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Human Factors for Connected Vehicles: Effective Warning Interface Research Findings

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16. Abstract

This project explored human factors issues in the development of Connected Vehicle (CV) driver vehicle interfaces with an emphasis on maximizing driver comprehension and appropriate responses to warnings. Four distinct research efforts are described in this report. Experiment 1 investigated the perceived urgency of various driving event scenarios in a laboratory setting. The objective of the experiment was to identify the structure of user perceptions of urgency so that CV systems might be made consistent with user expectancies. Results showed that several factors affected participants’ perceptions of perceived urgency, and that ratings of urgency tended to fall into one of three general categories: High threat, caution, and no urgency. Experiment 2 used a series of psychophysical experiments to determine how the manipulation of various alert parameters affects perceived urgency. The experiment also developed and validated a method to determine and compare perceived urgency across visual, auditory, and tactile modalities and within different parameters of each of these modalities. Experiment 3 investigated whether collision avoidance systems should present individual crash alerts in a multiple conflict scenario, or only present one alert in response to the first conflict and suppress the subsequent alert to the second conflict. The closed-course procedure showed that participants’ responses to a surprise even were generally more appropriate when both alerts were presented, and participants subjectively preferred this approach. Experiment 4 investigated the extent to which driver response to imminent crash warnings is affected by the degree of integration when there are multiple CV products in the vehicle. The closed-course procedure showed that participants recognized warnings most quickly when only one display was active in the car. When both displays were active, response times generally improved when messages and warnings were integrated into a single physical location. The authors used the research findings as a basis for a discussion of implications for the design and use of crash-related warning displays within the CV context.

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EXECUTIVE SUMMARY

The Connected Vehicle (CV) program is a major initiative that will improve surface transportation safety and mobility through the use of communications technology to enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission. The key to the CV concept is connectivity. “Connectivity” in this context means that there are networked wireless communications among vehicles, the transportation infrastructure, and personal communications devices. The human factors issues concern how to integrate and display all of the information a driver may want or need in a manner that is safe and usable. The specific issue of concern for the present project is the question of how to ensure that important safety messages are effective (i.e., result in high rates of driver comprehension and proper responses). The challenges are that the CV concept may provide drivers with a large number of safety messages, many sorts of non-safety information, and a variety of different design and display concepts implemented by various manufacturers and developers.

Four distinct research efforts are described in this report. Each effort was designed to address one or more key knowledge gaps related to CV that were identified by a literature review effort.

Experiment 1: User-Based Structure for Message Coding. This experiment, conducted by Westat, had the goal of investigating the perceived urgency of various driving event scenarios by drivers. Participants observed a variety of computer-generated driving scenarios in a laboratory setting. These scenarios differed in terms of the type of event (various safety and non-safety situations), temporal or spatial proximity, the type of roadway, and travel speed. For each of 78 scenarios, participants rated “How important is it that you receive information about this situation right NOW?” using a 10-point rating scale. They also selected the preferred manner in which they would like the information handled (priority), from a list of alternatives. Priority and urgency are related, but different concepts.

Several factors affected participants’ perceived urgency about driving situations. First, the type of situation with respect to safety had a significant impact on level of urgency perceived. Participants rated situations focusing on convenience and sustainability as least urgent and safety related situations as most urgent. Road type also had a significant effect. Situations on rural four-lane roads were rated as more urgent than parallel situations on arterials and freeways. There was a relationship of distance or time to event from nearest (D1) to farthest (D4). There was no significant impact of speed on urgency ratings, though there was an interaction of speed and distance. Participants' priority preferences for the presentation of information about a situation were strongly correlated with their ratings of urgency. Based on the findings and the general characteristics of each variable, three general categories seemed to emerge: High threat, caution, and no urgency.

Experiment 2: Urgency Coding Within and Across Modes. Experiment 2 was a series of related experiments, which developed and validated a method to determine and compare perceived urgency across visual, auditory, and tactile modalities and within different parameters of each of these modalities. The study was conducted in three stages.

Experiment 2A was a series of experiments in which participants rated perceived urgency, annoyance, and acceptability of signals in a given modality (either visual, auditory, or tactile) that differed along certain parameters including intensity, interpulse interval (i.e., duration of time between signal pulses), flash rate, and so forth. Experiment 2B used the general protocol used in Experiment 2A with the exception that participants experienced and rated stimuli while engaged in a simulated driving task. The results of Experiments 2A and 2B revealed how the manipulation of various message parameters influenced urgency ratings. The scales of urgency ratings were then used to create a developer's tool that allows users to generate message parameters to achieve a desired level of urgency.

Experiment 2C was conducted in a high fidelity motion base driving simulator to validate the urgency scales obtained from Experiments 2A and 2B. Four driving scenarios containing potential collision events were implemented. After completing the four drives, participants were asked to rate the urgency levels, annoyance, and acceptability of the three stimuli in the modality they had just experienced during the drives. Driving performance metrics were analyzed as well. Comparable ranges of urgency as predicted from Experiments 2A and 2B were achieved. Providing a warning resulted in fewer crashes than in the no-warning (control) condition, but there were no significant differences in the frequency of crashes between the visual, auditory, and tactile modalities.

Experiment 3: Multiple Warning Events. This experiment, conducted by Virginia Tech Transportation Institute, investigated whether collision avoidance systems should present individual crash alerts in a multiple conflict scenario, or only present one alert in response to the first conflict and suppress the subsequent alert to the second conflict. During driving on a closed course, participants were exposed to a surprise event that led to both a forward and a lateral hazard in rapid succession. Half of the participants received a forward collision warning (FCW) and a lane change warning (LCW), while the other half received only a FCW. Both warnings were auditory-only and one second in duration. Each had different spectral frequency characteristics.

Participants began by engaging in training drives in which they practiced receiving FCW and LCW alerts in response to a lead pickup truck and an adjacent confederate vehicle, and responding to them in an appropriate way. Next, participants followed the lead pickup truck while the confederate vehicle kept pace a few car lengths behind in the adjacent left lane. While participants were distracted, the confederate vehicle sped up to take a position in the participant's blind spot, two lanes over, and a large cardboard box was released from the bed of the lead pickup truck in the driver's path. An FCW was triggered when the box hit the ground. If participants steered left to avoid the box, those in the FCW + LCW condition also received the LCW.

Results showed that participants in the FCW + LCW condition steered away from the confederate vehicle significantly more quickly than participants in the FCW only condition. There were no significant differences in maximum distance traveled into the left lane, in the number of participants who steered right after steering left, or the number of participants who looked left as they swerved left (FCW + LCW versus FCW only). Participants were also asked to make subjective ratings of the warnings they experienced. Drivers ranked the FCW + LCW alert approach as more appropriate than the FCW alone. They liked receiving the LCW alert, considered it useful, found it easy to understand, and did not find it to be startling. A subset of participants who were commercial motor vehicle (CMV) drivers also felt that the FCW + LCW was appropriate for use in CMVs, but had generally negative reactions to the idea of using a haptic modality for warning presentation, possibly because they were unfamiliar with this alert mode.

Experiment 4: Portable Device Pairing. This experiment, conducted by Westat, investigated the extent to which driver response to imminent crash warnings is affected by the degree of integration when there are multiple CV products in the vehicle. Two displays were placed in an experimental vehicle, one representing an original equipment manufacturer (OEM) display and one representing a portable, portable device. For each device, a comparable set of messages was created to present information to drivers about traffic conditions, weather conditions, nearby attractions, safety information, phone call and text messages, and imminent crash warnings. While the messages designed for each device were largely equivalent in terms of content and meaning, each device had its own distinct visual design theme and sounds. The study was a between-subjects evaluation with participants randomly assigned to one of five experimental conditions: OEM device only, portable device only, both devices with no integration or prioritization, both devices with prioritization of warnings, and both devices with all messages presented via the OEM display.

The experimental task was the same in all experimental conditions. As participants drove in a prescribed path on a test track (guided by a voice navigation system), they were occasionally presented with a visual/auditory message. The message was either non-urgent information or an urgent crash warning. Urgent warnings either occurred alone or 3 seconds after the initiation of a non-urgent message. If the message was non-urgent, participants' only responsibility was to read the message and be able to answer a comprehension question about it. If the message was an urgent crash warning, participants were instructed to honk the car horn as quickly as possible (to indicate that they recognize the warning as urgent) and then locate a light that has changed color from blue to red around the perimeter of the vehicle (to indicate that they recognize the location of the threat indicated by the warning).

Findings show that participants recognized warnings most quickly when only one display (e.g., OEM or portable) was active in the car. When both displays were active, response times generally improved when messages and warnings were integrated into a single physical location. The data also show that warning recognition times were longer when a warning followed a non-urgent message on the *other* display than when a warning followed a non-urgent message on the *same* display. When messages and warnings from both source displays were integrated into a single display, this effect was not observed. This suggests that the separate display locations are responsible for the increased warning recognition time rather than the different formats of the messages from each source device.

Research Implications: Based on the findings of the project, a set of implications for the design and use of safety-related warnings within the CV context is discussed. These implications are categorized under three topic headings:

- Defining and conveying appropriate message urgency in all modes;
- Dealing with multiple events in temporal proximity; and
- Integration of multiple CV devices.

1.0 BACKGROUND AND OBJECTIVES

1.1 Warning Effectiveness Within the Connected Vehicle Concept

This report presents the findings of research studies on human factors issues related to effective crash avoidance warnings within the context of the U.S. Department of Transportation's CV program.

The CV program is a major initiative that will improve surface transportation safety and mobility. As described on the DOT's Research and Innovative Technology Administration (RITA) Web site (www.its.dot.gov), "Connected Vehicle research at U.S. Department of Transportation is a multimodal program that involves using wireless communication between vehicles, infrastructure, and personal communications devices to improve safety, mobility, and environmental sustainability." Specifically regarding the safety component, the RITA site states that "Connected vehicle safety applications are designed to increase situational awareness and reduce or eliminate crashes through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission that supports: driver advisories, driver warnings, and vehicle and/or infrastructure controls. These technologies may potentially address up to 82 percent of crash scenarios with unimpaired drivers, preventing tens of thousands of automobile crashes every year (further research will incorporate heavy vehicle crashes including buses, motor carriers, and rail)."

The key to the CV concept is connectivity. "Connectivity" in this context means that there is a wireless network supporting communications between vehicles, the transportation infrastructure, and personal communications devices. The mature program is envisioned to provide a driver with "360-degree awareness" of surrounding traffic, as well as the status of roadway and traffic conditions and travel options. This represents a new context in which drivers will acquire many sorts of information, including a wide range of safety-related messages. The human factors issues concern how to integrate and display all of the information a driver may want or need in a manner that is safe and usable. A wide variety of important safety messages may ultimately be included within CV applications. Among the potential applications that have been suggested are:

- Blind spot warning/lane change warning,
- Forward collision warning,

- Electronic emergency brake lights (vehicle ahead that driver cannot see is braking),
- Intersection movement assist (unsafe to enter intersection due to conflicting traffic),
- Intersection violation warning (driver is about to commit a violation),
- Do not pass warning (opposing traffic, insufficient gap),
- Vehicle control loss warning (driver is on verge of loss of vehicle control),
- School zone,
- Curve speed warning, other warnings about road geometry (e.g., lane drop),
- Work zone warning,
- Pedestrian or bicyclist presence,
- Slippery road warning,
- Dangerous weather conditions (snow, fog, heavy rain),
- Stopped traffic ahead (e.g., backup on a freeway),
- Traffic signal status
- Road departure, lane departure

The specific issue of concern for the present project is how to ensure that important safety messages are effective (i.e., result in high rates of driver comprehension and proper responses). The challenge is that the CV concept may provide drivers with a large number of safety messages, many types of non-safety information, and a variety of different design and display concepts as implemented by various manufacturers and applications developers. Within this context, the driver's reaction to any particular urgent safety message must remain rapid and appropriate.

The project under which the research studies presented here were conducted is one of several complementary parallel projects dealing with human factors aspects of the driver interface within the CV context. The purpose of this project was to conduct new empirical research to address key knowledge gaps that limit the ability to provide supportable guidance for CV system developers. Based on the findings, implications for warning interface design were derived. While the initial research findings related to these complex issues are preliminary, they provide an improved basis for effective CV warning interfaces. Together these efforts provide human factors guidance on how the CV driver interface can support effective, safe, and user-acceptable displays.

1.2 Key Gaps to Address in Research

Initial tasks of this project had the objective of identifying key gaps in current knowledge that may be important to address for the CV program. Under Task 1 of the project, the project team conducted a critical review of literature on interface approaches and prioritization strategies for the presentation of in-vehicle warnings. The review was organized around the following set of questions:

- For CV applications, what are the key empirical findings and existing guidance related to message (especially warning message) prioritization?
- For CV applications, what are the key empirical findings and existing guidance related to urgency mapping (i.e., conveying degree of urgency to the driver)?
- For CV applications, what are the key empirical findings and existing guidance related to the timing of warnings?
- What do we know about driver ability to handle multiple sources of information?
- For CV applications, what are the key issues for compatibility of all information sources (CV sources, autonomous vehicle sources, roadway-based information, and other information sources)?
- What modes of warning display (e.g., auditory, visual, haptic, voice) are appropriate and what are their relative virtues and integration requirements?
- What are the issues in having drivers understand the functions and operations of complex driver information systems ("mental model" and expectancy)?
- What interface research and guidance exists for roadway applications of portable (i.e., portable) consumer electronic equipment?
- What unique CV interface concerns exist for special types of vehicles (e.g., trucks, transit)?

In Task 2, based on the literature review, the project team identified a number of key issues and unanswered questions that might be addressed by subsequent research. These potential research questions were analyzed and prioritized in terms of criticality, practicality, and compatibility with project resources and schedule. Based on this, a research plan for a collection of experiments was developed in Task 3. The research reported here was based on that plan and is given in overview in Chapter 2.

2.0 OVERVIEW OF EXPERIMENTAL STUDIES

Four distinct research efforts are described in this report. The research was conducted by a team of research institutions that included Westat, George Mason University, and Virginia Tech Transportation Institute. Table 2-1 provides an overview of these experiments. For each experiment, the table indicates a descriptive title, describes the gap addressed by the experiment, indicates the lead institution that conducted the experiment, and presents a capsule description of the approach.

The first two studies listed in Table 2-1 (User-Based Structure for Message Coding and Urgency Coding Within and Across Modes) both dealt with issues of driver-perceived urgency. The first dealt with the perceived urgency of various driving scenarios and the second dealt with the perceived urgency of particular signals. The first investigated how people perceived the urgency of the driver's need for information for a wide variety of driving situations. These scenarios differed in terms of the event (various safety and non-safety situations), temporal or spatial proximity, the type of roadway, and travel speed. The intent was to identify the structure of user perceptions of urgency so that potential CV systems might be made consistent with user expectancies. The second study investigated how various signal features contribute to the perceived urgency of a signal, with attention also given to cross-modal aspects of urgency equivalence. A sequence of experiments addressed basic perceptual processes and driver response to warnings in a driving simulator environment. The experiment on Multiple Warning Events dealt with the difficult situation of two imminent crash threats occurring within close temporal proximity. The issue is how to best inform the driver without causing delayed responses, confusion, or inappropriate driver actions. This experiment introduced the multiple events during a drive on a test track and compared alternative warning strategies. This study also included a post-drive procedure for collecting additional information related to some unique considerations for heavy vehicle applications. A subsample of the participants was heavy vehicle operators, who were asked a series of directed questions regarding the application of various CV options for the truck environment. The final study listed in Table 2-1 (Portable Device Pairing) deals with the issue of integration between multiple CV products that might be present in a vehicle. CV applications may potentially be provided by automobile manufacturers as original equipment systems. However, there may be aftermarket products and portable devices (e.g., smartphones) that also provide CV information. The independent systems might be integrated to various degrees, or not at all. This experiment considered the consequences, in terms of rapid response to emergency warnings, of dealing with multiple sources of CV information.

Together, the set of studies shown in Table 2-1 addressed issues of urgency, priority, concurrent events, message modality, integration, and driver mental models of how a warning component of a CV system might work. While these empirical efforts represent early steps in our understanding of these issues, they are intended to help advance current human factors guidance for the design and implementation of CV systems.

In the sections that follow, each of these experimental studies shown in Table 2-1 is presented in further detail. Given the large number of experiments, the treatment of methods and results for each individual study is relatively brief. Selected details are provided in Appendices to this report.

Table 2-1. Summary of research studies

Title	Gap addressed	Lead	Capsule description
User-based structure for message coding	The structure of the message categories, warning types, and prioritization schemes need to be consistent with driver perceptions, behaviors, and mental models; little information exists on this.	Westat	Participants observed a variety of computer-generated driving scenarios. These scenarios differed in terms of the type of event (various safety and non-safety situations), temporal or spatial proximity, the type of roadway, and travel speed. For each of 78 scenarios, participants rated "How important is it that you receive information about this situation right NOW?" using a 10-point rating scale. They also selected the preferred manner in which they would like the information handled (priority) from a list of alternatives. The analysis was directed at identifying the structure of user perceptions of urgency so that potential CV systems might be made consistent with user expectancies and best support driver information acquisition and decision-making.
Urgency coding within and across modes	Existing literature mainly for visual and acoustic parameters; need to be able to define for all display modes, including haptic, speech, visual and acoustic icons, active interventions; need to be able to map across modes for equivalent urgency.	George Mason University	A combination of psychophysical and driving simulator research investigations examined urgency coding. The combined approach facilitated rapid development of urgency coding scales and calibration across modes based primarily on subjective ratings. The scales for a subset of these modes were validated in a simulated driving context. The impact of multiple modes and context (using a range of safety-relevant messages with different degrees of urgency and non-safety but time critical messages) on perceived urgency and behavioral response were also examined.
Multiple warning events; truck and bus needs	Lacking proven means for dealing with multiple hazards in a single event situation; issues of delayed response, confusion, inappropriate action; unique considerations for larger commercial vehicles.	Virginia Tech Transpor-tation Institute	Drivers in a controlled test track environment were exposed to a conflict situation in which multiple warning alerts were issued in close temporal proximity to each other. Vehicle instrumentation captured key driving performance measures (steering, braking, visual search). Data were analyzed to assess the degree to which multiple near simultaneous warnings impacted drivers' responses by comparing performance to a baseline condition with a single warning. Participants also provided subjective measures of warning appropriateness. A subset of commercial motor vehicle (CMV) drivers also participated in the study and provided subjective responses to questions about appropriateness of multiple warnings for CMVs.
Portable device pairing	Need for coordination among original equipment manufacturer (OEM) and portable device applications and displays; need to determine if response to an urgent warning is slowed if multiple devices are in effect	Westat	Two displays were placed in an experimental vehicle, one representing an OEM display and one representing a portable, portable device. For each device, a comparable set of messages presented non-urgent information and imminent crash warnings. Five conditions represented various levels of device integration and prioritization. Analyses investigated correct identification of warnings, response time, and a measure of correct identification of hazard location.

3.0 EXPERIMENT 1: USER-BASED STRUCTURE FOR MESSAGE CODING

3.1 Introduction

This experiment investigated how people perceived the urgency of the driver's need for information for a wide variety of driving situations. These scenarios differed in terms of the event (various safety and non-safety situations), temporal or spatial proximity, the type of roadway, and travel speed.

The main objective of this experiment was to identify the structure of user perceptions of urgency and prioritization so that potential CV systems might be made consistent with user expectancies and best support driver information acquisition and decision-making. Two main questions were investigated in this experiment:

1. What are the important situational dimensions of perceived urgency and priority?
2. How many categories of urgency are naturally perceived by participants?

3.2 Method

3.2.1 Design

The experiment included the presentation of 78 different roadway scenarios that a driver may face. The scenarios presented differed in terms of the type of event (various safety and non-safety situations), temporal or spatial proximity, type of roadway, and travel speed.

Types of event-specific messages presented were:

- Forward collision,
- Blind spot,
- Lane departure,
- Do not pass,
- Electronic brake light,
- Intersection conflict,

- Intersection violation,
- Stopped traffic,
- Pedestrian,
- School bus,
- Emergency vehicles,
- Red signal,
- Too fast for curve,
- Lane ends,
- School zone,
- Work zone,
- Weather ahead,
- Low tire pressure,
- Low fuel,
- Engine malfunction,
- Impending turn,
- Congestion ahead,
- Route change,
- Traveler service,
- Parking available,
- E-mail or text, and
- Excessive fuel.

Roadway type and speed were defined as:

- Arterial 35 mph,
- Freeway 60 mph,

- Rural 4-lane 35,mph, and
- Rural 4-lane 55,mph.

The key dependent variables in this study were:

- Urgency (the need for information at a certain moment), and
- Priority of information about event.

3.2.2 Procedure

Participants were presented with a variety of computer-generated driving scenarios (see Appendix A for scenario list). All clips were generated from scenarios authored using the National Advanced Driving Simulator (NADS) Interactive Scenario Authoring Tool (ISAT) and were run on the NADS MiniSim simulator platform. The presentation of the computer-generated driving scenarios took place at the Westat computer laboratory. The scenarios differed in terms of the type of event, temporal or spatial proximity, type of roadway, and travel speed. Seventy-four participants between 25-50 years of age were tested. Age ranges and gender were relatively balanced.

Participants were provided a basic description of an event and shown a simulated clip of the event. For example, a participant may have been presented with a clip of traffic moving down a four-lane roadway at normal speed following another vehicle. The lead vehicle braked and the participant's vehicle continued until just before colliding with the vehicle it was following. This demonstrates the hazard of the situation (for those scenarios where there was a potential hazard—some situations did not contain a dangerous event). The participant was shown an overall clip that shows the event almost to the hazard outcome. Then, the overall clip was sliced into subsections to show different points in time, with a sliding 5-second band. For example, a 10-second forward collision situation described above was shown in an overall clip. Then, three subclips were shown (each with accompanying questions and ratings), portraying different times to collision. Subclip 1 would last from 8.2 seconds to 3.2 seconds time-to-collision. Subclip 2 would start at 7.1 seconds away and last until 2.1 seconds, and so on. Following each clip, participants used a 10-point rating scale to respond to the question, "How important is it that you receive information about this situation right NOW?" This question was a proxy for urgency. Participants were then asked to choose one of six possible presentation prioritization schemes. Another clip of a closer moment in time followed and the process repeated. Upon the presentation of all clips from that context, a different situation (e.g., do not pass scenario) was then presented with contextual information with the same set of questions to follow. This process was repeated through all scenarios. There were two sequences of situation presentation, with sets of clips within a cluster kept in the appropriate order (distance or time from farthest to nearest).

The sequence of screenshots in Figure 3-1 provides an example of what a participant would see in a set of clips. The process then repeats with the next clip, which is a section of the scene closer to the farm tractor (see Figure 3-2).

Figure 3-1. Progression of screens and video clips, distant situation

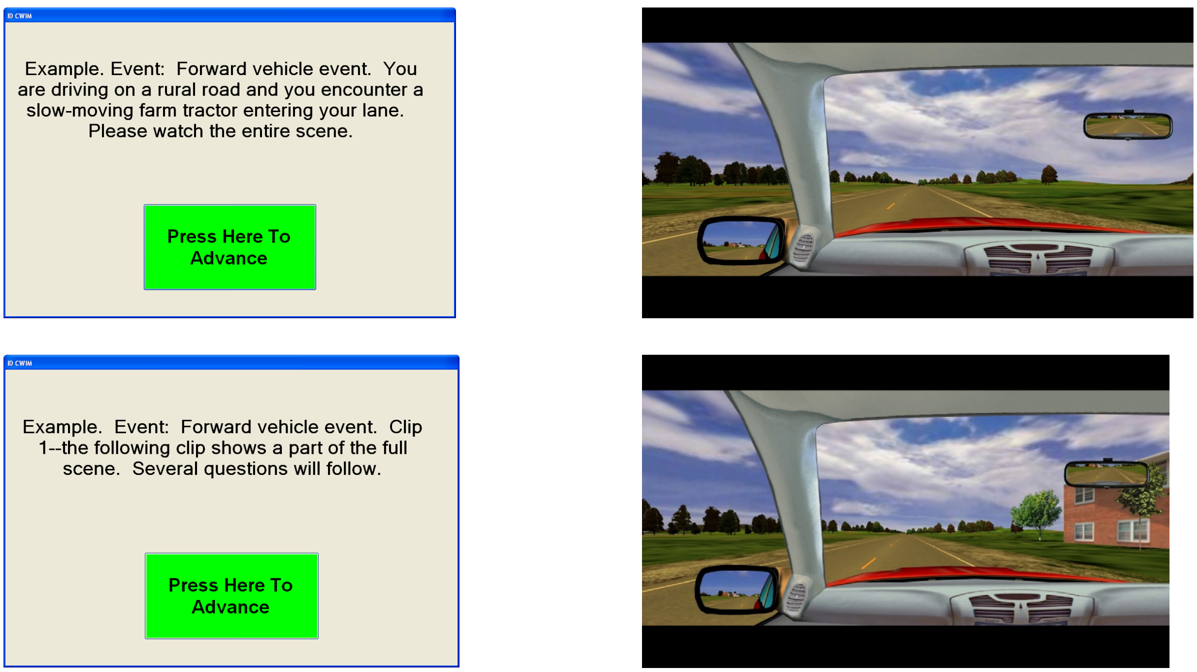
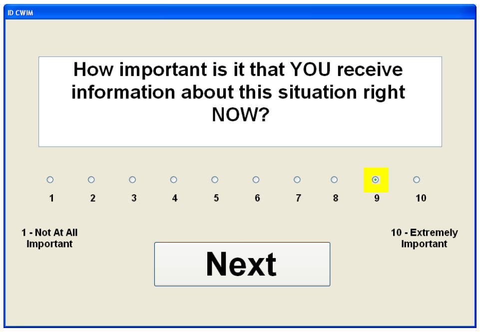
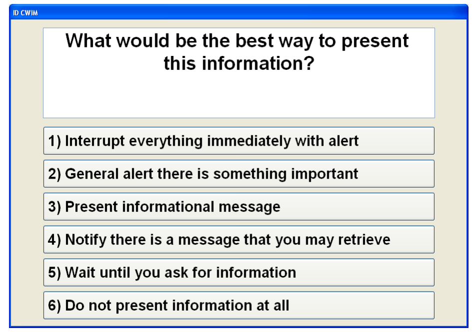


Figure 3-1. Progression of screens and video clips, distant situation (continued)

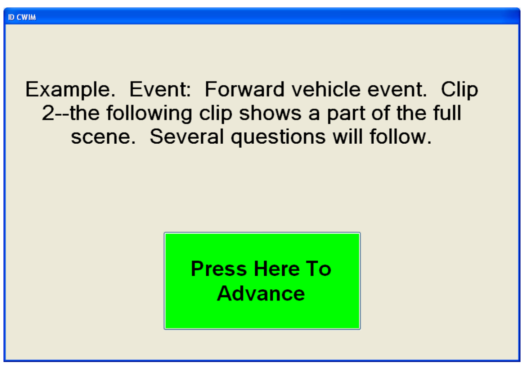


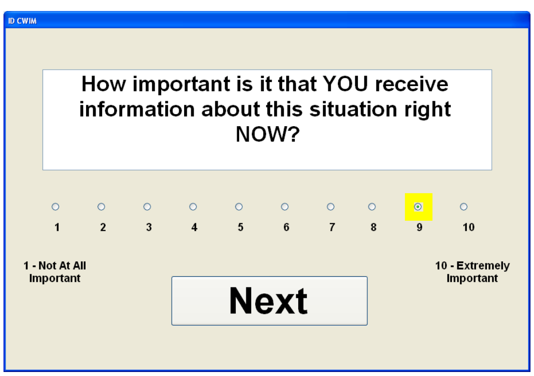
Rating screen

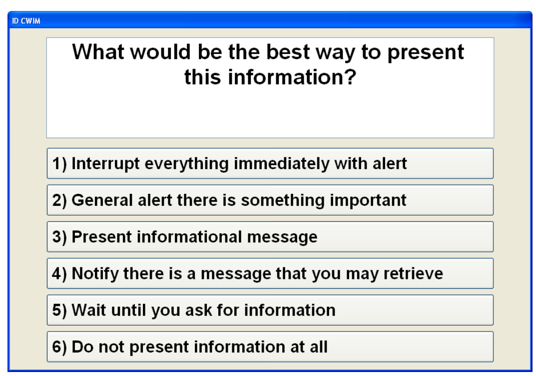


Presentation prioritization scheme

Figure 3-2. Progression of screens and video clips, closer situation







3.3 Findings

Four participants were removed from analyses because of noncompliance or inattentiveness during the session. Consequently, 70 participants' data were used in the following analyses.

The analyses were conducted in two phases based on different analytical approaches. First, several factors were identified a priori as important to perceptions of urgency and priority. We manipulated those factors—the descriptive and inferential analyses are presented below. Due to the large number of potential situations and influencing factors, there was not an attempt to completely and exhaustively cross all factors. Consequently, experimental analytical techniques are limited. The second approach is based on an exploratory examination of patterns that participants generated regardless of how we structured the items.

3.3.1 Experimental Analytical Approach

SAS PROC MIXED was used to analyze urgency and prioritization ratings for each of the dimensions. Participant was included as a random effect while the specific dimension was entered into the model as a fixed effect. The general model for each of these analyses is specified in matrix notation as:

$$\mathbf{y} = \mathbf{X}\beta + \mathbf{Z}\gamma + \varepsilon$$

where y denotes vector of observed y_i's; **X** is the known matrix of x_{ij}'s; β is the unknown fixed effects parameter vector (road type, safety message, relative distanced, or speed), Z is the known design matrix; γ is the vector of unknown random effect parameters (participants in this case); and ε is the unobserved vector of independent and identically distributed Gaussian random errors. There is also the key assumption that γ and ε are normally distributed with:

$$\mathrm{E}\begin{bmatrix}\gamma \\ \varepsilon\end{bmatrix} = \begin{bmatrix}0 \\ 0\end{bmatrix}$$

$$\mathrm{Var}\begin{bmatrix}\gamma \\ \varepsilon\end{bmatrix} = \begin{bmatrix}G & 0 \\ 0 & R\end{bmatrix}$$

"Urgency Rating" gives the significance for self-reported urgency ratings on a scale from 1 to 10, with 1 being "extremely urgent" and 10 being "not at all urgent." Similarly, "Prioritization Preference" gives the significance for self-reported prioritization preference ranging from 1 (approximates highest priority preference for a message) to 6 (lowest priority preference for a message). Priority was not given to participants in a numerical format, but rather category descriptions. Numerical values for these categories were assigned subsequently for the analyses and results presentation. For specific mean values, refer to Appendix A. The category descriptions were:

1. Interrupt everything with alert,
2. General alert – there is something important,
3. Present informational message,
4. Notify – there is a message that you may retrieve,
5. Wait until you ask for information, and
6. Do not present information at all.

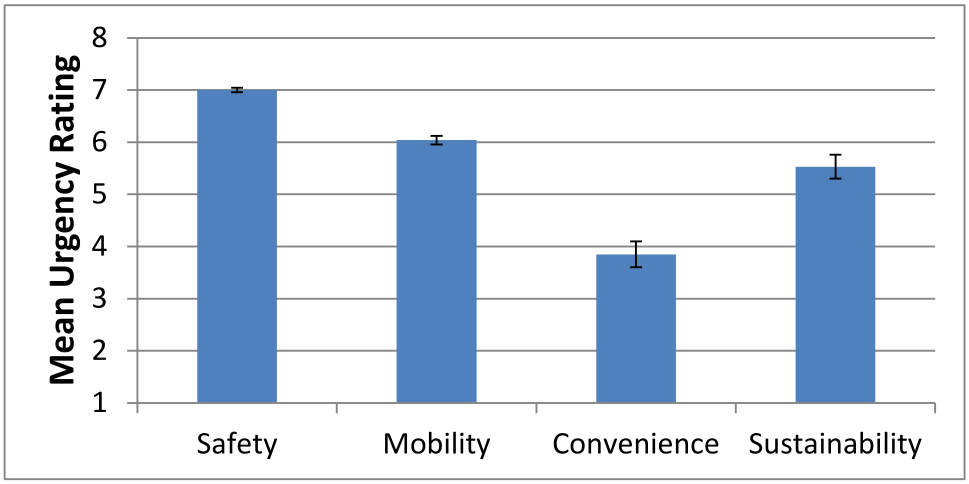
There were several factors coded for analyses based on characteristics that were non-systematically varied across items:

- Message type: 4 levels: safety, mobility, convenience, or sustainability (see Appendix A for list of messages by type).
- Road type: 3 levels: rural 4-lane highway, arterial, or freeway.
- Relative distance: 5 levels: nearest (D1), nearer (D2), farther (D3), farthest (D4), and non-applicable (see Appendix A for list of messages by distance level).
- Speed: 2 levels: 35, 55/60.

3.3.2 Results

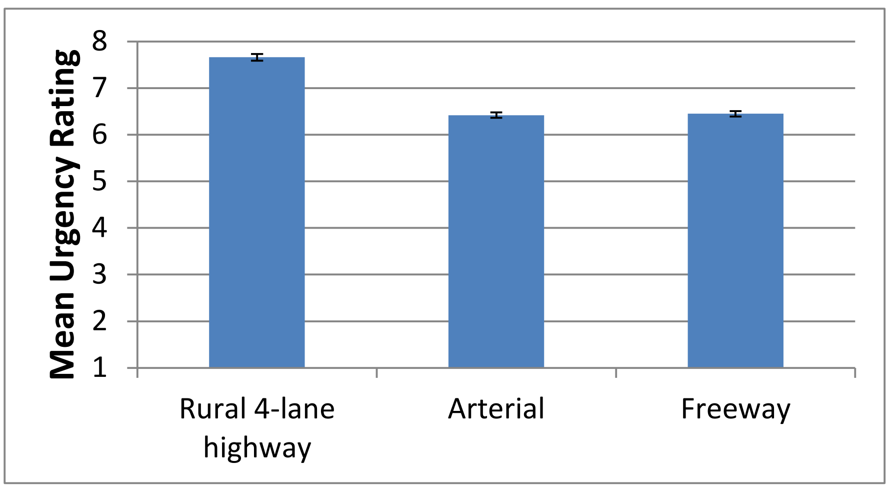
Urgency. Several factors affected the urgency with which participants perceived driving situations. First, the type of message situation with respect to safety had a significant impact on level of urgency perceived, $F = 84.38$, $p < .05$. Not surprisingly, situations focusing on convenience and sustainability were rated as the least urgent ($M = 3.85$ and 5.53, respectively), while safety-related situations were rated the most urgent ($M = 7.00$) (see Figure 3-3). Interestingly, mobility-related situations such as impending turns were perceived as the second most urgent situation, yielding a relatively high mean = 6.04. There was a significant distance by safety situation interaction, $F = 7.71$, $p < .05$. The interaction is largely driven by more urgent ratings at D3 for the safety situations.

Figure 3-3. Mean urgency rating by type of situation



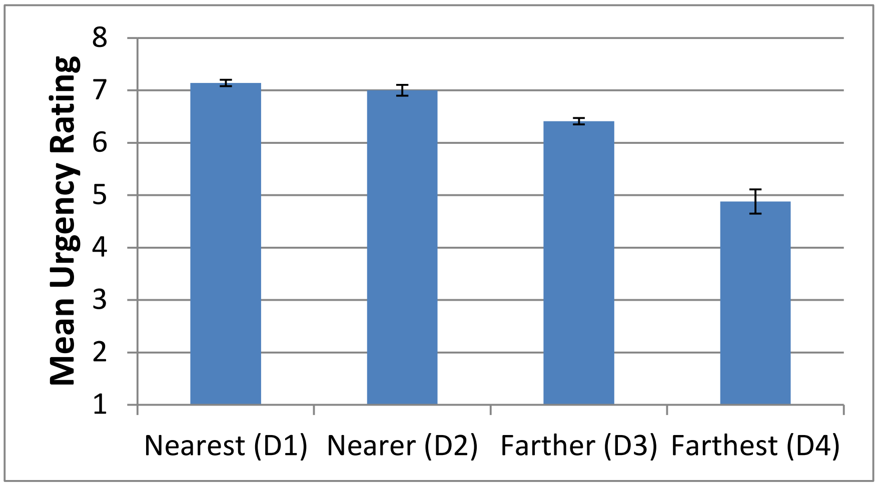
In addition to safety issues impacting urgency perception, road type also had a significant effect, $F = 52.86$, $p < .05$. Situations on rural 4-lane roads were rated as more urgent ($M = 7.66$) than situations on arterials and freeways ($M = 6.42$ and 6.45, respectively) (see Figure 3-4).

Figure 3-4. Mean urgency rating by road type



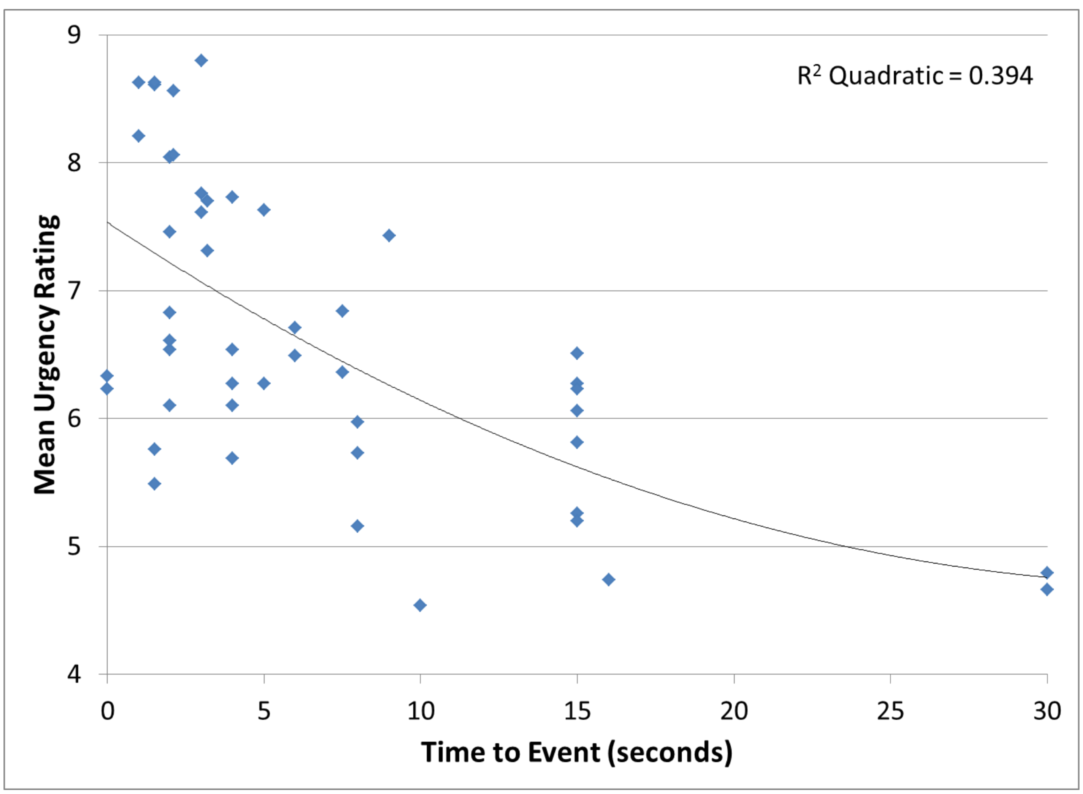
Distance- or time-to-event was also significant, $F = 38.91$, $p < .05$. There was a predicted negative function from nearest (D1) to farthest (D4) (in distance or time). D1 and D2 were rated as the most urgent, but not significantly different between the two ($M = 7.14$ and 7.00, respectively) (see Figure 3-5). There was a slight but significant drop-off in urgency rating at the next level of D3 ($M = 6.41$) and a much more distant drop-off in urgency of the D4 situations ($M = 4.88$).

Figure 3-5. Mean urgency rating by proximity to event



There is also a curvilinear relationship between time-to-event (for the subset of situations that occur between 0 and 30 seconds time to collision) and mean urgency rating. Figure 3-6 plots mean urgency rating and time to event (where applicable) (see Appendix A for scenario definitions that are denoted by the numbers in the graph).

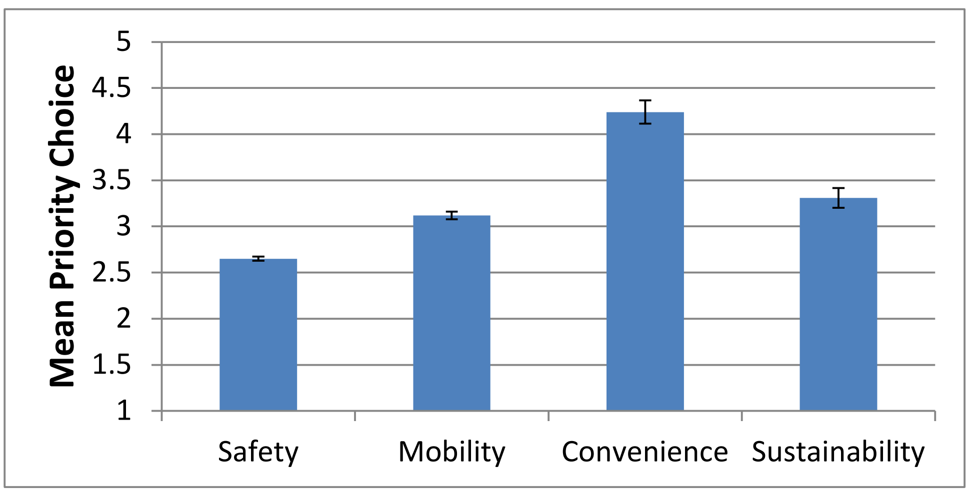
Figure 3-6. Mean urgency rating as a function of time to event



Finally, there was no significant impact of speed on urgency ratings, but there was an interaction of speed and distance, $F = 3.34$, $p < .05$. The interaction is driven by a reversal of the descending linear decline in urgency rating by distance at higher speeds. That is, for lower speeds, the D1 situations are perceived to be as urgent as the D2 situations. But, at higher speeds, D2 items are considered more urgent than the D3 items, and so on. Also, speed was not as perceptible as the other characteristics when viewed in a laboratory setting, based on the granularity of simulation image delivery and lack of kinesthetic inputs.

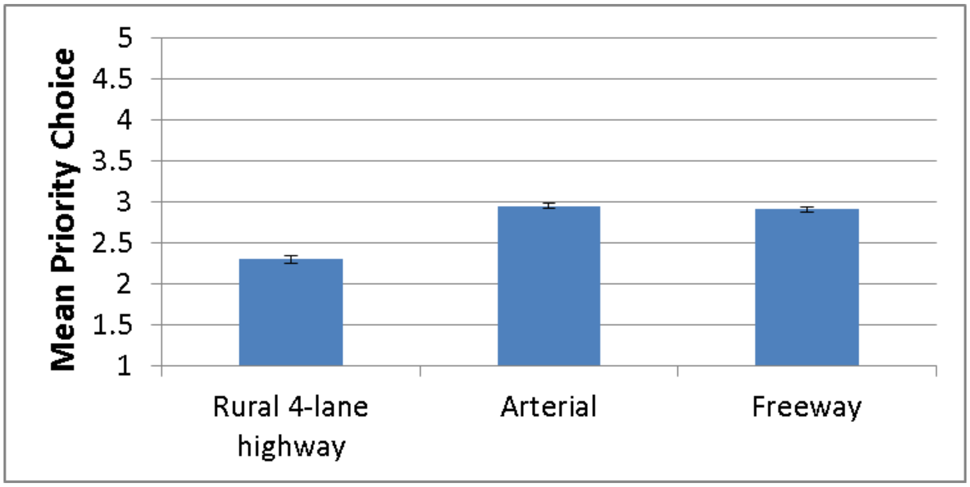
Priority Preference. Several factors affected the participant's priority preference for having information about a situation presented. First, the type of message situation with respect to safety had a significant impact on priority preference, $F = 65.44$, $p < .05$. Note that higher priority is equal to a lower rating. Not surprisingly, situations focusing on convenience and sustainability were rated as the lowest priority ($M = 4.24$ and 3.31, respectively), while safety-related situations were chosen as the highest priority ($M = 2.65$) and mobility was the next highest ($M = 3.12$) (see Figure 3-7).

Figure 3-7. Mean priority choice by type of situation



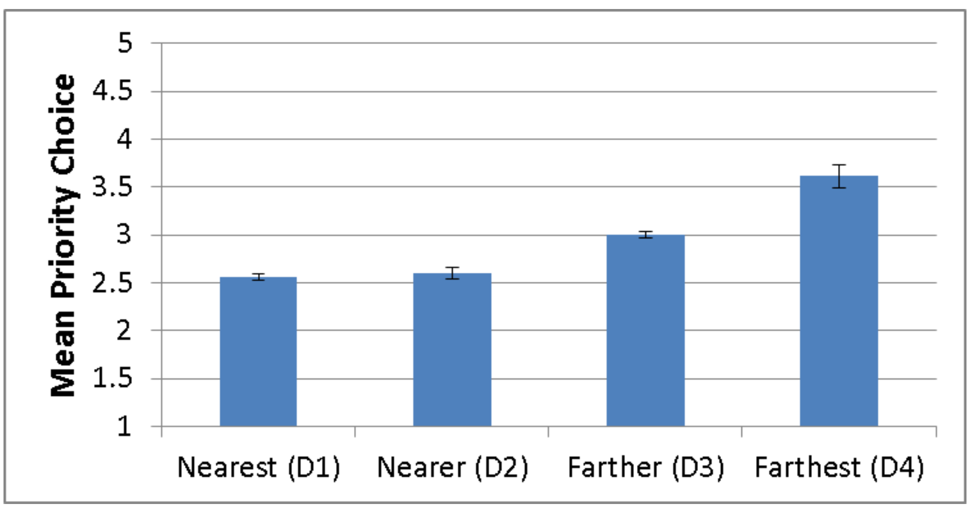
In addition to safety issues impacting priority preference, road type also had a significant effect, $F = 35.27$, $p < .05$. Situations on rural 4-lane roads were given higher priority ($M = 2.30$) than situations on arterials and freeways ($M = 2.95$ and 2.91, respectively) (see Figure 3-8).

Figure 3-8. Mean priority choice by road type



Distance- or time-to-event was also significant, F = 25.44, $p < .05$. The D1 and D2 situations were given almost identical priority, but not significantly different between the two (M = 2.56 and 2.60, respectively) (see Figure 3-9). There was a slight but significant drop-off in priority preference at the D3 level (M = 3.00) and a lower priority drop-off of the D4 situations (M = 3.61). There was also a significant interaction with road type, but this was an artifact of the lack of D3 events on rural 4-lane highways.

Figure 3-9. Mean priority choice by proximity to event



Finally, there was no significant impact of speed on priority preference ratings, $F < 1$. But, it should be noted that there was an interaction of speed and distance, F = 4.30, $p < .05$, which may have obscured an effect of speed on priority preference. The interaction is being driven by a reversal of the descending linear increase in priority preference by distance at higher speeds. That is, for lower speeds, the D1 situations are perceived as similar in priority as the D2 items. But, at higher speeds, D2 items are considered higher priority than the D3 items, and so on. Also, speed was not as perceptible as the other characteristics when viewed in a laboratory setting, based on the granularity of simulation image delivery and lack of kinesthetic inputs

Relationship between Urgency and Priority. Participants demonstrated a strong relationship between ratings of urgency and the prioritized need for information across scenarios. Across all situations, there was a strong and significant -.67 nonparametric (Kendall's Tau $_b$) correlation. Figure 3-10 plots urgency rating by priority rating for each scenario (see Appendix A for scenario definitions that correspond to the labels below). Figure 3-11 plots the modal level of priority rating by mean urgency rating.

Figure 3-10. Relationship between mean urgency rating and mean priority choice

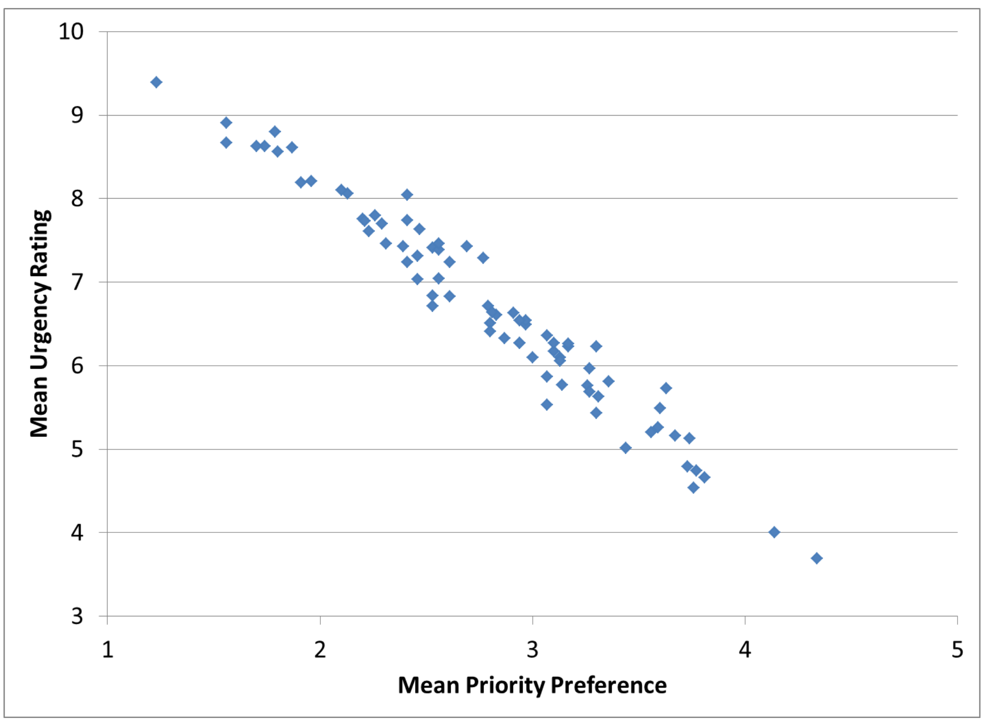
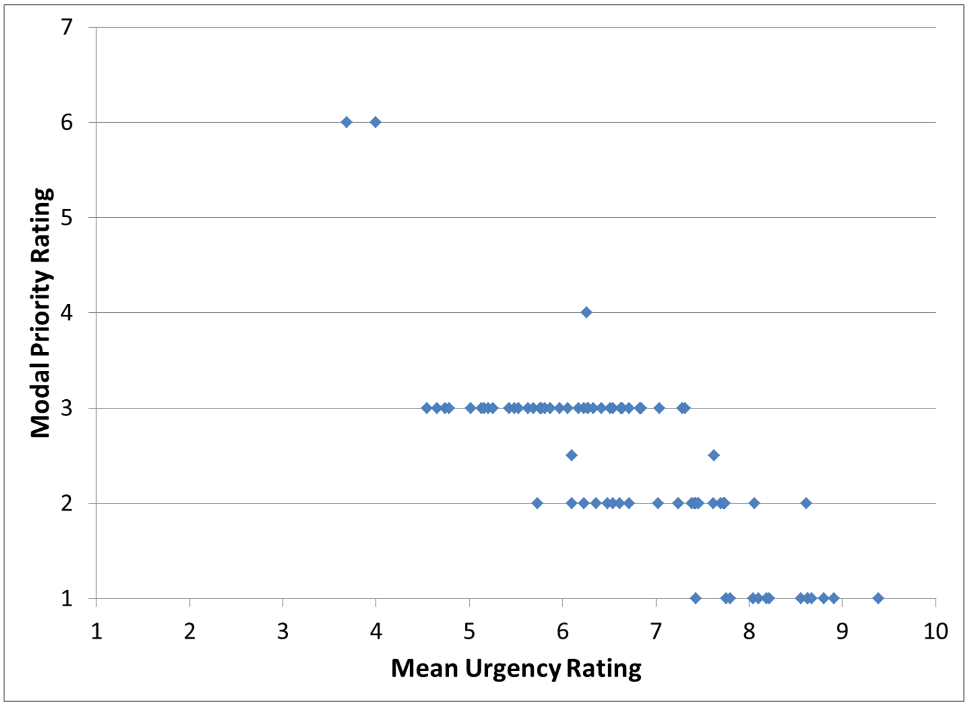


Figure 3-11.   Modal level of priority rating by mean urgency rating



3.4 Discussion

The objective of this experiment was to determine what characteristics affect participant's perceived urgency and priority, as well as explore the natural mental models of categories individuals overlay across situations. Overall, the type of safety message, the type of road, and distance/time to event all had a significant impact on urgency and priority ratings that participants gave to a particular situation. In addition, there are also a variety of interactions denoting the complex nature of both perceived urgency and priority. Participants also demonstrated a high linkage between their perception of urgency and priority for a given situation (not surprisingly, with more urgent situations being given higher priority). As expected, there was also a strong relationship between time to collision and urgency, with less time to collision leading to stronger perceived urgency.

Based on these findings and the general characteristics of events that were manipulated, we believe three potential groupings emerged to describe natural levels of perceived urgency across situations. These three general categories are consistent with expectations and other experiments in this report:

- High threat and immediate action required;
- Caution, non-immediate action required; and
- No urgency, no action required.

Alerts for a given system should be framed within these natural categories of expectations in which participants perceive urgency.

4.0 EXPERIMENT 2: URGENCY CODING WITHIN AND ACROSS MODES

4.1 Introduction

The objective of the experiment was to develop and validate a method to determine and compare perceived urgency across visual, auditory, and tactile modalities and to compare the influence of various stimulus parameters within each of these modalities.

Urgency mapping is critical to appropriate display design. Within the CV context, appropriate urgency mapping will be particularly important. Connected vehicles will be capable of presenting a multitude of displays and information for a wide range of criticalities (i.e., from hazard warnings to email alerts). Additionally, these advanced vehicles will be capable of presenting information to the driver in several modalities and combinations of modalities. The aim of this project was to provide a means of determining how perceived urgency is scaled across visual, auditory, and tactile modalities in order to provide guidance for display design within a CV context. A particular focus was placed on examining the perceived urgency of tactile signals since little research currently exists in this domain. A series of experiments sought to determine scales of perceived urgency across several parameters of each modality with varying levels of context. Experiments were organized into three separate series. As explained in more detail below, the first series examined perceived urgency, alerting effectiveness, and acceptability of signals in each modality when little or no context was provided. This low context series allowed examination of a number of key parameters and most closely resembled the majority of studies in the existing literature. The second series involved ratings for signals presented within a simulated driving context though not signifying any particular event. It allowed examination of the potential influence of a driving context on ratings. Finally, a validation study was then carried out in a driving simulation context by using the scales developed in the initial experiments to design collision warnings of three levels of urgency in each of the three modalities. Warnings predicted to be of low, medium and high perceived urgency based on the ratings of the first two series of studies were developed and deployed to signify potential collision events. Behavioral responses to the event as well as post-drive ratings were used to validate the subjective parameter estimates obtained in the first two series.

4.2 Method

4.2.1 Experiment 2A: Method

The general approach was to conduct a series of psychophysical experiments and apply Stevens' Power Law (Stevens, 1957) to allow comparison of perceived urgency, annoyance, and acceptability across and within modalities. This approach and basic procedure has been used successfully in previous research developing urgency scales in the auditory modality (e.g., Hellier & Edworthy, 1999; Hellier, Edworthy, & Dennis, 1993). Stimuli were presented via a custom program developed in a MATLAB framework. For each experiment, participants were presented with stimuli of a specific modality (visual, auditory, or tactile) and asked to rate the perceived urgency, annoyance, and acceptability of each. Acceptability in these experiments was verbally defined as "likeliness to own or operate a vehicle with a similar alert." Participants were instructed to imagine they were in a driving context while rating these items on a 0-100 scale, 0 being the least urgent, annoying, or acceptable and 100 being the most. These items of interest were rated on a slider scale where participants could select the location on the scale between 0-100 that they felt the stimuli should be rated after it had been presented. For each modality, the stimuli were presented in a randomized order. Each stimulus was presented three times over the course of the experiment and averaged ratings across the three presentations were then used to compute the final rating. A list of each of the parameters examined in the auditory, visual and tactile modality can be found in Table 4-1. A summary of the key experimental manipulations is presented followed by a more detailed description of the specific experiments.

- Auditory, visual, and tactile modalities were examined.
- Perceived urgency, annoyance, and acceptability ratings for key parameters in each modality were obtained.

- Each modality was examined at three levels of context (ranging from simply rating signals being presented while looking at a static picture of a dashboard to while engaged in a simulated driving task to responding to signals in each modality in conjunction with a potential collision event in a high fidelity driving simulator).
- Scales were developed from the ratings obtained to allow cross-modal comparison of urgency ratings.
- Scales were validated through their use in constructing new alerts in each modality and obtaining both behavioral responses to the alerts as well as post-drive subjective ratings.

Visual Pilot Study. Twenty-seven college undergraduates (8 male, 19 female) between the ages of 18 and 34 (mean, 22.07) participated in the study. All participants were run on a 6BU PB1 E-4500D Gateway PC with an Intel 82945G Express Chipset video card with Intel Graphics Media Accelerator Drive. All visual stimuli were presented on a Samsung 24” LCD monitor.

The visual parameters investigated were background color and alert word. Background colors used were red, orange, and yellow. The alert words that were used for this experiment were “brake,” “danger,” “notice,” and “warning.” When using the red background words were presented in white font. When using the orange and yellow background, words were presented in black. The colors and words were chosen based on Wogalter, Conzola, and Smith-Jackson (2002). We also added the word “brake” to the alert words since it is already being used in vehicles. The colors were made on a Dell Latitude D820 laptop using an RGB color scale. Each color was then transformed using a code based on the Bradford color transformation. The color yellow was calculated as 580 nanometers (nm), orange was calculated as 625 nm, and red was calculated as 645 nm. All stimuli were presented in a dashboard.

Visual 1. Thirty-five college undergraduates (15 male, 20 female) between the ages of 18 and 43 (mean, 21.11) participated in the study. All participants were run on one of two 6BU PB1 E-4500D Gateway PCs with an Intel 82945G Express Chipset video card with Intel Graphics Media Accelerator Drive. All visual stimuli were presented on a Dell 24” ST2420L monitor.

The three visual parameters investigated were background color, alert word, and flash rate. Background colors used were red, orange, yellow, and green. The colors were made on a Dell Latitude D820 laptop using an RGB color scale. Each color was then transformed using a code based on the Bradford color transformation. The flash rates were coded in MATLAB based on the pulse rates from Hellier et al. (1993).

The color red was defined as 255R, 0G, and 0B, which were calculated as equal to a wavelength of 645 nm. The color orange was defined as 255R, 137G, and 0B, which was equal to 615 nm (approximately halfway between yellow and red). When conducting the experiment, the color orange was found to show up lighter on the monitors used for testing than on the laptop used for creation. This led to a mini color matching experiment conducted to determine the final wavelength to be used in later calculations. Thirteen participants volunteered for the color matching experiment; all were graduate students. They were shown the stimulus on the experimental monitor and asked to change the color of a color box on the laptop used for stimuli creation until the two colors matched. The average rating for the orange stimuli was 608 nm, which was the number used later in calculations. Finally, the color yellow was defined as 255R, 255G, and 0B and was calculated as 580 nm (approximately halfway between green and red). Green was defined as 0R, 255G, and 0B and was calculated as 510 nm. These parameters led to colors that closely matched those used in the Visual Pilot Study, though the specific RBG system was not used in the Visual Pilot Study.

Flash rate stimuli lasted 3000 ms, the amount of time each stimulus was visible was 200 ms per flash with a between flash interval ranging between 475 and 9 ms. Rate was derived from the formula Total Time/ (Flash time on + Inter flash time). Note that Flash rate is the visual analog to pulse rate for auditory and tactile stimuli as discussed below. Flash and pulse rates are more intuitively discussed as interpulse intervals (IPIs) defined as the time interval between subsequent flashes/pulses. However, IPI generally results in a negative relationship (meaning that decreases in IPI are associated with higher ratings of urgency) and therefore some researchers choose to use pulse rate rather than IPI.

The words used were danger, warning, brake, and notice. The words were printed in black on the green, yellow, and orange backgrounds but in white on the red background for better visibility. All stimuli were presented embedded in a dashboard.

Auditory 1a. Thirty-two college undergraduates (16 male, 16 female) between the ages of 18 and 34 (mean, 23.56) participated in the study. All participants were run in a sound-attenuated laboratory on an Optiplex 745 Dell PC with a SoundMAX Integrated Digital HD Audio Driver Analog Device sound card. All auditory stimuli were presented through Sennheiser stereo headphones.

The stimuli presentation was as follows: Participants would receive a fixation cross on a black screen for 500 ms followed by an auditory stimulus. Immediately following the stimulus, the three rating sliders for urgency, annoyance, and acceptability appeared in succession respectively. Participants received feedback as to the exact value they were selecting and were able to modify their selection on each slider if they so desired.

The three auditory parameters investigated were fundamental frequency, intensity, and pulse rate. Fundamental frequency and pulse rate stimuli were created following the specifications of Hellier, Edworthy, and Dennis (1993). Each stimulus was built by variations on a basic pulse created in the freeware program Praat. The basic pulse was a 200 ms sine wave (20 ms on/offset) with 15 harmonic components at 300 Hz. Because we were interested solely in main effects in this experiment, only one parameter was manipulated at a time while all other parameters of the stimulus were held constant to the basic pulse as described above. Unless intensity was being specifically manipulated, the basic pulse was presented at a sound pressure level (SPL) of 75 decibels (dB). In keeping Patterson's (1990) guidelines, all stimuli were kept at least 20 dB louder than the ambient background noise (40 dB SPL) in the experiment room. Fundamental frequency of the basic pulse also only varied from 300 Hz when it was being specifically manipulated.

Fundamental frequency stimuli consisted of six basic pulses of the same frequency played in succession with a pulse duration of 200 ms. In the standard, there was no silence between pulses. For example, a 320 Hz frequency stimulus would consist of six 200 ms basic pulses, each with a fundamental frequency of 320 Hz played in succession for a total duration of 1200 ms. The 20 ms onset/offset allowed the pulses to be discerned without the need for silence between pulses.

Intensity stimuli were structured in a similar fashion: Each stimulus consisted of six basic pulses at 300 Hz with a pulse duration of 200 ms and a total duration of 1200 ms; the intensity of each stimulus was varied through Adobe Audition CS 5.5. Using a Brüel & Kjær sound level meter, we verified the intensity of each stimulus through the headphones. Decibel measurements were taken from the individual pulses rather than the stimulus as a whole to avoid including the decreasing intensity of the onset and offset in our measurement. There was no evidence of intensity disparity between the left and right channel.

Pulse rate stimuli consisted of between four and 12 basic pulses at 300 Hz, the interpulse interval (IPI) varied from 475 to 9 ms. The duration of each stimulus approached, but did not exceed, 2500 ms so each stimulus varied slightly in total duration. Pulse rate was derived via the following formula from Hellier et al. (1993):

Pulse rate = stimulus duration / (pulse duration + interpulse interval)

The 2500 ms duration was used to standardize the rates for all stimuli although the total durations of the stimuli varied slightly. For example, a stimulus with a pulse rate of 3.69 would consist of four basic pulses of 200 ms each separated by 475 ms of silence. Because following the last pulse was simply 275 ms of silence, the total true duration of this stimulus is 2225 ms rather than 2500 ms.

Auditory 1b. Thirty-one college undergraduates (9 male, 22 female) between the ages of 18 and 25 (mean, 20.08) participated in the study. Auditory 1b followed the same methodology as Auditory 1a, however, in order to keep the context between auditory and visual experiments comparable, we included the image of an automobile dashboard while the auditory stimulus was being presented and in place of the fixation cross.

Tactile 1. Nineteen college graduates and undergraduates (6 male, 12 female, 1 undeclared) between the ages of 18 and 25 (mean, 20.47) participated in the study. All participants were run in the same experiment room and computer setup as the auditory studies. Tactile stimuli were presented through a single C2 tactor and a RadioShack amplifier that was modified to act as a microcontroller. Through this set up, the tactor acted as a speaker. Tactile stimuli were generated by playing audio files through the computer's sound card and output via the tactor. The tactor was affixed to the top of the participants arm approximately 1 inch above his or her wrist. An athletic sweatband (5.75 cm length; 15 cm diameter) was used to hold the tactor in place. A single layer of store brand plastic wrap was also wrapped around the participant's arm beneath the tactor to prevent any perspiration from coming in contact with the experiment equipment. The participant also listened to white noise to prevent the sounds from the tactor to confound the experiment.

Pulse rate was the tactile parameter manipulated. Similar to Auditory 1a, each stimulus was based on a basic pulse following the Hellier et al. (1993) specifications and were created in Praat. However, to produce optimal tactor response, the basic pulse consisted of a single sine wave with no harmonic components at 250 Hz. The length of the pulse remained 200 ms with 20 ms onset/offset and the formula for calculating pulse rate also remained identical to Auditory 1a. As with Auditory 1b, while the tactile stimuli were presented, an automobile dashboard was on screen to give the driving context.

4.2.2 Experiment 2B: Method

Experiment 2B used the general experimental protocol used in Experiment 2A with the primary exception that participants experienced and rated stimuli while engaged in a simulated driving task presented via a medium fidelity driving simulator (Realtime Technologies, Inc. [RTI]). Specifically, the participant was engaged in a car following task while intermittently being presented with stimuli to rate. Another difference is that in Experiment 2B, the time interval between presentations of stimuli ranged randomly within an interval of 10-15 s, with an average of 12 s. This manipulation allowed participants to maintain adequate driving performance. An additional difference was that in Experiment 2B, response time for the initial rating was obtained. Participants were instructed to maintain performance on the driving task at all times and to make their ratings as soon as they safely could without disrupting their driving performance.

One final difference was that in Experiment 2B, all participants provided ratings for each of the three modalities. Participants were 29 college undergraduate and graduate students (8 male, 21 female), ranging from 20 to 30 years of age (m = 25.03). All reported no vision or hearing problems and all had a driver's license.

- ***Visual 2.*** Visual stimuli were very similar to Experiment 2A, except that they were modified to be more like the auditory stimuli. We did this by holding two parameters constant while changing one and changing the time presented from 3 seconds to 2.5 seconds. For changing color, we used green, yellow, orange, and red, like Experiment 2A, Visual 2, with no flash rate and the word "warning." For signal word, the words used were "notice," "brake," "warning," and "danger." These stimuli were all yellow and had no flash rate. For flash rate, all seven flash rates were used. These stimuli were all yellow with the word "warning."
- ***Auditory 2.*** The auditory stimuli for this experiment were the same as Experiment 2A, Auditory. The only change was that the intensity parameter was removed and we only examined the fundamental frequency and pulse rate stimuli.

- ***Tactile 2.*** The tactile stimuli for this experiment were the same as Experiment 2A. A list of each of the parameters examined across the three modalities in total across Series 2A and 2B is provided in Table 4-1 below.

Table 4-1. Parameters examined in Experiments 2A and 2B

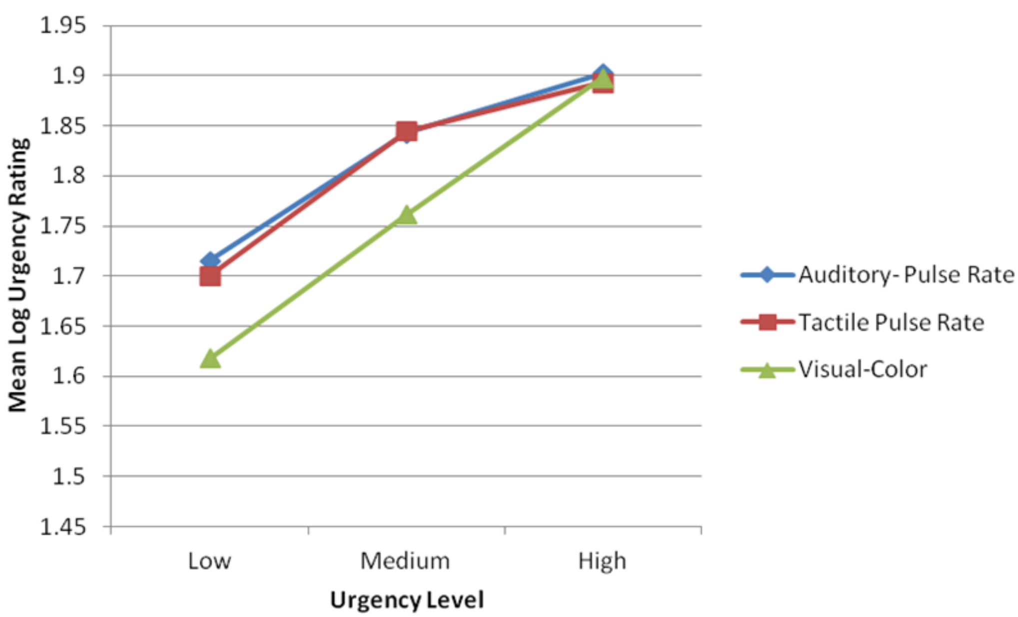
- Auditory
  - Frequency
  - Pulse Rate or Interpulse Interval (IPI)
  - Intensity or "loudness" (dB level)
- Visual
  - Color (text and background)
  - Word Choice
  - Flash Rate (visual pulse rate) or Interpulse Interval (IPI)
- Tactile
  - Pulse Rate or Interpulse Interval (IPI)

4.2.3 Experiment 2C: Validation Study Method

Design.

Experiment 2C was designed to validate the urgency scales obtained from Experiments 2A and 2B. It was conducted in the high fidelity motion base driving simulator (RTI) with the primary objective of examining the validity of the urgency scales obtained in Experiments 2A and 2B when signals in each modality were presented in conjunction with a simulated potential collision event. Four driving scenarios containing potential collision scenarios were implemented. In each scenario, participants were asked to follow a lead vehicle which was yoked to the participants' car so that it maintained a relatively consistent headway of roughly 2 s despite minor fluctuations in the participant's speed. Each scenario contained one potential collision event. In two of the scenarios the lead car applied its brakes unexpectedly and came to a complete stop. One lead car braking event occurred on a rural road and another occurred on a highway. A third scenario consisted of a vehicle that cut in front of the participant's vehicle and then decelerated rapidly resulting in the need for the participant to make an evasive maneuver to avoid a collision. In the fourth event the lead car slowed down to make a left hand turn and the subject vehicle also slowed in preparation to make the left hand turn. A car approaching the subject vehicle from behind failed to slow, creating a rear-end collision threat. In this instance the participant needed to continue swiftly through the left hand turn to avoid the collision. These events are referred to as the rural brake event, highway brake event, cut-in event, and left turn – rear end event, respectively. Further descriptions and illustrations of the collision scenarios can be found in Appendix B. Collision scenarios were presented to participants in counterbalanced order in conjunction with one of four levels of urgency in one modality (no warning-control, urgency levels of low, medium, and high). A mixed design was implemented with urgency level of the warning as a within-subjects factor such that each participant drove through each of the four scenarios and received a warning at each of the three levels of urgency plus one collision event with no warning. Warning modality was a between-subjects factor. The urgency levels for each modality were determined by the results of Experiments 2A and 2B. Average log transformed and non-transformed ratings of perceived urgency for the parameters used from Experiments 2A and 2B are illustrated in Figure 4-1.

Figure 4-1. Ratings of urgency obtained averaged across Experiments 2A and 2B for the stimuli used to construct low, medium, and high urgency warnings in Experiment 2.3



Warnings

Visual Warning. The visual warning was presented as a head-up display on the simulated windscreen. The low and medium urgency level warnings consisted of the word "WARNING" presented in black font on a green and yellow background, respectively. The high urgency level consisted of the word "WARNING" presented in white font on a red background. Figure 4-2 illustrates the visual warnings used.

Figure 4-2. Example of the visual warnings implemented in Experiment 2C.

Auditory Warning. The auditory warnings were presented through the simulator's speakers at an intensity approximating 15 dB above ambient background level (~80 dB). Each warning consisted of pulses of a tone with a fundamental frequency of 300 Hz with 5 harmonics, a pulse duration of 200 ms and a total duration of approximately 2500 ms. Urgency was manipulated by repeating the individual pulses at specific IPIs taken from Experiments 2A and 2B. Specifically, the low urgency alert had an IPI of 302 ms, the medium urgency alert had an IPI of 118 ms, and the high urgency alert had an IPI of 9 ms.

Tactile Warning. Tactile warnings were presented using a tactor seat which consisted of eight tactors (tactors were Engineering Acoustics Inc. C-2 model). For each tactile warning four tactors were used and the same four were used for each level of urgency. Presentation of only four out of the possible eight tactors were only were used to avoid presenting too intense of a vibration. The front two and the back two were used. As with the auditory warnings, urgency was manipulated by varying the IPI at levels determined to be appropriate in Experiments 2A and 2B. The IPI for the low urgency warning was 238 ms, the medium urgency warning was 118 ms, and the high urgency warning was 50 ms.

Procedure

Participants were asked to drive as they would normally drive, obeying all traffic laws, signs and posted speed limits. Participants were also engaged in a distraction task consisting of a peripheral detection task (PDT). For the PDT task participants held a small response button in their dominant hand and responded as quickly as possible when they detected the onset of a red light emitting diode (LED) in one of nine locations. LED lights were located around the periphery of the visible scene at approximately the level of the top side of the dashboard. LEDs were equally spaced with three on the left, three on the right and three in the driver's field forward view and were programmed to come on for a duration of 1 s (during which the participant had to respond). The interstimulus interval varied between 3 to 5 seconds after either the participant's response or the end of the 1-s trial. Three of the nine LEDs were presented along the field forward view and three LEDs were presented on each side covering a total range of approximately 180 degrees.

Participants were 66 volunteers ranging in age from 18 to 60 (M = 24.12, SD = 7). All reported normal or corrected to normal vision and hearing and all possessed valid U.S. driver's licenses. Participants received warnings in only one modality. There were 22 participants in the visual condition, 21 in the auditory condition, and 23 in the tactile condition. In each scenario (counterbalanced across modality of the alert) participants would experience a high collision situation. In all but the control conditions, an alert was initiated at a time to collision (TTC) of 1.8 s. After completing the four drives, participants were asked to rate the urgency levels, annoyance, and acceptability of the three stimuli in the modality they had just experienced during the drives. In addition to the ratings, the primary driving performance metrics of interest were the proportion of crashes, crash severity (defined as percent speed reduction for those who crashed), and response time for the initial collision avoidance maneuver (i.e., generally brake response time [BRT]) or steering wheel response, except for in the Left Turn scenario, which often required acceleration to avoid the collision).

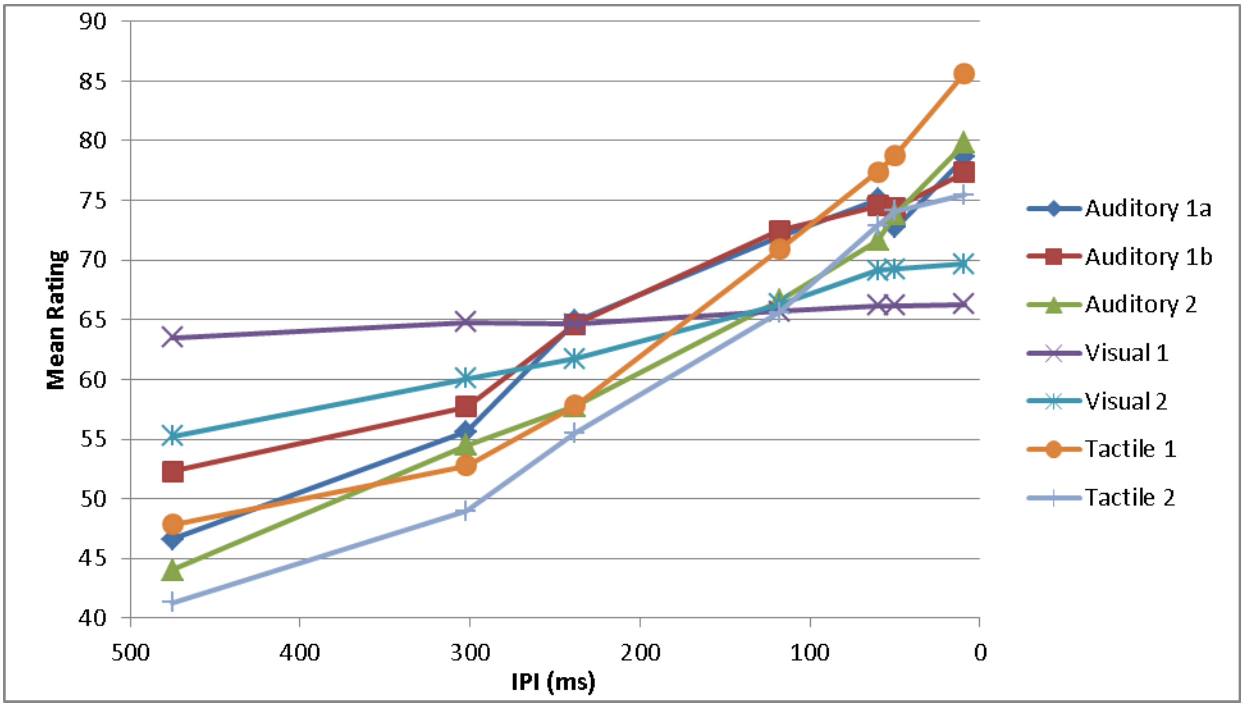
4.3 Findings

4.3.1 Experimental Analytical Approach

The subjective rating results for perceived urgency, annoyance, and acceptability were computed in the same way in all experiments in this series. First, data were log transformed to normalize the data (see Figure 4-2). Then we computed Stevens' Power Law for the log transformed values to allow comparison across modalities and parameters. Specifically, we used the formula $\log(S) = a \log(I) + \log(K)$, where S equals the subjective rating, K is a constant determined by the unit of measurement, I is the physical stimulus parameter (i.e., pulse rate, intensity) and a is the power exponent that is determined by the slope of the line derived from the linear relationship between the log transformed subjective ratings and the log transformed physical parameters: $S = KI^a$.

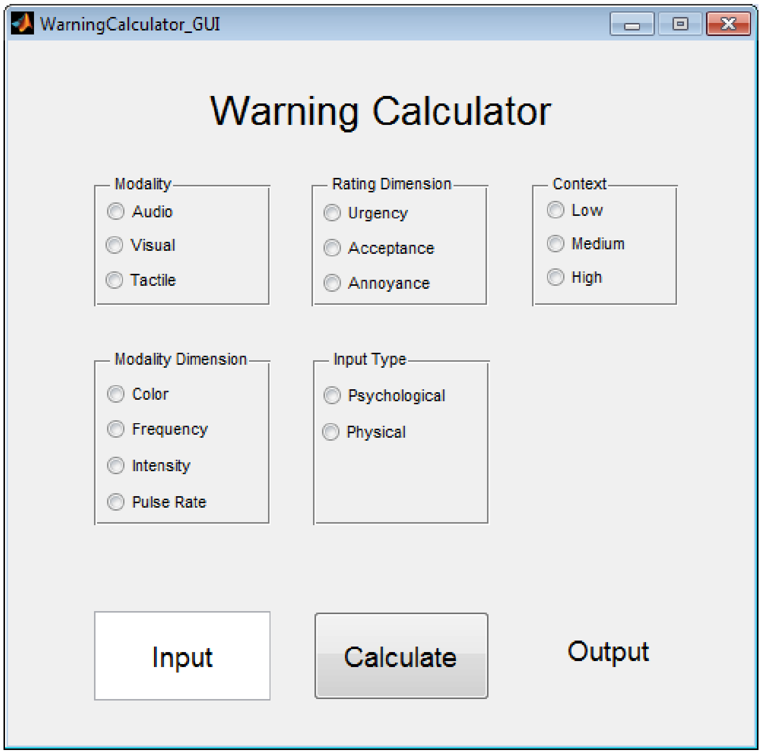
The average perceived urgency ratings prior to transformation for the interpulse interval (IPI) parameter in the visual, auditory, and tactile modalities are illustrated in Figure 4-3.

Figure 4-3. Comparison of mean urgency rating across modalities as a function of interpulse interval



The parameters obtained in Experiments 2A and 2B were used to construct a prototype of a developer's tool for determining the relationship between perceived urgency and various physical dimensions of visual, auditory, and tactile modalities. A prototype tool is illustrated in Figure 4-4. The tool allows a designer or researcher to enter a desired urgency level and then obtain the predicted physical parameter needed to achieve this urgency level in a given modality. Or conversely, the physical parameter can be entered and the tool will calculate the expected perceived urgency level that will result if that physical stimulus is used. At present the developer's tool is in a preliminary form. It contains only values for the specific parameters examined in Experiment 2A and 2B that are discussed in this report.

Figure 4-4. Prototype developer's tool



4.3.2 Experiment 2C Results

Post-Drive Ratings

All the post-drive ratings were log transformed, like the ratings in Experiments 2A and 2B. Results are illustrated in Figures 4-5 through 4-7.

Figure 4-5. Subjective ratings in the auditory modality

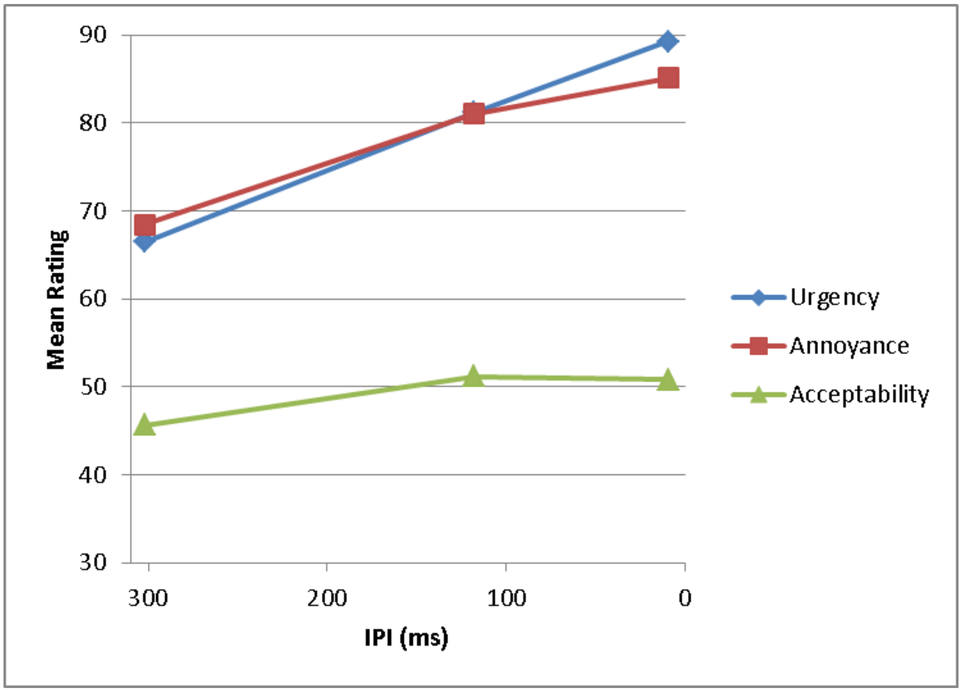


Figure 4-6. Subjective ratings in the visual modality

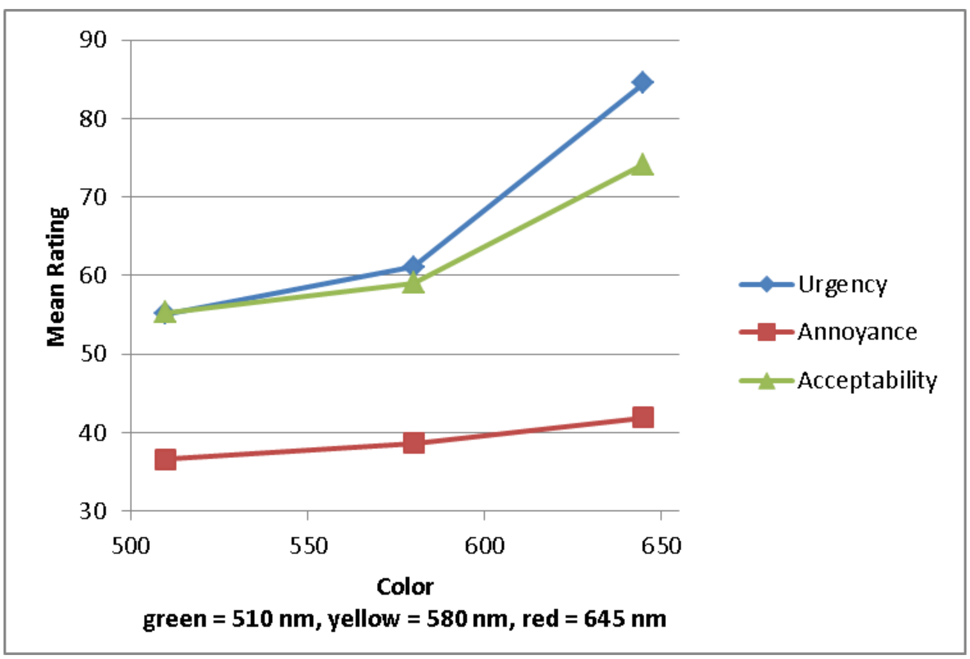
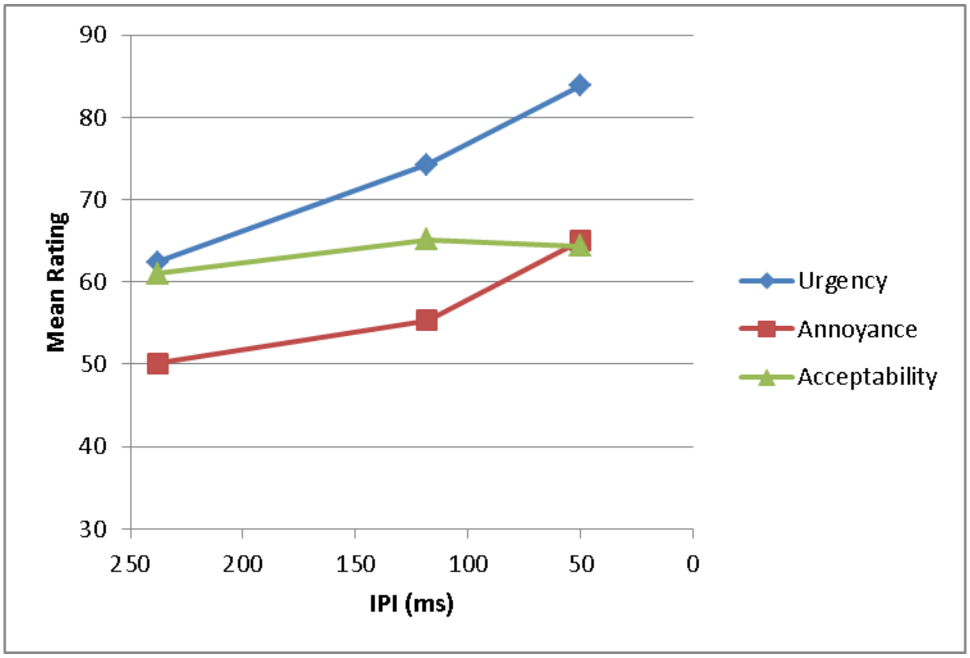


Figure 4-7. Subjective ratings in the tactile modality

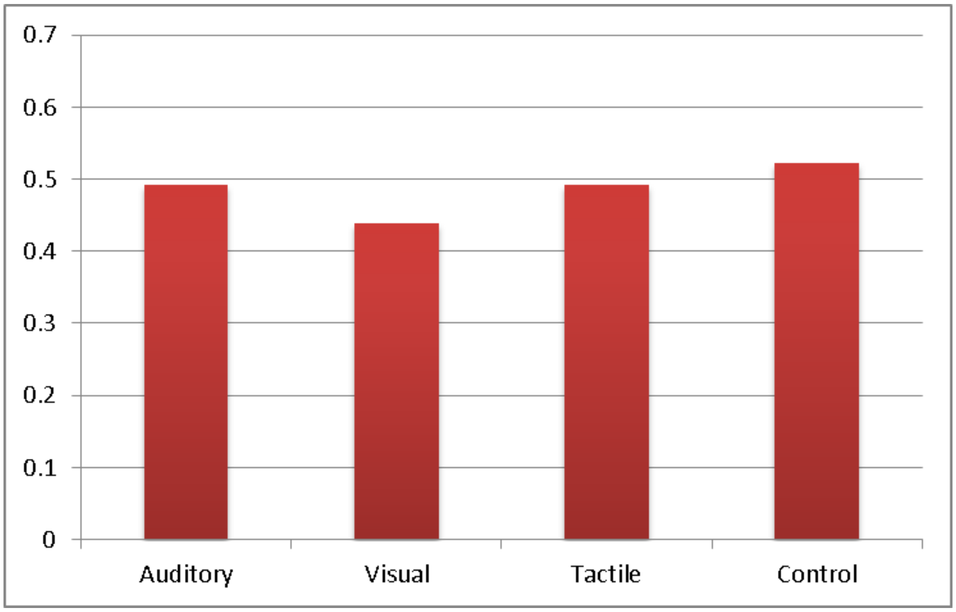


As illustrated, comparable ranges of urgency as predicted from Experiments 2A and 2B were achieved in this validation study. The one exception to the predicted urgency levels can be seen in Figure 4-6 for the Visual Modality. The manipulation of color (green, yellow, and red) showed less distinct patterns of changes in perceived urgency in this validation experiment than would have been predicted from Experiments 2A and 2B. However, this was likely due to the presence of a yellow speed indicator message that was continuously present in the simulated driving environment. Since the visual warning appeared near this yellow speed message, the yellow was likely less salient than it would otherwise have been.

Crash Avoidance Response

When averaged across all scenarios, providing a warning significantly decreased crash probability as illustrated in Figure 4-8. There was no significant difference between crash reduction capabilities as a function of modality. Note that as illustrated in Figure 4-8 providing an alert in any modality reduced crash probability. There was a non-significant trend for the visual warning to be even more effective than the auditory and tactile modality warnings. The use of a rather large visual head-up display presented directly at eye level in the driver's forward field of view likely contributed to its effectiveness. Visual warnings presented in the dashboard console or of smaller size are less likely to be as effective.

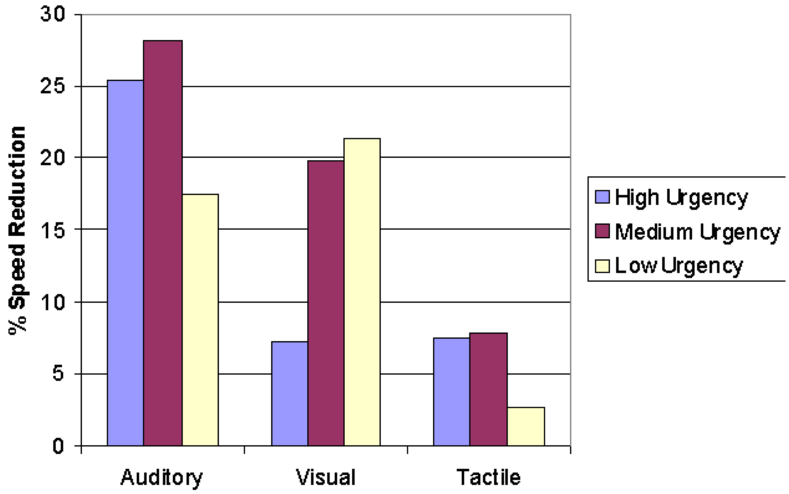
Figure 4-8. Crash proportions due to FCWs in each modality, plus control



The four scenarios differed in crash risk probability. The scenario with the lead car braking event had lower crash probabilities than the other two scenarios. Calculated as the percentage of people who crashed if not provided a warning (control condition), the crash probability in the highway lead car braking scenario was 37.5 percent, (6 of the 16 participants). The crash probability for the rural lead car braking event was comparable, with 35.3 percent (6 of the 17 participants) having a collision when not provided a warning. The left turn event had a collision probability of 68.8 percent (11 of 16 crashed). Finally, the cut-in scenario had an overall crash probability of 62.5 percent (10 of the 16 participants) in the control condition.

When collapsed across all urgency levels, providing a warning in the high risk cut-in scenario did not significantly decrease crash probability; however, providing a warning did significantly decrease crash severity. Crash severity was calculated as the percentage of speed reduction that the participant obtained, based on the speed of travel at the time of the warning (or when the warning would have been presented in the control condition) and the speed of travel upon impact. In the cut-in scenario, providing a high urgency auditory warning significantly reduced crash severity relative to the visual and tactile warnings, which did not differ (see Figure 4-9).

Figure 4-9. Crash severity as a function of FCW modality and urgency level in the cut-in scenario



4.4 Discussion

The methods and paradigm of psychophysical scaling using Stevens' Power Law yielded scales of urgency, annoyance, and acceptability that could be compared across visual, auditory, and tactile modalities and across various key parameters within each of those modalities. A wide range of urgency levels were obtained in each of the modalities. Parameters could be determined that resulted in nearly equivalent perceptions of urgency level across each of the three modalities.

Results of the validation Experiment 2C demonstrated that predictable levels of perceived urgency could be obtained using signal parameters based on the subjective ratings from prior studies (2A and 2B). Comparing across modalities, as illustrated in Figures 4-5 through 4-7, we see that the highest urgency ratings were obtained for auditory modality and these high urgency ratings were accompanied by high annoyance and low acceptability ratings. Conversely, for the visual and tactile modalities annoyance ratings were considerably lower and acceptability ratings were higher, even though urgency ratings were relatively lower in all but the highest urgency levels compared to those for auditory signals. The red visual display was rated as highly urgent, but also had higher acceptability ratings than auditory and tactile alerts of comparable urgency. It is interesting to note that though participants rated the auditory signals as being the least acceptable and most annoying, they were the most effective (relative to the visual and tactile signals which did not differ) at decreasing crash severity. As illustrated in Figure 4-9, auditory signals assisted drivers in decreasing their speed the most rapidly, relative to the other modalities - a factor that would be likely to decrease crash severity.

Importantly, the subjective ratings of urgency obtained in this series of investigations are some of the first ever for tactile stimuli. The current results indicate that the tactile modality is well suited for presenting information of varying criticalities to the drivers. The tactile stimuli also resulted in ratings of annoyance and acceptability that were comparable, and in some cases preferable, to stimuli in other modalities.

The urgency ratings obtained in both low- and medium-level contexts were successfully used to construct warnings of predictable urgency level in the higher context validation study (Experiment 2C). These results are encouraging and lend support for the usefulness of the prototype developer's tool for urgency calculation developed in this series of investigations. Further development and validation of this tool warrants further research.

In future research it would also be beneficial to validate the predicted urgency levels obtained in the current experiments to different types of driver interface applications (other than the collision situations examined here). For example, it would be of interest to determine if low urgency alerts would result in both appropriate response and acceptability for low urgency situations (i.e., low fuel) relative to pairings of high urgency alerts with high urgency situations (i.e., collision situations of various types).

A few limitations are worth noting. In the current series, due to practical constraints only a limited number of parameters in each of the modalities could be examined. Future research examining additional parameters, such as pulse duration and pulse pattern, is warranted. Additionally, the current series of investigations examined urgency scaling for unimodal stimuli. Future applications of this work (particularly for high criticality signals) will likely involve presentation of stimuli in two or more modalities (i.e., tactile and auditory, visual and tactile). Previous research involving the redundant target effect (Miller, 1991; Sinnett, Soto-Faraco, & Spence, 2008) indicates that presenting redundant information in two modalities results in faster response time than either modality alone. However, this laboratory finding has yet to be adequately confirmed within a driving context and further, there is little if any information regarding the impact of multiple modality presentation on perceptions of urgency and annoyance. Further work in this area is warranted. Presenting stimuli in multiple modalities may result in redundant, additive, or multiplicative effects on urgency.

In conclusion, the objective of this experiment—to determine urgency scaling within and across visual, auditory, and tactile modalities—and specifically, to develop and test a methodology for determining these cross modal scales was achieved in the current experiment. Further, the tactile modality appears as though it could be well suited for displaying a wide range of criticality levels to automobile drivers.

5.0 EXPERIMENT 3: MULTIPLE WARNING EVENTS

5.1 Introduction

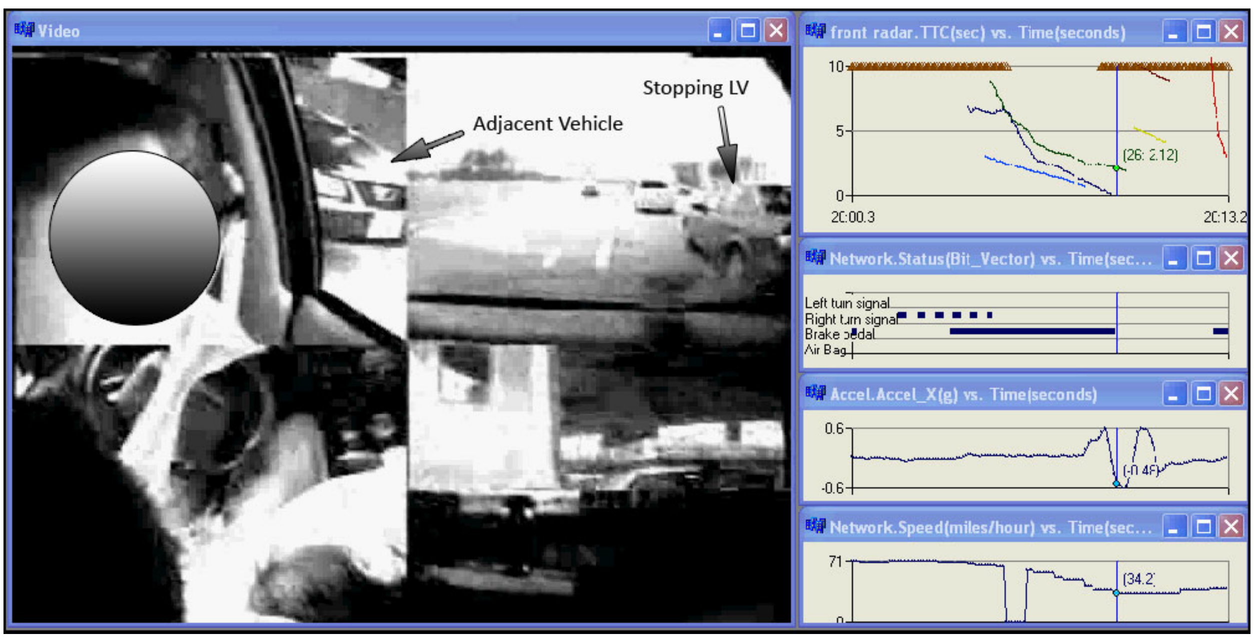
Collision Avoidance Systems (CASs) alert drivers to an impending crash threat so that an appropriate avoidance maneuver can be executed in a timely manner. The role of CAS alerts in a multiple conflict scenario, where distinct conflicts occur in close temporal proximity to each other, has been questioned by human factors engineers. On one hand, it is believed that individual alerts that notify drivers of each unfolding conflict would be able to direct drivers' attention to the appropriate location in the correct sequence so that an appropriate avoidance maneuver could be performed. On the other hand, it is also foreseeable that any alert presented subsequently to the first crash alert could startle, confuse, or interfere with drivers' execution of the avoidance maneuver. If the latter is true, then it may be more appropriate to only present the first crash alert, and suppress all subsequent alerts. That is, simply directing drivers' attention to the roadway and allowing them to determine how to best respond to the multiple conflict scenario, may be more effective. As CAS technology becomes readily available and cost-effective to implement, CAS designers may benefit from guidance on the best approach to alert drivers in a multiple conflict scenario. This study set out to provide such guidance.

The objective of this study was to investigate whether CASs should present individual crash alerts in a multiple conflict scenario, or only present one alert in response to the first conflict and suppress the subsequent alert to the second conflict. Because drivers are limited in their ability to quickly process information under high stress (Hancock & Warm, 1989), this study was designed under the hypothesis that drivers would have difficulty responding to a second crash alert because their attention would be consumed in responding to the first crash alert.

5.1.1 Multiple Conflict Scenario Selection

The multiple conflict scenario used in this study was modeled after a type of lane change near-crash reported in Fitch, Lee, Klauer, Hankey, Sudweeks, & Dingus (2009), which analyzed lane change crashes and near-crashes recorded in the 100-Car Naturalistic Driving Study (Dingus et al., 2006). The near-crash event type consisted of the driver swerving into an adjacent lane to avoid a crash with a suddenly decelerating lead vehicle, but then in doing so, nearly crashing with a vehicle travelling in the adjacent lane. As compared to non-evasive lane changes, the drivers in these types of near-crashes were observed to use their turn signals less frequently and look at their blind spot less frequently prior to swerving into the adjacent lane, suggesting that these drivers did not have sufficient time or ability to perform these secondary tasks during the evasive maneuver. Figure 5-1 shows the multiplexed video data collected from a lane change near-crash event. The top right video quadrant shows the lead vehicle that the driver is swerving into the left lane to avoid. The adjacent vehicle travelling in the left lane can be seen through the participant's left window in the top left video quadrant.

Figure 5-1. Example of video data collection



5.1.2 Use of Multiple Alerts

The following CASs are believed to be potentially effective countermeasures to the multiple conflict scenario described above. First, an FCW system could generate an alert to notify a distracted driver of the decelerating lead vehicle. This alert is intended to direct the driver's attention back to the forward roadway. The driver would then apply the brakes and bring the vehicle to a stop provided there is sufficient stopping distance. In the case where there is insufficient stopping distance, such as the case described above, the driver may swerve to avoid the stopping vehicle. At this point, an LCW system could generate an alert to notify the driver of the vehicle travelling in the adjacent lane. The LCW alert is intended to lessen the severity of the sideswipe conflict by prompting the driver to steer away from the adjacent vehicle, allowing it to straddle the outside half of the lane and the road's shoulder. It is worth noting here that although a lateral crash threat does not arise until the subject vehicle crosses the lane markings, it may be more appropriate to generate an LCW alert once a steering maneuver is initiated, rather than once the lane markings are crossed. This is because Fitch et al. (2009) found that sideswipe near-crashes can unfold, on average, in 2.3 s. Delaying the LCW alert until the lane markings are crossed may not provide drivers with a sufficient amount of time to execute an avoidance maneuver.

5.1.3 Research Questions

To meet the objective of this study, the following research questions were posed:

1. Do drivers who receive an LCW alert after swerving left in the above multiple conflict scenario *steer right more frequently* than drivers who receive just the FCW alert?

2. Do drivers who receive an LCW alert after swerving left in the above multiple conflict scenario *steer right sooner* than drivers who receive just the FCW alert?

3. Do drivers who receive just an FCW in the above multiple conflict scenario *travel farther into the destination lane* than drivers who receive both an FCW and LCW alert?

4. Do drivers who receive an LCW alert after swerving left in the above multiple conflict scenario *look to the left more frequently* than drivers who receive just the FCW alert?

5. Do drivers *prefer receiving the FCW and LCW alert* in a multiple conflict scenario more than receiving just the FCW alert?

5.2 Method

5.2.1 Participants

Fifty-one drivers between the ages of 20 and 55 participated in this study: 31 light vehicle (LV) drivers (13 females and 18 males) and 20 commercial motor vehicle (CMV) drivers, i.e., truck drivers and transit bus operators (8 females and 12 males). Drivers' mean age was 36.2 years old (SE = 1.6 years). Participants were recruited primarily through the existing Smart Road Participant database. Participants had a minimum visual acuity of 20/40, were able to hear a 1 KHz tone at 50 dB with their best ear, and were in good health.

5.2.2 Testing Facility and Vehicle Instrumentation

The experiment took place on the Virginia Smart Road – a 2.2 mile controlled-access research facility. Participants drove a 2006 Cadillac STS instrumented with a data acquisition system (DAS) that captured key driver performance measures (steering, brake application, deceleration, visual search, speed, etc.) allowing driver performance to the crash alerts to be measured. The vehicle was factory-outfitted with anti-lock brakes, dual front and side airbags, and traction control. To minimize risk for participants and experimenters, an emergency passenger-side brake was installed such that the experimenter (seated in the front passenger seat) could take control of braking the vehicle. However, this feature was never needed.

5.2.3 CAS Alerts

Two CAS alerts were used in this study, an FCW alert and an LCW alert. Both alerts were provided by the University of Michigan Transportation Research Institute, which had developed them for use in an investigation of integrated vehicle-based safety systems (Sayer et al., 2008). The alerts were 1 s in duration and comprised five pulses that were generated at 80 dBA as measured by a microphone positioned at the headrest. The FCW alert was generated by speakers mounted on the top left and right side of the seat back, while the LCW alert was generated by only using the top left speaker. The alerts also had unique spectral frequency characteristics.

5.2.4 Procedure

Participants read and signed an informed consent form upon arrival. After completing the vision and hearing screening tests as well as a set of demographic questions, an experimenter escorted the participant to the test vehicle. The in-vehicle experimenter oriented the driver to the basic vehicle controls (i.e., seat, steering wheel, and mirror adjustment), and ensured that the participant's seat belt was fastened. The experimenter then explained that the purpose of the study was to evaluate in-vehicle warning systems and guided the participant to the Smart Road.

Participants were instructed to follow a truck driven by a trained Virginia Tech Transportation Institute (VTTI) experimenter at a specified distance (five car lengths), travelling 40 mph. The participant was also informed that a vehicle driven by another trained VTTI experimenter would be travelling in the adjacent lane (five car lengths behind). Participants were asked to maintain an awareness of the two vehicles as if they were driving on a public road. The participant completed one half lap (2.2 miles) on the Smart Road with these two confederate vehicles in order to become familiar with the test vehicle and the study scenario. Participants then performed two training sessions, one that focused on responding to an FCW alert, and another that focused on responding to an LCW alert. The order of the two training sessions was counterbalanced across participants.

The FCW alert training session consisted of the lead pickup truck slowly decelerating and the in-vehicle experimenter manually generating an FCW alert. Participants were instructed to change into the left lane and pass the decelerating lead vehicle in response to the FCW alert. This maneuver was performed four times spanning 2.5 laps of the road. In between trials, participants were asked to perform various non-driving tasks, such as search for a song on an iPod, interact with a Dell tablet PC mounted to the vehicle's dash, and set the vehicle's temperature using the HVAC controls. Participants were also asked if there was a vehicle in their blind spot at various points in the road (the adjacent vehicle remained five car lengths back). Participants answered questions about the FCW alert at the end of the training session.

The LCW alert training session involved the adjacent vehicle travelling in the participant's blind spot. Participants were then asked to accelerate and safely merge in front of the adjacent vehicle.

Participants performed this maneuver six times. In four of the trials, however, participants received an LCW alert signifying a rapidly approaching vehicle. They were to quickly return to the original lane. The adjacent vehicle would then accelerate past the participant's vehicle so that a connection between the alert and the simulated threat was made. It should be noted that the lead pickup truck would also accelerate during each lane change maneuver in order to maintain a safe distance from the participant's vehicle. In between lane change trials, the adjacent vehicle would fall back five car lengths and participants would perform various non-driving tasks. Participants were also asked if there was a vehicle in their blind spot at various times when the adjacent vehicle was five car lengths back. Participants answered questions about the LCW alert at the end of the training session.

Participants then followed the lead truck up a segment of the Smart Road that had a 6 percent grade, while the adjacent vehicle trailed 10 car lengths back. Participants were asked if there was a vehicle in their blind spot, forcing them to notice that the vehicle was farther back than usual. Participants were then asked to locate an application on the tablet PC that did not exist. As the experimenter instructed the participant to perform the task, the adjacent vehicle unknowingly accelerated into the participant's blind spot, but hugged the left shoulder of the road creating one lane of room. Once the participant began the search task, the experimenter remotely triggered the lead pickup truck to silently lower the tailgate and drop a cardboard box on the road (Figure 5-2). An FCW alert was programmed to activate as the box landed on the road. In reacting to the surprise event, it was anticipated that participants would swerve left into the available left lane rather than into the right shoulder. Half of the participants were therefore assigned to receive an LCW alert once they initiated a left swerve maneuver.

Figure 5-2. Multiple conflict scenario used

Once the box was passed, struck, or the vehicle came to a stop in front of the box, participants were debriefed on the additional purpose of the study. All participants consented to continue with the study, which involved answering questions and performing the same braking maneuver to the box. This time, participants received the alternative alerting approach (i.e., just the FCW alert, or the FCW and LCW alerts). After executing the second braking maneuver, another set of questions was completed. Since a component of this study involved assessing how multiple alerts apply to CMVs, the CMV drivers completed a final set of questions pertaining to the applicability of the alerts on a heavy vehicle. After testing was completed, participants were asked to drive the test vehicle back to the parking lot, thanked for their participation, and were paid $20 per hour for their time.

5.2.5 Experimental Design

To investigate the most effective alerting approach in a multiple conflict scenario, participants had to unknowingly encounter a multiple conflict scenario. Participants who did not swerve left in avoiding the box were thus excluded from the analyses. A one-way between-subjects Analysis of Variance was conducted to compare the effects of the alert approach on drivers' response performance. The two levels of the alert approach were (1) only generating an FCW alert, and (2) generating an FCW alert then an LCW alert.

The following dependent variables were used to assess drivers' response performance to the CAS alerts. Note that the reductionist (i.e., data coder) was not blind to the experimental condition because alerts were indicated in the reduced videos.

Number of Drivers Who Steered Right After Swerving Left to Avoid the Box (Categorical). A reductionist inspected video footage of the forward roadway and the drivers' hands and face to assess whether a driver steered to the right after swerving into the left lane.

The Elapsed Time From Swerving Left to Steering Right Away From the Adjacent Vehicle (Interval). The reductionist entered the time point at which the driver initiated the left swerve to avoid the box as well as the time point at which the driver began to steer right away from the adjacent vehicle. The elapsed time between these two time points was computed for each maneuver.

Swerve Magnitude (Interval). The maximum distance travelled into the left lane was measured using a lane tracking tool called Road Scout developed by VTTI. Road Scout uses computer vision to determine the distance in centimeters the test vehicle enters into the left adjacent lane. The lane excursion data was reviewed by a reductionist who identified the maximum excursion.

Distance to Box When Steering Began (Ordinal). Despite best efforts to detect the box with the range sensor (e.g., placing a tin-foil-wrapped beach ball inside the box to maximize radar returns), it was difficult to reliably measure the range to the cardboard box. As such, a transparency that had horizontal lines drawn onto it was taped to the video monitor and used by a reductionist to categorically assess the box's range when steering began (Figure 5-3). The lines were drawn in Adobe Photoshop by underlining pictures of the lead truck that was positioned at 5 m intervals in front of the subject vehicle.

Figure 5-3. Example of distance grid overlaid on video image. Categories 0, 5, 10, 15, 20, 25, and 30 were used to assess the distance in meters to the box when it was dropped

Number of Drivers Who Looked Left (Categorical). Count of drivers who looked left (i.e., either to the left side-view mirror, their left blind-spot, or the rear-view mirror) when swerving left to avoid the box. Note that this count does not include any glances made after the box was passed.

The Elapsed Time from Swerving Left to Looking Left (Interval). Computed as the difference between the time point at which the driver initiated a left steering maneuver and the time point at which a driver first looked left (i.e., either to the left side-view mirror, their left blind-spot, or the rear-view mirror). Both time points were identified by a reductionist inspecting the video data.

5.3 Findings

Of the 51 drivers who participated in this experiment, the box drop failed for two, one withdrew from the study prior to the box drop event, five swerved right to avoid the box, 13 stopped in front of the box, and three hit the box. Twenty-seven drivers swerved left to avoid the box (although one driver swerved left after the confederate vehicle passed by). Therefore, 26 drivers were exposed to a multiple conflict scenario. Table 5-1 shows a breakdown of these 26 participants by alert condition, sex, and driving experience.

Table 5-1. Breakdown of the drivers who swerved left to avoid the box

Condition	Sex	Experience	Count	Total
FCW + LCW	Female	LV	5	13
		CMV	1	
	Male	LV	2	
		CMV	5	
FCW Only	Female	LV	3	13
		CMV	2	
	Male	LV	5	
		CMV	3	
Total				26

5.3.1 Do Drivers React to the LCW Alert in a Multiple Conflict Scenario?

Thirteen of the 26 drivers received just the FCW alert, while the other 13 drivers received an FCW alert and then an LCW alert after the steering input was initiated (the LCW alert was generated on average 2.76 seconds after the FCW alert was generated, SE = 0.18 s, Min = 1.46 s, Max = 3.92 s). Eleven of the 13 drivers who only received the FCW alert steered right after swerving left to avoid the box, while all 13 drivers who received both the FCW and LCW alert steered right after swerving left to avoid the box. These frequency counts were not found to be significantly different, $\chi^2(1) = 2.667$, $p = 0.141$.

The mean amount of time drivers took to steer right after swerving left was 2.76 s for the drivers who only received the FCW alert (SE = 0.41 s, n = 11, Min = 0.86 s, Max = 5.36 s) and 1.70 s for drivers who received both alerts (SE = 0.31 s, n = 13, Min = 0.35 s, Max = 4.64 s). This 1.06 s difference in mean steering response time was found to be statistically significant, $F(1, 22) = 4.40$, $p = 0.0476$.

The maximum distance travelled into the left lane was 83 cm for the drivers who only received the FCW alert (SE = 28 cm, n = 13, Min = -18 cm, Max = 292 cm), while it was 75 cm for the drivers who received both alerts (SE = 21 cm, n = 13, Min = -58 cm, Max = 225 cm). Note that a negative value represents a vehicle that swerved left, but did not pass over the lane markings. This 8 cm difference in mean lane deviation was not found to be statistically significant, $F(1, 24) = 0.05$, $p = 0.8267$.

Ten of the 13 drivers who received both alerts looked left (i.e., either to the left side-view mirror, their left blind-spot, or the rear-view mirror) when swerving left to avoid the box. Nine of the 13 drivers who only received the FCW alert looked left when swerving left to avoid the box. A Chi-square test was performed and did not find these frequency counts to be significantly different, $\chi^2(1) = 0.1955$, $p = 0.9584$. Although this result suggests that the LCW alert may not compel drivers to look left any more than baseline, it is important to note that the LCW alert was only activated once a steering input was made. Therefore, the number of drivers who looked left *after* a steering input was made was also analyzed. Eight of the 10 drivers who received both alerts looked left *after* swerving left to avoid the box, while 8 of the 9 drivers who only received the FCW alert looked left *after* swerving left to avoid the box. Overall, these findings suggest two things: (1) that drivers are more likely to steer left first, rather than look left first, when avoiding a box on the road, and (2) that the LCW alert may not compel drivers to look left any more than baseline.

The performance of the 16 drivers who looked left *after* steering left was examined in order to investigate whether the LCW alert affected drivers' visual behavior as well as their subsequent manual response performance. Interestingly, the drivers who received both alerts took an average of 0.68 s to look left *after* initiating a left steering maneuver (SE = 0.25 s, n = 8, Min = 0.06 s, Max = 2.07 s), while drivers who only received the FCW alert took an average of 0.52 s to look left (SE = 0.18 s, n = 8, Min = 0.01 s, Max = 1.51 s). This 0.16 s difference was not found to be statistically significant, but could potentially indicate a trend that drivers who received the LCW alert delayed looking to the left after initiating a steering response, $F(1, 14) = 0.3$, $p = 0.5925$. Despite this potential delay, the drivers who received both alerts took an average of 1.95 s to steer right after initiating a left steering maneuver (SE = 0.50 s, n = 8, Min = 0.35 s, Max = 4.64 s), while drivers who only received the FCW alert took an average of 3.15 s to steer right after initiating a left steering maneuver (SE = 0.52 s, n = 7, Min = 1.81 s, Max = 5.36 s). This 1.20 s difference was also not found to be statistically significant, but suggests that drivers who received the LCW alert may have steered away from the lateral threat sooner, despite taking longer to look left, compared to drivers who only received the FCW alert, $F(1, 13) = 2.8$, $p = 0.1182$.

Of the 10 drivers who looked left after receiving both alerts, 9 looked left *before* steering back to the right. There was thus 1 driver who steered right without visually validating the LCW alert. Of the 9 drivers who looked left after only receiving the FCW alert, the 8 who steered back to the right all looked left *before* doing so (note that there was 1 driver who looked left who did not steer back to the right). The findings suggest that drivers were likely to look left prior to steering back to the right to avoid the lateral threat, regardless of whether or not they received an LCW alert. There is thus no clear evidence that drivers felt compelled to visually validate an LCW alert in the multiple conflict scenario tested.

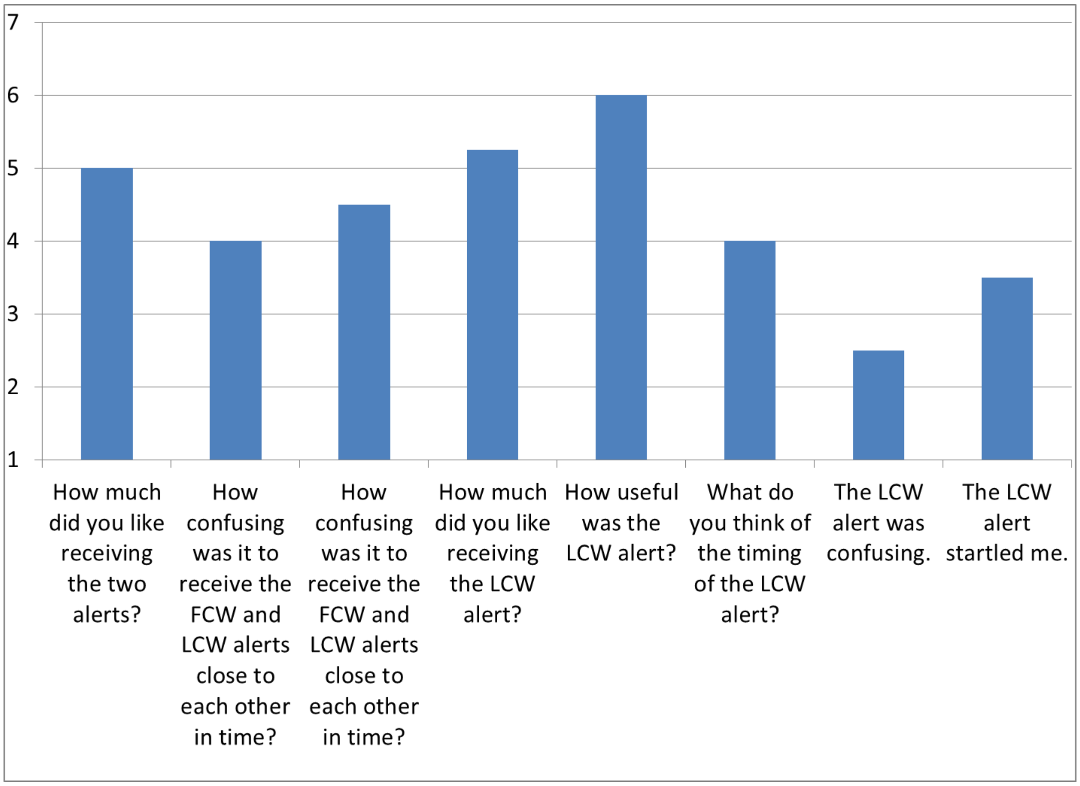
To check that the 26 drivers experienced similar conditions in the multiple conflict scenario, drivers' speed when the box was dropped, their distance to the lead truck when the box was dropped (as measured using a range sensing radar), their steering response time, and their distance to the box when steering left (as measured using the transparency in the video reduction) were compared across the two-alert approaches. The 13 drivers who received both alerts had a mean speed of 63.20 km/h, while the 13 drivers who only received the FCW alert had a mean speed of 63.17 km/h. The drivers who received both alerts took on average 1.74 s to steer to the left after the box was dropped, while the drivers who only received the FCW alert took on average 1.62 s to steer to the left after the box was dropped. The lead truck was an average of 46.53 m from the subject vehicle when the FCW alert was generated for the drivers who received both alerts, while it was an average of 48.99 m from the subject vehicle when the FCW alert was generated for the drivers who only received the FCW alert. Furthermore, the drivers who received both alerts had a median distance to the box of 20 m when they steered left, while the drivers who only received the FCW alert had a median distance to the box of 25 m when they steered left. None of these differences were found to be statistically significant. These results help show that drivers were exposed to roughly similar conditions.

5.3.2 Driver Preferences

Drivers' answers to questions revealed some interesting findings. Of the 13 drivers who received both alerts, two did not recall hearing any alert, four indicated that they heard only one alert (three only recalled hearing the LCW alert, while one only recalled hearing the FCW alert), and seven indicated that they heard two distinct alerts. Of the 13 drivers who only received the FCW alert, 3 did not recall hearing an alert, and 10 indicated that they heard one alert (6 recalled hearing the FCW alert, 1 thought he heard the LCW alert, and 3 could not remember what the exact alert was). It is important to note that the questions pertaining to participants' experiences with the surprise event were administered after debriefing had taken place and consent to continue the experiment had been obtained. As a consequence, approximately 6 minutes elapsed from the surprise event to the questions being administered, which may have affected participants' ability to recall hearing the alerts.

Participants' ratings were made on Likert scales with values ranging from 1 to 7, with a neutral point of 4. High ratings indicate positive/agree, while low ratings indicate negative/disagree. The ratings are presented graphically in Figure 5-4. The 7 drivers who correctly recalled hearing two alerts had a median rating of 5 (like it) when asked "How much did you like receiving the two alerts?" However, their ratings ranged from 2 (very much dislike it) to 7 (extremely like it). They had a median rating of 4 (neutral) when asked "How confusing was it to receive the FCW and LCW alerts close to each other in time?" They also had a median rating of 4.5 (somewhat easy) when asked "How easy was it to differentiate the FCW alert from the LCW alert?" These 7 drivers, combined with the 3 drivers who recalled hearing at least the LCW alert, had a median rating of 5.25 (like it) when asked "How much did you like receiving the LCW alert?" They had a median rating of 6 (very useful) when asked "How useful was the LCW alert?" They had a median rating of 4 (just right) when asked "What do you think of the timing of the LCW alert?" They had a median rating of 2.5 (disagree) when asked how much they agreed with the statement: "The LCW alert was confusing." They also had a median rating of 3.5 (somewhat disagree) when asked how much they agreed with the statement: "The LCW alert startled me." Overall, the 10 drivers who recalled hearing the LCW had favorable ratings toward it after experiencing the multiple conflict scenario.

Figure 5-4. Median ratings for post-drive questions



Yet, it is important to acknowledge that some of the 7 drivers who correctly recalled hearing two alerts found it difficult to differentiate the two alerts (1 driver), found it confusing to have received two alerts close in time (3 drivers), and did not like receiving the two alerts (1 driver). This could be because the multiple conflict scenario consumed their attention, or perhaps the alerting approach was suboptimal.

Recall that there were 26 drivers who were exposed to the multiple conflict scenario during the first trial. Of these, 11 drivers also swerved left during the anticipated box drop event, exposing them to the multiple conflict scenario a second time. These 11 drivers received the alternative alerting approach and provided rating data on which approach they preferred (4 drivers experienced both alerts in the anticipated event, while 7 drivers experienced just the FCW alert in the anticipated event). It was found that all 4 drivers who received both alerts during the anticipated event preferred the two-alert approach and indicated that receiving both alerts close in time was clear. However, the results were not unanimous for the 7 drivers who only received the FCW in the anticipated event (but were provided with a description of the two-alert approach). Three drivers preferred the two-alert approach, 2 drivers preferred the FCW only approach, and 2 drivers did not provide an answer. Taken as a whole, 7 of the 11 drivers preferred the two-alert approach, 2 of the 11 drivers preferred the FCW only approach, and 2 did not indicate a preference. An examination of the comments participants provided indicated that the drivers who preferred the two-alert approach did so because they felt it was appropriate for the scenario they were exposed to. In contrast, 1 of the 2 drivers who preferred the FCW only approach indicated that "it all happened so fast and all the noises freak me out." The other driver indicated that he "would rather have one thing go wrong than two things go wrong." However, his response suggests that he may not have fully understood the question.

5.3.3 Application to Commercial Motor Vehicles

The 11 CMV drivers who experienced the multiple conflict scenario were asked additional questions oriented toward truck implementation of FCW and LCW systems. Drivers' modal responses indicated that participants liked the idea of FCW (mode = 7, or "extremely like it") and LCW (mode = 6, or "very much like it") systems on their trucks. The participants also responded that the alerts would be useful, with the FCW system being seen as slightly more useful than the LCW system (both FCW and LCW mode = 1, or "useful"). Both FCW (mode = 1, or "effective") and LCW (mode = 2) alerts were viewed as being effective for trucks. Participants agreed that it would be appropriate to generate both FCW and LCW alerts in the case of multiple conflicts when driving a truck (mode = 6, or "agree"). Participants were asked to rate the appropriateness of hypothetical haptic alerts. Their responses were mixed—the seat, steering wheel, and seat belt were viewed as unpractical (mode = 5, or "unpractical" for all), while the brake pulse was seen as very unpractical (mode = 6, or "very unpractical"). The demographic questions revealed that these participants had no experience with automotive haptic alerts, so the responses indicate attitudes toward haptic alerts, but not reactions based on use.

5.4 Discussion

This study investigated the utility of multiple CAS alerts presented in a multiple conflict scenario. The scenario consisted of presenting drivers with a forward crash threat (i.e., dropping a box on the road) such that they swerved left to avoid it and, in doing so, nearly sideswiped an adjacent vehicle. Half of the drivers received an FCW alert in connection to the forward crash threat, and then an LCW alert after swerving left in connection to the lateral crash threat. The other half of the drivers only received the FCW alert in connection to the forward crash threat. Whether the LCW alert effectively assisted drivers avoid the lateral crash threat was examined.

It was found that drivers who received both the FCW and LCW alerts were significantly quicker at steering away from the lateral crash threat than the drivers who only received the FCW alert (1.70 s versus 2.76 s, respectively). This finding demonstrates that drivers benefited from receiving the LCW alert when executing an avoidance maneuver in the multiple conflict scenario. Weaker trends that were also observed include: (1) every driver who received both alerts steered away from the lateral crash threat, while 2 drivers who only received the FCW alert did not steer away at all, and (2) 10 of the 13 drivers who received both the FCW and LCW alerts looked left when performing the swerve maneuver, while 9 of the 13 drivers who only received the FCW alert looked left during this maneuver. Overall, because steering response time is a crucial component to a sideswipe evasive maneuver, the use of two individual alerts in the multiple conflict scenario can be justified based on this study.

Drivers' median ratings also supported the use of the two alerts in the multiple conflict scenario. They ranked the FCW and LCW alert approach as more appropriate than only receiving the FCW alert. They liked receiving the LCW alert, rated it to be useful, found it easy to understand (despite being presented after the FCW alert), and did not find it to be startling. However, it is worth noting the following. First, 5 of the 26 drivers did not remember hearing any alert (two were given both alerts, while 3 were only given the FCW alert), and 4 drivers (who were given both alerts) only remembered hearing one alert (three recalled the LCW alert, and one recalled the FCW alert). Although these findings may be an outcome of participants having to recall the alert characteristics roughly six minutes after receiving the alert(s), they could be an indication that drivers subconsciously respond to the alerts in a multiple conflict scenario. Second, a few drivers did not like the two-alert approach. One driver found it difficult to differentiate the two alerts, three drivers found it confusing to have received two alerts close in time, and one driver did not like receiving the two alerts. Overall, participants' median ratings suggest that the two-alert approach in a multiple conflict scenario was preferred, but that there will be some drivers who do not like this approach. Further research is required to determine whether this was because they did not like receiving any alert in a multiple conflict scenario, or whether the alerting approach was suboptimal.

It has been thought that drivers would visually validate a CAS alert prior to responding to it. This is because the alert's reliability can be imperfect, generating false alarms. In this study, the LCW alert was generated four times during six practice lane changes. It was then found that 10 of the 13 drivers who received the LCW alert looked left during the evasive lane change maneuver. Although this might suggest that drivers visually validated the LCW alert, it was also found that

9 of the 13 drivers who did not receive the LCW alert looked left during the same maneuver. Therefore, drivers are believed to look left regardless of whether they receive an LCW alert, although it is interesting that some drivers swerved left without looking left.

With respect to CMV driver ratings, the data from the CMV drivers who were subjected to the multiple conflict scenario suggest that CMV drivers liked the idea of both FCW and LCW alert systems being installed in their trucks. The CMV drivers expressed a belief that the FCW and LCW systems would be effective in operation, with the FCW system being viewed as slightly more useful than the LCW system. These CMV drivers also believed that receiving both FCW and LCW alerts in response to multiple conflicts would be appropriate. Interestingly, CMV drivers' views on the use of haptic modality alerts were unfavorable, although none had indicated that they had experience with automotive haptic interfaces.

In summary, this study shows that drivers may benefit from, and feel it is appropriate, to generate multiple alerts in a multiple conflict scenario. Furthermore, a method for evaluating CAS alert approaches in a multiple conflict scenario was validated. Drivers rated that they were surprised that the box fell out of the lead truck and that the multiple conflict scenario used felt very similar to an actual emergency driving event. This scenario may therefore be used to test new alerting approaches.

When considering the findings of this experiment, it is important to consider the following limitations. First, there was an imprecise measure of the distance to the box. Attempts were made to use the range sensing radar on the vehicle to detect the box by placing a tin-foil-wrapped beach ball inside of it, the idea being that the round metallic surface would increase the chances of the radar being bounced back to the vehicle. However, this did not always work. Second, a measure of the distance to the adjacent vehicle was not taken. This was because the study budget and timeline did not allow such instrumentation to be developed. Third, only auditory alerts were employed in this study. Future systems might use haptic alerts, different auditory alerts, or combinations of various warning modes. The generality of the findings is not known.

Another procedural factor of unknown consequence is the degree of experience participants have with the warning system. In this experiment, participants were relatively well-trained with the FCW and LCW alerts and practiced specific avoidance responses in reaction to the alerts. In this sense, the experiment modeled the situation of "somewhat experienced" with the CAS. The situation was also one in which there was some expectancy that events might occur, although the dropped box event itself was unique and unexpected. The generality of the findings to participants who were less experienced with the system or encountered the events under different circumstances is not known.

6.0 EXPERIMENT 4: PORTABLE DEVICE PAIRING

6.1 Introduction

This experiment investigated the extent to which driver response to imminent crash warnings is affected by the use of multiple CV systems. It is probable that CV applications will be available both as original equipment on vehicles and as standalone devices or apps for portable devices that could be brought into the vehicle. CV systems from different makers could potentially offer different applications, features, styles, alerts, and so forth. The present experiment was conducted to investigate whether the presence of more than one CV device in a vehicle could potentially have a negative impact on comprehension and responses to urgent crash warnings. This experiment did not address the case where two independent systems might issue near-simultaneous urgent warnings that could result in less effective driver response. Rather, it addressed the more general concern that just having to monitor and interpret two sources of information might result in slower reaction to, or less awareness of, urgent crash warning displays.

6.2 Method

6.2.1 Overview

To investigate the extent to which driver response to imminent crash warnings is affected by the use of multiple CV systems in the vehicle, two displays were placed in an experimental vehicle, one representing an OEM display and one representing a portable, portable device. For each device, a comparable set of messages was created to present information to drivers about traffic conditions, weather conditions, nearby attractions, safety information, phone call and text messages, and imminent crash warnings. While the messages designed for each device were largely equivalent in terms of content and meaning, each device had its own distinct visual design theme and sounds.

The study was a between-subjects evaluation with participants randomly assigned to one of five experimental conditions:

1. **OEM device only.** All messages are shown on the OEM device. The portable device is blank for the entire session.
2. **Portable device only.** All messages are shown on the portable device. The OEM device is blank for the entire session.
3. **Both devices operational, no message integration or prioritization.** Half of the messages are shown on each device. Warning messages *do not* pre-empt preceding messages on the opposite display.
4. **Both devices operational, with prioritization of warning message.** Half of the messages are shown on each device. Warning messages pre-empt preceding messages on the opposite display.
5. **Both devices operational, with all messages presented via the OEM display.** This condition simulates a situation in which messages that would normally be displayed on the portable device are "streamed" to the OEM display, so that messages from both devices are shown solely through the OEM display.

The experimental task was the same in all experimental conditions. As participants drove in a prescribed path on a test track, they were occasionally presented with a visual/auditory message. The message was either non-urgent information or an urgent crash warning. In the instructions read to participants, urgent crash warnings were defined as indicating that "…the driver must take an immediate action such as braking or steering in order to avoid a possible crash. Not all safety messages are this urgent. Some may tell you about situations that are coming up or help you to be more alert to your surroundings. But the "urgent" warnings are different because you need to react right away to an immediate danger." If a message was non-urgent, participants' only responsibility was to view the display and be able to answer a comprehension question about it. If the message was an urgent crash warning, participants were instructed to honk the car horn as quickly as possible (to indicate that they recognized the warning as urgent) and then locate a light that had changed color from blue to red around the perimeter of the vehicle (to indicate that they recognized the location of the threat indicated by the warning), and key that response into a touchpad with a vehicle/light location analogy displayed on it. The key dependent variables were, therefore:

- Horn honk in response to urgent warning (correct response) versus non-urgent message (incorrect response);

- Horn honk response time; and
- Red light localization input response time.

Warnings were sometimes issued with no temporal proximity to a non-urgent message, and sometimes issued 3 seconds after the issuance of a non-urgent message. There were a total of 13 urgent warning trials and 40 non-urgent message trials during the course of each session. A detailed description of the study method is presented in the following sections.

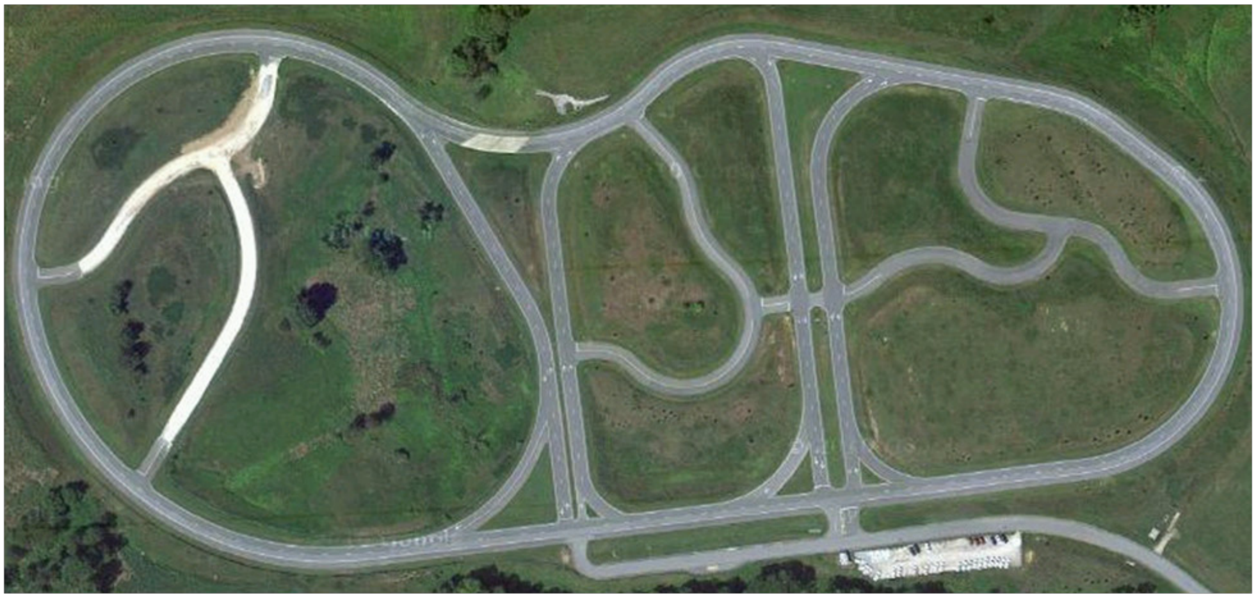
6.2.2 Participants

Fifty-two people participated in this study. Participants were recruited using online advertisements posted on Craigslist in Baltimore and Frederick, Maryland, and were screened by telephone. All participants were between 18 and 65 years of age, had valid driver's licenses, and had no self-reported color vision deficiencies. Participants were not permitted to wear tinted glasses during the session (this was explained during the telephone screening). None owned vehicles with advanced crash warning systems. Participants received $100 for participating in the study which took about 1½ hours.

6.2.3 Test Track

The experiment was conducted on the highway response course test track at the Maryland Police and Correctional Training Commissions Public Safety Education and Training Center in Sykesville, Maryland. The test track includes a 1-mile loop road (one-way clockwise) and numerous interior roads representing a variety of driving conditions (see Figure 6-1). The course also features realistic pavement markings, named roads with street name signs, and traffic control devices including stop signs, yield signs, and one-way signs.

Figure 6-1. Highway response course test track



Imagery copyright Google, 2014

6.2.4 Experiment Vehicle and Instrumentation

Vehicle. The vehicle used for this experiment was a 2011 Subaru Outback with an automatic transmission. The vehicle was instrumented with technologies for stimulus presentation, recording of vehicle metrics, and participant responses. Figure 6-2 shows the interior of the experiment vehicle, the two displays (with default screens), and the response touchpad (blank).

Figure 6-2. Experiment vehicle interior showing OEM display, portable display, and response touchpad

6.2.5 Visual and Acoustic Displays

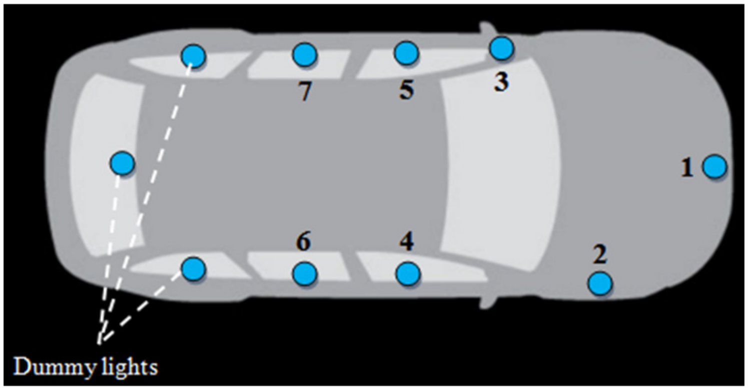
Two visual displays were installed in the vehicle. One display was located in the center stack and intended to represent a prototypical display that might be provided by an OEM. This display was a motorized popup screen that replaced the original LCD screen in the vehicle. The OEM display was a full-color LCD screen with a diagonal size of seven inches and an effective resolution of 800 x 600 pixels. Sounds associated with the OEM messages played through the vehicle's 5-speaker sound system.

The other display was located to the left of the steering wheel and represented a portable, portable device such as a smartphone. The portable display was attached to the windshield by a suction mount. The portable display was oriented vertically and had a full color LCD display with a diagonal size of four inches, comparable to currently available smartphones. Sounds associated with the portable messages played through the display's built-in speaker.

LED Lights. The vehicle was instrumented with 10 LED lights around the perimeter of the vehicle. A photo of one of these lights is shown in Figure 6-3. All of the lights were blue in their default state, but when a participant honked the car horn in response to an urgent crash warning, one of the lights turned red. It was the responsibility of participants to identify which light turned red and press the appropriate button on the response touchpad. The lights were located as shown in Figure 6-4 (note that the lights are numbered in the figure, but were not numbered in the vehicle for participants). As noted in the figure, the 3 lights nearest to the rear of the vehicle were "dummy" lights that never turned red during the experiment, but were included to increase the demands of the search task. Participants were not told that these lights would not be used. All of the lights were on the exterior of the vehicle with the exception of the one on the rear window, which was attached to the inside of the window.

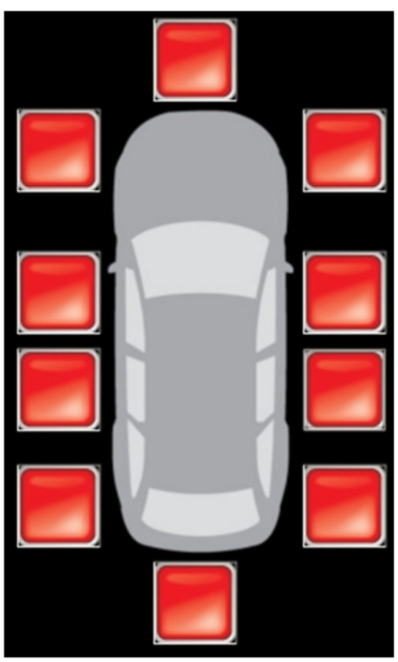
Figure 6-3. Blue LED light on front of hood from driver's perspective

Figure 6-4. Location of LED lights around perimeter of experiment vehicle (size not to scale)



Response Touchpad. A response touchpad was located below the OEM visual display. The touchpad was vertically oriented and had a diagonal size of seven inches and an effective resolution of 480 x 800 pixels. The response pad was used by participants to indicate which LED light around the perimeter of the vehicle had changed color following an urgent crash warning. The display remained blank until the participant honked the car horn in response to a warning, at which point the response screen appeared, showing a button representing the location of each LED light (see Figure 6-5).

Figure 6-5. Response touchpad display



Voice Navigation. Participants were guided along a prescribed test track route by voice navigation. The navigation provided in this experiment consisted of a set of pre-recorded voice turn instructions that were cued by the experimenter at appropriate times. A female voice presented simple instructions (e.g., "turn right on Carroll Expressway"). Navigation instructions were presented through the vehicle's speakers and did not include any visual component. Navigation instructions were presented approximately 6 seconds before arriving at an intersection, and never overlapped with experimental stimuli (i.e., warnings or non-urgent messages).

Urgent Warnings and Non-Urgent Messages. A prototype set of displays was created for each of the two display types used in this study (OEM and portable). Each display included a visual component and an acoustic component. The displays were created as matched sets so that each device could display the same message types with equivalent content. Each device had its own distinct visual style for both non-urgent messages and urgent crash warnings. Table 6-1 below outlines the visual styles of the different displays and messages and Figures 6-6 through 6-8 show paired examples of messages on both types of displays. In experimental condition 5, visual displays generated by the portable display were shown on the OEM display. These messages retained their source formatting, minus header and footer, but were shown against the background format of the OEM device. An example of a portable device display shown on the OEM device is shown in Figure 6-9. For the full set of warnings and non-urgent messages for both displays, see Appendix C.

Table 6-1. Visual display styles of warnings and non-urgent messages

	OEM warning	Portable warning	OEM non-urgent	Portable non-urgent
Theme	Vehicle schematic showing direction of threat	Overhead view of subject vehicle and interaction with external threat	High resolution icons, horizontally structured text	Simple in-vehicle signing, vertically structured text
Characters	None	None	Light blue	Dark brown
Legend	Dark gray	Beige gradient	Dark gray	Beige gradient
Status bar	No	Yes	Yes	Yes
Header	Red border	Dark brown	Blue gradient	Dark brown
Footer	Red border	Dark brown	Dark gray	Dark brown

Figure 6-6. Forward collision warning on portable display (left) and OEM display (right)

Figure 6-7. Curve ahead message on portable display (left) and OEM display (right)

Figure 6-8. Nearest dining message on portable display (left) and OEM display (right)

Figure 6-9. Example portable device warning shown on OEM device in experiment condition 5

Five urgent crash warning functions were selected for use in this experiment based on their existence in current production vehicles and/or their potential for use in CV applications. When presented with an urgent crash warning, participants' task was to first honk the car horn, then locate the red LED around the perimeter of the car, then tap the touchpad to indicate the location of the red light. The light that changed color was in the direction of the hazard indicated by the crash warning. Table 6-2 lists the crash warning functions used in the experiment along with the LED that turned red after the horn was honked (refer to Figure 6-4):

Table 6-2. Urgent crash warning functions and associated LED lights

Function	LED light (refer to Figure 6-4)
Forward collision warning	1
Intersection collision warning	3
Pedestrian collision warning	1
Lane change conflict warning	6 or 7
Lane departure warning	4 or 5

The non-urgent messages presented in this study were categorized according to the type of information presented: Safety (non-urgent), vehicle status, services, traffic, weather, and communications. In experimental conditions 1 and 2, where only one display device was active, all messages were presented via the active display. In conditions 3-5, where both display devices were active, each of the categories of information was assigned to one of the devices so that some information types were presented via the OEM device and some were presented via the portable device. For conditions 3-5, each urgent crash warning function was also assigned to one of the two devices. Table 6-3 shows each message category, its default device, and the full set of messages in that category.

Table 6-3. Message categories, default device, and full set of messages

OEM warning	Portable warning	Safety	Vehicle status	Weather	Communi-cation	Traffic	Services
		Default: OEM	Default: OEM	Default: OEM	Default: Nomad	Default: Nomad	Default: Nomad
FCW	Lane change	Stop for school bus	Toll charged	Severe weather	Incoming phone call	Travel time	Parking availability
Lane departure	Intersection collision	Curve ahead	Low fuel	Icy roads	Incoming text message	Incident ahead	Rest area
	Pedestrian	Emergency vehicle approaching	Excessive fuel consumption	Fog ahead		Congestion ahead	Gas ahead
		Lane ends, merge left				Alternate route	Food ahead
		Work zone ahead				Train approaching crossing	
		Traffic signal about to change					
		School zone ahead					

Each message category, including warnings, had its own sound,[1] which was played simultaneously with the appearance of the visual display. The primary purpose of including a different sound for each category was to create a rich and diverse sound environment in the vehicle comparable to the environment that might exist in vehicles with multiple CV devices, each capable of providing a wide variety of messages. Each of the two display devices had its own warning sound with two variations. Each warning sound had a highly urgent sound for the most critical warning events (FCW, intersection collision, pedestrian collision) and a slightly less urgent sound for events that were potentially somewhat less critical (lane change conflict

1 Within the communications category, however, incoming call and incoming text message each had a unique sound.

warning, lane departure warning). The less urgent sounds were created by digitally slowing the playback speed of the sound by 30 percent, thereby reducing the pitch as well. The non-urgent messages were cuing sounds; they alerted drivers to the presence of a visual message, but did not directly convey any messages on their own. All warning messages had durations of 1.1 to 1.4 seconds. The warning sounds all had a peak sound pressure level (SPL) of 85 dB(A), as measured by a sound level meter at the driver's approximate head position. Non-urgent messages all had a peak SPL of 78 dB(A). The ambient noise level in the vehicle during experimental sessions ranged from about 50 to 60 dB(A). The SPL of warnings and non-urgent messages were consistent with recommendations in the literature to achieve SPLs 15-25 dB above the masked threshold without exceeding 90 dB (Brown, McCallum, Campbell, & Richard, 2007).

6.2.6 Experiment Choreography

The order of stimulus presentation was determined by randomization. As a first step, each of the 24 non-urgent messages was put in a random order. Then a second randomized set of the 24 non-urgent messages was appended after the first set for a total of 48 non-urgent messages. Next, 13 urgent warning trials were randomly inserted among the non-urgent warning trials. The 13 warning trials were created as a function of warning type and temporal proximity to a non-urgent message, as shown in Table 6-4. Therefore, warnings presented alone were inserted between 2 non-urgent messages, and warnings presented 3 seconds after a non-urgent message were linked to the preceding non-urgent message as a single trial (non-urgent message immediately followed by urgent warning). This procedure resulted in a total of 53 trials (40 non-urgent message trials and 13 urgent warning trials).

Table 6-4. Warning trials shown as a function of warning type and temporal proximity to a non-urgent message

Warning type	Alone	3 s after message from same device	3 s after message from other device*
Forward collision	X	X	X
Intersection collision	X	X	X
Lane change collision	X	X	X
Lane departure	X	X	X
Pedestrian collision	X		

*In experiment conditions 1 and 2, where only one device was active, the "3 s after message from other device" condition was replaced by a second trial of "3 s after message from same device."

To minimize order effects, a second counterbalance scheme was created in which all non-urgent message trials were presented in the original randomized order, but all warning trials were presented in the reverse order. For each counterbalance order, a driving route on the test track was scripted. Routes were planned so that there would be at least 30 seconds between each trial and so that messages would be presented at appropriate locations (e.g., intersection collision warning was presented on approach to intersection, school zone message was presented on an interior street, and rest area message was presented on the "expressway" main loop). Each trial was presented at the same location on the test track across both counterbalance orders. The voice navigation system instructed participants to turn on the appropriate streets.

Each visual display had a duration of 8 seconds. In conditions 3 and 4, in which it was possible for a warning to appear 3 seconds after the beginning of a non-urgent message on the other device, the non-urgent message either remained on its display for the full 8 seconds (condition 3) or disappeared as soon as the warning message appeared (condition 4). Whenever a display was not showing a particular message, the device's default menu screen appeared. The default messages are shown in Table 6-3. There were no sounds associated with the default menus.

The laptop experiment control screen tracked the vehicle in real time using GPS, and informed the experimenter when the vehicle was in the correct location to trigger a trial or navigation instruction. Stimulus presentation timing and location were ultimately controlled by the experimenter, who was present in the right rear seat of the vehicle during sessions. This scheme was intended to improve the robustness of the trials by ensuring that event triggering would have "eyes-on" verification of appropriateness by the experimenter.

6.2.7 Procedure

Upon arrival at the test track location, participants showed the experimenter their driver's license, then reviewed and signed an informed consent form. The participant then sat in the experimental vehicle driver's seat and adjusted the seat, mirrors, and steering wheel as needed for comfort. The experimenter was seated in the rear-right seat. Following a basic introduction to the purpose of the experiment, the participant took a brief (approximately 3-minute) familiarization drive around the test track, guided by the voice navigation system. Following the familiarization drive, the experimenter provided detailed instruction about the experimental task. Once the participant understood the task, a brief (approximately 5 minute) practice drive was performed. During the practice drive, the participant experienced a total of four non-urgent messages and two urgent crash warnings (these warnings were not reused during the experiment). For the first half of the practice drive, the experimenter informed the participant of what type of message would be presented next so that they could more easily understand how they were supposed to respond. For the second half of the practice, no clues were provided. Following the practice drive, participants were given the opportunity to ask questions.

After the practice was completed, the experimental drive began. During the experimental drive, participants experienced 13 crash warning trials and 40 non-urgent message trials. Seven of the non-urgent message trials were followed by a comprehension question about the preceding message. Drive duration was approximately 45 minutes, with some variation depending primarily upon participants' driving speed. The test track does not have any speed limit signs and participants were not told at what speed to drive. If participants asked about driving speed, the experimenter responded that they should drive at a speed that they found safe and comfortable. Participants were guided along a predetermined route by the voice navigation system.

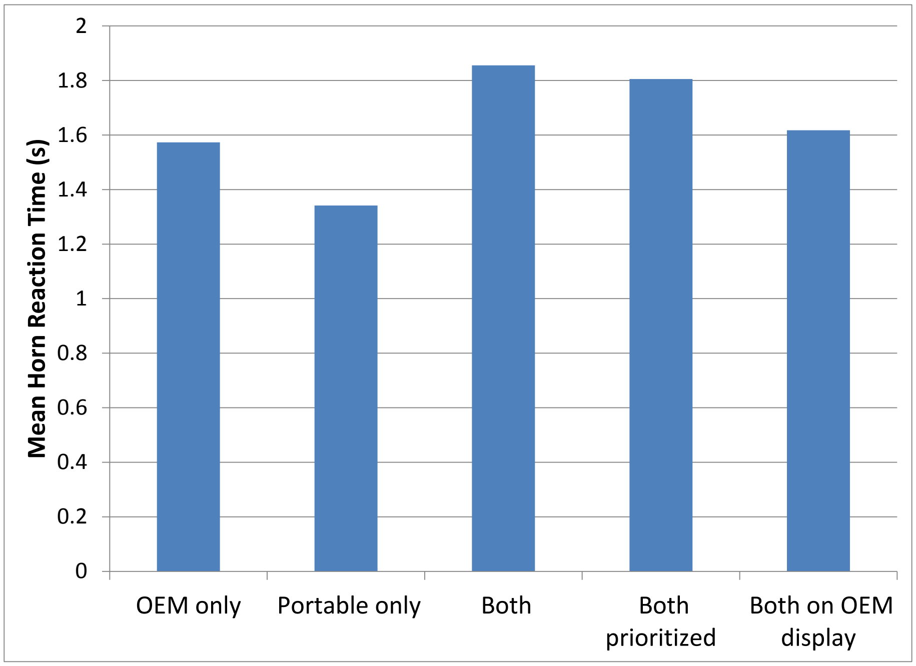
6.3 Findings

The central objective of this experiment was to compare driver responses to urgent crash warnings and non-urgent messages across five different device integration and prioritization conditions (between subjects). The key dependent measure of this study was the speed of warning response, which was measured as reaction time to honk the vehicle's horn after a warning was issued. Primary analyses used inverse transformed data to compare warning response time as a function of display condition and other variables. Warning response times greater than 5 seconds (0.04% of trials) were considered outliers and were excluded from analyses. Trials in which the participant did not honk at all (i.e., did not recognize that an urgent crash warning had occurred) were also removed from reaction time analyses, but separate analyses were conducted on these trials. All ANOVAs performed were repeated-measures, unless noted otherwise.

6.3.1 Effects of Display Condition

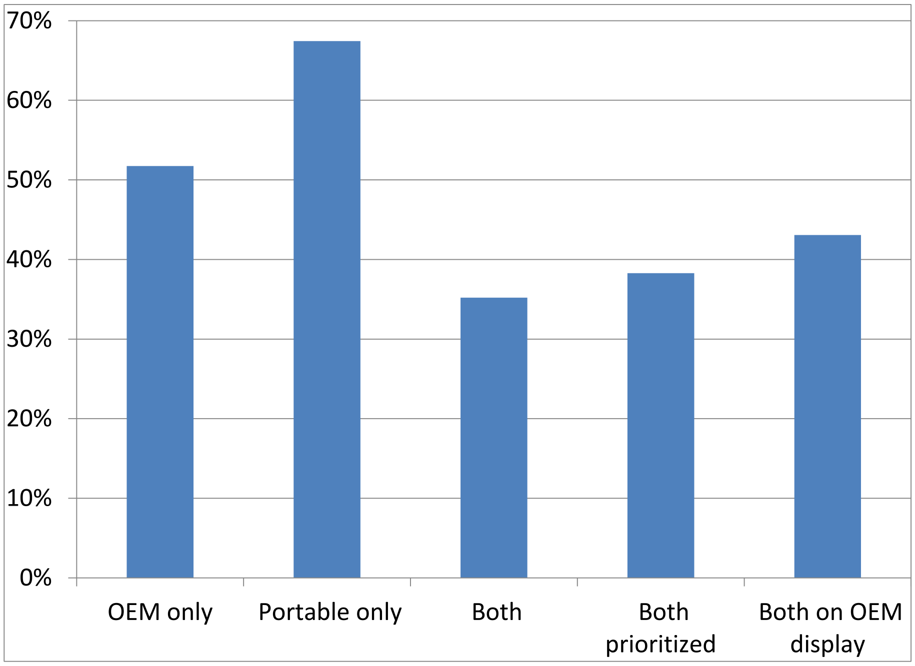
A between-subjects ANOVA revealed that display condition had a significant effect on warning response time [$F(4,47)= 2.69$, $p < 0.05$). Paired comparisons (uncorrected) showed that this effect was driven by significantly faster responding in the portable-only condition (M=1.33 s) compared to each of the three conditions in which both source devices presented messages: Both (M=1.86 s; $p<.01$); both prioritized (M=1.79 s; $p<.01$); and both on OEM display (M=1.60 s; $p<.05$). No other paired comparisons showed significant differences. Figure 6-10 shows mean horn reaction time for each of the five experimental conditions.

Figure 6-10. Mean horn reaction time by condition



In addition to mean response time, it is also useful to analyze the data in terms of the proportion of trials in which participants responded quickly to the warning. This measure gives an indication of how often the warning results in a timely response that might be associated with crash avoidance or mitigation. For these analyses, a warning response time of 1.5 s or less was considered fast. This cutoff point was selected because it was slightly faster than the overall mean response time of 1.63 s and reflects reasonable cutoff point for acceptable warning response times within the context of this experiment. Based on a binomial logit model (using SAS PROC GENMOD), the portable-only condition (67% fast) resulted in a significantly higher proportion of fast responses than each of the three conditions in which both source devices presented messages: Both (35%; $p<.05$); both prioritized (38%; $p<.05$); and both on OEM display (43%; $p<.05$). No other paired comparisons showed significant differences. Figure 6-11 shows the percentage of "fast" response times to warnings in each display condition.

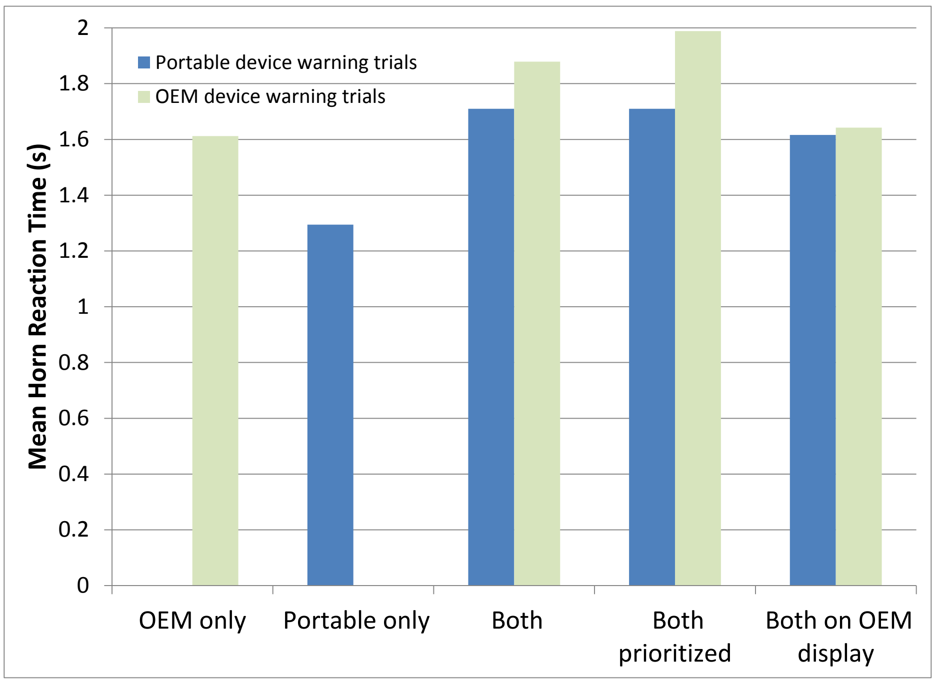
Figure 6-11. Percentage of urgent warning trials in each display condition in which warning response time was 1.5 s or faster



6.3.2 Effects of Warning Source Device

For the OEM-only and portable-only display conditions, all messages and warnings originated from the same source device. In the three conditions where both devices were active, however, messages and warnings originated from both devices, each with its own unique display characteristics. In the "both" and "both prioritized" conditions, each display device presented its own messages. In the "both on OEM display" condition, however, messages and warnings from both source devices were integrated and presented on the OEM display. Therefore, in these three conditions, about half of the warning participants experienced came from each source device. To better understand the differences between the single source display conditions and the dual source display conditions, it is useful to compare participants' responses to identical warnings (i.e., warnings that originated from the same source device). Two analyses of these data were conducted. The first compared the OEM-only condition to the equivalent warnings in the "both" and "both prioritized" conditions. An ANOVA found no significant effect for OEM device warnings [$F(2,30)=1.53$, $p=.23$]. The second analysis compared the portable-only condition to the equivalent warnings in the "both" and "both prioritized" conditions. An ANOVA found no significant effect for portable device warnings [$F(2,30)=2.83$, $p=.08$], though the result reveals a possible trend. Follow-up paired comparisons show a significant difference between the portable-only condition and the “both” condition [F(1,28)=2.22, p<.05], indicating that participants were significantly faster in responding to portable-device warnings in the portable-only condition (M=1.29 s) than in the “both” condition (M=1.81). Figure 6-12 shows participants’ reaction times by display condition and warning source device. The figure shows that, although these analyses revealed limited statistical significance, there appear to be noteworthy decrements in warning response time in the conditions where both display devices are active and there is no display integration. For example, responses to equivalent OEM device warnings in the “both prioritized” condition were on average 0.4 s slower than responses in the OEM-only condition. Differences of this magnitude are important from a safety standpoint, and may have been statistically significant with a larger sample size.

Figure 6-12. Mean reaction time by warning source display

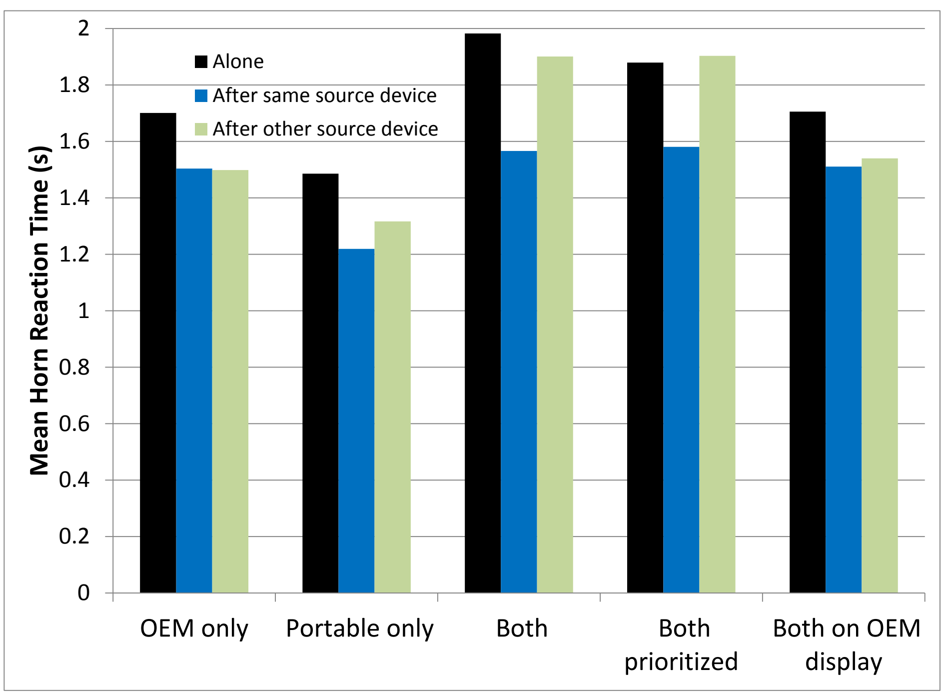


6.3.3 Effects of Preceding Message

For the three display conditions in which both source devices were active, crash warnings could occur either alone, 3 seconds after a non-urgent message from the same source device, or 3 seconds after a non-urgent message from the other source device (in the “both on OEM display” condition, messages from both source devices were shown on the OEM display). In the OEM-only and portable-only conditions, crash warnings could only occur alone or 3 seconds after a non-urgent message from the same source device. Analyses of warning predecessor effects used only data from the "both" and "both prioritized" conditions because only these two conditions used both source devices and both display devices. An ANOVA found a significant effect of warning predecessor [$F(2,230)=12.87$, $p<.0001$]. Paired comparisons showed that the participants responded significantly faster to a warning when it followed a non-urgent message on the same device ($M=1.49$ s) than when it occurred alone ($M=1.74$ s, $p<.0001$) or when it occurred after a non-urgent message on the other device ($M=1.72$, $p<.01$). Potential explanations for this effect are addressed in the Discussion section.

Figure 6-13 shows warning reaction time data for each display condition broken out by whether the warning occurred alone, after a non-urgent message from the same source display, or after a non-urgent message from the other source display. Whereas the statistical analyses of these data were limited to two of the display conditions, this figure shows the data from all five display conditions. Note that for the "OEM only" and "portable only" conditions there was no "other" device active, so the same/other data in these conditions essentially serve as a control condition in which no difference was expected, and none was observed.

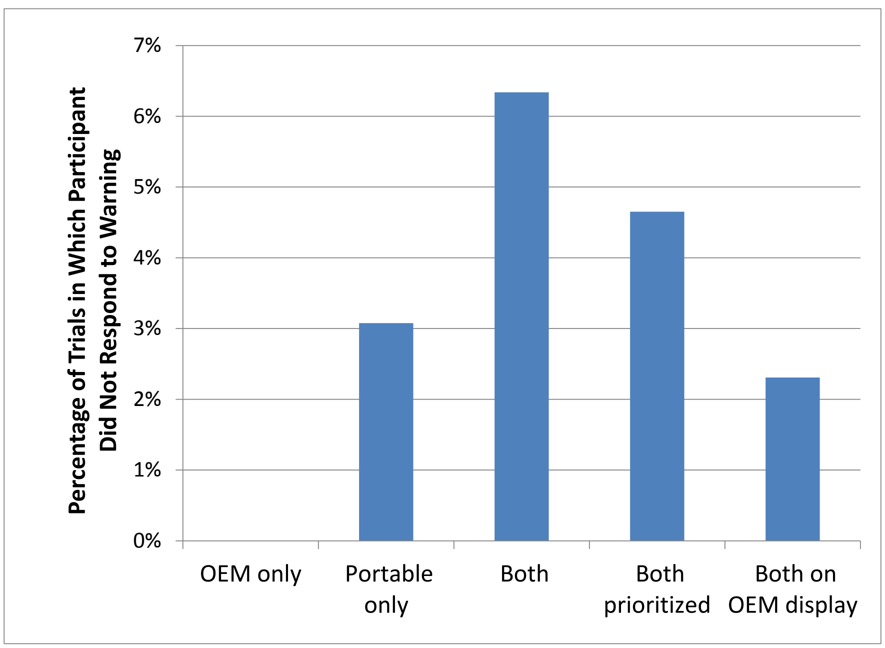
Figure 6-13. Mean horn reaction time by condition and warning predecessor



6.3.4 Warning Recognition Errors

In the vehicle environment, it is important that urgent crash warnings are accurately recognized and discriminated from other messages and signals. Errors in which drivers mistakenly interpret urgent warnings as non-urgent messages, or interpret non-urgent messages as urgent warnings, can lead to inappropriate and delayed behaviors, as well as lack of system trust and acceptance. Drivers were generally very good at recognizing warnings in this study; they only failed to recognize the presence of a warning in three percent of trials. Nonetheless, a Poisson log model (using SAS PROC GENMOD) revealed significant differences in failures to recognize warnings between conditions. Specifically, the "OEM-only" condition had significantly fewer missed warnings than "both" (χ^2=21.24, p<.0001), "both prioritized" (χ^2=101.89, p<.0001), and "both on OEM display" (χ^2=4.30, p=.038) conditions, and the "both on OEM display" condition had significantly fewer missed warnings than "both" (χ^2=6.22, p=.0126) and "both prioritized" (χ^2=11.02, p=.0009) conditions. Figure 6-14 shows the percentage of trials in each display condition in which participants failed to honk in response to an urgent crash warning.

Figure 6-14. Percentage of trials in which participant did not respond to warning

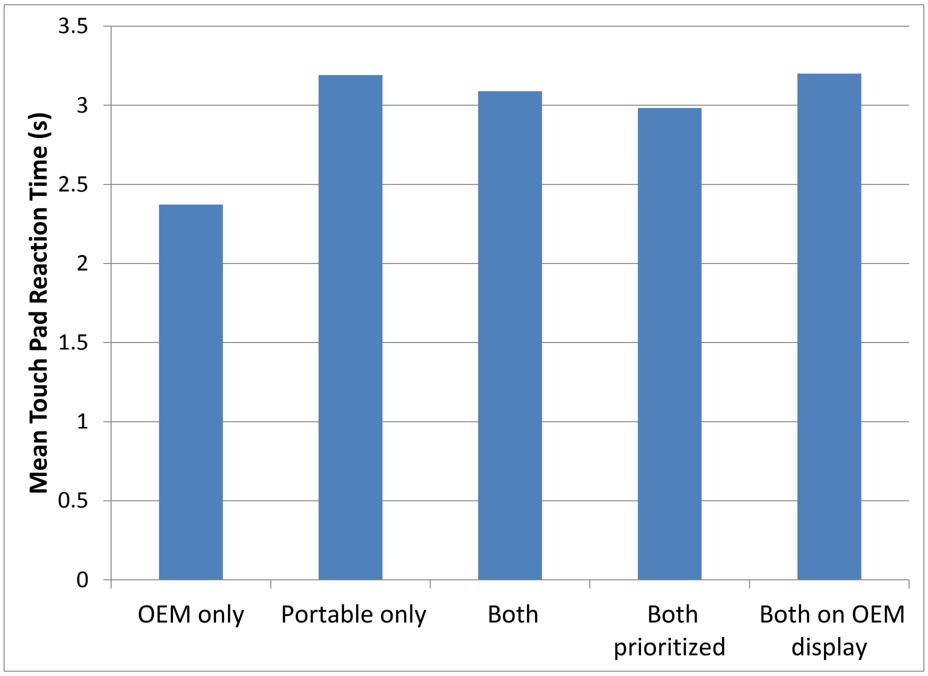


Errors in which participants interpreted non-urgent messages as urgent warnings were rare in this study; drivers only honked the horn in response to 1.5 percent of non-urgent messages presented to them. Eighty-four percent of these misinterpretations were in response to three messages: emergency vehicle approaching, traffic signal about to turn red, and stop for school bus. Each of these messages was safety-related, and could potentially be interpreted as a warning, though none fit the definition of urgent crash warnings presented to participants. A Poisson log model (using SAS PROC GENMOD) showed no significant differences between display conditions. Given the rarity of these errors in this study, there are too few data points to draw any clear conclusions from this analysis.

6.3.5 Hazard Location Detection

In addition to warning response time, analyses also looked at participants' reaction times to identify the direction of the hazard indicated by the crash warnings as a measure of warning comprehension. Participants were tasked to identify the location of a light on the perimeter of the vehicle that turned red at the moment when they honked the horn. Reaction time was measured as the time from the horn honk to the time when the participant touched the appropriate button on the touchpad, indicating the location of the changed light. To better understand the differences between the single source display conditions and the dual source display conditions, it is useful to compare participants' responses to identical warnings (i.e., warnings that originated from the same source device). Two ANOVAs were conducted: One compared identical warnings that issued from the OEM device and the other compared identical warnings that issued from the portable device. For both analyses, there were no significant differences between single source display condition (OEM only or portable only) and the dual source display conditions ("both" and "both prioritized"). This finding shows that once participants recognized that a warning was issued, they took about the same amount of time to identify the location of the threat regardless of the experimental condition. Figure 6-15 shows the mean hazard location detection response time for each display condition. While the figure shows an apparent reaction time benefit in the OEM only condition relative to the dual display conditions (likely due to the fact that the OEM device warnings directly indicate the general vicinity of the threat), the analyses described above reveal that, when only looking at the warnings issued by the OEM device, reaction times were statistically indistinguishable in the single display and dual display conditions.

Figure 6-15. Mean touchpad reaction time by condition



6.4 Discussion

In this experiment, participants drove an instrumented vehicle on a closed test course while following a route prescribed by a voice navigation system and intermittently experiencing a variety of non-urgent messages and urgent crash warnings. All messages and warnings included both a visual and an auditory component. Two display devices were present in the vehicle: one represented original equipment built into the vehicle (OEM device) and the other represented a portable device such as a smartphone (portable device). Participants were randomly assigned to one of five display conditions: only OEM device active; only portable device active; both devices active with no integration; both devices active with warning prioritization, and both devices active with all messages and warnings presented via the OEM device. Participants' task was to determine whether a given display was a non-urgent message or an urgent crash warning, and if it is an urgent crash warning, to honk the car horn as quickly as possible, then determine the location of the threat (represented by a light that changed color on the exterior of the vehicle) and touch the appropriate location on a touch pad.

Participants were generally accurate in their identification of warnings, with only 3 percent of trials resulting in failure to respond to warnings, and only 1.5 percent of non-urgent messages mistakenly responded to as warnings. Across all participants and conditions, the median warning response time was 1.52 s and the 85th percentile response time was 2.13 s.

In this experiment, warning response times were generally somewhat faster in the portable-only condition than in the OEM-only condition. This finding does not mean that there is a generalizable advantage of portable devices. Each device differed in terms of visual warning strategy, overall visual design theme, mounting location, and acoustic features. However, it does suggest that, given appropriate display features, mounting location, and device performance, a portable device such as a smartphone may be adequate for the presentation of CV warnings and other messages. This is consistent with research by Lee and Cheng (2010) that found that a small portable navigation system mounted in the driver's forward field of view was associated with better vehicle control performance than a built-in navigation system with a larger screen.

One potential advantage of the portable device, as it was implemented in this experiment, is that portable device sounds issued directly from the device itself, whereas OEM device sounds issued from the vehicle's multi-speaker sound system. As a result, the portable device sounds may have caused drivers to orient to the device more quickly, whereas the OEM sounds were diffuse and not localizable to the OEM device. Though sound source localization was not manipulated in this experiment, future research should address this potentially beneficial feature.

This experiment also showed that there is an apparent decrement in warning response time when two devices are active in the vehicle. This trend was not statistically significant for all comparisons, but it was observed in terms of mean response time and likelihood of failure to recognize the presence of a warning. The magnitude of the warning response decrement in the two-display conditions was generally in the range of 0.2 to 0.4 seconds, which could be substantial in the context of real-world crash warning response times. Given the methodology of this experiment (horn honk in response to an imaginary threat) it is not clear if the magnitude of the effect would be replicated under actual threat conditions in real-world driving.

Participants in this experiment showed no decrement in warning response time when a warning was preceded 3 seconds earlier by a non-urgent message. In fact, responding was significantly faster when there was a preceding message on the same display where the warning occurred. This is a potentially important finding for consideration in CV system design and integration. It is not clear whether this finding is robust, or is an artifact of the experimental design. There may have been a priming effect due to the fact that warnings in this experiment were occasionally issued 3 seconds after a non-urgent message. This effect, however, was not seen when the warning occurred after a non-urgent message on the other display, suggesting that the benefit only appears when a warning follows a message on the same display. It could also be the case that since there was no actual external threat, participants might have been more reliant on visual displays than would be the case in actual potential crash events. In fact, due to the lack of actual external threats, the warnings used in this study included more salient and descriptive visual components than most existing crash warning systems. Future research using actual external threats would help to further explore the source of this finding.

The time gap between non-urgent messages and urgent crash warnings might also have influenced the findings. In this experiment, the time gap was always 3 seconds. This gap was because it was short enough that participants would often still be attending to the preceding non-urgent message, but not so short that response to the urgent warning would be affected by a cognitive bottleneck. The bottleneck effect and associated psychological refractory period were not investigated in the present experiment. Rather than investigate a worst-case scenario, the objective of the present experiment was to gain a preliminary understanding of the possible effects of the use of multiple CV devices under fairly typical circumstances. Given this experiment's findings of performance decrements with multiple devices, further investigation of various temporal proximities of non-urgent messages and urgent crash warnings is warranted.

As an initial investigation into the effects of the use of multiple CV devices on driver responses, this experiment identified meaningful issues related to the level of display integration for CV devices and identified areas worthy of additional investigation:

- Measurement of driver vehicle control behaviors in response to apparent external hazards.
- Use of different messaging and warning strategies, including different visual and auditory elements, as well as haptic elements. For the sake of face validity in the present experiment, each device was given a distinctive visual feature set and warning strategy (general direction of threat for the OEM device and overhead schematic of threat scenario for the portable device). It is not clear to what extent the differences observed in responding to the two devices were related to the inherent features of the devices, or to the warning and messaging strategies. Furthermore, if future research includes apparent external threats, different warning strategies than were used in the present experiment could be included. Further investigation of warning features may lead to additional guidance on warning and message design for CV systems.
- Inclusion of other portable device locations, including driver-selected placement.

- Further exploration of potential orienting facilitation or interference effects from non-urgent messages and warnings, possibly including simultaneous warnings from multiple devices. If multiple devices present in a vehicle provide messages or warnings for the same event (e.g., forward collision warning), it is likely that simultaneous or near-simultaneous warnings could occur.

7.0 CONCLUSIONS AND IMPLICATIONS FOR CONNECTED VEHICLE APPLICATIONS

This project conducted a set of empirical studies to help address some of the key gaps in knowledge required to support human factors guidance for warning displays within the CV environment. In a number of cases, there has been only very limited research on the topic and the single experiment conducted on the issue here cannot resolve that issue. Nonetheless, these studies provide important initial steps towards answering key questions. The sections that follow summarize key implications based on all of the activities of this project.

The preliminary implications are grouped under three topic headings:

- Defining and conveying appropriate message urgency in all modes;
- Dealing with multiple events in temporal proximity; and
- Integration of multiple CV devices.

7.1 Defining and Conveying Appropriate Message Urgency in All Modes

Discriminability of Imminent Crash Warnings

Implication: Because there may be a wide variety of message types presented to drivers within the CV program, including non-safety information related to mobility and sustainability, it is important that critical safety messages requiring immediate driver response retain their salience. If critical safety messages are unique in some form and are perceived as more urgent than any other type of message, drivers’ response to these critical safety messages might be more appropriate and effective in avoiding the hazardous situation.

Limitations/Caveats: The specific means for discriminating urgent safety warnings from other messages is not determined and designers may approach this requirement in different ways. One important dimension is the perceived urgency of the display, which is addressed in several of the subsequent implication statements.

Design Consistency with Driver Perceptions

Implication: Driver performance, system acceptance, and consumer appeal are generally improved when systems are designed to be compatible with the perceptions and assumptions that users bring to the situation. While this is a consideration for the CV architecture as a whole, the research conducted under this project focused on safety applications in particular. If the attributes of safety-related messages are consistent with driver perceptions of need, timing, priority, urgency, etc., there may be fewer issues of perceived false alarms, message validity, distraction, and demand. The research conducted for this project identified certain driver perceptions that may support this (see following implication statements), but the understanding of the driver's mental model remains incomplete.

Limitations/Caveats: These user-centered design considerations for safety-related messages cannot be treated with independence from the broader structure of the CV architecture. The overall framework does not currently exist. There is also a very limited empirical basis for understanding users' mental models of CV safety communications, and it is not clear how diverse different individuals' mental models are from one another.

Appropriate Match to Objective and Perceived Urgency

Implication: When the level of urgency to be conveyed by a warning is determined by the objective urgency of the scenario and by the sense of urgency experienced by the driver, there might be a more appropriate match for the driver and might elicit a more appropriate and effective driver response. However, where a driver experiences more urgency than some non-subjective method may suggest, the system may be perceived as unreliable; where the driver experiences less urgency, the system may be viewed as intrusive, overly sensitive, and ignorable. Therefore, driver perceptions are important in determining message urgency, along with other considerations. Where differences exist between the designer's perception of urgency and the driver's perception of urgency, the designer may consider how a display might be designed to help convey a more appropriate sense of the situation.

Limitations/Caveats: The current project has started development of an empirical basis and predictive model for estimating the perceived urgency of various scenarios, but this basis is currently limited.

Levels of Urgency Coding

Implication: The experiment on user-based structure for message coding conducted a factor analysis that suggested three general categories of events. One factor ("high threat, act now") was defined by high-threat situations where an immediate driver response was required (e.g., forward collision, lane departure on a sharp curve, emergency vehicle in proximity). Another factor ("caution, measured action") encompassed events that were not so immediate that they allowed for some planning based on forewarning (e.g., upcoming turn, longer times to contact). The third factor ("no urgency, no action required) dealt with non-impending events that are more informational (e.g., fuel consumption, check engine light). Designers can create different categories of messages (e.g., traffic information versus driver services) within a given urgency level. This three-level concept is consistent with user expectations and will limit the use and protect the salience of the highest level of warning.

Limitations/Caveats: Beyond the initial findings of this research project, there is little information on the mental models that drivers may bring to the CV environment.

User-Anticipated Display Attributes for Various Levels of Urgency

Implication: The experiment on user-based structure for message coding found a very strong relationship between the perceived level of urgency in a scenario and the means of conveying priority. These display priority methods may be mapped onto the three levels of urgency that emerged from factor analysis. The analysis suggested that for the most urgent messages, if the warning display interrupts and overrides all other messages, it might elicit a more appropriate and effective driver response. Further, it is beneficial for cautionary messages to have a clear alert to indicate that there is something important to attend to. Finally, low urgency messages might only need to be presented or be accompanied by a low-urgency indicator cue.

Limitations/Caveats: The experiment from which these display attributes were drawn provided only a limited number of options.

Consistency of Perceived Urgency in Multimodal Displays

Implication: It is expected, based on current warning systems and demonstration vehicles, that safety-critical CV warnings will frequently have multiple components. For example, an intersection conflict warning might have an acoustic alert and also an illuminated panel to the side of the vehicle from which the threat is coming. Since the driver may be attending to either (or both) signals, if the urgency level conveyed by each is consistent with the threat and internally consistent with the other component, it might elicit a more appropriate and effective driver response.

Limitations/Caveats: It is assumed that conflicting levels of urgency among the components of a warning display would be unclear to the driver and therefore have the potential to impair driver response or reduce acceptance. However, we are not aware of any empirical evidence of this presumed effect. It may be the case that effects, if any, are quite small. Or it may be the case that a particular warning mode, or urgency level, controls driver perception, regardless of what another message component might convey. This implication is therefore based on the logic of the interface design but not any specific empirical findings.

Cross-Modal Consistency in Warning Urgency for Scenarios

Implication: Different CV products may convey warnings in quite different ways. They may use different perceptual modes (acoustic, visual, haptic) and different stimuli within a given mode (e.g., tone versus speech, text versus icon, seat pan vibration versus brake pulse). Whatever the signal, it is important that a similar level of perceived urgency be conveyed for any given scenario. Inconsistency in the perceived urgency of a particular event may result in driver confusion, delayed response, or system acceptance issues. Perceived urgency is important not only as a relative measure within a system, but also as appropriate to the threat in absolute terms and consistent across systems.

Limitations/Caveats: Cross-modal matching of perceived urgency was demonstrated in a set of perceptual experiments in this project. However, only a limited number of display parameters were manipulated. A stronger empirical basis to support this matching is required, and tools for predicting the level of perceived urgency of a given signal would be desirable.

Temporal Aspects of Perceived Urgency in Event Scenarios

Implication: A negative relationship between time-to-event and perceived urgency was observed in the experiment on user-based structure for message coding (i.e., lower time-to-event was associated with greater perceived urgency). Other (largely undefined) factors are also important, because at a given time-to-event, a range of mean perceived urgency ratings was obtained across different scenarios. However, the highest urgency ratings were generally confined to situations where the time-to-event was 5 seconds or less. This is not meant to imply that any situation in which an event is less than 5 seconds away must be considered to be in the most urgent warning category. A number of situations in which there was a short temporal aspect were not rated at the highest urgency (e.g., about to violate a red light, about to enter a curve at inappropriate speed). However, where there was some temporal aspect to the warnings, a brief ($\leq$ 5 s) time-to-event appears to be a necessary, but not sufficient, condition for that message to be perceived as highly urgent.

Limitations/Caveats: The relevant research findings come from a single experiment using computer-generated driving scenarios (from driver's perspective). Some findings could be idiosyncratic to the particular video implementation of the event. Additional research should confirm the findings and also extend knowledge regarding the situational factors that determine perceived urgency.

7.2 Dealing with Multiple Events in Temporal Proximity

Use of Multiple Auditory (Non-Speech) Imminent Crash Warnings

Implication: In practice, circumstances may warrant the presentation of near simultaneous, or multiple crash warnings to alert drivers to the presence of multiple hazards. Existing guidance (Campbell, Richard, Brown, & McCallum, 2007) suggests limiting warnings information under multiple threat situations to the visual modality in order to avoid overloading or confusing drivers. Current evidence from this project indicates that the presentation of near simultaneous non-speech auditory warnings can be executed without necessarily overloading drivers or sacrificing performance. Drivers were found to benefit from the provision of multiple warnings, even when presented in close temporal proximity, leading to faster response times relative to a single warning situation.

Limitations/Caveats: Results are specific to the provision of multiple warnings for forward and lateral threats denoted by an audible Forward Collision Warning (FCW) followed by an audible Lane Change Warning (LCW). Further research is needed to determine whether multiple warnings can be presented effectively in different temporal proximities, or with different combinations of warning events.

Minimize Multiple Warning Scenarios or Conflict Situations

Implication: The CV environment affords opportunities to increase communication among vehicles leading to advance notification of emerging conflict situations. This represents a significant advantage over traditional sensing mechanisms and approaches. Managing the pacing or flow of information to drivers can potentially reduce event urgency or the likelihood that drivers will be exposed to multiple conflict situations. Multiple warning scenarios can potentially be avoided if CV systems warn drivers sufficiently in advance of conflict, or use interfaces which guide drivers towards appropriate actions that will not result in secondary conflict situations.

Limitations/Caveats: This approach may not eliminate all types of secondary or multiple warning situations, but may significantly limit the number of exposures.

Map Warning Characteristics to the Appropriate Response to the Conflict Scenario

Implication: Current vehicle-based sensing essentially only allows for the one-to-one mapping of a triggering event (e.g., time to contact with a forward object) with a specific warning or vehicle response. If multiple threat events are emerging, each event triggers a particular warning. However, in the CV environment, it may be possible to define the surrounding traffic situation and identify the set of conflicts and emerging situations. Under these conditions, the desired "correct" driver maneuver or avoidance path can be determined – one which does not lead to supplemental conflict. The specific message to the driver may then be tailored to the situation. Channeling the appropriate response through an intuitive warning interface (e.g., directional steering torque, brake pulse, etc.) may provide a significant advantage by modeling the appropriate and desired behavior – one not likely to lead to a second conflict or loss of vehicle control (i.e., steering overcorrection).

Limitations/Caveats: Limitations in the sensed environment may make it challenging to address the full range of potential secondary conflicts or allow the "correct" desirable response to be defined. Also, the success of this approach may be correlated with the degree of penetration of CV technology within the vehicle fleet.

Defining Near Simultaneous or Multiple Warning Events

Implication: Even under multiple warning situations, the interval between alerts can vary substantially and may have an impact on shaping a driver's ability to process and respond to the multiple conflict situations. Operationally defining the boundary conditions and performance impacts associated with each event class can aid in identifying and managing these types of situations. Any rules for dealing with temporally proximal warnings must be able to indicate at what degree of separation the warnings no longer influence responding. Temporal aspects may include both the onset and the termination of the initial signal.

Limitations/Caveats: The degree of separation of events in research studies may vary considerably. The "multiple warning events" experiment conducted under this project issued the second warning an average of 2.76 s after the initiation of the first warning. Additional research is needed to better understand the temporal conditions under which successive warning signals may influence the appropriateness of the driver response.

Evaluation Methods for Collision Warnings: Performance versus Recall for Assessing Collision Warnings

Implication: Drivers may not necessarily be able to recall the timing or sequence of warnings issued under urgent situations, particularly if they are received in close temporal proximity to each other. Research under this project found that a substantial percentage of drivers were not able to reconstruct or recall the number or sequence of warnings received. However, performance-based measures served to reliably discriminate among the conditions of interest. Thus, relative to performance, driver recall of the timeline of events during a surprising, stressful conflict situation can be less reliable as a basis for evaluating alternative interface approaches.

Debriefing sessions following a warning event that take place as soon as possible following the event will likely maximize driver recall and minimize memory decay.

Limitations/Caveats: Recall was captured several minutes following an unexpected warning event during a debriefing session. Accuracy of recall immediately following the event was not evaluated.

7.3 Integration of Multiple Connected Vehicle Devices

Portable Device Mounting

Implication: In the portable device pairing experiment in this project, driver performance and subjective response to a portable (“smartphone”) display was comparable (and on some measures, superior) to that of a larger, simulated OEM display at a typical center stack location. The cell phone was located at about the level of the top of the dashboard, to the left of the steering wheel (attached to the windshield by suction cup). Although the present study did not manipulate the location of the portable device, a number of research studies have demonstrated that displays that are closer to the driver’s forward field of view result in better driving performance (e.g., Rydström, Broström, & Bengtsson, 2012; Wittmann et al., 2006; Fuller, Tsimhoni, & Reed, 2008; Klauer, Holmes, Harwood, & Doerzaph, 2011; Lee & Cheng, 2010). Wittman et al. (2006) found in simulated driving that lane keeping performance worsened exponentially as display location was shifted away from forward gaze, and that vertical shift caused greater performance decrements than horizontal shift. In simulated driving, Fuller et al. (2008) found that in addition to visual angle from forward gaze, reach distance to an interface impaired task completion times. Such findings have implications for mobile device use. Klauer et al. (2011) found that when an imminent red light warning was presented on an unmounted cell phone (drivers could place the phone in any location they chose but often placed it in a cup holder to the right of the driver’s leg), drivers engaged in test track driving were significantly less likely to respond to the warning than drivers who received the warning on an OEM-type or navigation-type display located in the center stack or fastened to the windshield. Together, these findings indicate the importance of promoting the proper locating of portable devices for CV applications.

Limitations/Caveats: Portable device displays and sounds designed for usability in the vehicle environment might distract drivers less and might elicit a more appropriate and effective driver response. Although the device used in this experiment required no interaction by the participant, the prototype set of displays developed for the portable device experiment in the present project was intended to be well-designed for in-vehicle use, in addition to having a smartphone "feel." Current actual phone applications may not be well-designed for use while driving, even when mounted in an appropriate location. Visually appealing features for non-driving use, such as dynamic features (scrolling, flashing, animation), multiple simultaneous messages, complex images, a range of text fonts, menu or touch screen interaction, and so forth, may be undesirable in a CV application. Criteria for acceptable displays are not clear at this time. The finding that portable devices are acceptable if properly mounted is based on the assumption of an appropriate interface. Research suggests that a good mounting location is a necessary but not sufficient requirement.

Multiple Connected Vehicle Products Integration

Implication: It appears probable that as CV applications develop, users may wish to employ more than one source of information. In particular, applications provided by an in-vehicle OEM system may be supplemented by applications from aftermarket or portable devices. In a test track study of driver response to warning messages within a broader, simulated CV context, response times were longest, and missed crash warning messages were most frequent, when there were two non-integrated products (simulated OEM and portable device). Responding to warnings when there were two separate displays was worse than to either display alone. When the responses from both systems were presented at a common location (the OEM display), even though they retained their separate characteristics, responding was better than to the independent displays. This was true even if the warning message occurred in temporal isolation from any other messages. There was also some suggestion that responding to warnings may be better if all of the messages were in a common format, rather than in two different formats, although this effect was not large in the experiment.

Limitations/Caveats: These findings come from a single empirical study. No other research has been identified that directly assessed the influence of multiple product system integration on the ability of drivers to quickly recognize critical warning messages within the broader message context of CV. Furthermore, this study did not directly measure driver vehicle control actions, but rather the response time to report that a message was an urgent warning. Various recommendations regarding integration may be derived from the general human factors literature, but empirical assessments specifically within the CV context are very limited.

Additional research is needed to define the magnitude of potential safety effects and the effectiveness of various means to address this.

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APPENDIX A

USER-BASED STRUCTURE FOR MESSAGE CODING

Appendix A: Full list of experiment trials with means and standard deviations of perceived urgency and priority choice

Number	Category	Type of Message	Time/dist to Event	Dist code	Speed	Roadway	Specific Message	Urgency Rating Mean	Urgency Rating SD	Priority Choice Mean	Priority Choice SD
1	Safety	Imminent Crash	3.2	3	35	rural 4-lane	Forward collision	7.7	2.3	2.29	1.
2	Safety	Imminent Crash	2.1	2	35	rural 4-lane	Forward collision	8.56	2.0	1.8	1.0
3	Safety	Imminent Crash	1	1	35	rural 4-lane	Forward collision	8.21	2.	1.96	1.
4	Safety	Imminent Crash	3.2	3	55	rural 4-lane	Forward collision	7.31	2.3	2.46	1.3
5	Safety	Imminent Crash	2.1	2	55	rural 4-lane	Forward collision	8.06	1.8	2.13	1.1
6	Safety	Imminent Crash	1	1	55	rural 4-lane	Forward collision	8.63	1.8	1.74	1.1
7	Safety	Imminent Crash	1.5	3	35	arterial	Blind spot	5.76	2.4	3.26	1.3
8	Safety	Imminent Crash	0	1	35	arterial	Blind spot	6.33	2.5	2.87	1.3
9	Safety	Imminent Crash	1.5	3	60	freeway	Blind spot	5.49	2.7	3.6	1.5
10	Safety	Imminent Crash	0	1	60	freeway	Blind spot	6.23	2.	3.3	1.
11	Safety	Imminent Crash	gradual	1	35	rural 4-lane	Lane departure	8.19	2.0	1.91	1.1
12	Safety	Imminent Crash	sharp	3	35	rural 4-lane	Lane departure	8.91	1.8	1.56	1.1
13	Safety	Imminent Crash	gradual	1	60	freeway	Lane departure	8.67	1.8	1.56	0.8
14	Safety	Imminent Crash	sharp	3	60	freeway	Lane departure	9.39	1.0	1.23	0.4
15	Safety	Imminent Crash	9	3	55	rural 4-lane	Do not pass	7.43	2.7	2.69	1.7
16	Safety	Imminent Crash	3	1	55	rural 4-lane	Do not pass	8.8	2.1	1.79	1.4
17	Safety	Emerging	long	3	35	arterial	Electronic brake light	6.63	2.5	2.91	1.4
18	Safety	Emerging	medium	2	35	arterial	Electronic brake light	7.24	2.1	2.41	1.2
19	Safety	Emerging	short	1	35	arterial	Electronic brake light	7.24	2.7	2.61	1.5
20	Safety	Emerging	long	3	60	freeway	Electronic brake light	6.17	2.6	3.1	1.6
21	Safety	Emerging	medium	2	60	freeway	Electronic brake light	6.71	2.2	2.53	1.3
22	Safety	Emerging	short	1	60	freeway	Electronic brake light	7.41	2.3	2.53	1.4
23	Safety	Emerging	6	3	35	rural 4-lane	Intersection conflict	6.71	2.4	2.79	1.3
24	Safety	Emerging	3	1	35	rural 4-lane	Intersection conflict	7.76	2.	2.2	1.2
25	Safety	Emerging	6	3	55	rural 4-lane	Intersection conflict	6.49	2.8	2.97	1.7
26	Safety	Emerging	3	1	55	rural 4-lane	Intersection conflict	7.61	2.4	2.23	1.
27	Safety	Emerging	16	4	35	arterial	Intersection violation	4.74	2.7	3.77	1.6
28	Safety	Emerging	8	3	35	arterial	Intersection violation	5.16	2.7	3.67	1.6

Appendix A: Full list of experiment trials with means and standard deviations of perceived urgency and priority choice (continued)

Number	Category	Type of Message	Time/ dist to Event	Dist code	Speed	Roadway	Specific Message	Urgency Rating Mean	Urgency Rating SD	Priority Choice Mean	Priority Choice SD
29	Safety	Emerging	4	2	35	arterial	Intersection violation	5.69	2.71	3.27	1.57
30	Safety	Emerging	2	1	35	arterial	Intersection violation	6.1	2.93	3	1.66
31	Safety	Emerging	15	3	35	arterial	Stopped traffic	5.81	2.74	3.36	1.61
32	Safety	Emerging	7.5	1	35	arterial	Stopped traffic	6.36	2.78	3.07	1.54
33	Safety	Emerging	15	3	60	freeway	Stopped traffic	6.27	2.48	2.94	1.3
34	Safety	Emerging	7.5	1	60	freeway	Stopped traffic	6.84	2.18	2.53	1.02
35	Safety	Potential Hazard	4.0	3	35	arterial	Pedestrian	6.54	2.74	2.97	1.64
36	Safety	Potential Hazard	1.5	1	35	arterial	Pedestrian	8.61	1.78	1.87	1.09
37	Safety	Potential Hazard	4	3	35	arterial	School bus no pass	7.73	2.26	2.21	1.06
38	Safety	Potential Hazard	1.5	1	35	arterial	School bus no pass	8.63	2.12	1.7	1.15
39	Safety	Potential Hazard	n/a	5	35	arterial	Emergency vehicle	7.46	2.47	2.31	1.23
40	Safety	Potential Hazard	n/a	5	60	freeway	Emergency vehicle	8.1	2.43	2.1	1.41
41	Safety	Upcoming	8	3	35	arterial	Red signal	5.73	2.93	3.63	1.64
42	Safety	Upcoming	4	1	35	arterial	Red signal	6.1	2.87	3.13	1.72
43	Safety	Upcoming	8	3	55	rural 4-lane	Too fast for curve	5.97	2.77	3.27	1.43
44	Safety	Upcoming	4	1	55	rural 4-lane	Too fast for curve	6.27	2.62	2.94	1.32
45	Safety	Upcoming	2	1	60	freeway	Lane ends	6.54	2.59	2.94	1.32
46	Safety	Upcoming	15	3	60	freeway	Lane ends	6.23	2.65	3.17	1.48
47	Safety	Situational	15	3	35	arterial	School zone	5.26	2.84	3.59	1.51
48	Safety	Situational	2	1	35	arterial	School zone	6.83	2.31	2.61	1.01
49	Safety	Situational	15	3	60	freeway	Work zone	6.06	2.51	3.13	1.18
50	Safety	Situational	2	1	60	freeway	Work zone	6.61	2.52	2.83	1.22
51	Safety	Environment	5 miles	3	60	freeway	Weather ahead	7.04	2.66	2.56	1.29
52	Safety	Environment	1 mile	1	60	freeway	Weather ahead	7.8	2.49	2.26	1.3
53	Safety	Vehicle status	n/a	5	35	arterial	Low tire pressure	6.26	2.44	3.17	1.23
54	Safety	Vehicle status	n/a	5	60	freeway	Low tire pressure	7.29	2.37	2.77	1.22
55	Safety	Vehicle status	n/a	5	35	arterial	Low fuel	7.43	2.52	2.39	1.12
56	Safety	Vehicle status	n/a	5	60	freeway	Low fuel	7.39	2.64	2.56	1.26

Appendix A: Full list of experiment trials with means and standard deviations of perceived urgency and priority choice (continued)

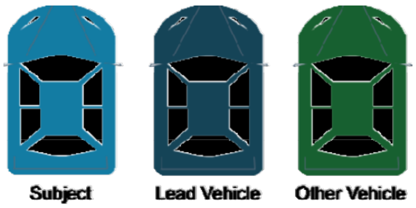
Number	Category	Type of Message	Time/ dist to Event	Dist code	Speed	Roadway	Specific Message	Urgency Rating Mean	Urgency Rating SD	Priority Choice Mean	Priority Choice SD
57	Safety	Vehicle status	n/a	5	35	arterial	Engine malfunction	6.64	2.53	2.81	1.3
58	Safety	Vehicle status	n/a	5	60	freeway	Engine malfunction	7.03	2.39	2.46	1.14
59	Mobility		15	3	35	arterial	Impend turn	6.51	2.19	2.8	1.08
60	Mobility		5	2	35	arterial	Impend turn	7.63	2.13	2.47	1.3
61	Mobility		2	1	35	arterial	Impend turn	8.04	2.49	2.41	1.55
62	Mobility		15	3	60	freeway	Impend turn	5.2	3.07	3.56	1.4
63	Mobility		5	2	60	freeway	Impend turn	6.27	2.59	3.1	1.32
64	Mobility		2	1	60	freeway	Impend turn	7.46	2.65	2.56	1.36
65	Mobility		.5 mile	1	60	freeway	Congest ahead	5.77	2.25	3.14	1.11
66	Mobility		1 mile	2	60	freeway	Congest ahead	5.87	2.52	3.07	1.23
67	Mobility		2 mile	3	60	freeway	Congest ahead	5.53	2.45	3.07	1.04
68	Mobility		4 mile	4	60	freeway	Congest ahead	5.01	2.71	3.44	1.33
69	Mobility		3 mile	3	60	freeway	Route change	6.41	2.58	2.8	1.19
70	Mobility		.5 mile	1	60	freeway	Route change	7.74	1.97	2.41	1.22
71	Mobility		120	3	60	freeway	Traveler service	5.13	2.56	3.74	1.43
72	Mobility		30	1	60	freeway	Traveler service	4.66	2.5	3.81	1.48
73	Mobility		30	3	35	arterial	Parking avail	4.79	2.56	3.73	1.45
74	Mobility		10	1	35	arterial	Parking avail	4.54	2.55	3.76	1.6
75	Convenience		n/a	5	35	arterial	Email or text	3.69	2.83	4.34	1.51
76	Convenience		n/a	5	60	freeway	Email or text	4	3.05	4.14	1.49
77	Sustainability		n/a	5	35	arterial	Excess fuel	5.43	2.76	3.3	1.33
78	Sustainability		n/a	5	60	freeway	Excess fuel	5.63	2.69	3.31	1.2

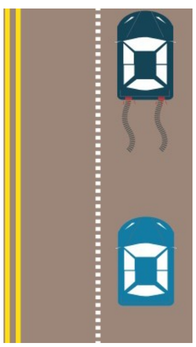
APPENDIX B

URGENCY CODING WITHIN AND ACROSS MODES

Appendix B: Driving Scenarios used in Experiment 2C

In all of the scenarios the participant was engaged in a car following task. The lead vehicle was yoked to the participant's vehicle and thus maintained a constant headway despite fluctuations in the in the participant vehicle's speed. Potential collision situations triggered an alert in all but the
control conditions. The alert was presented at a time to collision approximating 1.7 seconds. Two Lead Car Break events in different locations in the scenario were presented. One Left Turn event and one Cut-in event were presented to each participant in a counterbalanced order. Alert modality was manipulated as a between subjects variable and urgency level within each modality was counterbalanced across scenario types such that each participant received one alert at each of the three urgency levels and one control condition in which no alert was provided. Each collision scenario is further described and illustrated below.

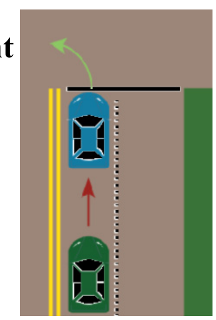




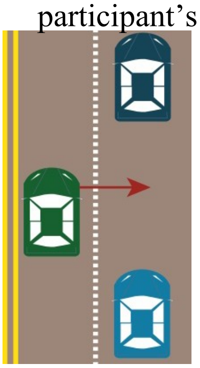
Lead Car Break Event (Rural and Highway)

In the lead car break event, the car that the participant's vehicle was following unexpectedly initiated a rapid deceleration. This happened on both highway and rural roads.

Left Turn – Rear End Event



In the left turn event, the car that the participant was following made a left hand turn at an intersection. The traffic light remained green throughout the event. A vehicle approaching rapidly from behind the participant's vehicle failed to slow thus resulting in a potential collision with the rear of the participant's vehicle.



Cut-in Event

In the cut in scenario a third car unexpectedly swerved into the participant's lane between the participant's vehicle and the lead car and then initiated a rapid deceleration.

APPENDIX C

PORTABLE DEVICE PAIRING

Appendix C: Full set of warnings, with sounds

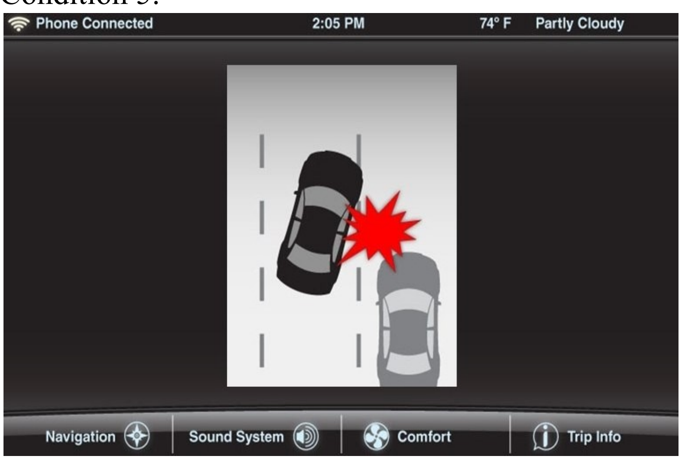
ITEM 7: LCW alone

Condition 1: Moderate warning OEM.wav

Condition 2: Moderate warning nomadic.wav

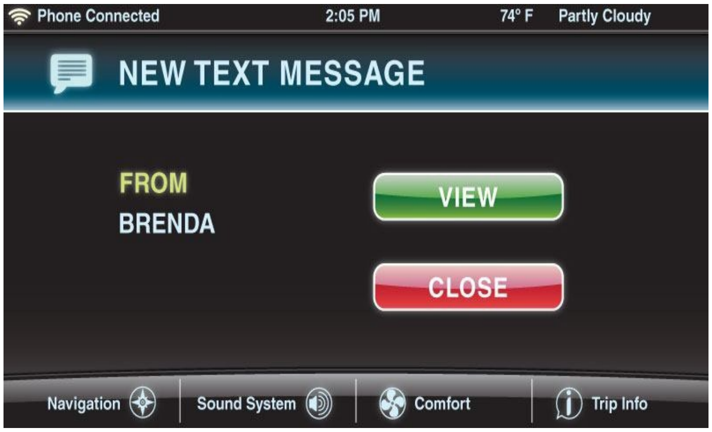
Condition 3/4: Moderate warning nomadic.wav

Condition 5: Moderate warning nomadic.wav



ITEM 13: LDW after text message

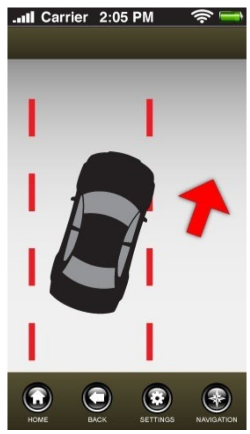
Condition 1: Text OEM.wav



Moderate warning OEM.wav

Condition 2: Text Nomad.wav

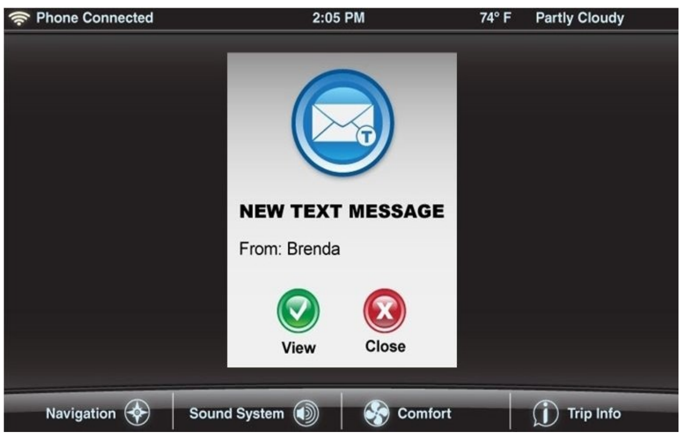
Moderate warning nomadic.wav



Conditions 3/4: Text Nomad.wav

Moderate warning OEM.wav

Condition 5: Text Nomad.wav



Moderate warning OEM.wav

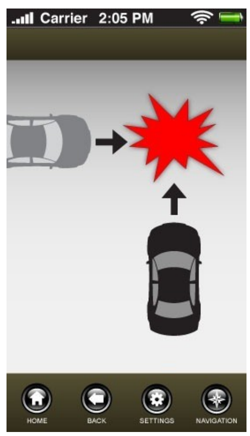
ITEM 23: Intersection collision warning after icy roads ahead message

Condition 1: Weather OEM.wav

Urgent warning OEM.wav

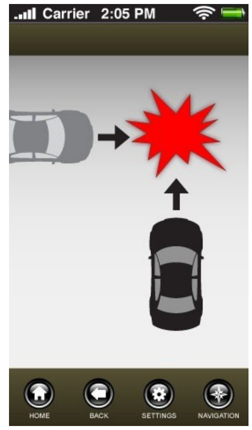
Condition 2: Weather Nomad.wav

Urgent warning nomadic.wav



Conditions 3/4: Weather OEM.wav

Urgent warning nomadic.wav



Condition 5: Weather OEM.wav

Urgent warning nomadic on OEM.wav

Item 28: LCW after delays ahead message

Condition 1: Traffic OEM.wav

Moderate warning OEM.wav

Condition 2: Traffic Nomad.wav

Moderate warning nomadic.wav

Conditions 3/4: Traffic Nomad.wav

Moderate warning nomadic.wav

Condition 5: Traffic Nomad.wav

Moderate warning nomadic on OEM.wav

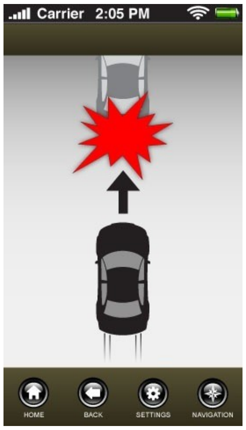
ITEM 34: FCW after rest area ahead message

Condition 1: Service OEM.wav

Urgent warning OEM.wav

Condition 2: Service Nomad.wav

Urgent warning nomadic.wav



Conditions 3/4: Service Nomad.wav

Urgent warning OEM.wav

Condition 5: Service OEM.wav

Urgent warning OEM.wav

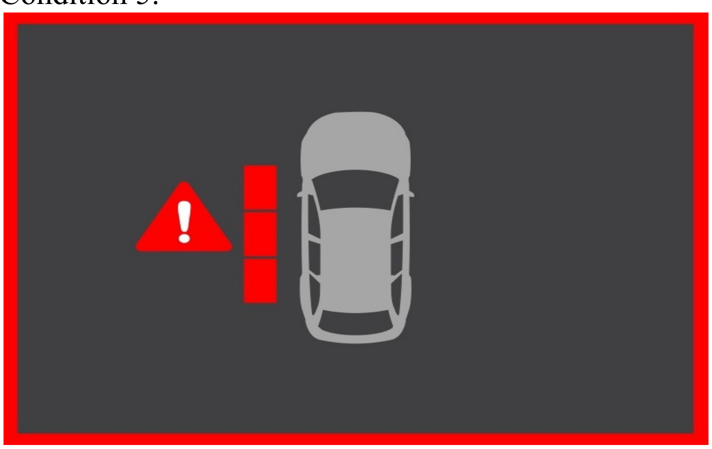
ITEM 39: LDW alone

Condition 1: Moderate warning OEM.wav

Condition 2: Moderate warning nomadic.wav

Conditions 3/4: Moderate warning OEM.wav

Condition 5: Moderate warning OEM.wav



ITEM 47: Forward collision warning after stop for school bus message

Condition 1: Safety OEM.wav

Urgent warning OEM.wav

Condition 2: Safety Nomad.wav

Urgent warning nomadic.wav

Conditions 3/4: Safety OEM.wav

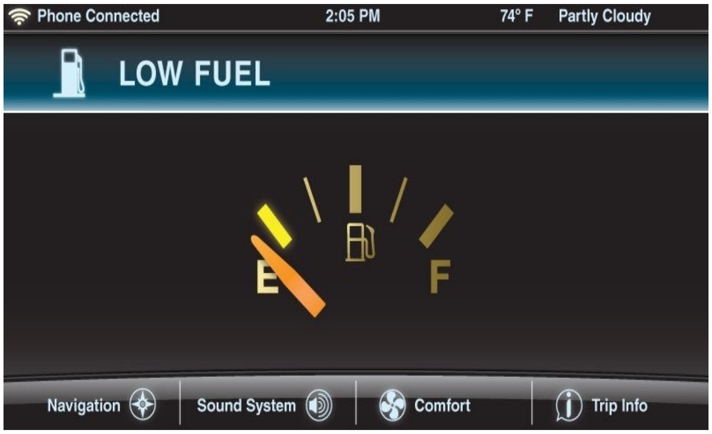
Urgent warning OEM.wav

Condition 5: Safety OEM.wav

Urgent warning OEM.wav

ITEM 57: LCW after low fuel message

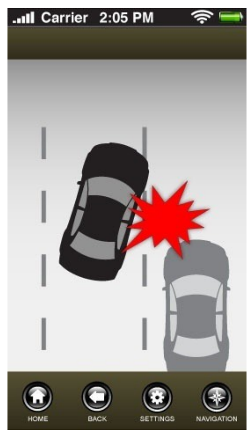
Condition 1: Status OEM.wav



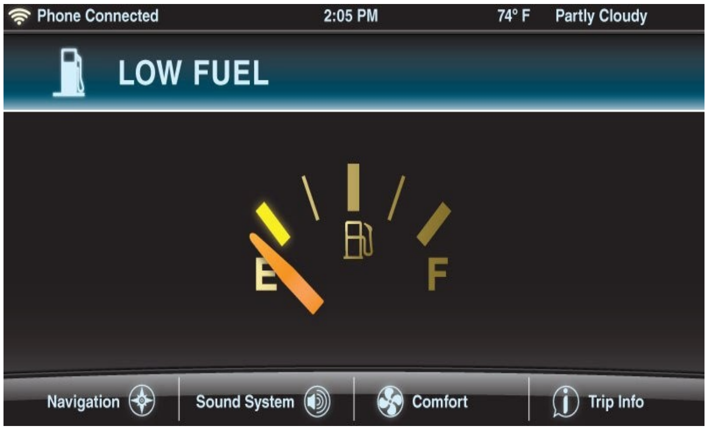
Moderate warning OEM.wav

Condition 2: Status Nomad.wav

Moderate warning nomadic.wav

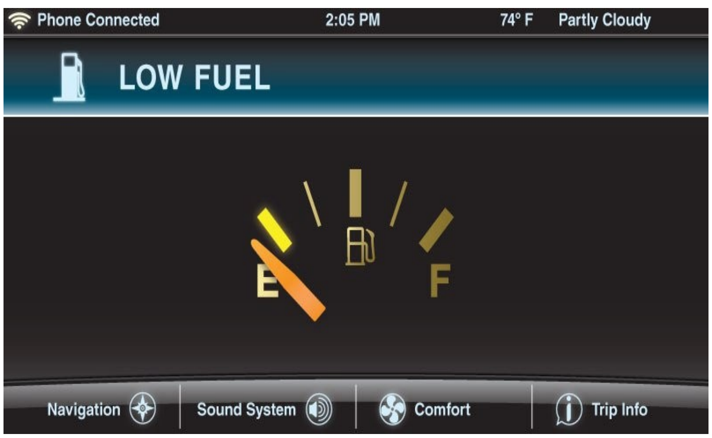


Conditions 3/4: Status OEM.wav



Moderate warning OEM.wav

Condition 5: Status OEM.wav



Moderate warning OEM.wav

ITEM 62: Pedestrian collision warning alone

Condition 1: Urgent warning OEM.wav

Condition 2: Urgent warning nomadic.wav

Conditions 3/4: Urgent warning nomadic.wav

Condition 5: Urgent warning nomadic on OEM.wav

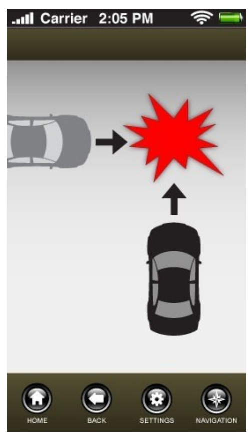
ITEM 72: Intersection collision warning after train at crossing ahead message

Condition 1: Traffic OEM.wav

Urgent warning OEM.wav

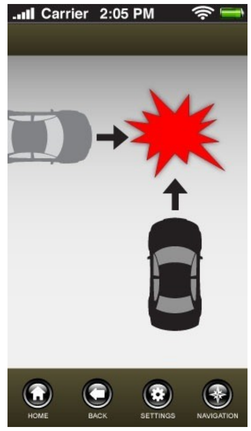
Condition 2: Traffic Nomad.wav

Urgent warning nomadic.wav



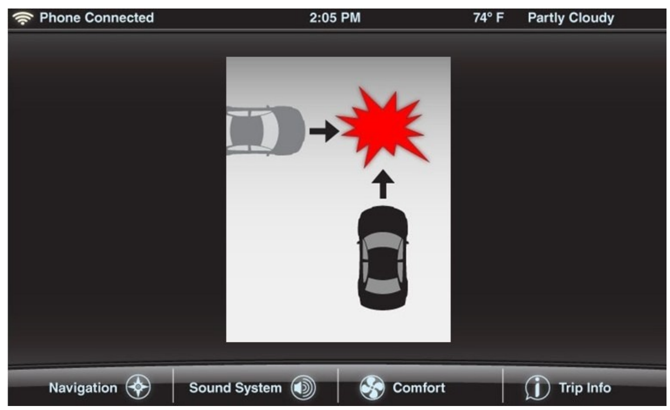
Conditions 3/4: Traffic Nomad.wav

Urgent warning nomadic.wav



Condition 5: Traffic OEM.wav

Urgent warning nomadic on OEM.wav



ITEM 77: LCW after right lane ends message

Condition 1: Safety OEM.wav

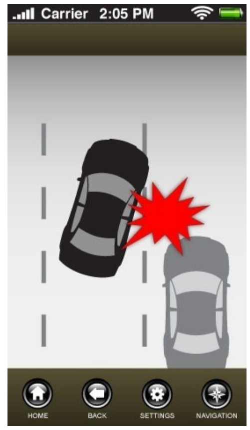
Moderate warning OEM.wav

Condition 2: Safety Nomad.wav

Moderate warning nomadic.wav

Conditions 3/4: Safety OEM.wav

Moderate warning nomadic.wav



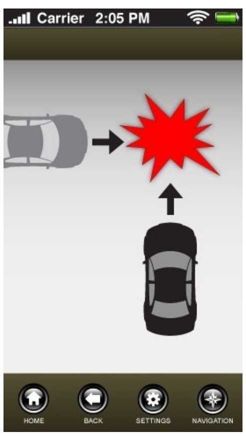
Condition 5: Safety OEM.wav

Moderate warning nomadic.wav

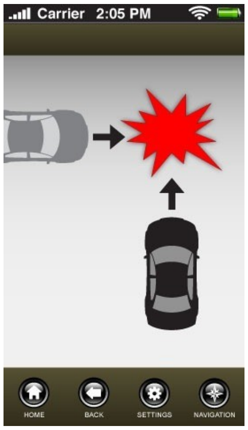
ITEM 80: Intersection collision warning alone

Condition 1: Urgent warning OEM.wav

Condition 2: Urgent warning nomadic.wav



Conditions 3/4: Urgent warning nomadic.wav



Condition 5: Urgent warning nomadic on OEM.wav

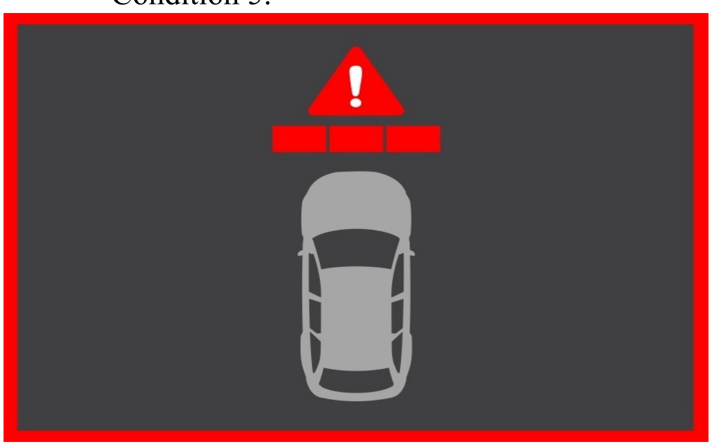
ITEM 85: Forward collision warning alone

Condition 1: Urgent warning OEM.wav

Condition 2: Urgent warning nomadic.wav

Conditions 3/4: Urgent warning OEM.wav

Condition 5: Urgent warning OEM.wav



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**National Highway
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