the best at attention capture by Pilot Study participants. Further confirming the use of this sound's classification as a warning with very high perceived-urgency is its use in commercial aircraft as a low-fuel warning.

Finally, the car horn was chosen as the auditory icon for the present study. The car horn and screeching tires were rated similarly throughout the Pilot Study, however, the car horn was selected for the present study because it was more frequently associated with the moments *before* the forward collision becomes imminent, while participants demonstrated a tendency to associate the screeching tires with having *already failed* to avoid the forward collision.

APPENDIX C

PILOT STUDY QUESTIONNAIRE

1. Year in school: (*circle one*)
1st Year Sophomore Junior Senior Other: _____
2. Age: _____ years
3. Gender: (*circle one*) Male Female
4. Do you have a valid U.S. driver's license? (*circle one*) Yes No
5. How many years have you been driving? _____ years

STOP. PLEASE WAIT FOR INSTRUCTIONS.

6. Sound #1

- _____ My car is experiencing mechanical failure.
- _____ There is a vehicle in front of my car.
- _____ I am close to the vehicle in front of my car.
- _____ If I don't respond within the next few seconds,
I will collide with the vehicle in front of my car.
- _____ It is too late to avoid a collision with the vehicle in front of my car.
- _____ I have crashed into the vehicle in front of my vehicle.

7. Sound #2

- _____ My car is experiencing mechanical failure.
- _____ There is a vehicle in front of my car.
- _____ I am close to the vehicle in front of my car.
- _____ If I don't respond within the next few seconds,
I will collide with the vehicle in front of my car.
- _____ It is too late to avoid a collision with the vehicle in front of my car.
- _____ I have crashed into the vehicle in front of my vehicle.

8. Sound #3

- _____ My car is experiencing mechanical failure.
- _____ There is a vehicle in front of my car.
- _____ I am close to the vehicle in front of my car.
- _____ If I don't respond within the next few seconds,
I will collide with the vehicle in front of my car.
- _____ It is too late to avoid a collision with the vehicle in front of my car.
- _____ I have crashed into the vehicle in front of my vehicle.

9. Sound #4

- _____ My car is experiencing mechanical failure.
- _____ There is a vehicle in front of my car.
- _____ I am close to the vehicle in front of my car.
- _____ If I don't respond within the next few seconds,
I will collide with the vehicle in front of my car.
- _____ It is too late to avoid a collision with the vehicle in front of my car.
- _____ I have crashed into the vehicle in front of my vehicle.

10. Sound #5

- _____ My car is experiencing mechanical failure.
- _____ There is a vehicle in front of my car.
- _____ I am close to the vehicle in front of my car.
- _____ If I don't respond within the next few seconds,
I will collide with the vehicle in front of my car.
- _____ It is too late to avoid a collision with the vehicle in front of my car.
- _____ I have crashed into the vehicle in front of my vehicle.

STOP. PLEASE WAIT FOR INSTRUCTIONS.

Rank the 5 sounds that you just heard according to the following properties:

11. Rank the sounds from most to least **ANNOYING**:

(1 = most annoying, 5 = least annoying)

- _____ Sound #1
- _____ Sound #2
- _____ Sound #3
- _____ Sound #4
- _____ Sound #5

12. Rank the sounds from most to least **STARTLING**:

(1 = most startling, 5 = least startling)

- _____ Sound #1
- _____ Sound #2
- _____ Sound #3
- _____ Sound #4
- _____ Sound #5

13. Rank the sounds from the best to the worst at **CAPTURING YOUR ATTENTION**:

(1 = best, 5 = worst)

- _____ Sound #1
- _____ Sound #2
- _____ Sound #3
- _____ Sound #4
- _____ Sound #5

GO TO NEXT PAGE.

14. Imagine you are driving and you've taken your eyes off the road, to look down at your radio for example. As you are looking down, the car in front of you unexpectedly slams on their brakes! Which sound do you feel would **best alert** you?

- _____ Sound #1
- _____ Sound #2
- _____ Sound #3
- _____ Sound #4
- _____ Sound #5

15. Imagine that you hear this sound several times a week in your vehicle and many times it does **not** appear to correspond with any real collision threat (false alarms). Which sound would **least annoy** you?

- _____ Sound #1
- _____ Sound #2
- _____ Sound #3
- _____ Sound #4
- _____ Sound #5

16. Which sound, do you feel, would be best for **alerting** drivers to the threat of potential collisions, **but** not be too **annoying** during false alarms (situations with no potential collision threat).

- _____ Sound #1
- _____ Sound #2
- _____ Sound #3
- _____ Sound #4
- _____ Sound #5

THANK-YOU!

APPENDIX D

PILOT STUDY RESULTS

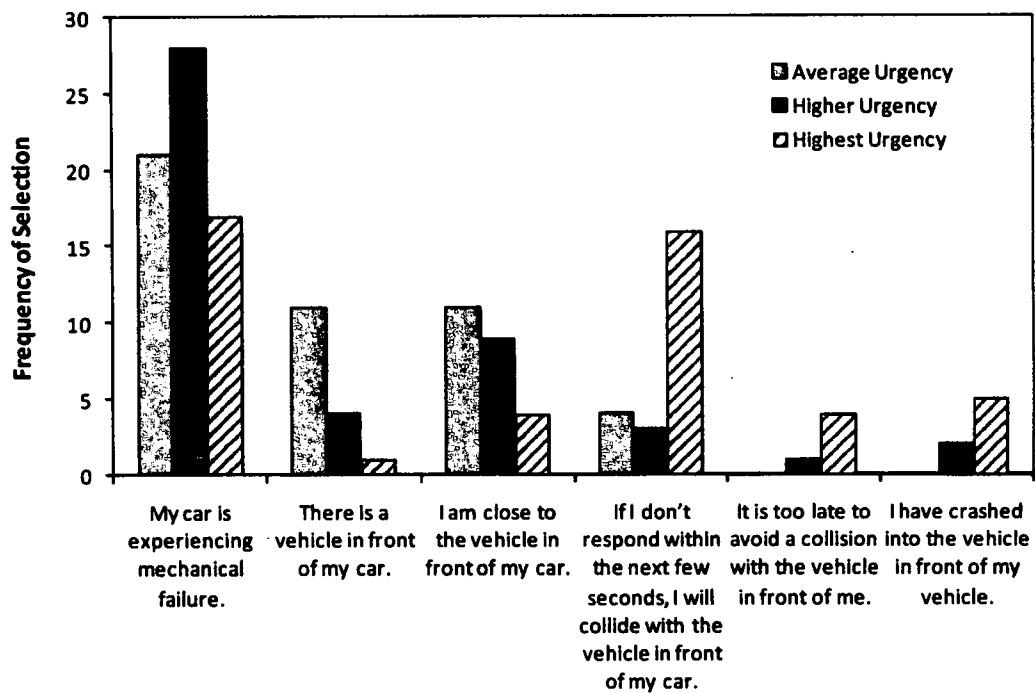


Figure D-1. Pilot Study Tonal Warnings: "Which meaning best reflects the sound you just heard?"

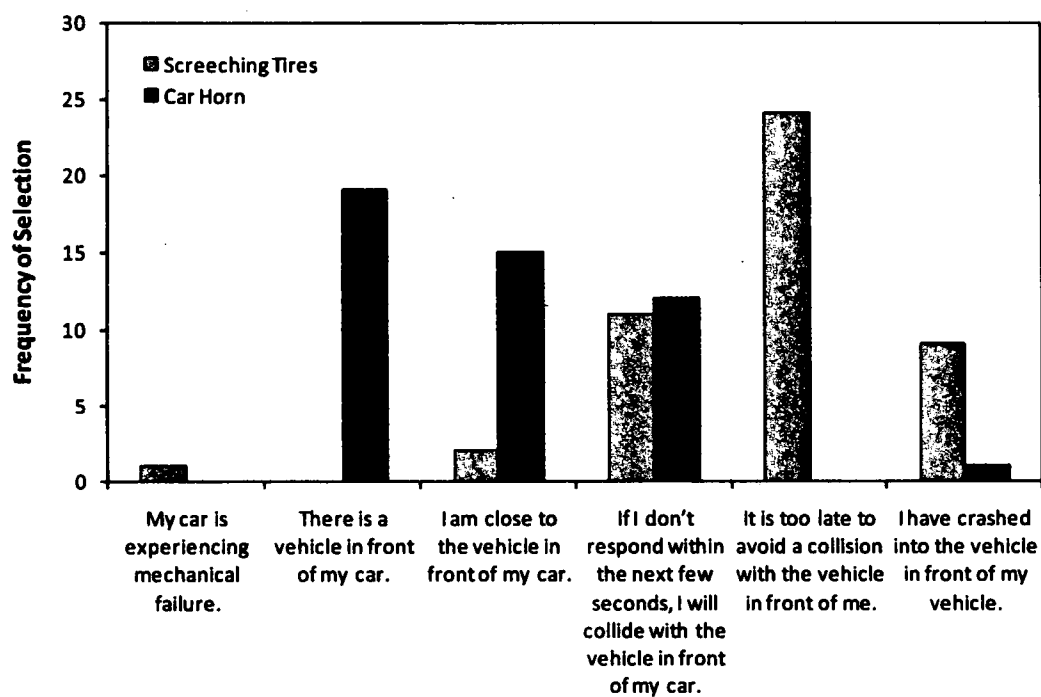


Figure D-2. Pilot Study Auditory Icons: "Which meaning best reflects the sound you just heard?"

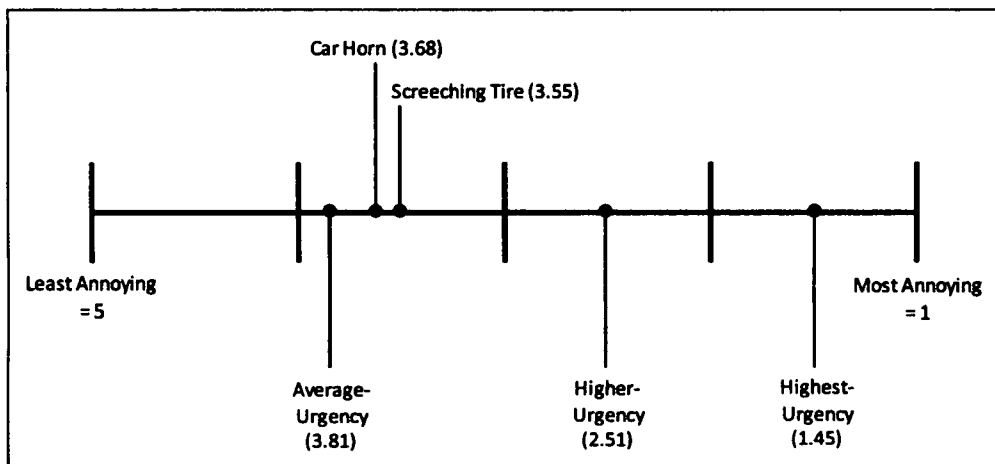


Figure D-3. Pilot Study: Mean rank of five auditory warning sounds by "annoyance".

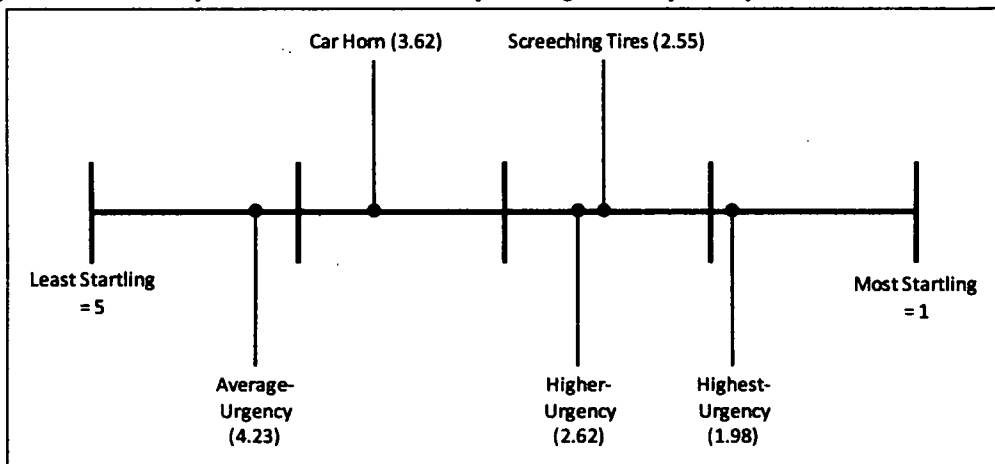


Figure D-4. Pilot Study: Mean rank of five auditory warning sounds by "startle".

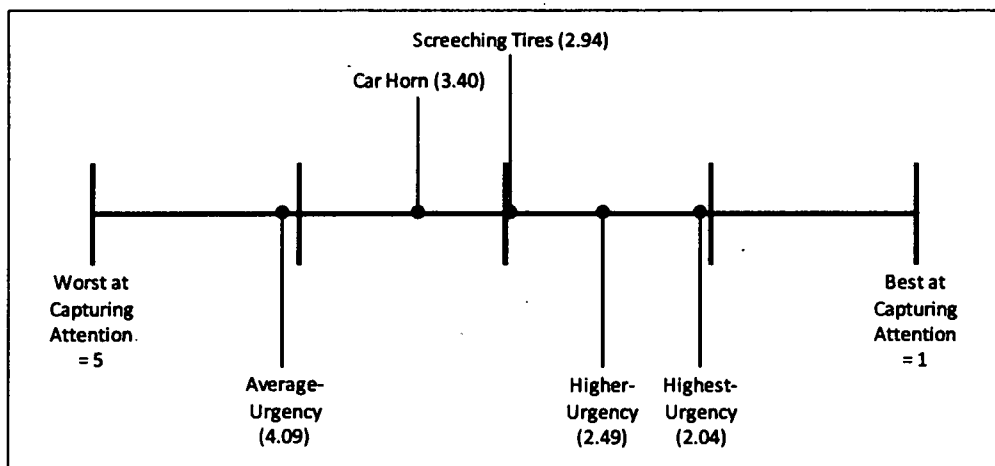


Figure D-5. Pilot Study: Mean rank of five auditory warning sounds by "attention capture".

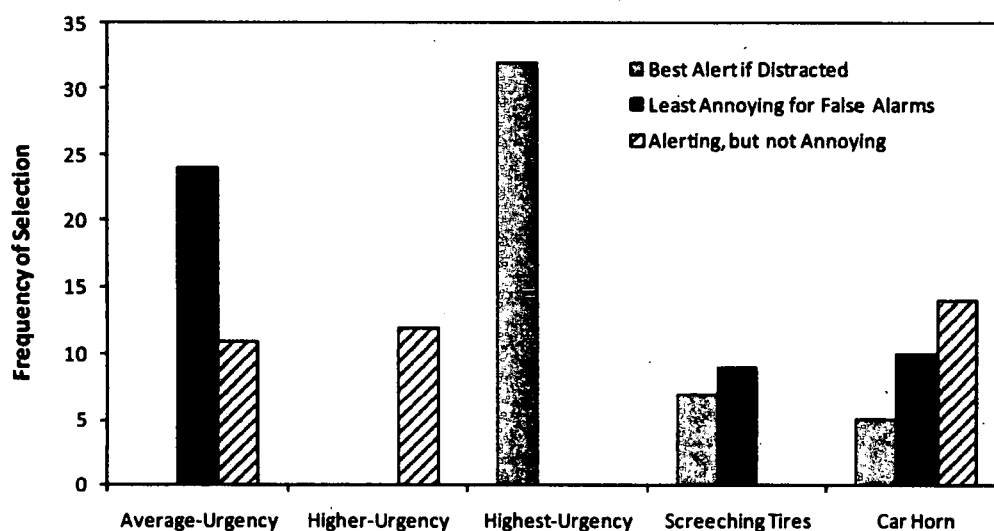


Figure D-6. Pilot study: Best for distracted, false alarms, and alert-annoyance balance.

a. "Imagine you are driving and you've taken your eyes off the road, to look down at your radio. As you are looking down, the car in front of you unexpectedly slams on their brakes! Which sound do you feel would best alert you?" b. "Imagine that you hear this sound several times a week in your vehicle and many times it does not appear to correspond with any real collision threat (false alarms). Which sound would least annoy you?" c. "Which sound, do you feel, would be best for alerting drivers to the threat of potential collisions, but not be too annoying during false alarms (situations with no potential collision threat)?"

APPENDIX E

DELPHI STUDY INVITATION

Delphi Advanced Engineering Research needs your participation in a 45-minute driving-simulator study at the Delphi Kokomo campus. If you are willing to participate, you will earn a \$30 Best Buy gift certificate.

You have been randomly selected for a human factors study from the e-mail database of all Kokomo-based Delphi employees, to investigate the effects of driver distraction in a driving simulator setting at the Kokomo Campus. This study will benefit Delphi by providing experimental data that will answer some important questions about the products that we are developing. The study will last for approximately ½ hour and you will be paid with a \$30 gift card from Best Buy. Please contact Debi Bakowski (debi.bakowski@delphi.com) if you have any questions and let her know if you are willing to participate. If you are willing to participate, please fill out the attached Participant Screening Form return it by email.

To be eligible for this study, you must:

- Have a valid U.S. driving license.
- Be 35-55 years old.
- Have normal or corrected-to-normal vision (e.g., glasses, contacts).
(You must bring your glasses or contacts).
- Not be pregnant.
- Not be prone to motion sickness, vertigo, claustrophobia, or chronic migraines.
- Not consume alcohol or driving-impairing drugs before driving.

APPENDIX F

PARTICIPANT SCREENING QUESTIONNAIRE

Participant Screening Questionnaire Study: SAVE-IT Task 9 – Driver Distraction

1. What is your age? _____ years
2. What is your gender? Male Female
3. Are you an engineer? Yes No
4. Do you possess a valid U.S. driver's license? Yes No
If yes, which state is the license issued in? _____ Indiana _____ Other, list: _____
5. How many years have you been driving? _____ years
6. How many miles do you drive per year? _____ miles
7. What vehicle do you drive most often? Year:
Make:
Model:
8. Do you have normal or corrected-to-normal vision (e.g., glasses, contacts)? Yes No
9. What vision correction do you use when driving?
No-correction Contacts Glasses (e.g., bifocals, reading, far-vision)
10. What vision correction do you use when reading?
No-correction Contacts Glasses (e.g., bifocals, reading, far-vision)
11. Can you agree not to take alcohol or driving-impairing drugs (e.g., allergy, cold medicine) for at least 4
hours before participating in the study? Yes No

12. Have you ever participated in an experiment involving a driving simulator?

Yes No If yes, please describe:

13. Have you had any previous experience with Forward Collision or Lane Departure Warning Systems?

Yes No If yes, please describe:

This study will require you to drive in a simulator. In the past, some participants have felt uncomfortable after participating in studies using the simulator. To identify people who might be prone to simulator discomfort, we would like to ask the following questions:

14. Do you have or have you had a history of migraine headaches or vertigo? Yes No

If yes, please describe:

15. Do you have or have you had a history of claustrophobia? Yes No

If yes, please describe:

16. Do you have or have you had a history of motion sickness? Yes No

If yes, please describe:

17. Are you or is there a possibility that you might be pregnant? Yes No

Name:

Phone #:

Preferred times and days to participate:

APPENDIX G

PARTICIPANT INFORMATION

Table G-1

Participants' Mean Age and SD

	FCW System Training			
	No-Training		Training	
Auditory Warning	Mean	SD	Mean	SD
HUD + No-Auditory Warning	45.9	7.56	40.7	6.50
HUD + Average-Urgency	46.0	6.50	45.1	8.94
HUD + Highest-Urgency	49.8	4.54	44.3	7.63
HUD + Car Horn	45.7	8.29	42.8	8.98

Note. Means and SD reflect only those participants included in the final analysis.

Table G-2

Participants' Mean Years of Driving Experience and SD

	FCW System Training			
	No-Training		Training	
Auditory Warning	Mean	SD	Mean	SD
HUD + No-Auditory Warning	29.4	8.5	24.0	6.1
HUD + Average-Urgency	30.7	6.8	28.1	9.4
HUD + Highest-Urgency	33.7	4.5	28.3	7.6
HUD + Car Horn	29.9	8.1	26.9	8.3

Note. Means and SD reflect only those participants included in the final analysis.

Table G-3

Participants' Mean Miles Driven per Year and SD

	FCW System Training			
	No-Training		Training	
Auditory Warning	Mean	SD	Mean	SD
HUD + No-Auditory Warning	16,650	6,000	12,556	6,821
HUD + Average-Urgency	17,444	5,790	18,900	7,279
HUD + Highest-Urgency	14,350	6,455	20,833	15,788
HUD + Car Horn	13,111	3,822	20,167	9,899

Note. Means and SD reflect only those participants included in the final analysis.

APPENDIX H

UNIVERSITY OF DAYTON INFORMED CONSENT

Informed Consent (University of Dayton)

Project Title:	Driving Performance and In-Vehicle Information
Investigator(s):	Deborah Bakowski, University of Dayton Dr. Susan Davis, University of Dayton (Thesis Committee) Dr. William Moroney, University of Dayton (Thesis Committee)
Description of Study:	This study is designed to investigate how roadside and in-vehicle visual information affect driver's driving performance. This experiment will be done in a driving simulator at the Delphi Electronics and Safety Systems Human Factors Laboratory in Kokomo, Indiana. The experiment will last for approximately 45 minutes, including set up time, driving, and filling out a questionnaire. In each drive/block, you may follow a lead- vehicle and in the meantime be prompted to read text on roadside signs or on a computer screen near where a radio would normally be. As in real-world driving, traffic conditions may change, and you should react to the changes and maintain good speed and lane position as if you were in a real car. The drives will end upon arrival at the instructed destination.
Adverse Effects and Risks:	Participants may experience some symptoms of "simulator discomfort," which feel similar to motion sickness. Symptoms vary, but can range from general discomfort to headache or nausea. Participants are instructed to stop, inform the researcher immediately upon any feeling of discomfort, and may withdraw. Participants who withdraw will receive the \$30 Best Buy gift certificate.
Duration of Study:	It will take approximately 30 minutes to set-up and complete the drives in the simulator and another 15 minutes to complete the Questionnaire.
Confidentiality of Data:	Results of this experiment will be used by the Delphi Electronics and Safety Systems Human Factors Laboratory and in a master's thesis at the University of Dayton. The results of this research study may be presented at meetings or in publications and video images may be used. Your identity will not be disclosed in those presentations or in the course of completing the thesis.

Contact Persons:

If a participant has questions about the study, he/she should contact:

Deborah Bakowski (primary researcher)
University of Dayton Graduate Student
300 College Park, Dept. 1430, Dayton, OH 45469
debi.bakowski@delphi.com or bakowsdl@notes.udayton.edu
301-442-9648 (cell)

Dr. Susan Davis
Assistant Professor
Department of Psychology, University of Dayton, SJ327
300 College Park, Dept. 1430, Dayton, OH 45469
susan.davis@notes.udayton.edu
937.229.1345

If a participant has ethical concerns about the study, he/she should contact:

Dr. Charles E. Kimble
Chair, Research Review and Ethics Committee
Professor, Department of Psychology, University of Dayton, SJ319
300 College Park, Dept. 1430, Dayton, OH 45469
charles.kimble@notes.udayton.edu
937.229.2167

Consent to Participate:

I have voluntarily decided to participate in this study. The investigator named above has adequately answered any and all questions I have about this study, the procedures involved, and my participation. I understand that the investigator named above will be available to answer any questions about research procedures throughout this study. I also understand that I may voluntarily terminate my participation in this study at any time and still receive the \$30 Best Buy gift certificate. I also understand that the investigator named above may terminate my participation in this study if he/she feels this to be in my best interest. In addition, I certify that I am 18 (eighteen) years of age or older.

Signature

Name (printed clearly)

Date ____/____/ 06

Signature of Witness

Date ____/____/ 06

APPENDIX I

DELPHI INFORMED CONSENT

RESEARCH SUBJECT INFORMATION AND CONSENT FORM (Delphi)

Title: SAVE-IT Task 7 - Effects of Visual Distraction on Driving Performance

Protocol No.: WIRB® 20030835

Sponsor: Delphi Delco Electronic Systems
Kokomo, IN 46904

Investigator: Matthew Smith, Ph.D.
Delphi Delco Electronic Systems
World Headquarters, M/C E110
1800 East Lincoln
Kokomo, IN 46904
(765) 451-9816 (24 hours)

Site: Delphi Delco Electronic Systems
World Headquarters, M/C E110
1800 East Lincoln
Kokomo, IN 46904-9005

This consent form may contain words that you do not understand. Please ask the study doctor or the study staff to explain any words or information that you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

Purpose: You are being asked to participate in a research study. This study is designed to investigate how roadside and in-vehicle visual information affects driver's sight and driving performance.

Design and Procedure: This experiment will be done in a driving simulator at the Delphi Human Factors Laboratory. The experiment will last for approximately 30 minutes, including set up time, two drives, and filling out a questionnaire. In each drive/block, you may follow a lead-vehicle and in the meantime be prompted to read aloud text on roadside signs or on a computer screen near where a radio would normally be. As in real-world driving, traffic conditions may change, and you should react to the changes and maintain good speed and lane position as if you were in a real car.

Subject Screening: You must have a valid driver's license, normal or corrected-to-normal vision, and have not consumed alcohol or driving-impairing drugs before participating. You must not be pregnant, and not prone to motion sickness, dizziness, feeling nervous in small spaces, or chronic migraines.

Benefits: There is no guarantee that you will receive any benefits from being in this study.

Risks: You may experience some symptoms of "simulator discomfort," which feels similar to motion sickness. Symptoms vary, but can range from general discomfort to headache or nausea. Tell the study staff if you feel uncomfortable.

The risks to an embryo, fetus, or infant from exposure to the study are unknown. Pregnant women may not participate.

Payment for Participation: You will receive a \$30.00 Best Buy gift card for participating.

Alternatives: This is not a treatment study. Your alternative is not to participate in this study.

Voluntary Participation/Withdrawal: You can withdraw from the study without penalty or loss of benefits to which you are otherwise entitled at this site, at any time during the experiment. The study doctor or sponsor may also end your participation in the study without your consent and without loss of benefits to you.

Confidentiality: Information from this study will be given to the sponsor. "Sponsor" includes any persons or companies which are contracted by the sponsor to have access to the research information during and after the study.

The information will also be given to the U.S. Food and Drug Administration (FDA). It may be given to governmental agencies in other countries where the study drug may be considered for approval. Medical records which identify you and the consent form signed by you will be looked at and/or copied for research or regulatory purposes by:

- the sponsor;

and may be looked at and/or copied for research or regulatory purposes by:

- the Western Institutional Review Board® (WIRB®).

Absolute confidentiality cannot be guaranteed because of the need to give information to these parties. The results of this research study may be presented at meetings or in publications and video images may be used. Your identity will not be disclosed in those presentations.

Source of Funding: Funding for this research study will be provided by Delphi Delco Electronic Systems.

Questions: If you have any question about this experiment or if you feel you have experienced a research-related injury, contact Dr. Matthew Smith, at (317) 451-9816 (24 hours), matt.smith@delphi.com.

If you have questions about your rights as a research subject, you may contact:

Western Institutional Review Board® (WIRB®)
3535 Seventh Avenue, SW
Olympia, Washington 98502
Telephone: 1-800-562-4789.

WIRB is a group of people who perform independent review of research.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

If you agree to participate in this study, you will receive a signed and dated copy of this consent form for your records.

Consent: I have read the information in this consent form. All my questions about the study and my participation in it have been answered. I freely consent to participate in this research study.

I authorize the release of my research records, including video images, for research or regulatory purposes to the sponsor and WIRB®.

By signing this consent form, I have not waived any of the legal rights which I otherwise would have as a subject in a research study.

Videotaping Permission: By signing herein, I specifically agree to be videotaped and understand that selected segments may be shown at presentations or publications to explain the results.

Subject's Signature for Videotaping Permission: _____

Participant's Name
(Printed) (18 years or older)

Participant's Signature

____/____/06
Date

Person Conducting Informed
Consent Discussion's Name
(Printed)

Person Conducting Informed
Consent Discussion's Signature

____/____/06
Date

Investigator's Name (Printed)
(if different from above)

Investigator's Signature

____/____/06
Date

APPENDIX J

SIMULATOR PHOTOGRAPHS

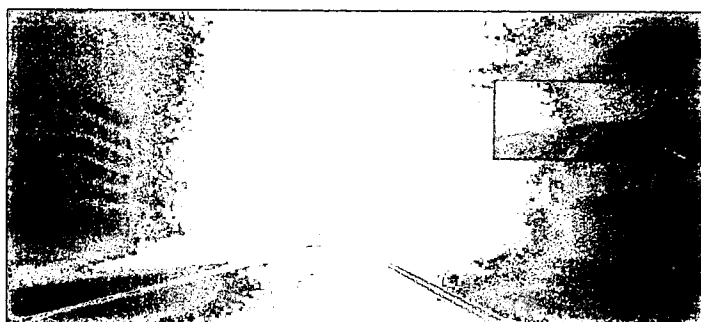


Figure J-1. Driving Simulator 1: Forward scene, from the host vehicle perspective.

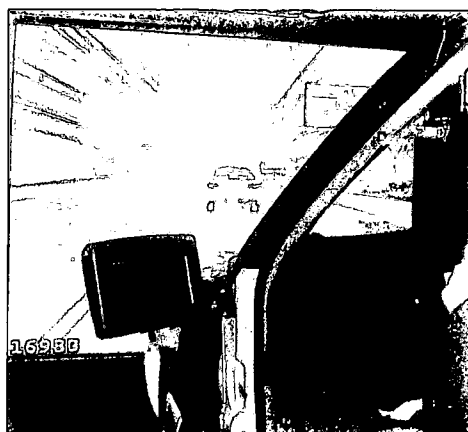


Figure J-2. Driving Simulator 2: Forward scene and vehicle. (Side-view mirror not used.)



Figure J-3. Driving Simulator 3: Console monitor with scrolling text in lower right corner.

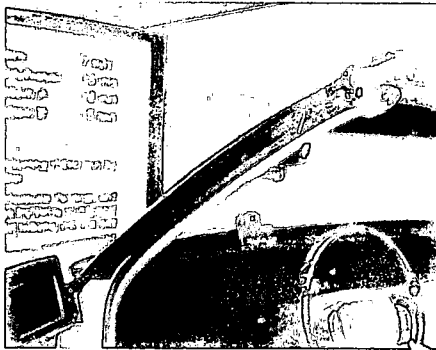


Figure J-4. Driving Simulator 4: Vehicle and forward screen .

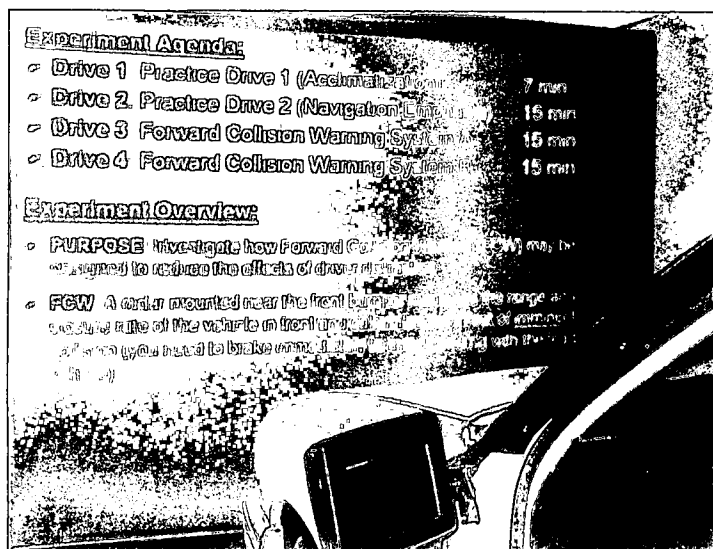
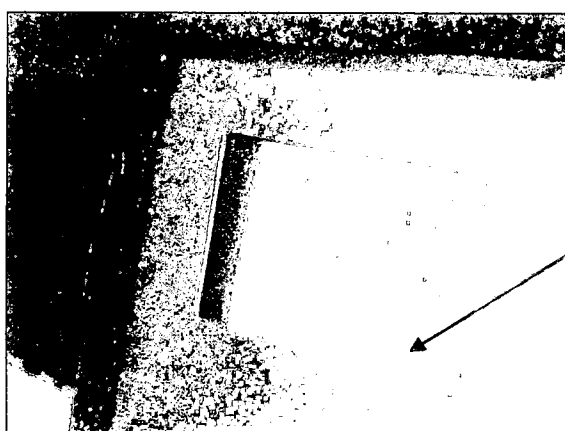


Figure J-5. Driving Simulator 5: Instruction slide (FCW training condition).



Scrolling Text

Figure J-6. Driving Simulator 6: Console monitor and scrolling (right to left) text area.

APPENDIX K

FCW QUESTIONNAIRE

Instructions: please circle your answer.	Participant # _____				
 1. I EXPECTED the vehicle in front of me to brake hard during my last drive. <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"><tr><td style="text-align: center; padding: 2px 10px;">Strongly Disagree</td><td style="text-align: center; padding: 2px 10px;">Somewhat Disagree</td><td style="text-align: center; padding: 2px 10px;">Somewhat Agree</td><td style="text-align: center; padding: 2px 10px;">Strongly Agree</td></tr></table>		Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree		
 2. I was SURPRISED when the vehicle in front of me braked hard during my last drive. <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"><tr><td style="text-align: center; padding: 2px 10px;">Strongly Disagree</td><td style="text-align: center; padding: 2px 10px;">Somewhat Disagree</td><td style="text-align: center; padding: 2px 10px;">Somewhat Agree</td><td style="text-align: center; padding: 2px 10px;">Strongly Agree</td></tr></table>		Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree		
 3. Some participants were not presented with an audio warning during the last drive. Did the system present you with an AUDIO warning when the car in front of you braked hard during the last drive? YES (Go to Question #4) NO (Stop, this questionnaire is complete)					
 4. Consider the audio warning sound that you heard. Which MEANING does that sound best reflect? Rank order (1-6); best = 1, worst = 6 ____ My vehicle is experiencing mechanical failure. ____ There is a vehicle in front of my car. ____ I am close to the vehicle in front of my car. ____ If I don't respond within the next few seconds, I will collide with the vehicle in front of my car. ____ It is too late to avoid a collision with the vehicle in front of my car. ____ I have crashed into the vehicle in front of my car.					

5. When the car in front of me braked hard during the last drive, the system presented an audio warning that was **UNDERSTANDABLE**.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

6. The audio warning was **USEFUL** for enhancing safety.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

7. The audio warning captured my **ATTENTION**.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

8. The audio warning **STARTLED** me.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

9. Did you collide with the vehicle in front of you?

YES (Go to Question #10)

NO (Go to Question #11)

10. The audio warning helped me to reduce the **SEVERITY** of the collision.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

(Go to Question #12)

11. The audio warning helped me to **AVOID** the collision.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

(Go to Question #12)

12. The audio warning would be **USEFUL** on real roadways for enhancing safety.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

13. If it were priced reasonably, I would recommend a Forward Collision Warning System like this one.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

14. The audio warning is likely to be **ANNOYING** on real roadways if I experience it several times a week and it often does not correspond to a real threat in the environment.

Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
-------------------	-------------------	----------------	----------------

APPENDIX L

SCROLLING TEXT MESSAGES PRESENTED TO DRIVER

In-vehicle scrolling text presented on the console monitor, in order of presentation:

“Pay close attention for instructions appearing in this scrolling window. On this first practice drive you will follow the white sedan down the highway to the Global Sim headquarters. The white sedan will lead you there so make sure you follow it. Follow the instructions you receive from this scrolling text as accurately as you can. When you are ready, depress the GAS pedal.”

“SPEED UP to 65 mph while following the white sedan. Maintain 65 mph.”

“When you get to the next intersection, take the west (2nd) highway EXIT.”

“Follow the white sedan and EXIT the highway.”

“CHANGE LANES LEFT to stay behind the white sedan. Continue following the white sedan.”

"TURN RIGHT at the white Global Sim sign."

"TURN RIGHT."

"PARK next to the red SUV and the drive will end."

"Drive 1 is complete. The next drive is also practice but will have a greater emphasis on navigation, so pay close attention for important instructions. Like the last practice, you will also start by following the white sedan. However, early on you will be given additional navigation instructions. Follow the white sedan until explicitly instructed otherwise. Follow the instructions as accurately as possible. Depress the GAS pedal to begin."

"MAINTAIN 65 mph as closely as possible."

"Don't worry if you crashed-- many people do. The last drive was not just practice. We told you it was to try to manage your expectations because in FCW experiments in driving simulators, people often expect braking events. Please don't tell anyone else about the braking event at the end in case they may run in a similar experiment. The previous drive was actually the final drive. When you complete the questionnaire, it will complete this experiment. Thanks for your participation."

APPENDIX M

UNIVERSITY OF DAYTON DEBRIEFING

DEBRIEFING FORM GUIDELINES (University of Dayton)

Information about the Study

This study was designed to investigate how 1) roadside and in-vehicle visual information and 2) Forward Collision Warning (FCW) audio warning type effects drivers' response to an unexpected imminent braking situation. The purpose of the scrolling text on the console screen is to study the effects of visual distraction. Different audio warning types were also used and were compared with using no warning. Reaction time and collision velocity (if applicable) were measured. The purpose of the FCW Questionnaire was to assess expectation and surprise with the imminent braking situation and to compare aspects such as understandability, usefulness, and annoyance between warning sounds.

This research is sponsored by the U.S. Department of Transportation's Research and Innovative Technology Administration. This multi-year research program, called SAFETY VEHICLES using adaptive Interface Technology (SAVE-IT), is lead by Delphi Electronics and Safety Systems in Kokomo, IN, in conjunction with the University of Iowa, the University of Michigan Transportation Research Institute, General Motors, and the Ford Motor Company. The goal of the SAVE-IT research program is to reduce distraction-related crashes by enhancing the effectiveness of safety warning countermeasures, such as FCW and Lane Departure Warning systems. This specific experiment serves to examine several different types of forward collision auditory warning signals in order to optimize driver response and reaction time to imminent braking events, those events in which if the driver does respond immediately, a collision will occur. The effectiveness of the warning system is measured in the simulator environment by how quickly drivers release the accelerator, how quickly drivers press the brake, and the car's speed at impact, if applicable. This experiment will contribute to designing the most optimal warning system for reducing distraction-related rear-end collisions.

Deception

As you read in the scrolling text message at the end of your second drive, the last drive was not merely practice. We told you that it was to try to manage your expectations because in FCW experiments in driving simulators, people often expect braking events. The deception used here was to make drivers believe they are completing a second practice drive and to decrease any expectation that the vehicle they are following will brake suddenly. Drivers were told that the second drive would end when they reach a specific destination. In fact, the drive ended when the lead-vehicle braked and created an imminent braking situation for the participant. The purpose of this was to achieve your most spontaneous and natural braking reaction. Please don't tell anyone else about the braking event that you experienced at the end of your drive as this experiment is ongoing.

References

- Smith, M., & Zhang, H. (2004). SAFETY VEHICLES using adaptive Interface Technology (Task 9): A Literature Review of Safety Warning Countermeasures. *SAVE-IT*.
http://www.volpe.dot.gov/hf/roadway/saveit/docs/dec04/litrev_9a.pdf
- Lee, J. D., McGehee, D. V., Brown, T. L., & Reyes, M. L. (2002). Collision Warning Timing, Driver Distraction, and Driver Response to Imminent Rear-End Collisions in a High-Fidelity Driving Simulator. *Human Factors*, 44, 314-334.

Assurance of Privacy

Results of this experiment will be used by the Delphi Electronics and Safety Systems Human Factors Laboratory and in a master's thesis at the University of Dayton. The results of this research study may be presented at meetings or in publications and video images may be used. Your identity will not be disclosed in those presentations or in the course of completing the thesis.

Contact Information

If you have questions about the study, please contact:

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If you have ethical concerns about the study, please contact:

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937.229.2167

Thank you for your participation.

APPENDIX N

PARTICIPANTS REPLACED DURING EXPERIMENT

Table N-1

Participants Replaced During Experiment

Replacement Cause	Men	Women	Total
Simulator Sickness	4	11	15
Failure to Follow Simulator-Operating Instructions	2	1	3
Accelerator Pedal Not Depressed (no ART)	2	0	2
Brake Pedal Not Depressed (no BRT)	0	1	1
Visually Attentive (not looking at console)	1	4	5
Speeding (>70 mph)	1	1	2
<i>Total Replaced</i>	10	18	28

APPENDIX O

QUALITATIVE RESULTS

1. I EXPECTED the vehicle in front of me to brake hard during my last drive.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Female				Male				Total				
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	
Female	8	1	1	0	2	3	2	2	10	4	3	2	
Mean	1.3		Median	1.0	Mode	1	Mean	2.4		Median	2.0	Mode	2
	n = 10				n = 9				n = 19				
Male	6	2	1	0	4	2	3	1	10	4	4	1	
Mean	1.4		Median	1.0	Mode	1	Mean	2.1		Median	2.0	Mode	1
	n = 9				n = 10				n = 19				
Major	7	1	1	0	5	1	3	0	12	2	4	0	
Mean	1.3		Median	1.0	Mode	1	Mean	1.8		Median	1.0	Mode	1
	n = 9				n = 9				n = 18				
Major - Car	6	2	0	2	5	2	2	0	11	4	2	2	
Mean	1.8		Median	1.0	Mode	1	Mean	1.7		Median	1.0	Mode	1
	n = 10				n = 9				n = 19				
Total and Grand	27	6	3	2	16	8	10	3	43	14	13	5	
Mean	1.5		Median	1.0	Mode	1	Mean	2.0		Median	2.0	Mode	1
	n = 38				n = 37				n = 75				

Table O-1. Number of respondents and descriptive statistics for the statement: "I EXPECTED the vehicle in front of me to brake hard during my last drive".

2. I was **SURPRISED** when the vehicle in front of me braked hard during my last drive.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Female - High School				Female - College				Male - College			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
Female - High School	0	0	3	7	1	1	5	2	1	1	8	9
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.7	4.0	4		2.9	3.0	3		3.3	3.0	4	
	n = 10				n = 9				n = 19			
Female - Associate's Degree	0	0	3	6	0	2	5	3	0	2	8	9
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.7	4.0	4		3.1	3.0	3		3.4	3.0	4	
	n = 9				n = 10				n = 19			
Female - Bachelor's Degree	0	0	0	9	0	0	3	6	0	0	3	15
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	4.0	4.0	4		3.7	4.0	4		3.8	4.0	4	
	n = 9				n = 9				n = 18			
Male - High School	0	1	2	7	0	2	3	4	0	3	5	11
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.6	4.0	4		3.2	3.0	4		3.4	4.0	4	
	n = 10				n = 9				n = 19			
Male - Associate's Degree	0	1	8	29	1	5	16	15	1	6	24	44
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.7	4.0	4		3.2	3.0	3		3.5	4.0	4	
	n = 38				n = 37				n = 75			

Table O-2. Number of respondents and descriptive statistics for the statement: "I was **SURPRISED** when the vehicle in front of me braked hard during my last drive".

4. Consider the audio warning sound that you heard. Which **MEANING** does that sound best reflect?

Rank order (1-6); best = 1, worst = 6

- ☐ My vehicle is experiencing mechanical failure.
☐ There is a vehicle in front of my car.
☐ I am close to the vehicle in front of my car.
☐ If I don't respond within the next few seconds, I will collide with the vehicle in front of my car.
☐ It is too late to avoid a collision with the vehicle in front of my car.
☐ I have crashed into the vehicle in front of my car.

	Meaning 1	Meaning 2	Meaning 3
Mean Rank	Not Applicable	Not Applicable	Not Applicable
Mean Rank	Mean Rank 2.2 Close to vehicle in front. 2.6 Respond, or collide. 3.0 There is a vehicle in front. 3.7 Too late to avoid collision. 4.7 Mechanical failure. 4.9 I have crashed. n = 9	Mean Rank 2.3 Respond, or collide. 2.6 Close to vehicle in front. 3.0 There is a vehicle in front. 3.6 Too late to avoid collision. 4.3 I have crashed. 4.4 Mechanical failure. n = 9	Mean Rank 2.4 Close to vehicle in front. 2.4 Respond, or collide. 3.0 There is a vehicle in front. 3.6 Too late to avoid collision. 4.6 Mechanical failure. 4.6 I have crashed. n = 18
Mean Rank	Mean Rank 1.6 Respond, or collide. 2.6 Close to vehicle in front. 3.6 Too late to avoid collision. 4.0 There is a vehicle in front. 4.1 Mechanical failure. 5.3 I have crashed. n = 7	Mean Rank 1.8 Respond, or collide. 2.2 Close to vehicle in front. 3.6 Too late to avoid collision. 4.0 There is a vehicle in front. 4.6 Mechanical failure. 4.9 I have crashed. n = 9	Mean Rank 1.7 Respond, or collide. 2.4 Close to vehicle in front. 3.6 Too late to avoid collision. 4.0 There is a vehicle in front. 4.4 Mechanical failure. 5.1 I have crashed. n = 16
Mean Rank	Mean Rank 1.6 Respond, or collide. 2.0 Close to vehicle in front. 3.0 There is a vehicle in front. 3.6 Too late to avoid collision. 4.3 I have crashed. 5.4 Mechanical failure. n = 8	Mean Rank 1.6 Respond, or collide. 1.9 Close to vehicle in front. 3.2 There is a vehicle in front. 3.9 Too late to avoid collision. 4.3 I have crashed. 5.9 Mechanical failure. n = 9	Mean Rank 1.6 Respond, or collide. 1.9 Close to vehicle in front. 3.1 There is a vehicle in front. 3.8 Too late to avoid collision. 4.3 I have crashed. 5.6 Mechanical failure. n = 17
Mean Rank	Mean Rank 2.0 Respond, or collide. 2.3 Close to vehicle in front. 3.3 There is a vehicle in front. 3.6 Too late to avoid collision. 4.8 Mechanical failure. 4.8 I have crashed. n = 24	Mean Rank 1.9 Respond, or collide. 2.2 Close to vehicle in front. 3.4 There is a vehicle in front. 3.7 Too late to avoid collision. 4.5 I have crashed. 5.0 Mechanical failure. n = 27	Mean Rank 1.9 Respond, or collide. 2.2 Close to vehicle in front. 3.4 There is a vehicle in front. 3.6 Too late to avoid collision. 4.6 I have crashed. 4.9 Mechanical failure. n = 51

Table O-3. Number of respondents and descriptive statistics mean rank for responses to the question: "Which meaning does that sound best reflect?"

Of the 56 participants who received an auditory warning (Average Urgency, Highest Urgency, or Car Horn), 52 of those participants recalled receiving the auditory warning. Their data are below.

5. When the car in front of me braked hard during the last drive, the system presented an audio warning that was **UNDERSTANDABLE**.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Strongly Disagree				Somewhat Disagree				Somewhat Agree				Strongly Agree			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
Not Applicable	Not Applicable				Not Applicable				Not Applicable				Not Applicable			
Mean	0	5	1	3	4	3	1	1	4	8	2	4	2.3	2.0	2	2
Median	2.8	2.0	2		1.9	2.0	1		2.3	2.0	2		2.3	2.0	2	
Mode																
n	n = 9				n = 9				n = 18							
Mean	1	5	2	0	0	0	2	7	1	5	4	7	3.0	3.0	4	4
Median	2.1	2.0	2		3.8	4.0	4		3.0	3.0	4		3.0	3.0	4	
Mode																
n	n = 8				n = 9				n = 17							
Mean	2	2	1	3	0	1	3	5	2	3	4	8	3.1	3.0	4	4
Median	2.6	2.5	4		3.4	4.0	4		3.1	3.0	4		3.1	3.0	4	
Mode																
n	n = 8				n = 9				n = 17							
Mean	3	12	4	6	4	4	6	13	7	16	10	19	2.8	3.0	4	4
Median	2.5	2.0	2		3.0	3.0	4		2.8	3.0	4		2.8	3.0	4	
Mode																
n	n = 25				n = 27				n = 52							

Table O-4. Number of respondents and descriptive statistics for the statement: "When the car in front of me braked hard during the last drive, the system presented an audio warning that was **UNDERSTANDABLE**".

6. The audio warning was **USEFUL** for enhancing safety.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	No. Respondents				Percentages				Percentages and Means			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
Overall	0	0	6	3	4	2	1	2	4	2	7	5
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.3	3.0	3		2.1	2.0	1		2.7	3.0	3	
	n = 9				n = 9				n = 18			
Female	1	0	6	1	0	0	0	9	1	0	6	10
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	2.9	3.0	3		4.0	4.0	4		3.5	4.0	4	
	n = 8				n = 9				n = 17			
Male	1	0	4	3	0	0	4	5	1	0	8	8
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.1	3.0	3		3.6	4.0	4		3.4	3.0	3	
	n = 8				n = 9				n = 17			
Younger than 40 years	2	0	16	7	4	2	5	16	6	2	21	23
	Mean	Median	Mode		Mean	Median	Mode		Mean	Median	Mode	
	3.1	3.0	3		3.2	4.0	4		3.2	3.0	4	
	n = 25				n = 27				n = 52			

Table O-5. Number of respondents and descriptive statistics for the statement: "The audio system was **USEFUL** for enhancing safety".

7. The audio warning captured my ATTENTION.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Strongly Disagree				Somewhat Disagree				Somewhat Agree				Strongly Agree			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
Not Applicable	Not Applicable				Not Applicable				Not Applicable				Not Applicable			
Mean	0	0	2	7	0	1	3	5	0	1	5	12	0	1	5	12
Median	3.8	4.0	4		3.4	4.0	4		3.6	4.0	4		3.6	4.0	4	
Mode	n = 9				n = 9				n = 18				n = 18			
Mean	0	0	1	7	0	0	0	9	0	0	1	16	0	0	1	16
Median	3.9	4.0	4		4.0	4.0	4		3.9	4.0	4		3.9	4.0	4	
Mode	n = 8				n = 9				n = 17				n = 17			
Mean	1	0	2	5	0	0	2	7	1	0	4	12	1	0	4	12
Median	3.4	4.0	4		3.8	4.0	4		3.6	4.0	4		3.6	4.0	4	
Mode	n = 8				n = 9				n = 17				n = 17			
Mean	1	0	5	19	0	1	5	21	1	1	10	40	1	1	10	40
Median	3.7	4.0	4		3.7	4.0	4		3.7	4.0	4		3.7	4.0	4	
Mode	n = 25				n = 27				n = 52				n = 52			

Table O-6. Number of respondents and descriptive statistics for the statement: "The audio warning captured my ATTENTION".

8. The audio warning **STARTLED** me.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	<table><tr><td colspan="4">Not Applicable</td></tr></table>	Not Applicable				<table><tr><td colspan="4">Not Applicable</td></tr></table>	Not Applicable				<table><tr><td colspan="4">Not Applicable</td></tr></table>	Not Applicable																																																			
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	<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>0</td><td>1</td><td>14</td><td>10</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>3.4</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 25</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	0	1	14	10	Mean	Median	Mode		3.4	3.0	3		n = 25				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>2</td><td>5</td><td>12</td><td>8</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>3.0</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 27</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	2	5	12	8	Mean	Median	Mode		3.0	3.0	3		n = 27				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>2</td><td>6</td><td>28</td><td>18</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>3.2</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 52</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	2	6	28	18	Mean	Median	Mode		3.2	3.0	3		n = 52			
StrDis	SoDis	SoAgr	StrAgr																																																												
0	1	14	10																																																												
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Mean	Median	Mode																																																													
3.2	3.0	3																																																													
n = 52																																																															

Table O-7. Number of respondents and descriptive statistics for the statement: "The audio warning **STARTLED** me".

Of the 52 participants who recalled the auditory warning that they received, 22 collided with the lead vehicle. Their responses are below.

10. The audio warning helped me to reduce the **SEVERITY** of the collision.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

Not Applicable	Not Applicable	Not Applicable																																																												
<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>0</td><td>1</td><td>3</td><td>1</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>3.0</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 5</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	0	1	3	1	Mean	Median	Mode		3.0	3.0	3		n = 5				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>2</td><td>1</td><td>2</td><td>0</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.0</td><td>2.0</td><td>1</td><td></td></tr><tr><td colspan="4">n = 5</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	2	1	2	0	Mean	Median	Mode		2.0	2.0	1		n = 5				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>2</td><td>2</td><td>5</td><td>1</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.5</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 10</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	2	2	5	1	Mean	Median	Mode		2.5	3.0	3		n = 10			
StrDis	SoDis	SoAgr	StrAgr																																																											
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<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>1</td><td>1</td><td>5</td><td>0</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.6</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 7</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	1	1	5	0	Mean	Median	Mode		2.6	3.0	3		n = 7				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>0</td><td>0</td><td>0</td><td>1</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>4.0</td><td>4.0</td><td>—</td><td></td></tr><tr><td colspan="4">n = 1</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	0	0	0	1	Mean	Median	Mode		4.0	4.0	—		n = 1				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>1</td><td>1</td><td>5</td><td>1</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.8</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 8</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	1	1	5	1	Mean	Median	Mode		2.8	3.0	3		n = 8			
StrDis	SoDis	SoAgr	StrAgr																																																											
1	1	5	0																																																											
Mean	Median	Mode																																																												
2.6	3.0	3																																																												
n = 7																																																														
StrDis	SoDis	SoAgr	StrAgr																																																											
0	0	0	1																																																											
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n = 1																																																														
StrDis	SoDis	SoAgr	StrAgr																																																											
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Mean	Median	Mode																																																												
2.8	3.0	3																																																												
n = 8																																																														
<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>0</td><td>1</td><td>3</td><td>0</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.8</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 4</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	0	1	3	0	Mean	Median	Mode		2.8	3.0	3		n = 4				No responses reported in this cell because there were no collisions in this condition and therefore participants did not receive this question.	<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>0</td><td>1</td><td>3</td><td>0</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.8</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 4</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	0	1	3	0	Mean	Median	Mode		2.8	3.0	3		n = 4																							
StrDis	SoDis	SoAgr	StrAgr																																																											
0	1	3	0																																																											
Mean	Median	Mode																																																												
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StrDis	SoDis	SoAgr	StrAgr																																																											
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Mean	Median	Mode																																																												
2.8	3.0	3																																																												
n = 4																																																														
<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>1</td><td>3</td><td>11</td><td>1</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.8</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 16</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	1	3	11	1	Mean	Median	Mode		2.8	3.0	3		n = 16				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>2</td><td>1</td><td>2</td><td>1</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.3</td><td>2.5</td><td>1</td><td></td></tr><tr><td colspan="4">n = 6</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	2	1	2	1	Mean	Median	Mode		2.3	2.5	1		n = 6				<table><tr><td>StrDis</td><td>SoDis</td><td>SoAgr</td><td>StrAgr</td></tr><tr><td>3</td><td>4</td><td>13</td><td>2</td></tr><tr><td>Mean</td><td>Median</td><td>Mode</td><td></td></tr><tr><td>2.6</td><td>3.0</td><td>3</td><td></td></tr><tr><td colspan="4">n = 22</td></tr></table>	StrDis	SoDis	SoAgr	StrAgr	3	4	13	2	Mean	Median	Mode		2.6	3.0	3		n = 22			
StrDis	SoDis	SoAgr	StrAgr																																																											
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Mean	Median	Mode																																																												
2.8	3.0	3																																																												
n = 16																																																														
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n = 6																																																														
StrDis	SoDis	SoAgr	StrAgr																																																											
3	4	13	2																																																											
Mean	Median	Mode																																																												
2.6	3.0	3																																																												
n = 22																																																														

Table O-8. Number of respondents and descriptive statistics for the statement: "The audio warning helped me to reduce the **SEVERITY** of the collision".

Of the 52 participants who recalled the auditory warning they received, 30 did not collide with the lead vehicle. Their responses are below.

11. The audio warning helped me to **AVOID** the collision.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Not Applicable				Not Applicable				Not Applicable			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
	0	0	1	3	1	0	1	2	1	0	2	5
	Mean	Median		Mode	Mean	Median		Mode	Mean	Median		Mode
	3.8	4.0		4	3.0	3.5		4	3.4	4.0		4
	n = 4				n = 4				n = 8			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
	0	0	0	1	0	0	1	7	0	0	1	8
	Mean	Median		Mode	Mean	Median		Mode	Mean	Median		Mode
	4.0	4.0		1	3.9	4.0		4	3.9	4.0		4
	n = 1				n = 8				n = 9			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
	0	0	2	2	0	1	3	5	0	1	5	7
	Mean	Median		Mode	Mean	Median		Mode	Mean	Median		Mode
	3.5	3.5		4	3.4	4.0		4	3.5	4.0		4
	n = 4				n = 9				n = 13			
	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr	StrDis	SoDis	SoAgr	StrAgr
	0	0	3	6	1	1	5	14	1	1	8	20
	Mean	Median		Mode	Mean	Median		Mode	Mean	Median		Mode
	3.7	4.0		4	3.5	4.0		4	3.6	4.0		4
	n = 9				n = 21				n = 30			

Table O-9. Number of respondents and descriptive statistics for the statement: "The audio warning helped me to **AVOID** the collision".

12. The audio warning would be **USEFUL** on real roadways for enhancing safety.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Not Applicable				Not Applicable				Not Applicable			
	StrDis 0	SoDis 0	SoAgr 4	StrAgr 5	StrDis 0	SoDis 0	SoAgr 7	StrAgr 2	StrDis 0	SoDis 0	SoAgr 11	StrAgr 7
	Mean 3.6	Median 4.0	Mode 4		Mean 3.2	Median 3.0	Mode 3		Mean 3.4	Median 3.0	Mode 3	
	n = 9				n = 9				n = 18			
	StrDis 0	SoDis 1	SoAgr 5	StrAgr 2	StrDis 0	SoDis 0	SoAgr 1	StrAgr 8	StrDis 0	SoDis 1	SoAgr 6	StrAgr 10
	Mean 3.1	Median 3.0	Mode 3		Mean 3.9	Median 4.0	Mode 4		Mean 3.5	Median 4.0	Mode 4	
	n = 8				n = 9				n = 17			
	StrDis 0	SoDis 0	SoAgr 4	StrAgr 4	StrDis 0	SoDis 0	SoAgr 4	StrAgr 5	StrDis 0	SoDis 0	SoAgr 8	StrAgr 9
	Mean 3.5	Median 3.5	Mode 3		Mean 3.6	Median 4.0	Mode 4		Mean 3.5	Median 4.0	Mode 4	
	n = 8				n = 9				n = 17			
	StrDis 0	SoDis 1	SoAgr 13	StrAgr 11	StrDis 0	SoDis 0	SoAgr 12	StrAgr 15	StrDis 0	SoDis 1	SoAgr 25	StrAgr 26
	Mean 3.4	Median 3.0	Mode 3		Mean 3.6	Median 4.0	Mode 4		Mean 3.5	Median 3.5	Mode 4	
	n = 25				n = 27				n = 52			

Table O-10. Number of respondents and descriptive statistics for the statement: "The audio warning would be **USEFUL** on real roadways for enhancing safety."

13. If it were priced reasonably, I would recommend a Forward Collision Warning System like this one.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

	Not Applicable				Not Applicable				Not Applicable			
	StrDis 0	SoDis 1	SoAgr 6	StrAgr 2	StrDis 0	SoDis 1	SoAgr 4	StrAgr 4	StrDis 0	SoDis 2	SoAgr 10	StrAgr 6
	Mean 3.1	Median 3.0		Mode 3	Mean 3.3	Median 3.0		Mode 3	Mean 3.2	Median 3.0		Mode 3
	n = 9				n = 9				n = 18			
	StrDis 0	SoDis 1	SoAgr 5	StrAgr 2	StrDis 0	SoDis 0	SoAgr 2	StrAgr 7	StrDis 0	SoDis 1	SoAgr 7	StrAgr 9
	Mean 3.1	Median 3.0		Mode 3	Mean 3.8	Median 4.0		Mode 4	Mean 3.5	Median 4.0		Mode 4
	n = 8				n = 9				n = 17			
	StrDis 0	SoDis 0	SoAgr 4	StrAgr 3	StrDis 0	SoDis 0	SoAgr 5	StrAgr 4	StrDis 0	SoDis 0	SoAgr 9	StrAgr 7
	Mean 3.4	Median 3.0		Mode 3	Mean 3.4	Median 3.0		Mode 3	Mean 3.4	Median 3.0		Mode 3
	n = 7				n = 9				n = 16			
	StrDis 0	SoDis 2	SoAgr 15	StrAgr 7	StrDis 0	SoDis 1	SoAgr 11	StrAgr 15	StrDis 0	SoDis 3	SoAgr 26	StrAgr 22
	Mean 3.2	Median 3.0		Mode 3	Mean 3.5	Median 4.0		Mode 4	Mean 3.4	Median 3.0		Mode 3
	n = 24				n = 27				n = 51			

Table O-11. Number of respondents and descriptive statistics for the statement: "If it were priced reasonably, I would recommend a Forward Collision Warning system like this one".

14. The audio warning is likely to be **ANNOYING** on real roadways if I experience it several times a week and it often does not correspond to a real threat in the environment.

Questionnaire Scale	Strongly Disagree	Somewhat Disagree	Somewhat Agree	Strongly Agree
Assigned Value	1	2	3	4

Not Applicable	Not Applicable	Not Applicable
StrDis 0 SoDis 0 SoAgr 2 StrAgr 7 Mean 3.8 Median 4.0 Mode 4 n = 9	StrDis 0 SoDis 3 SoAgr 6 StrAgr 0 Mean 2.7 Median 3.0 Mode 3 n = 9	StrDis 0 SoDis 3 SoAgr 8 StrAgr 7 Mean 3.2 Median 3.0 Mode 3 n = 18
StrDis 0 SoDis 1 SoAgr 5 StrAgr 2 Mean 3.1 Median 3.0 Mode 3 n = 8	StrDis 1 SoDis 0 SoAgr 5 StrAgr 3 Mean 3.1 Median 3.0 Mode 3 n = 9	StrDis 1 SoDis 1 SoAgr 10 StrAgr 5 Mean 3.1 Median 3.0 Mode 3 n = 17
StrDis 0 SoDis 0 SoAgr 7 StrAgr 1 Mean 3.1 Median 3.0 Mode 3 n = 8	StrDis 2 SoDis 2 SoAgr 3 StrAgr 2 Mean 2.6 Median 3.0 Mode 3 n = 9	StrDis 2 SoDis 2 SoAgr 10 StrAgr 3 Mean 2.8 Median 3.0 Mode 3 n = 17
StrDis 0 SoDis 1 SoAgr 14 StrAgr 10 Mean 3.4 Median 3.0 Mode 3 n = 25	StrDis 3 SoDis 5 SoAgr 14 StrAgr 5 Mean 2.8 Median 3.0 Mode 3 n = 27	StrDis 3 SoDis 6 SoAgr 28 StrAgr 15 Mean 3.1 Median 3.0 Mode 3 n = 52

Table O-12. Number of respondents and descriptive statistics for responses to: "The audio warning is likely to be **ANNOYING** on real roadways if I experience it several times a week and it often does not correspond to a real threat".

APPENDIX P

AUDITORY WARNING SOUND ANALYSIS

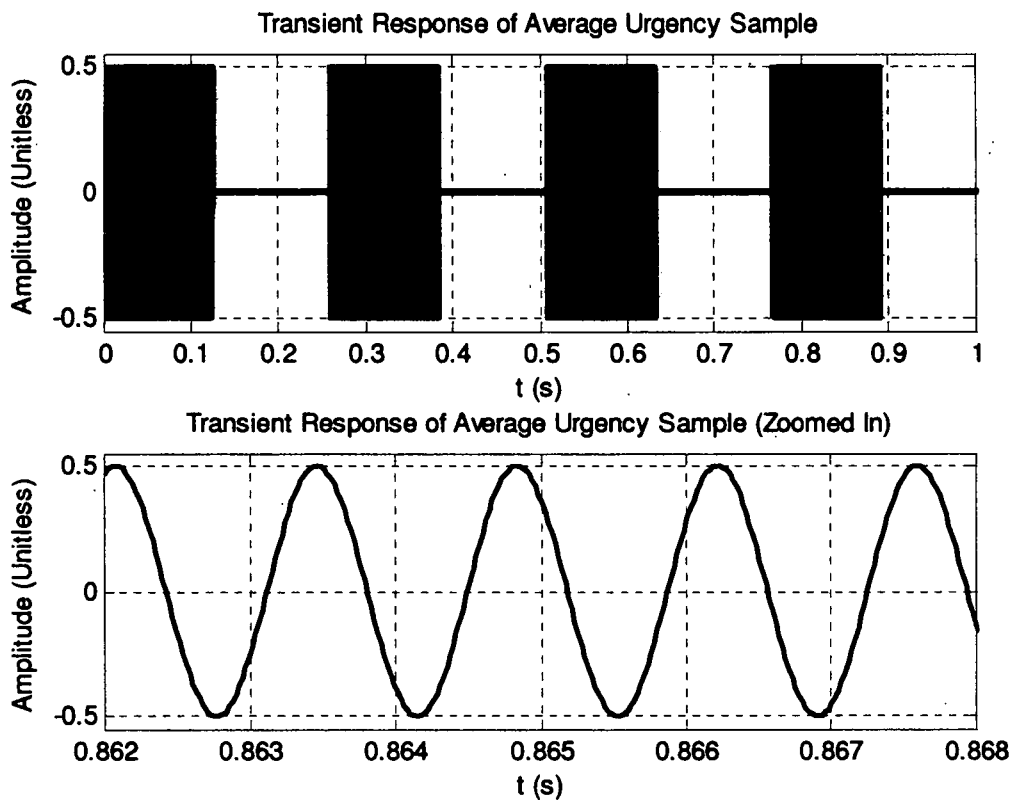


Figure P-1. Waveform shape of the average-urgency warning (experiment).

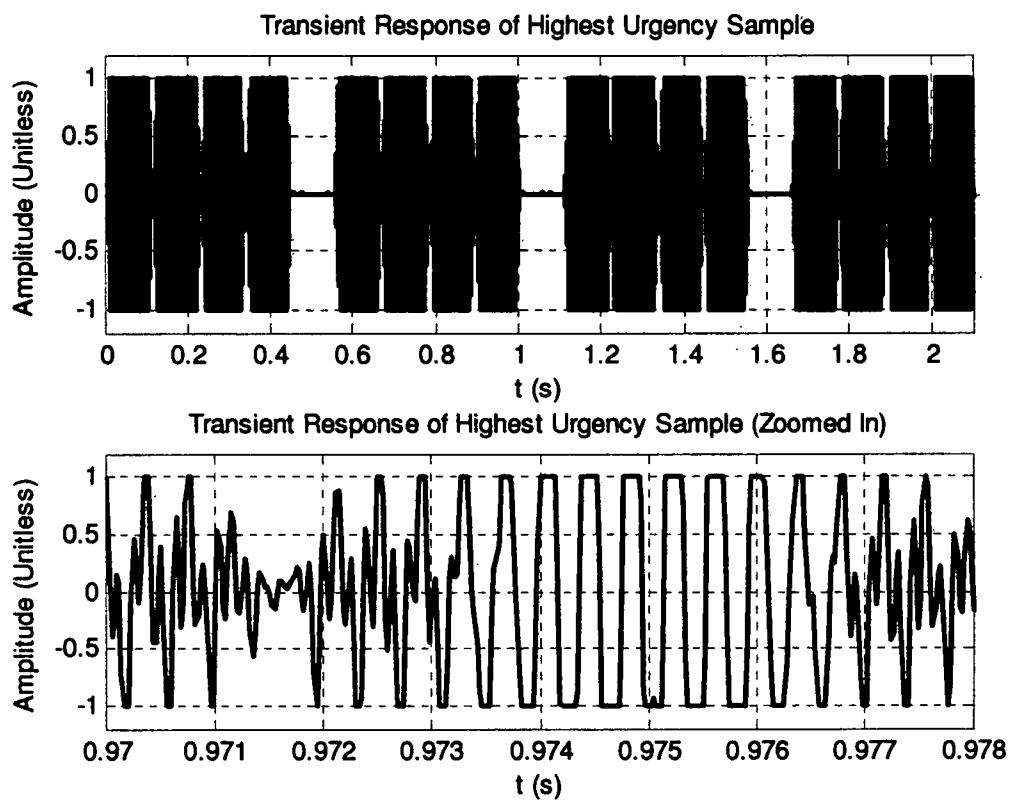


Figure P-2. Waveform shape of the highest-urgency warning (experiment).

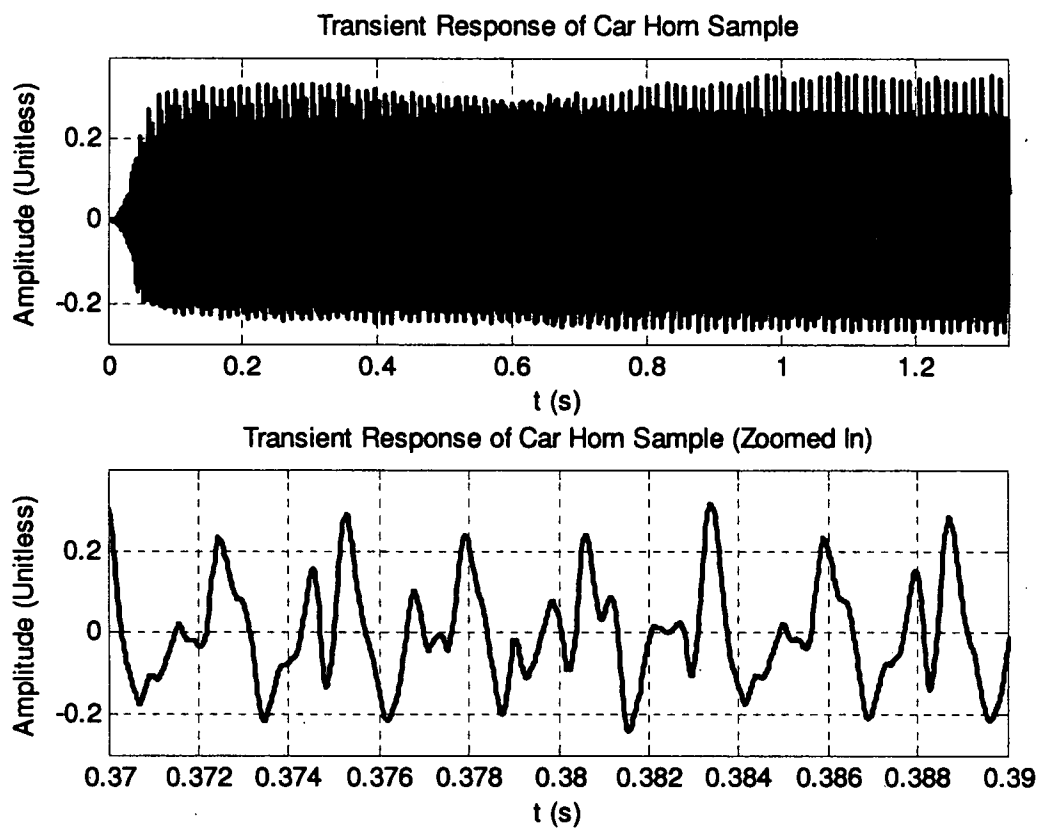


Figure P-3. Waveform shape of the car horn warning (experiment).

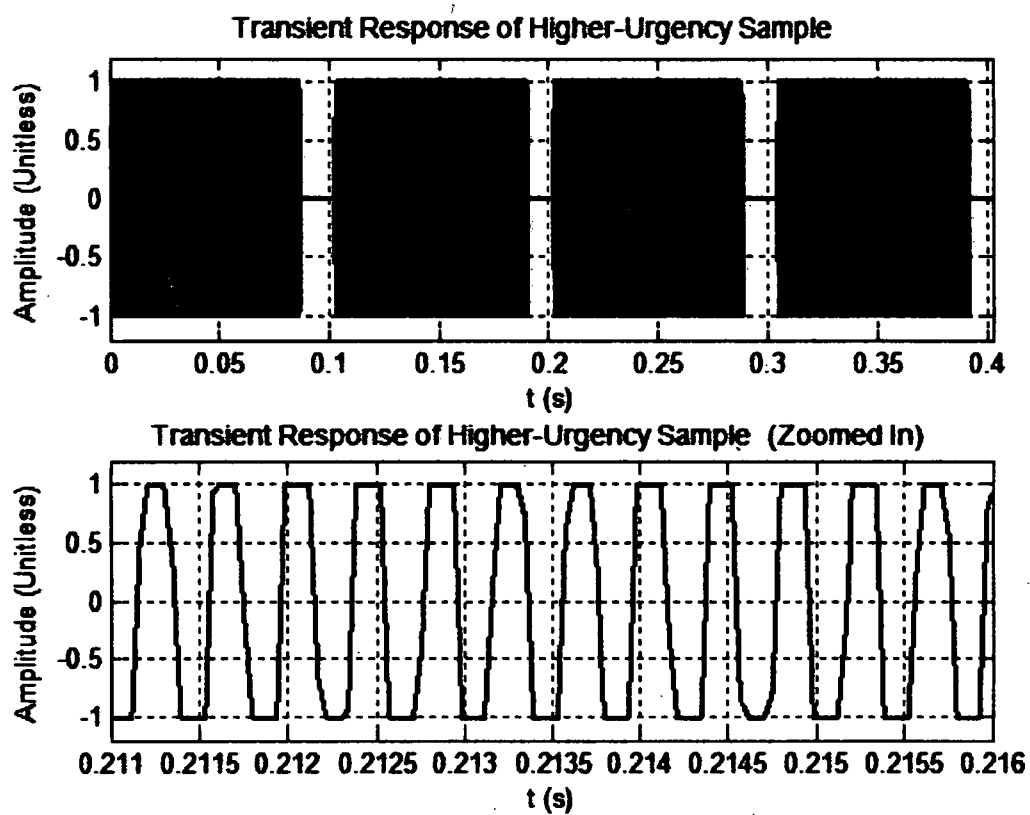


Figure P-4. Waveform shape of the higher-urgency warning (pilot study).

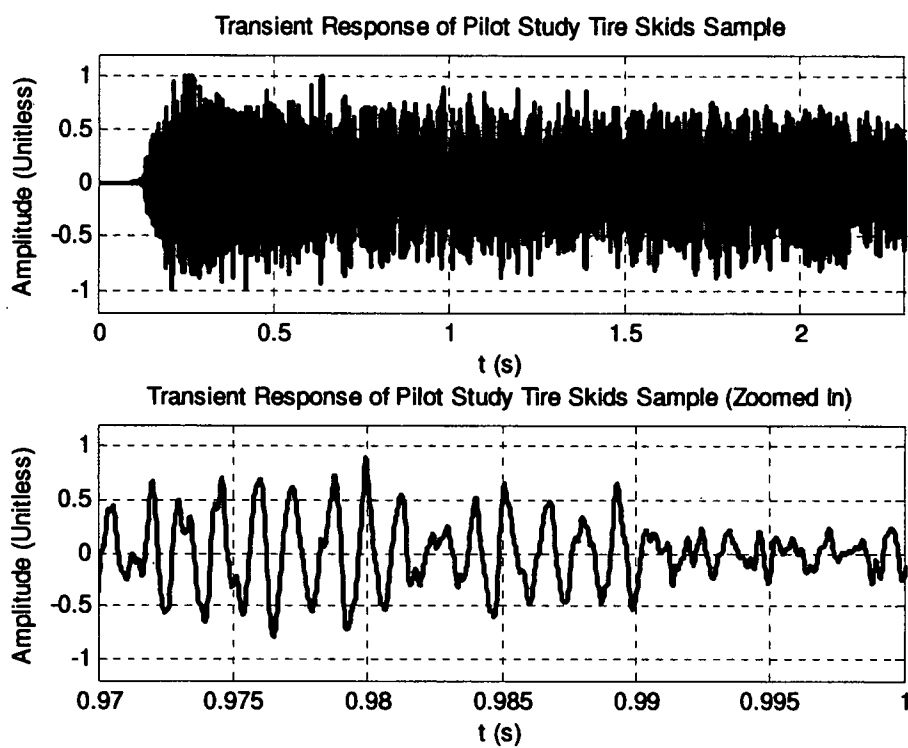


Figure P-5. Waveform shape of the screeching tires warning (pilot study).

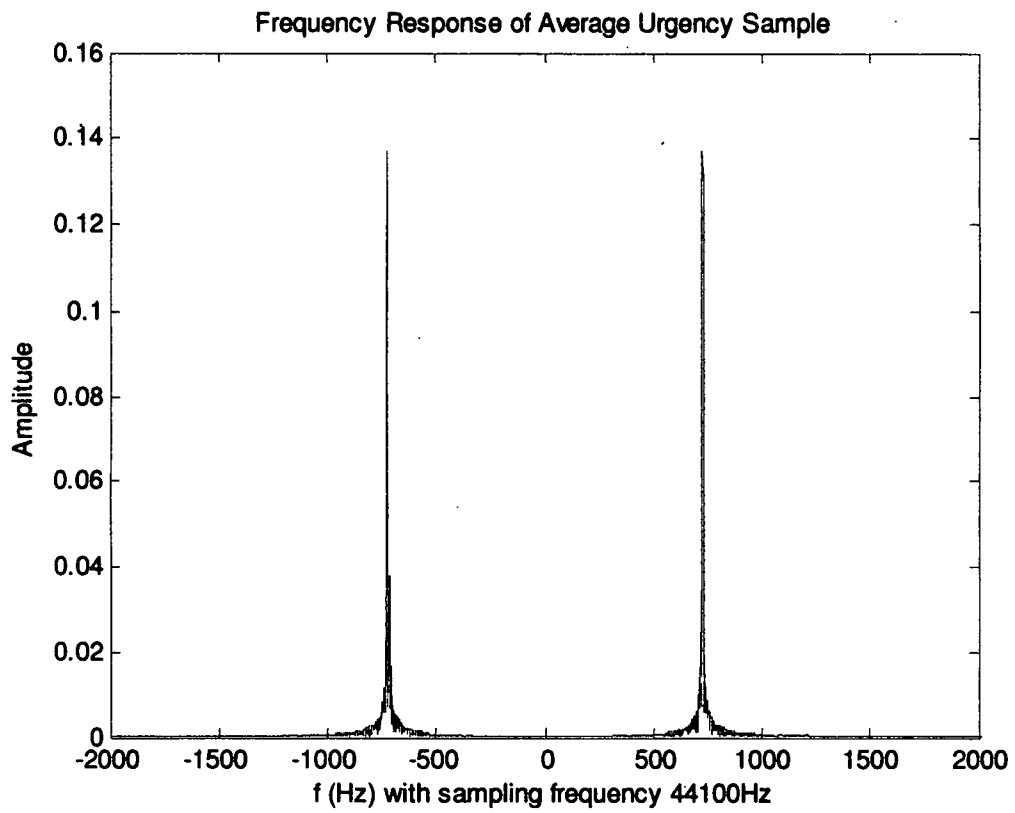


Figure P-6. Frequency response of the average-urgency warning (experiment).

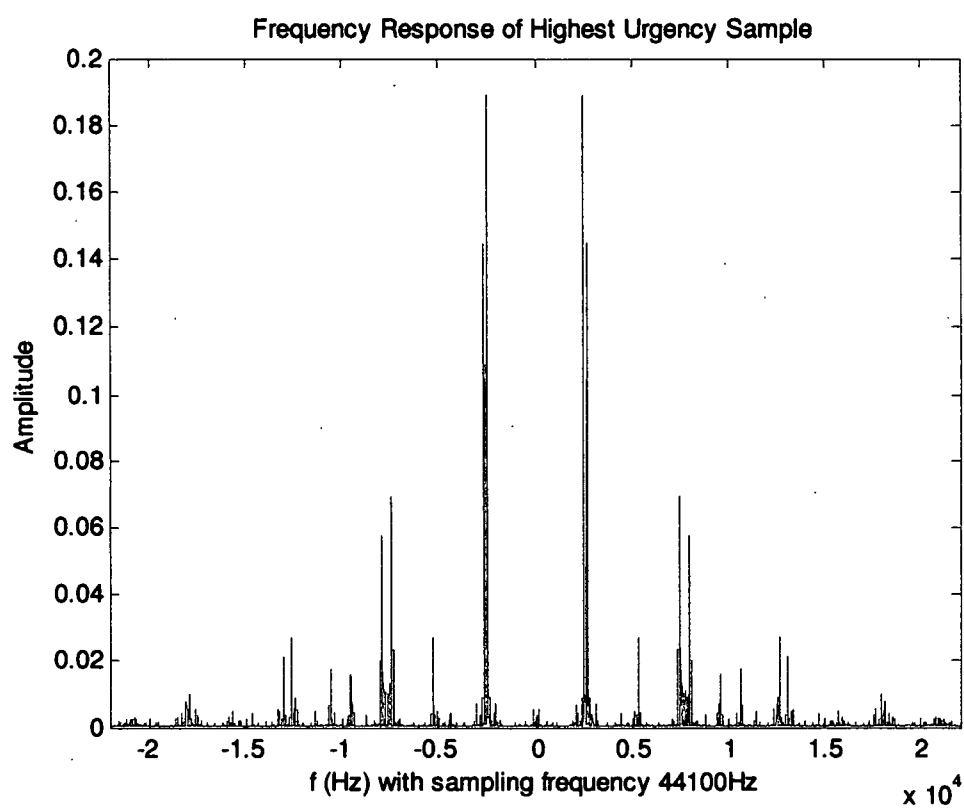


Figure P-7. Frequency response of the highest-urgency warning (experiment).

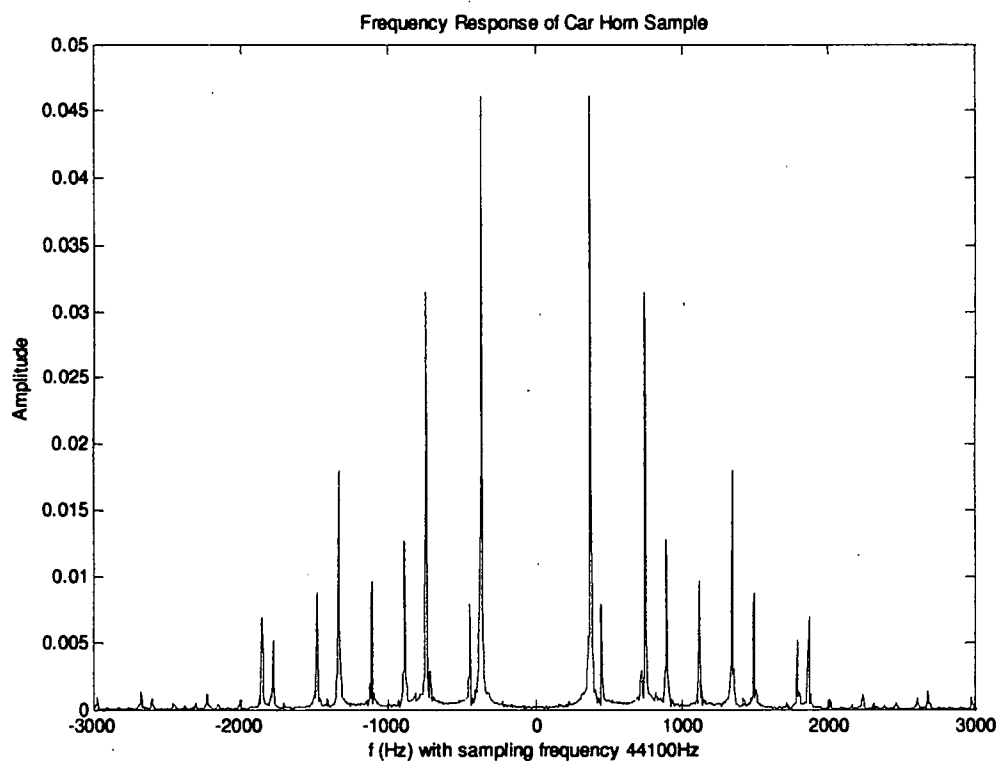


Figure P-8. Frequency response of the car horn warning (experiment).

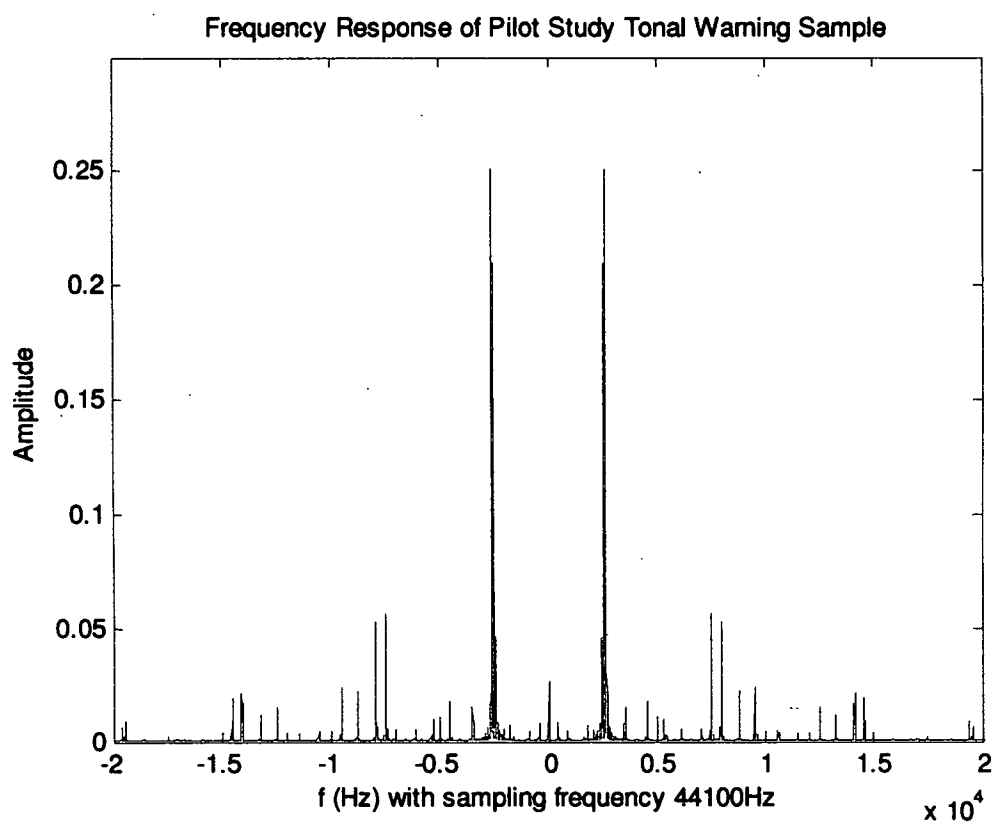


Figure P-9. Frequency response of the higher-urgency warning (pilot study).

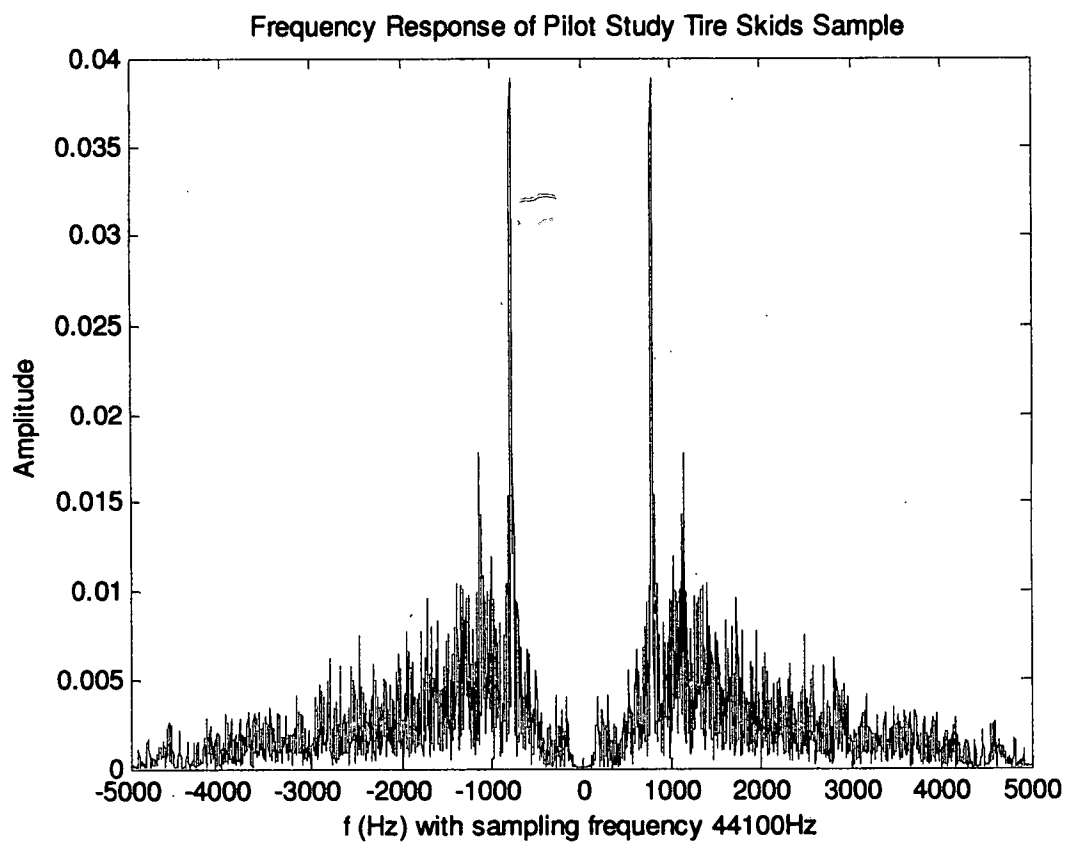


Figure P-10. Frequency response of the screeching tires warning (pilot study).

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