U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

People Saving People
www.nhtsa.dot.gov

DOT HS 809 462 May 2002

Automotive Collision Avoidance System Field Operational Test

Warning Cue Implementation Summary Report

This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161

Technical Report Documentation Page

1. Report No. DOT HS 809 462	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Automotive Collision Avoidance Field Operational Test Warning Cue Implementation Summary Report		5. Report Date May 23, 2002 6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address General Motors Corporation 30500 Mound Road Warren, MI 48090-9055	Delphi-Delco Electronic Systems One Corporate Center Kokomo, IN 46904	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTNH22-99-H-07019
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration U.S. Department of Transportation 400 Seventh Street, S.W. Washington, DC 20590		13. Type of Report and Period Covered Task Summary Report January - June 2001 14. Sponsoring Agency Code

15. Supplementary Notes

This project was carried out by a team lead by General Motors Corporation, North American Operations. Other major team members included: Delphi-Delco Electronic Systems, Delphi-Chassis, HRL Laboratories, HE Microwave and UMTRI.

16. Abstract

This report documents the human factors work conducted from January to June 2001 to design and evaluate the driver-vehicle-interface (DVI) for the Automotive Collision Avoidance System Field Operational Test (ACAS FOT) program. The objective was to develop an interface that most effectively supports the human interaction with the Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC) systems. The DVI visual display sequences were developed for projection onto a full-color head-up display (HUD). Unlike previous generation HUDs, the new design was reconfigurable, facilitating the display of multiple-stage multicolor icon sequences for communicating the FCW alert level. Whereas the CAMP (1999) FCW project had focused only on single-stage monochromatic alerts largely because of implementation practicalities, the flexibility of the new HUD platform allowed a deeper analysis of how the output of the forward collision warning algorithm should be displayed to the driver.

Two experiments were designed to examine the effectiveness of a range of multiple-stage alert candidates compared with a single-stage alert. Experiment 1 (Performance evaluation) employed a driving simulator to evaluate the impact of the display candidates on the brake reaction time (BRT) of drivers to an unexpected lead-vehicle braking event. The data revealed that some multiple-stage candidates facilitated earlier BRTs compared with the single-stage alert. This was evident of the display sequences that exhibited a looming quality (expanding visual image representing imminent collision), but not observed for the displays that did not. Experiment 2 (Preference evaluation) was designed to investigate the driver acceptance of the display candidates. Twelve drivers experienced four display candidates in the driving simulator and answered questions regarding their preferences and the annoyance induced by the displays. Although only twelve participants took part in the experiment, age appeared to have an influence on driver's responses. Whereas younger drivers appeared to prefer simpler (fewer stage) displays, middle and older drivers appeared to prefer more complex displays. Based on the combined data from the two experiments, the looming display was selected as the most promising candidate.

17. Key Words Collision avoidance, crash avoidance, collision warning, rear-end collisions, forward collision warning, human factors, human factors, head-up display		18. Distribution Statement This document is available to the public from the National Technical Information Service, Springfield, VA 22161 http//:www.ntis.gov	
19. Security Classif. (of this report) None	20. Security Classif. (of this page) None	21. No. of Pages 64	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

FIGURES .... **III**

TABLES .... **IV**

ACRONYMS .... **V**

EXECUTIVE SUMMARY .... **VI**

1. INTRODUCTION **1**

1.1 COLLISION WARNING DISPLAY GUIDELINES 1
1.2 ACAS FOT COLLISION WARNING DISPLAY DESIGN 4

2. EXPERIMENT 1: PERFORMANCE EVALUATION **10**

2.1 METHOD 10
2.1.1 Scenario *10*
2.1.2 Participants *11*
2.1.3 Apparatus *11*
2.1.4 Design *12*
2.1.5 Procedure *13*
2.2 RESULTS 17
2.2.1 Car-following Performance *17*
2.2.2 Sudden Braking Event Performance *17*
2.2.3 Absolute-judgments subjective measures *19*
2.2.4 Relative-comparison subjective measures *21*
2.3 DISCUSSION 22
2.3.1 Looming vs. Scale Stimuli *22*
2.3.2 Number of Stages *23*
2.3.3 Auditory tone and seat-vibration *24*

3. EXPERIMENT 2: PREFERENCE EVALUATION **25**

3.1 METHOD 25
3.1.1 Scenario *25*
3.1.2 Participants *26*
3.1.3 Apparatus *26*
3.1.4 Design and Procedure *26*
3.2 RESULTS 27
3.2.1 Absolute-judgments subjective measures *27*
3.2.2 Relative-comparison subjective measures *31*
3.3 DISCUSSION 34
3.3.1 False Alarms *34*
3.3.2 Driver Acceptance *34*
3.3.3 Auditory tone and seat-vibration *36*

4. INTERFACE SPECIFICATION **37**

4.1 FINAL SELECTION OF THE VISUAL ALERT LEVEL DISPLAY 37
4.2 DISPLAY MODING AND MESSAGES 40
4.3 AUDIO SYSTEM.. 42
4.4 STEERING WHEEL BUTTON REMAPPING.. 43

5. CONCLUSION 45

APPENDIX A 47

APPENDIX B 49

APPENDIX C 50

APPENDIX D 52

FIGURES

Figure 1.1 8
Figure 1.2 13
Figure 2.1 17
Figure 2.2 23
Figure 2.3 24
Figure 2.4 26
Figure 3.1 33
Figure 3.2 33
Figure 3.3 34
Figure 3.4 35
Figure 3.5 36
Figure 3.6 37
Figure 4.1 45
Figure 4.2 45
Figure 4.3 47
Figure 4.4 49

TABLES

Table 2.1 25
Table 3.1 41

ACRONYMS

Adaptive Cruise Control (ACC)

ANalysis Of VAriance (ANOVA)

ANalysis of COVAriance (ANCOVA)

Automotive Collision Avoidance Systems Field Operational Test (ACAS FOT)

Brake Reaction Time (BRT)

Collision Avoidance Metrics Partnership (CAMP)

Controller Area Network (CAN)

Driver Vehicle Interface (DVI)

Forward Collision Warning (FCW)

General Motors (GM)

General Linear Models (GLM)

Head-Up Display (HUD)

High-Head-Down Display (HHDD)

Instrument Flight Rules (IFR)

Least Squared Difference (LSD)

Standard Deviation (SD)

Time-Headway at Event Onset (THEO)

Visual Flight Rules (VFR)

EXECUTIVE SUMMARY

This report documents the human factors work conducted from January to June 2001 to design and evaluate the driver-vehicle-interface (DVI) for the Automotive Collision Avoidance System Field Operational Test (ACAS FOT) program. The objective was to develop an interface that most effectively supports the human interaction with the Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC) systems. The DVI visual display sequences were developed for projection onto a full-color head-up display (HUD). Unlike previous generation HUDs, the new design was reconfigurable, facilitating the display of multiple-stage multicolor icon sequences for communicating the FCW alert level. Whereas the CAMP (1999) FCW project had focused only on single-stage monochromatic alerts largely because of implementation practicalities, the flexibility of the new HUD platform allowed a deeper analysis of how the output of the forward collision warning algorithm should be displayed to the driver.

Two experiments were designed to examine the effectiveness of a range of multiple-stage alert candidates compared with a single-stage alert. Experiment 1 (Performance evaluation) employed a driving simulator to evaluate the impact of the display candidates on the brake reaction time (BRT) of drivers to an unexpected lead-vehicle braking event. The data revealed that some multiple-stage candidates facilitated earlier BRTs compared with the single-stage alert. This was evident of the display sequences that exhibited a looming quality (expanding visual image representing imminent collision), but not observed for the displays that did not. Experiment 2 (Preference evaluation) was designed to investigate the driver acceptance of the display candidates. Twelve drivers experienced four display candidates in the driving simulator and answered questions regarding their preferences and the annoyance induced by the displays. Although only twelve participants took part in the experiment, age appeared to have an influence on driver's responses. Whereas younger drivers appeared to prefer simpler (fewer stage) displays, middle and older drivers appeared to prefer more complex displays. Based on the combined data from the two experiments, the looming display was selected as the most promising candidate.

1. INTRODUCTION

The Automotive Collision Avoidance Systems Field Operational Test (ACAS FOT) program was initiated in 1999 to evaluate the effectiveness of an integrated Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC) system. This report describes the work conducted for the Driver Vehicle Interface (DVI) task of the ACAS FOT program to design and evaluate an interface that promotes an efficient interaction between the driver and the FCW and ACC systems. The objective of the DVI task was to develop an effective interface for the ACAS systems that will be installed in a fleet of vehicles for the subsequent field operational test. Research and development was initiated to advance the state-of-the-art in interface technology and concepts, and design an effective DVI to support the large-scale field testing. This section will discuss guidelines from previous human factors work on collision warning displays, and then describe the design and rationale of the interface candidates that were tested in the first DVI experiment.

1.1 Collision Warning Display Guidelines

Lerner, Kotwal, Lyons, and Gardner-Bonneau (1996) conducted a review of the human factors literature and compiled a set of guidelines for the design of collision warning systems. They suggested that all warning devices should be able to present at least two levels of warning—an imminent level, where an immediate corrective action is required to avoid collision and a cautionary level, where attention is immediately required because a corrective action may be necessary. The Collision Avoidance Metrics Partnership (CAMP) project, however, only investigated the effectiveness of single-stage candidates, (Kiefer, LeBlanc, Palmer, Salinger, Deering, and Shulman, 1999), arguing that the system should be kept simple unless one could find evidence that the additional complexity was beneficial. Lerner et al.'s (1996) rationale for multiple staged collision warning displays was that they could provide additional benefit because they are less constrained by the tradeoff between alert intrusiveness and early warning.

Lerner et al. (1996) argued that a multi-stage warning, in comparison to a single-stage warning, allows the warning system to provide an appropriate degree of intrusiveness at differing levels of urgency. In the maximally urgent situation of an impending collision, the alert must be sufficiently intrusive to immediately elicit an appropriate response from the driver. Because of the inherent correlation between intrusiveness and driver annoyance, the high degree of intrusiveness required by an imminent warning would render it inappropriate for less imminent situations. Constrained by a tradeoff between intrusiveness and advanced warning, earlier timing for a single-stage display requires less intrusiveness (which is less likely to capture the driver's attention). An effective single-stage alert is therefore limited in how much advanced warning it can provide. The advantage of a multi-stage display is that it provides the opportunity for both advanced warning and a highly intrusive imminent alert. A single-stage display must balance the intrusiveness of the alert stimulus with how early the alert is triggered. Providing the driver with an earlier warning results in a display that will be triggered more frequently, necessitating that the display be less intrusive. Whereas less intrusive displays are less likely to capture the driver's attention, more intrusive displays are more likely to annoy the driver. Lerner et al. argued that multiple stage displays could minimize the conflict between broader protection and greater annoyance.

Consistent with the principles of redundancy gain, the Lerner et al. guidelines recommended that the imminent crash avoidance warnings must be presented across at least two modes. The redundancy gain principle in human factors proposes that when a given message is expressed more than once, the likelihood that the message is correctly perceived increases (Wickens, Gordon, and Liu, 1998). This is especially evident when messages are presented across more than one sensory modality because factors degrading the message over one modality are not likely to degrade the message across the other modalities. For automotive collision warnings, Lerner et al. argued that an imminent message should be presented across the visual modality and either the auditory or tactile modality, because, unlike the visual modality, the auditory or tactile modalities do not require that the driver be oriented in any particular way to receive the message. The advantage of the visual modality is that icons can be created to unambiguously communicate information efficiently, compared with auditory tones which may be ambiguous, or speech which requires more time to comprehend. The guidelines suggest that the imminent display should employ a prominent rapidly flashing red icon, flashing at between three and five times per second with a 50 percent duty cycle).

The CAMP project investigated the effectiveness of several multiple-modality single-stage FCW displays. In response to a stationary target, participants started to brake earlier with a visual-plus-non-speech-tone display than with a visual-plus-speech display, but earlier with a visual-plus-speech display than with a visual-plus-brake-pulse display. The data suggested that the non-speech tone was the most effective stimuli for accompanying a visual warning icon. The experiment displayed the visual icon across both a Head-up Display (HUD) and a High-head-down Display (HHDD), that was located just below the windshield . Between these two locations, there was no statistically significance performance difference, however, participants consistently favored the HUD display on several subjective rating dimensions. The icon was used in the CAMP project is depicted in Figure 1.1.

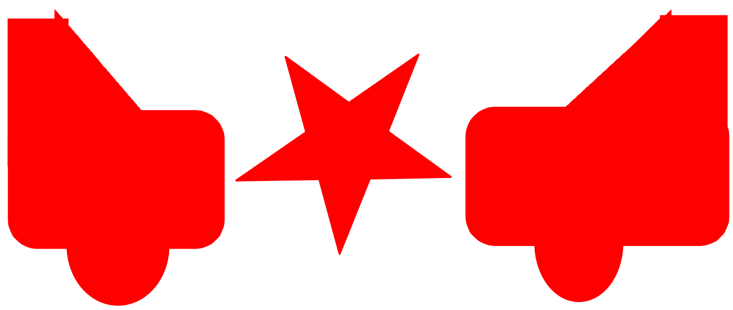


Figure 1.1. Depiction of the CAMP icon. This icon was accompanied by "WARNING" text below.

For the cautionary alert stages, Lerner et al. recommended that displays should consist of a visual stimulus only, because visual displays are less annoying than acoustic messages. Cautionary stimuli should be less intrusive and annoying and clearly discriminable from imminent stimuli. For cautionary visual stimuli, Lerner et al. recommended using either static (not-flashing) red or static amber icons.

Dingus, McGehee, Manakkal, Jahns, Carney, and Hankey (1997) developed and tested several time-headway displays. Unlike the CAMP experiments which used a collision warning algorithm based on the required deceleration to drive a single stage display, Dingus et al. used time-headway to drive their multiple-stage displays. Dingus et al. evaluated the following three displays:

(1) Car Icon Display – as headway decreased, a car icon expanded and moved down a sequence of three trapezoids, that represented the road in front of the driver. From top to bottom, the trapezoids were colored green, amber, and red, indicating the level of caution to the driver as headway decreased. The display was composed of four stages, including the three colors plus a flashing red condition for the most severe state.

(2) Bars Display – as headway decreased, a sequence of three green (top), three amber (middle), and three red (bottom) trapezoids would successively illuminate. Like the car icon display, the bars would flash at the most severe state.

(3) Blocks Display – two blocks (amber and red) would flash based on the current headway. When a target was acquired the amber block flashed, and when time-headway fell beneath 0.9 s, the red block would flash.

Analyses of coupled headway events revealed that only the Car Icon Display significantly increased time-headway. Analyses of braking events revealed that all three displays significantly increased the time-headway during these events. Subjects exhibited a preference for the Car Icon and Bars displays over the Blocks display. Dingus et al.'s experiments demonstrated that multiple-stage displays may have the potential of enhancing driving performance, while still being acceptable to drivers.

1.2 ACAS FOT Collision Warning Display Design

Given that the design of a single-stage alert reached maturity during the CAMP (1999) research program, the emphasis of this program was to develop a multi-stage warning system and to evaluate this display against a corresponding single-stage design. To support these requirements, a full-color reconfigurable head-up display was designed by Delphi Delco Electronics. A HUD was considered to be a desirable component of an FCW interface not only because of the favorable feedback it received in the CAMP project but because of its proximity to the forward visual scene, allowing the display to be noticed by a driver who is oriented toward the outside environment. Furthermore, because of its location, a HUD is less likely to attract driver visual attention away from the forward scene. An FCW display that attracts driver attention away from the forward scene at a critical moment would be highly undesirable. Because the HUD is located in close proximity to the forward visual scene and renders an image located several meters in front of the driver, it has the potential of offering drivers the opportunity to attend to the forward scene and the HUD content simultaneously. The custom-built HUD projects a 256-color 150 x 300-pixel image onto the windscreen, appearing as a 3 x 6-degree image that is located just above the front of the vehicle. The flexibility inherent in the new display technology facilitated a relatively unconstrained investigation into the most effective visual sequence for an FCW system.

Given the differing approaches exhibited in the literature between single-stage (CAMP, 1999) and multiple-stage (Lerner et al., 1996 and Dingus et al., 1997) displays, the primary research issue for the DVI became the optimal number of stages for the FCW display. The CAMP project focused on single-stage monochromatic displays because they were more realizable with the current display technology and because it was argued that multiple-stage displays were unjustifiably complex. Multiple-stage multicolor displays are becoming a more viable implementation alternative and given that multiple-stage displays are less constrained by the intrusiveness vs. timing tradeoff, the potential of multiple-stage alerts was investigated.

The optimal number of stages was expected to vary with the manner in which the display was implemented. There were several possible ways to implement an FCW alert sequence. As a starting point for the display design process, the Dingus et al. (1997) Car Icon display was selected, because in their experiment, this display had demonstrated the largest effect on driver headway selection in coupled headway events. This multiple-stage display featured the expanding rear-end of a vehicle, designed to emulate the natural optical expansion that occurs when one approaches a lead vehicle. It also featured a three-bar trapezoidal scale that was color-coded with green, orange, and red to represent differing levels of danger. The vehicle icon moved down across the three bars as the level of danger increased. Thus, information was redundantly coded across the three visual dimensions of color, scale (moving down the three bars), and icon size.

It has been demonstrated that a wide range of humans and animals of all ages, display an avoidance response to a quickly expanding pattern of optic flow (Schiff, 1965). This pattern of optical expansion, referred to as "looming" is a powerful source of information to specify impending collision and plays an important role in collision control behavior(see Smith, Flach, Dittman, & Stanard, 2001). Looming was identified as a promising source of information through which the FCW system could communicate proximity to the lead vehicle. Hoffman (1974) proposed that drivers adjust headway based on change in angular size of the lead vehicle. Given that drivers naturally use the angular size of the lead vehicle to control their relative position and avoid collision, it is likely that a display that uses size change to code the forward threat level would be immediately understandable and intuitive to drivers.

Dingus et al. (1997) had also employed a nine-bar display, presenting a clear scale to convey more finely-grained information to the driver. A scale stimulus is likely to be more effective than a looming stimulus for precisely communicating a specific value of a given dimension, relative to other potential values. The presentation of a scale permits the system to communicate more finely grained information, allowing a greater number of discriminable display states. Because an expanding-icon (looming) stimulus lacks an explicit point of reference, it may not communicate a specific value precisely. When used in isolation, this may limit the number of differentiable states. However, the advantage of an expanding-icon (looming) display, is that the stimulus is more salient and could potentially yield a greater benefit in recapturing a distracted driver's attention. Looming is also expected to be more easily understandable because of its natural association with impending collision. It could be argued using an aviation metaphor, that because a driver operates in VFR (visual flight rules) rather than IFR (instrument flight rules), more salient but less finely grained information may be of more value than less salient but more finely grained information. The primary purpose of the FCW display is to draw the driver's attention to a critical event rather than to provide a complete surrogate for the natural optic flow. Lerner et al. (1996) advised against presenting graphical information for warning displays because of the limited time for the driver to respond in an urgent situation.

Both looming and scale stimuli were incorporated into the Dingus et al. (1997) Car Icon Display, however, in their design the vehicle moved downwards on the scale as it grew. In natural optic flow, downward motion of a terrestrial object below the horizon specifies a shrinking object. This imprecision was implemented to preserve the scale stimulus, but may have diminished the effectiveness of the looming stimulus. To correct this imprecision, the display was modified into a new version that more accurately represented looming but also contained a six-trapezoid scale (see the “looming-plus-scale” display in Figure 1.2.) A more simplistic icon was designed, that was a single color at a given time but changed color as threat-level increased. Because the vehicle icon expanded, without moving downward, it occluded an increasing amount of the scale, so that only the trapezoids below the vehicle were visible. In the Dingus and McGehee display, the scale stimulus had taken precedence over the looming stimulus, but now the looming stimulus takes precedence over the scale. Because of the apparent tradeoff between looming and scale stimuli in an FCW display, the relative effectiveness of looming vs. scale stimuli became an important design consideration.

To investigate the looming vs. scale issue, two new displays were developed, one that contained looming without scale (the “looming” display) and one that contained scale without looming (the “scale” display). The conditions of no display, “looming” display, “scale” display, and “looming-plus-scale” display represent the factorial combination of scale and looming stimuli, allowing an analysis of which stimulus was more effective for an FCW display.

The displays of Experiment 1 were also designed to allow an analysis of the optimal number of display stages. The displays of Figure 1.2 include sequences of 1-stage, 2-stage, 3-stage (looming), and 5-stage (looming-plus-scale or scale). Note that the number of stages does not include the “vehicle detected” icon, because the “vehicle detected” icon does not represent a warning icon per se.

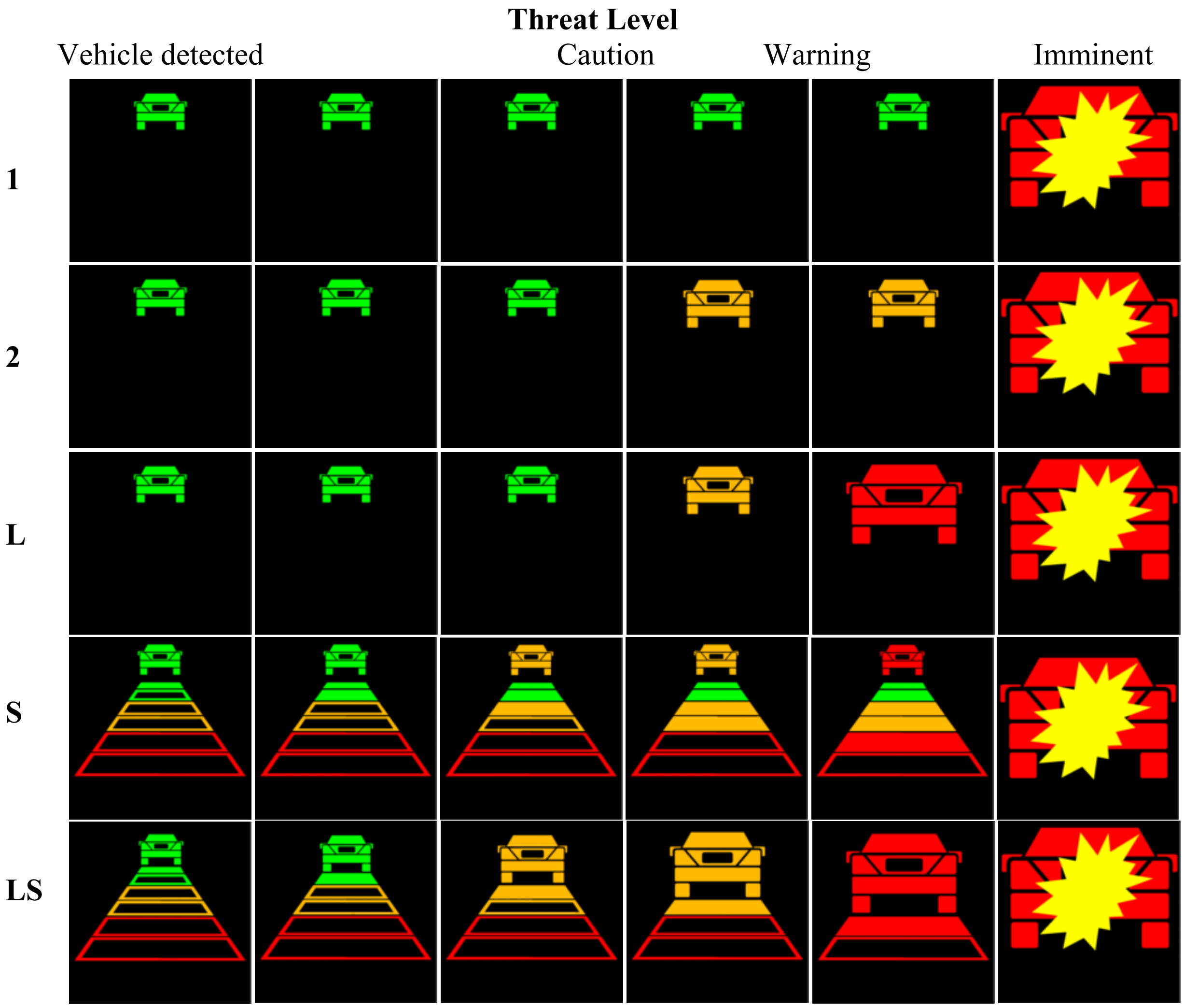


Figure 1.2. The one-stage (1), two-stage (2), three-stage or looming (L), scale (S), and looming-plus-scale (LS) displays used in Experiment 1 as a function of threat level. Note that the number of stages does not include the "vehicle detected" icon.

In order to provide a consistent imminent stimulus, a new icon was designed. The icon that is displayed in the right-hand panels of Figure 1.2, was designed to be a rear-end perspective version of the CAMP icon. Because all of the non-imminent icons shown in Figure 1.2 take a driver perspective (showing the rear-end of the lead vehicle), using the CAMP icon for the imminent stage would be likely to have caused some confusion in the drivers. The imminent icon was designed to follow the Lerner et al. guidelines in being distinct from the preceding stages. This was achieved by having the imminent icon include a bright yellow stimulus to represent the collision and having the imminent icon flash at 4 Hz. In some informal paper and pencil studies the two-color imminent icon (Figure 1.2) was preferred over the single-color CAMP icon (Figure 1.1). The inclusion of a consistent imminent icon permitted a more rigorous experimental approach, with differing displays all ending with a common icon. The effectiveness of the imminent icon was no longer confounded with the display type, allowing the observed differences to be more readily attributed to the type of display.

2. EXPERIMENT 1: PERFORMANCE EVALUATION

2.1 Method

2.1.1 Scenario

The first experiment investigated the relative effectiveness of looming versus scale and the potential benefits of an increased number of display stages. A simulator scenario was developed wherein participants followed a speed-varying lead vehicle for 12 min, during which they could interact with the FCW display and would have a tendency of becoming increasingly inattentive due to the constancy of the situation. The lead vehicle would begin from a stop and accelerate at a rate of 0.15 g to reach 50 mph. During the 12-min period that followed, the lead vehicle would intermittently change speed according to an algorithm that was designed to simulate natural traffic flow:

(1) If speed is greater than 43 mph, select a random target speed between 41 and 43 mph, else select a random target speed between 42 and 45 mph. Select a random time it takes to reach target speed between 7 and 11 s.

(2) When vehicle reaches target speed, select a random dwell time for which to stay at target speed between 1 and 3 s. Repeat the cycle.

The participant would follow the lead vehicle along a mostly-straight two-lane road with no intersections. Most of the road was rural, with a speed limit of 55 mph, however, to prevent excessive repetition of scenery, a short section of industrial scenery (speed limit 45 mph) was included in the middle of the course. As the car-following phase of the trial drew to a close, participants approached a police vehicle that was parked on the left side of the road, facing into the roadway. The police vehicle was used as a decoy, for distracting participant's from the lead vehicle. Timed so as to maximize the visual distraction caused by the police vehicle, the lead vehicle suddenly decelerated at 0.5 g to a complete stop. The car-following scenario provided a measure of time-headway magnitude and variability whereas the sudden braking scenario provided a measure of brake reaction time.

2.1.2 Participants

Eighty participants, between the ages of 21 and 64 (M=39.6, SD=9.6), were recruited from Delphi Delco Electronics. In attempt to balance these demographics within each group Participants were assigned to groups as they arrived based on their gender and age. The average age within groups ranged from 36.1 to 41.8. The sixteen female participants were divided evenly into eight groups, resulting in two females and eight males per group. All participants were licensed drivers and had normal or corrected-to-normal vision. The experiment was advertised on the local Delco website and in newsgroups and participants were compensated with a $10 gift certificate to a local restaurant. None of the participants were associated in any other way with the ACAS FOT project, nor had they participated in a collision avoidance study before.

2.1.3 Apparatus

For the purposes of this program, a fixed-base Hyperion simulator was installed at Delphi Delco Electronics in Kokomo. The simulator projected a 1024x768-pixel 50-deg-vertical forward field-of-view image located at the front bumper of the vehicle cab. The vehicle handling system was configured to represent a mid-size front wheel drive sedan, such as a Ford Taurus. Steering feedback was presented with a force-feedback torque motor, to reproduce the feel of the road at the steering wheel, as well as the forces on the front tires during evasive maneuvers. The vehicle cab consists of the front half of a 1995 Pontiac Bonneville exterior (with doors and roof removed), with a 1996 Buick Park Avenue instrument cluster and dashboard. The cab was equipped with a previous generation full-color reconfigurable 2.5x3-deg of visual angle HUD, driven by 230x263-pixel 1.3-inch-diagonal Seiko-Epson cell, which was used for this experiment to display speed and alert-level. The smaller field of view offered by the previous-generation HUD forced the speedometer and alert-level displays to be both slightly smaller and closer together, resulting in a display that appeared similar to that depicted in Figure 2.1. The HUD image was projected at the front bumper of the vehicle, displaying graphics that were generated using Altia software, and the supporting PC platform was linked to the simulator through a local ethernet network. The alert-level display was driven by an algorithm, developed by General Motors Research and Design, that was similar to the CAMP algorithm, but designed to provide multiple levels of warning to the driver. The HUD brightness was preset to an appropriate level for the lighting conditions of the simulator room, and was not adjustable by the participant. A seat-vibration system was added to the cab, to produce pulses of vibration on the seat surface at a rate of 4-Hz using a pair of 3-V DC motors with offset counterbalances. Speakers were placed in the engine compartment of the cab directly in front of the driver and the volume was set to play the alert tone that was designated as #8 in the CAMP project report (Keifer et al., 1999) at 72 dBA.

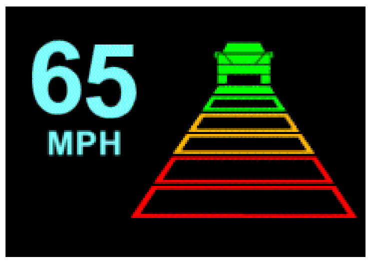


Figure 2.1. Relative size and position of the HUD images in the Delco driving simulator HUD. The alert-level indicator subtended a visual angle of approximately 1.5 x 2-deg of visual angle.

2.1.4 Design

A single-factor between-subjects experimental design was developed to examine the effects of the FCW display on headway maintenance (mean and variability) during the car-following phase and brake reaction time during the sudden braking event. Ten participants were assigned to each of the following eight levels of FCW display type:

C-- Control (No display)

1--One-stage (no audio)

2--Two-stage (no audio)

L-- Looming (no audio)

S-- Scale (no audio)

LS-- Looming-plus-scale (no audio)

LA-- Looming and Audio (CAMP #8 tone at the imminent stage)

LAV-- Looming, Audio, and Seat Vibration (CAMP #8 tone and seat-vibration at the imminent stage)

The eight levels permitted the evaluation several effects: number of stages (C, 1, 2, L, and LS), looming (L vs. C), scale (S vs. C), the interaction of looming with scale (C, L, S, and LS), audio (LA vs. L), and seat-vibration (LAV vs. LA).

During the steady-state car-following phase of the experiment time-headway and time-headway-variance were measured as dependent variables. Whereas time-headway-mean provided a measure of how close the driver was willing to travel to the lead vehicle, time-headway-variance provided a measure of how accurately participants could maintain constant time-headway during the trial.

After the onset of the 0.5-g lead-vehicle deceleration maneuver, brake-reaction-time (BRT) and required deceleration were measured as dependent variables. To ensure that it was the driver's response to the sudden braking event being measured, rather than routine speed or headway maintenance, BRT and required deceleration measured the driver response at the moment the brake was depressed by at least 50 percent. BRT was measured as the time between the deceleration maneuver and the 50-percent braking response. Whereas drivers routinely elicited small brake depressions throughout the car-following period, they only depressed the brake by 50 percent in response to the severe lead-vehicle deceleration event. Furthermore, five participants were already depressing the brake pedal by a small amount before the lead vehicle began the 0.5-g maneuver. Using a conventional BRT measure would have resulted in five missing values. The average control-group participant released the accelerator pedal 1.94 s after the 0.5-g maneuver began, contacted the brake pedal 0.41 s later, and 0.87 s later had depressed the brake pedal by 50 percent.

2.1.5 Procedure

After completing an informed consent form, participants were (falsely) informed that "the purpose of this exercise is to collect some driving data in order to calibrate various aspects of the simulator, and to get Delco employees to evaluate its realism." This ruse was similar to that used by John Lee (personal communication, 2001). Participants were subsequently briefed on how to operate the vehicle, and how to adjust the seat and HUD position. After participants were shown the HUD, they were instructed:

> *The head-up display will be used to present speedometer information to you as you drive. To the right of this, and still on the head-up display, it is possible that you may see some car-following information. This comes from an old experiment before we had the simulator upgraded. It presents the driver with information regarding proximity to the lead vehicle. If this information appears and you find it helpful, feel free to use it.*

These instructions were designed to prevent participants from paying an unrealistic amount of attention to the FCW display and anticipating a lead-vehicle collision event. By informing participants that the display was peripheral to the purposes of the experiment, it was expected that participants would better approximate someone accustomed to driving with an FCW display. Participants who considered the display to be peripheral would be more likely to pay attention to the extent that it was useful, and ignore it to the extent that it was not. On the other hand, if participants had been informed that the purpose of the study was to evaluate the FCW display, they would likely apply a disproportionate amount of attention toward the display and might expect the lead vehicle to suddenly brake at any moment. To provide an alternative explanation for the purpose of the study and to maximally distract the driver with the surrounding scenery, the following passage was read to participants:

> *You will begin parked behind a stationary car. In order to evaluate the realism as you drive, pay attention to the feel of your vehicle and oncoming traffic, and in particular, pay attention to see if there are any anomalies in the surrounding scenery (like trees and houses etc). I will ask you some questions about this when you complete your driving. When I put you in drive, the car in front of you will begin to move. Do not overtake but make sure you keep up with traffic. Drive as you normally*

would if you were trying to get somewhere in a reasonable time. Try to travel at least as fast as the speed limit wherever you can, so keep an eye out for speed-limit signs along the roadside. After you have been driving for about 15 minutes I will come back to get you.

The emphasis on keeping up and trying to travel at the speed limit was added after it was observed in pilot testing that several participants failed to keep up with the lead vehicle and reached time headway in excess of 10 s. Driving in the simulator differs from driving in the real world in that there is no intrinsic desire to reach a destination. The instructions to "keep up", "travel at least as fast as the speed limit", and "drive as you normally would if you were trying to get somewhere in a reasonable time" were designed to provide a surrogate for the natural desire to reach a destination in a timely fashion.

Upon completion of the trial, participants were debriefed on the true purpose of the experiment asked not to discuss the details of the experiment with others until the end of May. Participants then answered a series of questions that they viewed through a Powerpoint presentation (attached as Appendix A). The questionnaire queried participants on which aspects of the display they noticed and what did the imminent icon mean. It also asked participants to rate the display that they had experienced according to how much they agreed that they display was:

(1) "A good method for presenting car-following and collision-warning information"

(2) Detectable

(3) Understandable

(4) Startling

(5) Interfering

(6) Attention-getting

(7) Annoying

Because participants only experienced a single display, these responses were absolute judgments because they had no explicit basis of comparison. To examine relative comparisons between displays, participants were exposed to a range of different visual displays, iterating through the different stages of the displays in a Powerpoint presentation so that they could experience them dynamically. The displays included 1, 2, L, S, LS, and an expanding line display (Li) that was similar to the looming display except that rather than using a vehicle icon, the display was an expanding horizontal line (see Appendix A). This display was added in response to a NHTSA suggestion to include a display that could mimic a set of expanding brake lights. Displays were ranked from most to least according to the extent that they were:

(1) Preferred

(2) Discriminable

(3) Understandable

(4) Startling

(5) Interfering

(6) Attention-getting

(7) Annoying

2.2 Results

2.2.1 Car-following Performance

Time-headway and time-headway-variance were recorded during the period of time between 2 min after the participant began the trial until the onset of the 0.5-g deceleration maneuver. The average time-headway-mean across all participants was 1.61 s with a standard deviation of 0.49 s. A single-factor between-group ANOVA was conducted using time-headway as the dependent measure. The effect of display on time-headway failed to reach statistical significance, $F(7, 72) = 0.533$, $p = 0.807$. The average time-headway-variance across all participants was 545 ms^2 with a standard deviation of 345 ms^2. Like time-headway, time-headway-variance also failed to reach statistical significance, $F(7, 72) = 1.209$, $p = 0.309$. No measurable displays effects were observed during the steady-state car-following phase of this experiment.

2.2.2 Sudden Braking Event Performance

Although there were no observable effects of display type on car-following performance, a large amount of variation in time-headway was present at the onset of the lead-vehicle deceleration maneuver (M = 1.648 s, SD = 0.794 s). This time-headway variance presented serious implications for the severity of the event to which drivers reacted. If the driver had a large time-headway at the deceleration onset (e.g., greater than 3 s) then the 0.5-g maneuver was not particularly threatening, and the driver could safely wait several seconds before reacting to the situation. On the other hand, a driver with a small time-headway (e.g., less than half a second) at the deceleration event would be required to respond almost immediately in order to avoid collision. As expected, time-headway at the deceleration event was highly correlated with BRT ($r = 0.847$), implying that over 68 percent of the variance in BRT could be accounted for by the time-headway at the deceleration event. If an ANOVA was conducted, which did not take into account the influence of time-headway, the amount of error variance introduced by the time-headway would make it exceedingly difficult to detect differences between displays.

In order to attribute the variance to the appropriate source (time-headway) rather than to error, a between-group analysis of covariance (ANCOVA) was performed on each of the dependent measures. Given that time-headway at the event onset (THEO) was unrelated to display type; $F(7,79) = 1.97$, $p = 0.316$, THEO could be included in the model as a random covariate. The ANCOVA tables for BRT and required-deceleration are included in Appendix B.

Display type significantly effected BRT, $F(7,79) = 4.675$, $p < 0.0005$, and required deceleration, $F(7,79) = 2.797$, $p < 0.05$. LSD pairwise comparisons revealed that, compared with the control condition, all displays resulted in a statistically significant benefit across both performance measures, except for the one-stage and scale displays. BRT values and required decelerations (evaluated at the THEO mean value) are plotted as a function of display type in Figures 2.2 and 2.3 respectively.

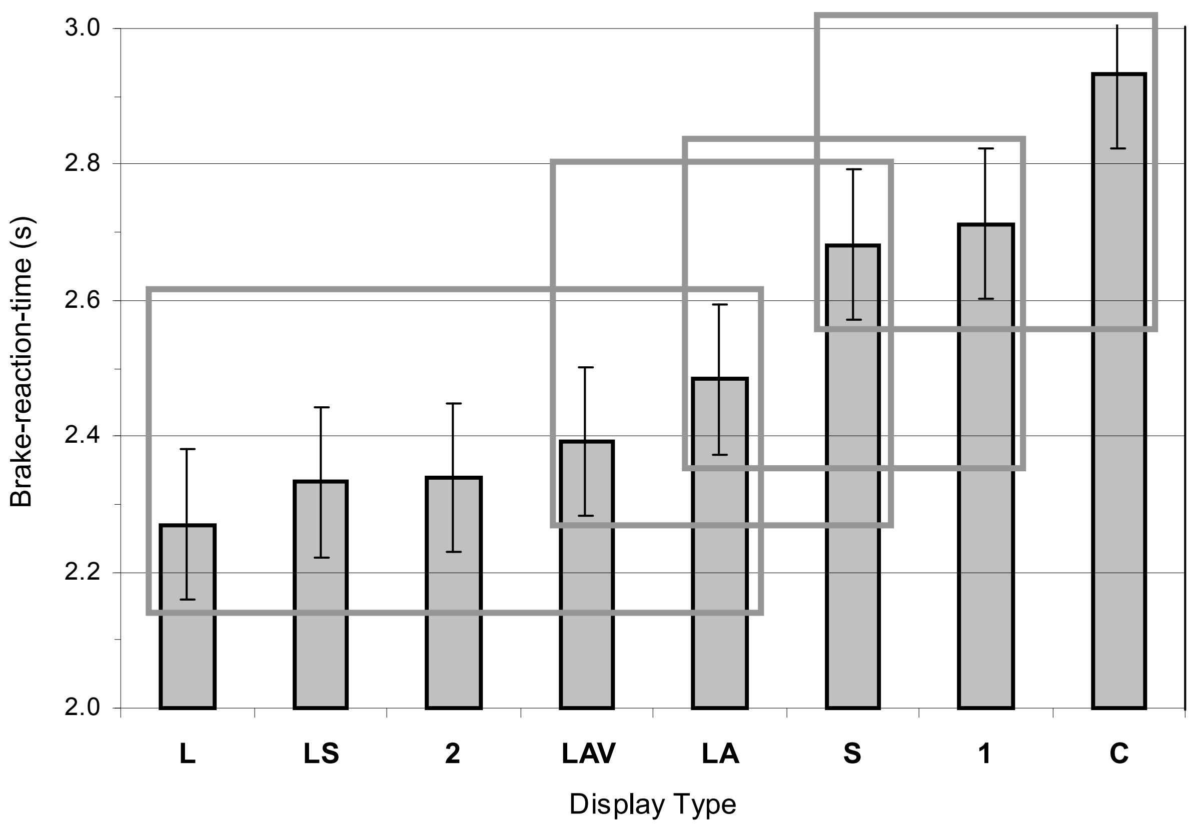


Figure 2.2. Brake-reaction-time (evaluated at the THEO mean value) as a function of display type. The error bars represent plus or minus one standard error of the mean. The gray boxes represent groups of displays that are not statistically different, according to LSD pairwise comparisons using an alpha level of 0.05. If one display does not co-occur with another display in any of the boxes, then the two displays are statistically distinct. For example, L, LS, and 2 are statistically different from S, 1, and C, however 2 is not statistically different from LAV because they co-occur in the first box.

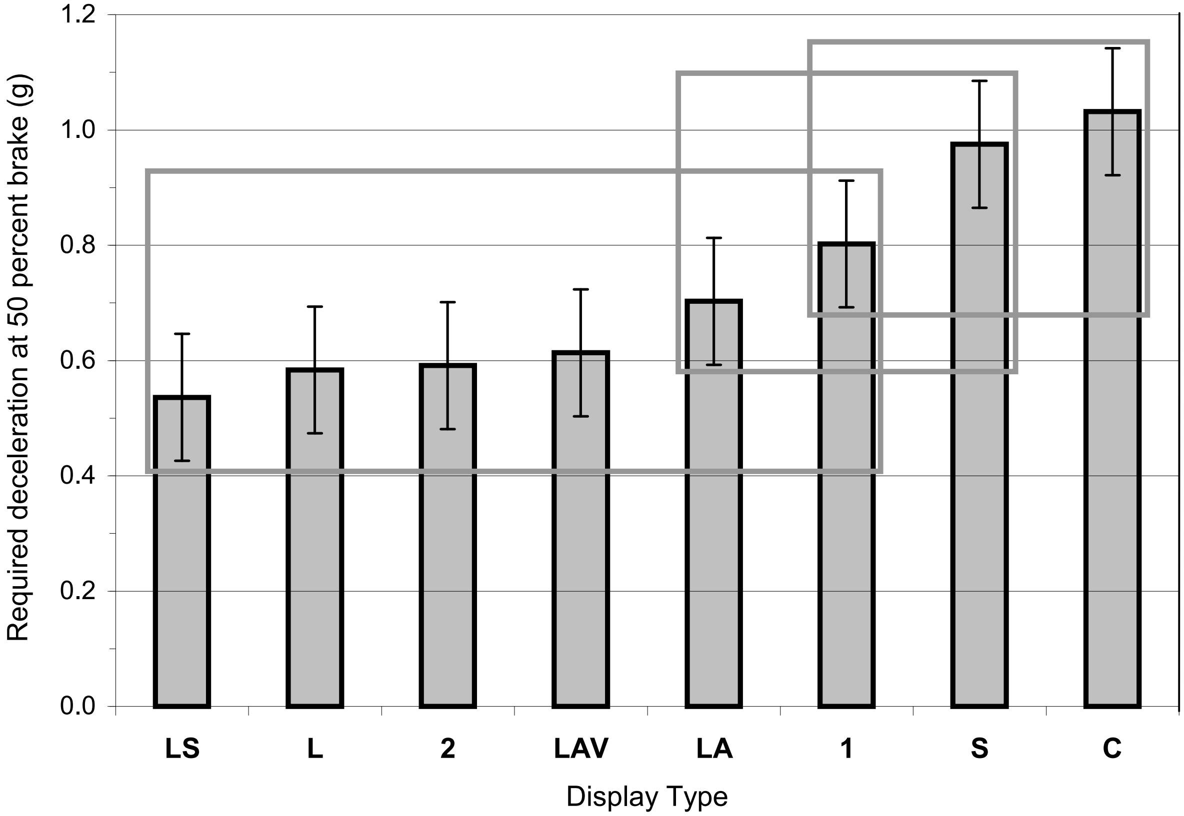


Figure 2.3. Required deceleration at the 50 percent braking response (evaluated at the THEO mean value) as a function of display type. The error bars represent plus or minus one standard error of the mean. The gray boxes represent groups of displays that are not statistically different, according to LSD pairwise comparisons using an alpha level of 0.05. If one display does not co-occur with another display in any of the boxes, then the two displays are statistically distinct.

2.2.3 Absolute-judgments subjective measures

A single-factor between-subjects ANOVA was conducted on the responses to questionnaire items that asked participants to rate the displays that they had experienced in the simulator. Table 2.1 presents the responses to the items as a function of display type. There were significant display-type effects for the items corresponding with **understandability** [*This method could clearly tell me that I am in danger and need to react immediately,* $F(6,63) = 4.722$, $p < 0.0001$] and **attention-getting** [*This method would get my attention effectively if I was distracted and not concentrating on the driving task*, $F(6,63) = 3.96$, p M 0.005]. LSD post-hoc comparisons, with an alpha level of 0.05, revealed that the scale display was less understandable than all but the one-stage and the looming-plus-scale displays, and that the looming-plus-scale was less understandable than all but the scale display. Post-hoc comparisons also revealed that the two displays with audio (LA and LAV) were more attention-getting than the looming, scale, and looming-plus-scale displays, and that the one- and two-stage displays were more attention-getting than the scale display.

Questionnaire Item	1	2	L	S	LS	LA	LAV	M	SD
This is a good method for presenting car-following and collision-warning information to drivers.	4.56	5.00	4.90	4.00	4.40	5.10	5.00	**4.71**	*1.16*
Using this method, changes of display-state would be clearly detectable.	4.33	4.50	5.00	3.70	4.10	4.80	4.90	**4.48**	*1.28*
This method could clearly tell me that I am in danger and need to react immediately.	4.56	5.30	5.20	3.70	3.60	5.20	5.00	**4.65**	*1.21*
This method would NOT startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement.	4.22	4.30	4.80	4.60	4.80	4.30	5.00	**4.57**	*1.43*
This method would NOT interfere with my ability to make a quick and accurate decision about the safest driving action to take (brake, steer, brake and steer, do nothing).	4.56	4.70	4.90	5.10	4.60	4.90	5.20	**4.85**	*1.07*
This method would get my attention effectively if I was distracted and not concentrating on the driving task.	4.44	4.20	4.00	3.00	3.70	5.30	5.20	**4.26**	*1.45*
This method would be annoying.	2.78	1.80	2.00	2.80	2.20	2.30	2.30	**2.31**	*1.16*

Table 2.1. Participants' responses to absolute-judgments questionnaire items as a function of the display types that they had experienced. Participants rated the extent to which they agreed with the above statements on a scale from 1 to 6, corresponding to strongly disagree, moderately disagree, perhaps disagree, perhaps agree, moderately agree, and strongly agree.

Out of the twenty participants who experienced the auditory tone with the alert, 70 percent indicated that they noticed it, compared with 8 percent who indicated that they noticed a tone when no tone was actually present (out of 50 participants). The seat-vibration was detected less frequently-- only 20 percent of the ten participants in the seat-vibration condition indicated that they detected its presence, compared with 6.67 percent of the 60 participants who did not experience the seat-vibration.

2.2.4 Relative-comparison subjective measures

Friedman χ^2 tests were conducted on the ranking data for each of the subjective measures. There were significant main effects of display type for each measure: preference [$\chi^2(5) = 216.67$, $p < 0.0001$], discriminability [$\chi^2(5) = 192.79$, $p < 0.0001$], understandability [$\chi^2(5) = 216.96$, $p < 0.0001$], startle [$\chi^2(5) = 121.21$, $p < 0.0001$], interference [$\chi^2(5) = 48.39$, $p < 0.0001$], attention-getting [$\chi^2(5) = 181.73$, $p < 0.0001$], and annoyance [$\chi^2(5) = 80.54$, $p < 0.0001$]. The relative rank scores for each measure (except startle) are displayed in Figure 2.4. The results for the startle measure are not displayed because the only observed difference was that the Line display was ranked as being less startling than the other displays. The Line display was consistently ranked last on every measure, whether desirable or undesirable.

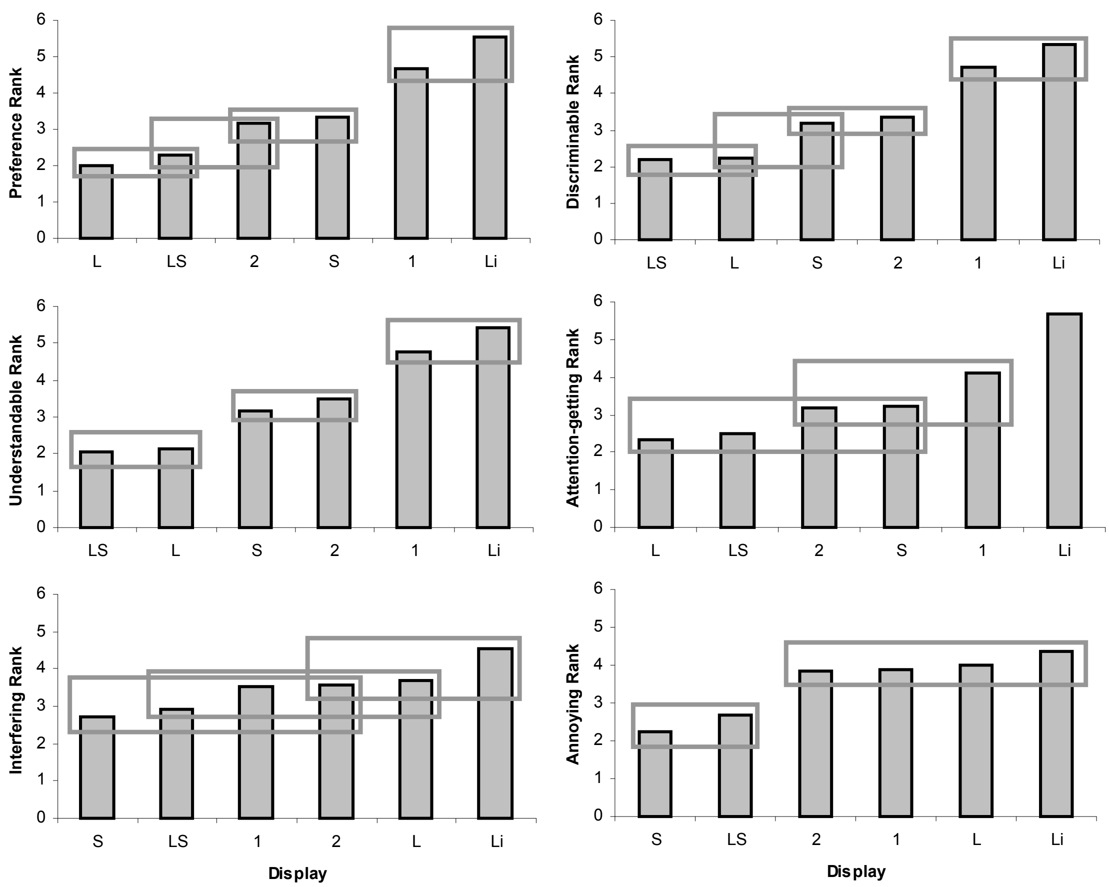


Figure 2.4. Participant rankings of displays for the measures of preference, discriminability, understandability, attention-getting, interference, and annoyance. Participants ranked the displays in order from most to least, so that lower numbers indicate that participants consider the display to be more representative of the given measure. The gray boxes represent groups of displays that are not statistically different, according to Nemenyi'a procedure for post-hoc comparisons (using an alpha level of 0.05.) If one display does not co-occur with another display in any of the boxes, then the two displays are statistically distinct.

2.3 Discussion

2.3.1 Looming vs. Scale Stimuli

The variables of looming and scale can be considered as separate factors, allowing the independent manipulation of each factor into the four factorial combinations: C (without looming or scale), S (scale without looming), L (looming without scale), and LS (looming plus scale). In terms of brake reaction performance, L and LS are statistically equivalent, but different from C and S, which are also statistically equivalent. This implies that adding scale to either no display or a looming display yields no performance benefit. There were no observable performance effects of scale, nor was there an interaction between scale and looming. The differences between these four conditions can be entirely accounted for by the effects of looming. In short, the looming display reduced BRTs and required-deceleration, whether it was accompanied by the scale or not.

However, there is some evidence of a driver-acceptance cost of the scale. In the absolute judgments, the two displays with the scale were rated as less understandable than the looming display. Strangely, this effect was not reiterated in the relative rankings, where the looming display and the looming-plus-scale displays were similarly ranked. This may have occurred because participants in the scale conditions (LS and S), faced with graphics of higher complexity, may have felt like there was more information being communicated to them than the other participants, and thus more room for confusion. However, when participants had viewed all of the displays, they may have believed that the displays were communicating the same basic concepts, and the additional complexity of the scale may have helped to clarify the meaning of the display. In addition to this, by the time participants began answering the relative rankings questions, they had more opportunity to learn the meaning of the displays through the preceding questions. The learning process may have clarified the meaning of the graphics to a greater extent for the more complex displays.

The looming and looming-plus-scale displays were consistently ranked as being superior on the desirable dimensions (where more implies better). They were preferred to the scale, one-stage, and line displays, considered to be more discriminable than the one-stage, two-stage and line displays, more understandable than the scale, one-stage, two-stage, and line displays, and more attention-getting than the one-stage and line displays. The inclusion of a scale, however, appeared to have a negative effect on the undesirable dimensions (where more implies worse). The scale display was considered to be more interfering than the looming and line displays, and more annoying than the one-stage, two-stage, looming and line displays. The looming-plus-scale display was also considered to be more annoying than the one-stage, two-stage, looming and line displays.

There is little evidence that the consistent scale provides any added benefit to either performance or driver-acceptance, however, there is evidence to suggest that the addition of a scale increases driver annoyance.

2.3.2 Number of Stages

The experimental design included displays of one, two, and three stages (C, 1, 2, and L). Note that the "vehicle detected" icon was not considered to be a stage because it does not represent a warning per se. Performance data revealed little additional benefit after the display contains at least two stages. There was no statistical basis to differentiate the displays with two or three stages, but both displays decreased BRT more than the one-stage and control conditions. The subjective data mirror this, with similar ratings for the displays with two and three stages. The looming display, however, was ranked as being more preferred, more discriminable, and more understandable than the two-stage display. Both the looming and two-stage were ranked as being more preferred, more discriminable, and more understandable than the one-stage display and the looming display was ranked as being more attention-getting than the one-stage display. There were no observed benefits of having a one-stage display over a two-stage or looming display. Although there may be no brake reaction benefit of increasing the number of display stages beyond two, there may be some subjective benefits of having a greater number of stages. Increasing the number of stages beyond three appears to require a display that is more graphical in nature, such as the scale or looming-plus-scale display, and therefore three may be the upper limit for a simplistic display that uses only size change and color coding.

2.3.3 Auditory tone and seat-vibration

There was no evidence that the auditory tone or the seat-vibration decreased driver reaction time. Numerically, the reaction times with the inclusion of auditory tone or seat-vibration were actually larger, although the difference was not statistically significant. This result may have occurred because of limitations of the simulator. Because the field of view of the simulator was only 50 degrees and there were no visual distractions outside of this area, it is likely that all participants were able to detect the change occurring on the HUD. If this is correct and all participants were sufficiently oriented toward the primary visual display, the auditory tone and seat-vibration were redundant. Without any requirement for their presence, the auditory tone and seat-vibration could have even slightly increased reaction time by startling the driver and providing additional unnecessary stimulation. Although the HUD is an effective means of alerting the driver, in reality there are likely to be many instances where the driver's attention is oriented too far away from the HUD eye-box for the driver to detect a warning, requiring an additional means of alerting the driver. Both the auditory tone and seat-vibration fulfill these criteria because they do not require that the driver be oriented in any direction (Lerner et al., 1996). For this reason, these additional sensory modes cannot be eliminated. Although only fourteen of the twenty participants who experienced the auditory tone during the imminent stages indicated that they detected the tone, the tone did significantly increase attention-getting ratings.

Surprisingly, only two out of the ten participants experiencing seat-vibration indicated that they detected its presence. This rate of detection is especially low given that four participants (of 60) who did not experience the seat-vibration also indicated that they detected it. This was not expected because the seat-vibration had previously seemed to be detectable to the engineers who were involved in its creation. One explanation for the low rate of detection may be that the visual (flashing imminent icon and braking vehicle) and auditory stimuli perceptually masked the vibrating seat, especially because participants were not expecting it and were unaware that the seat was capable of vibrating. If the auditory stimuli had been removed and participants were aware that the vehicle was equipped with a seat-vibration system, it is likely that detection rates may have been far greater. However, the fact that it was difficult to detect may indicate that seat-vibration is not an effective means of alerting a driver.

3. EXPERIMENT 2: PREFERENCE EVALUATION

3.1 Method

3.1.1 Scenario

In Experiment 1, the scale display provided no evidence for any benefit to the driver and made the display overly annoying. The objective and subjective results of the first experiment combined to provide sufficient basis for rejecting the scale display. Due to poor subjective rankings, the line display was also removed from consideration. The one-stage display failed to provide evidence for any performance benefit, however, because of its simplicity and because the CAMP (1999) program has invested so much towards a one-stage display (and did reveal a BRT benefit), the one-stage display was included in the second experiment.

After the first experiment, the looming display appeared to be the most effective candidate, balancing good performance with high driver acceptance. The purpose of Experiment 2 was to better evaluate driver acceptance of the remaining displays (one-stage, two-stage, looming, and looming-plus-scale), therefore focusing on questionnaire responses rather than performance data. Unlike Experiment 1, in the second experiment participants drove through the simulator scenario with each level of display type, so were able to more accurately evaluate the different display alternatives. Participants were instructed that their task was to evaluate the different display types. The simulated scenario was similar to that of Experiment 1 except that each trial lasted for only 4 min, and drivers were instructed to drive so as to evaluate the display. In addition to this, the lead vehicle's behavior was programmed to be more erratic, following a similar algorithm to the lead vehicle of Experiment 1, except that the speed varied between 35 and 55 mph.

Experiment 2 was also designed to evaluate the effect of the number of false alarms on driver acceptance of the different displays and to examine whether the displays differed in their resistance to the annoyance or reduced trust caused by false alarms. False alarms will be defined here as an imminent alert level activation that is unrelated to the presence of a relevant vehicle. In the real FCW system, false alarms could be caused by radar returns from bridges or signs, however, in this experiment false alarms were generated as randomly occurring 0.5-s activations of the imminent alert.

3.1.2 Participants

Twelve participants, between the ages of 24 and 60 (M=40.75, SD=12.33), were recruited from the same subject pool that was used in Experiment 1.

3.1.3 Apparatus

The apparatus was the same as that used in Experiment 1.

3.1.4 Design and Procedure

A 3 (Number-of-false-alarms) x 4 (Display type) repeated-measures factorial design was developed. Participants experienced each of the following displays:

1— One-stage (audio and seat-vibration)

2— Two-stage (audio and seat-vibration)

L— Looming (audio and seat-vibration)

LS— Looming-plus-scale (audio and seat-vibration)

The combination of number-of-false-alarms and display type created twelve unique trials. Participants completed three trials of each display type with zero, one, and two false alarms (in that order) and the order of display type was counterbalanced using a Latin Square. No performance variables were measured because participants were instructed in the following way:

> *Drive as you normally would, however, make sure that you interact with the different displays that you are experiencing to a sufficient extent that you can make informed comparisons between them. As you drive, try*

to evaluate the display in terms of how annoying or distracting it is, how reliable it is, and how much you like the display.

Because the emphasis of the instructions was on evaluating the display rather than driving normally, the driving performance may have been somewhat abnormal, rendering performance measures less reliable. The dependent measures consisted of the participants' responses to questionnaire items, which were administered after each trial (absolute judgments) and responses to a questionnaire that was administered after participants had completed all twelve trials (relative comparisons). The questionnaires are included in Appendix C.

After experiencing the CAMP auditory tone in the GM Engineering Development Vehicle and in the Delco Driving Simulator, it was agreed that the CAMP tone was overly annoying and that a less annoying alternative should be used. A half-second tone using a double sequence of 2500-Hz and 2650-Hz pulses was created and substituted for the CAMP tone. Based on recordings of interior noise levels in the Buick LeSabre, the imminent level icon was accompanied by the new tone at 72 dBA and seat-vibration for all display types.

3.2 Results

3.2.1 Absolute-judgments subjective measures

After the data was collected, it was observed that the age of participants was an important factor in determining their responses. Post hoc, participants were divided into three age groups: younger (24, 25, and 28 years old), middle (34, 38, 38, 38, 45, and 46 years old), and older (56, 57, and 60 years old). Age group, number-of-false-alarms, and display-type were entered as independent variables into a general linear model (GLM) analysis, and the responses to the absolute-judgments questionnaire were entered as the dependent measures.

The results of the GLM analysis are included in Appendix D. For the responses to the item "*This display would assist me in avoiding collisions with the lead vehicle*" (Avoidance rating), there was a significant interaction between number-of-false-alarms and age group, $F(2,20) = 4.088$, $p < 0.05$. The interaction is plotted in Figure 3.1. It appears that although younger participants were more approving of the displays in general, they appeared to be less tolerant of false alarms, because their responses to the avoidance item declined as number-of-false-alarms increased. Surprisingly, this was the only statistically significant effect of number-of-false-alarms for any dependent measure that emerged from the analysis. There were no main effects of number-of-false-alarms.

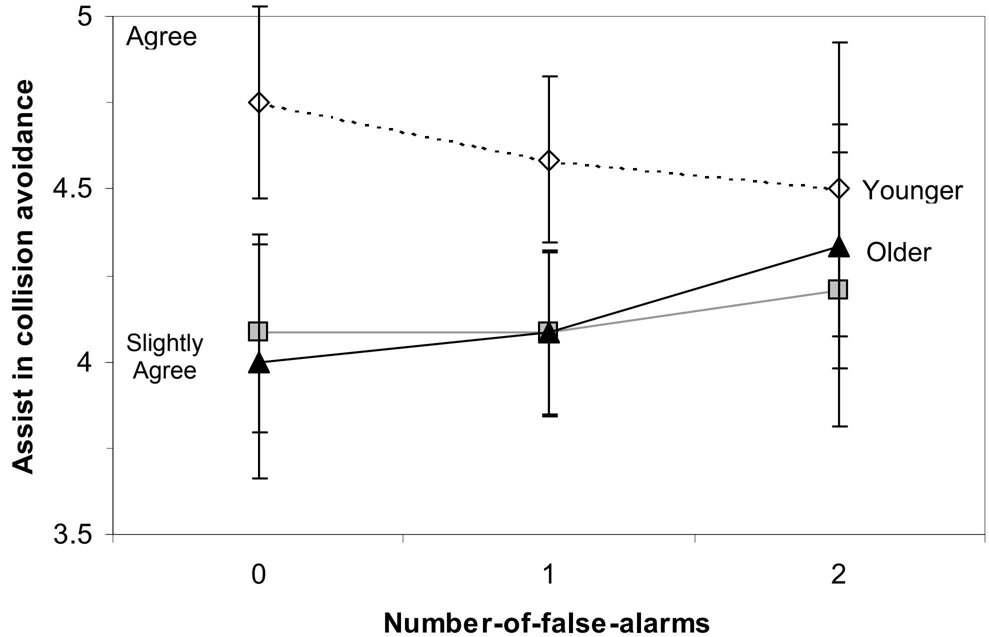


Figure 3.1. Avoidance rating as a function of number-of-false-alarms for each age group. Error bars represent plus or minus one standard error of the mean.

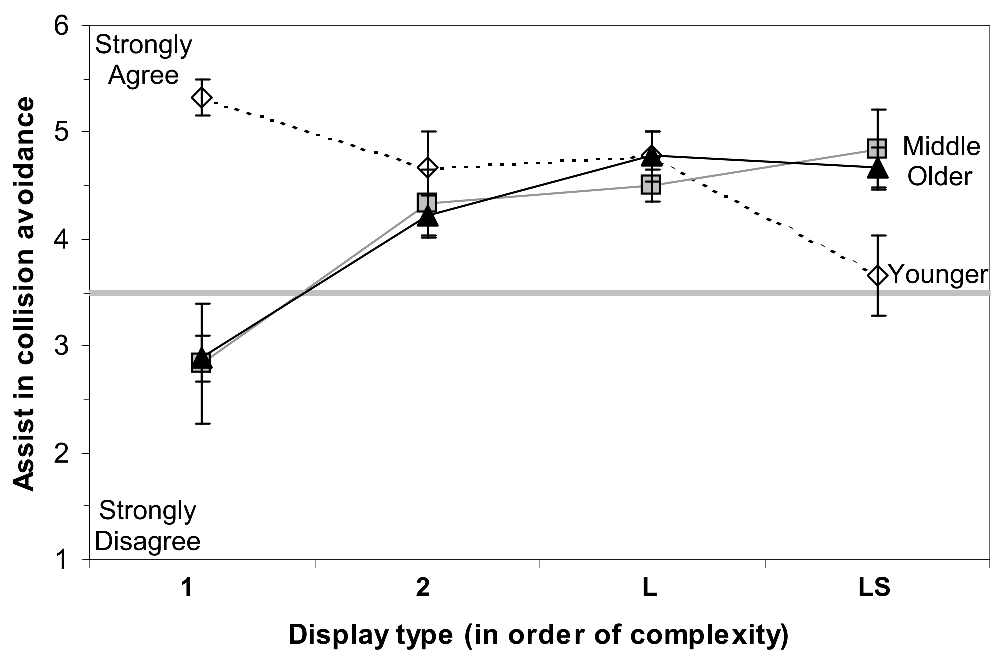


Figure 3.2. Avoidance rating as a function of display type for each age group. Error bars represent plus or minus one standard error of the mean. The horizontal gray line represents the boundary between agreement and disagreement for the questionnaire item.

The significant interaction between age group and display type for the Avoidance rating dependent variable, $F(3,30) = 2.968$, $p < 0.05$, is displayed in Figure 3.2. Whereas Middle and Older group Avoidance ratings tended to increase as a function of display complexity, this trend was reversed for the Younger group. There was no main effect of display type for the Avoidance rating.

Figure 3.3 displays the significant interaction between age group and display type for the responses to the item "*This display is overly annoying*" (Annoyance rating), $F(3,30) = 3.390$, $p < 0.05$. Younger and middle age groups indicated that the displays became increasingly annoying as the display complexity increased, whereas the older group appeared to be less affected by the increase in display complexity. The main effect of display type was also significant for Annoyance rating, $F(3,30) = 7.414$, $p < 0.001$. Posthoc LSD tests revealed that the looming-plus-scale display was rated as more annoying than the one-stage, two-stage, and looming displays and that the looming display was rated as more annoying than the one-stage display.

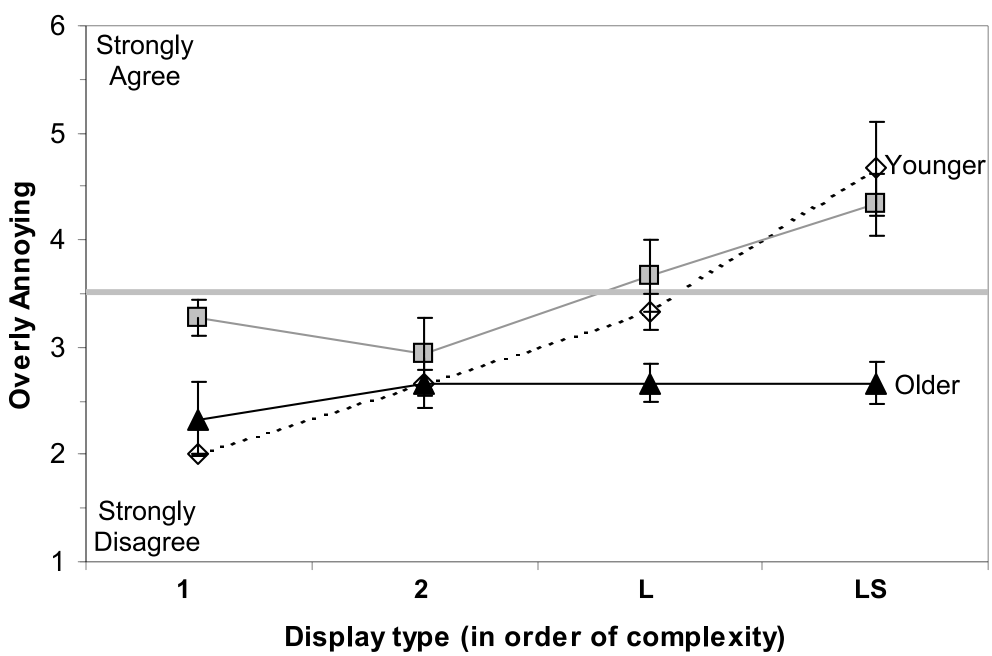


Figure 3.3. Annoyance rating as a function of display type for each age group. Error bars represent plus or minus one standard error of the mean. The horizontal gray line represents the boundary between agreement and disagreement for the questionnaire item.

Figure 3.4 displays the significant interaction between age group and display type for the responses to item "*I would buy this warning system for my vehicle if it were reasonably priced*" (Buy rating), $F(3,30) = 4.472$, $p < 0.05$. Unlike the younger group, the middle and older groups appeared to be resistant to buying a system with the one-stage display. Unlike the older group, the younger and middle groups appeared to be resistant to buying a system with the looming-plus-scale display. The main effect of display type was also significant for Buy rating, $F(3,30) = 4.650$, $p < 0.01$. Posthoc LSD tests revealed that participants would be more likely to buy a system with the looming display than the one-stage or looming-plus-scale displays.

Figure 3.5 displays the significant interaction between age group and display type for the responses to item "*This display would assist me in the task of maintaining safe headway*" (Headway rating), $F(3,30) = 3.568$, $p < 0.05$. Whereas Middle and Older group Headway ratings tended to increase as a function of display complexity, this trend was reversed for the Younger group. There was no main effect of display type for Headway rating.

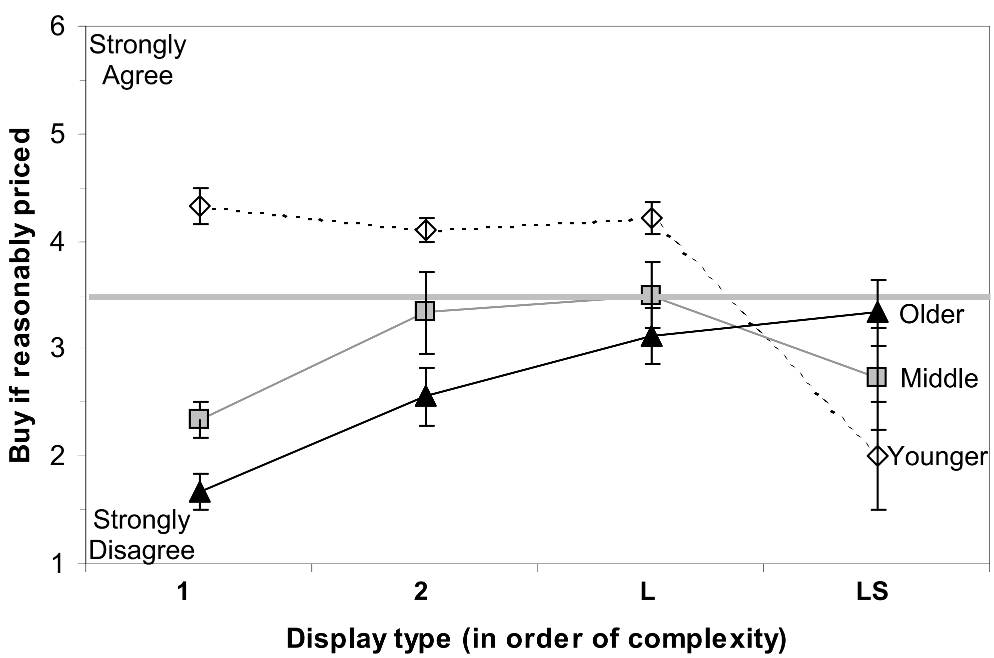


Figure 3.4. Buy rating as a function of display type for each age group. Error bars represent plus or minus one standard error of the mean. The horizontal gray line represents the boundary between agreement and disagreement for the questionnaire item.

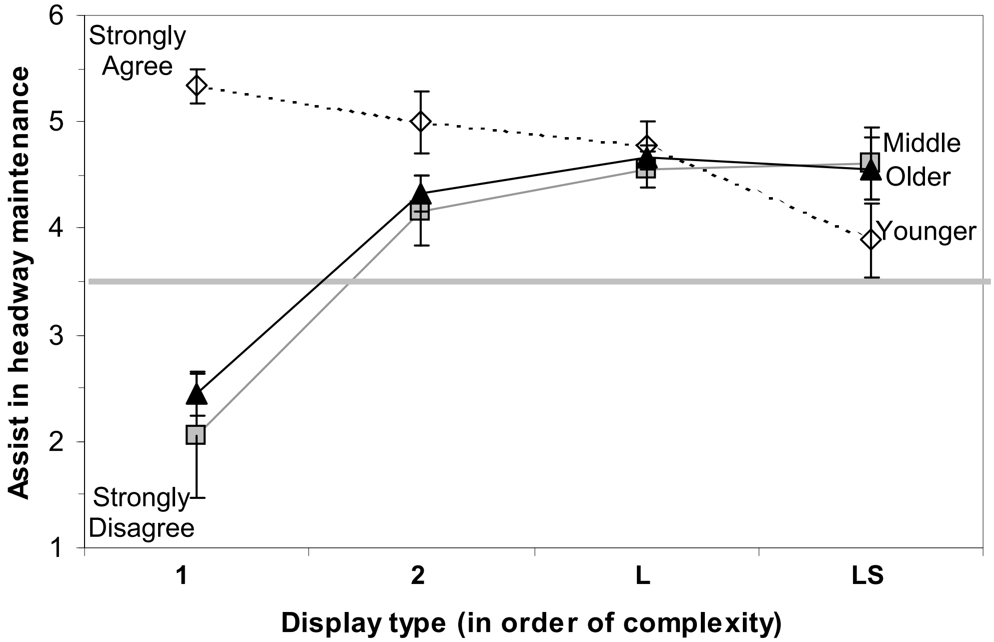


Figure 3.5. Headway rating as a function of display type for each age group. Error bars represent plus or minus one standard error of the mean. The horizontal gray line represents the boundary between agreement and disagreement for the questionnaire item.

Although the interaction between age group and display type for the response to the item "*This system would distract me from the driving task*" (Distraction rating) was not significant, a significant main effect of display type was observed for Distraction rating, $F(3,30) = 4.648$, $p < 0.01$. Posthoc LSD tests revealed that participants rated the looming-plus-scale display (M = 3.667, SD = 0.629) as more distracting than the one-stage (M = 2.611, SD = 0.465), two-stage (M = 2.889, SD = 0.474), and looming displays (M = 3.028, SD = 0.448).

3.2.2 Relative-comparison subjective measures

Friedman χ^2 tests were conducted on the rank data for each of the subjective measures. There were significant main effects of display type for annoyance [$\chi^2(3) = 10.90$, $p < 0.02$], distraction [$\chi^2(3) = 20.70$, $p < 0.0005$], attention-getting [$\chi^2(3) = 11.10$, $p < 0.02$], and understandability [$\chi^2(3) = 9.90$, $p < 0.02$]. The effect of preference approached significance [$\chi^2(3) = 7.00$, $p < 0.1$]. The rank scores for each measure are displayed in Figure 3.6. Nemenyi's post-hoc procedure revealed the following comparisons to be significant:

(1) The looming-plus-scale display was more annoying than the one- and two-stage displays

(2) The looming-plus-scale display was more distracting than one- and two-stage displays

(3) The looming display was more distracting than the one-stage display

(4) The looming display was more attention-getting than the one- and two-stage displays.

(5) The looming and looming-plus-scale displays were more understandable than one-stage display.

(6) The looming display was more preferred than the one-stage display

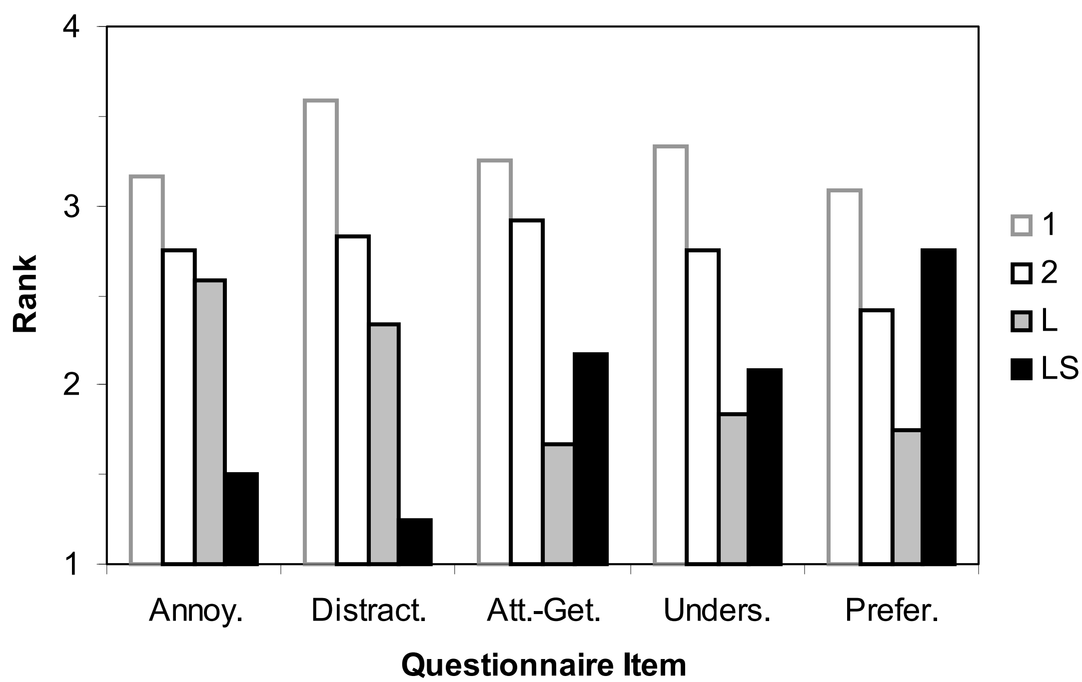


Figure 3.6. Mean rank as a function of display type for the questionnaire items annoyance, distraction, attention-getting, understandability, and preference. The four displays were ranked from most (1) to least (4) for each item, so a lower score indicates that participants rated the display as being more representative of the given dimension, whether desirable or undesirable.

When participants were asked to rate the urgency of the display tone from 1 (far too urgent) to 6 (not nearly urgent enough) the mean response was 3.58 (SD = 0.67), where a score of 3.5 would have indicated no bias towards too urgent or not urgent enough. Participants were also asked to rate the timing of the transition between display levels from 1 (far too early) to 6 (far too late). The mean response was 3.42 (SD = 0.90), compared with a score of 3.5 that would have indicated no bias.

Participants were asked to respond to a series of questionnaire items addressing the effectiveness of the seat-vibration as an alerting stimulus. When asked whether they noticed the seat-vibration associated with the alert, 92 percent responded affirmatively, compared with only 20 percent in Experiment 1. They indicated the extent to which they agreed on a scale from 1 [strongly disagree] to 6 [strongly agree] with the following statements:

(1) *The seat-vibration enhanced the display*, M = 4.33, SD = 1.72 (9 of 12 agreed to some extent.)

(2) *The seat-vibration made the display more annoying*, M = 2.17 SD = 0.94 (11 of 12 disagreed to some extent)

(3) *If I had this display in my vehicle, I would want S-V to accompany the alert*, M = 4.33 SD = 1.97 (8 of 12 agreed to some extent)

(4) *I would turn off the sound if this alert system was in my vehicle*, M = 3.58 SD = 1.73 (7 of 12 agreed to some extent)

3.3 Discussion

3.3.1 False Alarms

Surprisingly, there appeared to be little effect of the number-of-false-alarms. The younger drivers were the only participants that demonstrated any downward trend in display acceptance as a function of number-of-false alarms and this only occurred for a single dependent measure (avoidance rating). The absence of this effect might be attributed to the number-of-false-alarms being confounded with trial order. Participants experienced each display with zero false alarms, one false alarms and two false alarms. If participants became increasingly accepting of the display over the course of the three trials, this effect could work directly against a number-of-false-alarms effect. The absence of a number-of-false-alarms effect might also be attributed to the short exposure duration (4-min trials). Perhaps, false alarms do not become annoying until the driver experiences the system for several hours under normal driving conditions. Alternatively the result could be valid, indicating that with this given display (including a 0.5-s 72 dBA tone), high false alarm rates are tolerable to a large number of drivers. Lerner, Dekker, Steinberg, and Huey (1996) revealed a wide range of annoyance sensitivity to false alarms exists and that tonal (as opposed to voice) alarms were generally more tolerable.

3.3.2 Driver Acceptance

The age of participants appeared to have a large impact on how they rated the different display alternatives. Younger drivers rate more complex displays (especially the looming-plus-scale display) as less effective (in terms of headway maintenance and collision avoidance), more annoying, and less desirable. Buy rating dropped dramatically for younger drivers when the scale was added to the looming-display (Figure 3.4). Middle and older drivers, on the other hand, rated the more complex displays as being more effective, however, there is little difference between the looming and looming-plus-scale displays of the headway and avoidance ratings. Middle drivers indicated a general increase in annoyance associated with more complex displays, whereas, older drivers indicated little increase in annoyance as a function of display complexity. Middle drivers indicated that they would be more likely to buy the two-stage and looming displays than the one-stage and looming-plus-scale displays, whereas, the older drivers revealed a buy rating that monotonically increased with display complexity. Averaged across all groups, the looming-plus-scale display was rated as being the most distracting display candidate.

Because these conclusions are based on such a small sample of participants, the effect of age must be observed cautiously. The younger and older groups included only three participants each. Because the age trends appeared to be internally consistent and reliable, age was included as a variable in the statistical analysis. This data is strongly suggestive that there are meaningful differences between age groups in the preference of forward collision warning displays, however, these results should not be considered conclusive until further research replicates these trends.

Overall the looming-plus-scale display was ranked as being more annoying and distracting than the simpler displays. The only positive attribute of the looming-plus-scale display was that it was ranked as being significantly more understandable than the one-stage display. The looming display was ranked as being more understandable and more attention-getting than the one- and two-stage displays, and more preferable than the one-stage display. The only negative attribute of the looming display was that it was ranked as being more distracting than the one-stage display. This analysis shows a clear driver-acceptance advantage of the looming display over the looming-plus-scale display.

Table 3.1 displays the preference ranks from the participants. It can be observed that five participants ranked the looming display as their first choice, compared with three for the one-stage, two for the two-stage, and four for the looming-plus-scale display. The looming display was the second choice of five participants. Therefore the looming display was the first or second choice of ten out of twelve participants. The remaining two participants (who ranked the looming display as their third choice) ranked the displays in order of complexity (least to most) and therefore selected the one-stage display as their first choice. Although the one-stage display was ranked by two-thirds of the participants as their last choice, it received the second highest of first choices after the looming display, demonstrating that their is a group of participants who favor its simplicity.

1st Choice	2nd Choice	3rd Choice	Last Choice	Frequency
Looming	*Loom+Scale*	*2-Stage*	*1-Stage*	3
Looming	*2-Stage*	*Loom+Scale*	*1-Stage*	1
Looming	*1-Stage*	*2-Stage*	*Loom+Scale*	1
2-Stage	Looming	*Loom+Scale*	*1-Stage*	2
Loom+Scale	Looming	*2-Stage*	*1-Stage*	2
1-Stage	Looming	*2-Stage*	*Loom+Scale*	1
1-Stage	*2-Stage*	Looming	*Loom+Scale*	2

Table 3.1. The frequency of participants responses grouped by looming as first choice, looming as second choice, and looming as third choice.

3.3.3 Auditory tone and seat-vibration

The responses to the auditory item on the questionnaire revealed that participants were generally comfortable with the urgency conveyed by the auditory tone that was used, indicating that it was neither too urgent nor not urgent enough. This tone used the same frequency peaks (2500 and 2650 Hz) as the CAMP #8 sound so may share many similar positive features. Despite positive urgency ratings, many participants (seven of twelve) also indicated that they would want to turn the sound off. Ratings of the extent to which participants agreed that they would want to turn the sound off were highly correlated ($r = 0.64$) with ratings of the extent to which they agreed that the seat-vibration enhanced the display. This suggests that many might want to substitute seat-vibration for the auditory warning tone.

The seat-vibration stimulus received low annoyance ratings with only one participant (slightly) agreeing that the seat vibration was annoying. One advantage of the seat-vibration warning is that the stimulus would not impinge on other passengers. This feature would be similar to the vibration function on a cellular phone where the user is alerted without impinging on other people. It might be especially important if there were large numbers of false alarms. Unlike visual stimuli, seat-vibration and the auditory stimuli both share the common feature that they do not require the driver to be oriented in a particular direction. This may imply that the seat-vibration is a suitable candidate for replacing the auditory stimulus. However, until further research validates that seat-vibration is as beneficial to driver reaction performance as an auditory stimulus, an auditory stimulus must accompany the imminent alert. The fact that only two out of ten participants detected the seat-vibration in the first experiment suggests a potential weakness of this stimulus.

4. INTERFACE SPECIFICATION

4.1 Final selection of the visual alert level display

The two experiments provided little evidence that the scale addition provided any benefit to the looming display. Participants in the looming-plus-scale display condition showed no brake reaction time benefit over participants with the looming display. The scale in isolation also failed to provide any benefit when compared with no display. These results suggest that the scale is an ineffective means of presenting forward collision warning information. One explanation for the failure of the scale component may be that it is overly graphical and complex in nature, requiring too much attention from a driver who must react immediately. Whereas the two-stage and looming displays present a global change in color and size between each stage, the change in a scale display is more local, occurring in only a small portion of the display. The fine-grained distinction provided by the scale may be unnecessary given that the driver controls the position of the vehicle using the external visual scene rather than the internal instruments. Given that the driver is able to use the external visual scene to make fine tuning speed adjustments, salience is more important than precision in a forward collision warning display.

Although no display effects were observed on headway maintenance, based on Dingus et al.'s (1997) it is expected that the looming display can be as effective as the looming-plus-scale display for increasing headway. In Dingus et al.'s first experiment only their display with a car icon significantly increased temporal headway during coupled headway events, suggesting that the car icon may have been the most active component of the display. Despite this result, Dingus et al. discarded the car icon display in the next two experiments, choosing to focus instead on the bar display.

The scale addition to the looming display appears to provides little advantage, however, there is evidence for a driver-acceptance cost. The looming-plus-scale display was rated as being more annoying than the looming display in both experiments and for the absolute judgments of Experiment 2, it was rated as being more distracting than the looming display. Participants rated themselves as being significantly less likely to buy a system that used the looming-plus-scale display than the looming display and preferred the looming display over the looming-plus-scale display.

The decreased driver acceptance of the scale display may relate to the fact that the scale display violates the "display by exception" axiom of display design, suggesting that displays should only present information when the message is important and relevant. Even when no vehicle is detected, the scale and looming-plus-scale display presents an empty scale on the HUD. The ever-present scale provides little additional information and may to some extent mask the arrival of a more urgent state when such a state is detected. Lerner et al. (1996) claim that it is easier for drivers to detect a change from nothing to something than it is to detect a change from something to something else. For all of the above reasons, the looming-plus-scale display is rejected.

The two-stage and the looming displays differ only in that the looming display provides a distinction between an amber and static red cautionary stage (see Figure 1.2). These displays performed very similarly in most regards throughout the two experiments, however, the looming display showed a significant advantage over the two-stage display in participant ratings of preference (Experiment 1), discriminability (Experiment 1), understandability (Experiment 1), and attention-getting (Experiment 2). Given that the displays are so similar in nature, implying that there can be little benefit of one display over the other, selecting the looming display over the two-stage display appears to be a safe option. Therefore, although the two-stage display also appeared to be an effective candidate, it is rejected in favor of the looming (three-stage) display.

The one-stage display exhibited significantly more resistance to annoyance and distraction than the looming display. Younger participants rated the one-stage display as being more effective for collision avoidance and indicated that they would be more likely to buy a one-stage display. However, in Experiment 1 the one-stage display failed to demonstrate any performance benefit over no display (inconsistent with the 1999 CAMP work). The looming display led to significantly shorter brake reaction times than the one-stage display and was significantly more preferred in both experiments. Although there may be a group of drivers who prefer the one-stage display and there may be times when the looming display provides too much distraction, based on the overall pattern of data in the two experiments, the looming display appears to be the most effective candidate. However, there appears to be a means of utilizing the benefits of both displays.

The sensitivity setting functions in the ACAS FOT algorithm by adjusting the timing of the pre-imminent phases of the alert level, while leaving the imminent phase fixed. When the driver selects a more aggressive sensitivity setting with the looming display, the cautionary phases are pushed later in time (closer to the imminent phase). More aggressive settings allow less time for the cautionary phases to be presented. The sensitivity settings are mapped into the algorithm in units of time (either time headway or time to the imminent margin). If drivers were permitted to select a sensitivity setting that corresponded to zero seconds, they would be able to select a one-stage display as the most aggressive sensitivity setting. Because the zero value represents the logical aggressive extreme of the sensitivity spectrum, it is likely that providing drivers with the option of a zero setting will make intuitive sense to the driver. They can think of the sensitivity settings as the amount of pre-warning before the imminent phase and they can select no pre-warning as the most aggressive setting. This implementation (a looming display allowing a zero sensitivity setting) extends the capability of the sensitivity setting, allowing the driver to select a one-stage display wherever appropriate. For this reason, this display was selected for the ACAS FOT.

The color of the "vehicle detected" indicator was changed from green to a the same color that was used for the vehicle speed, ACC set speed text, and gap/sensitivity setting text on the HUD. Because of the association between green and safety, it would be beneficial to avoid the potential liability implications of informing the driver that they are "safe". In the scale display, green was used because the scale represented a continuum of the amount of threat from the forward vehicle. One extreme clearly communicates danger, therefore the opposite extreme must imply safety. However, because the looming display is not necessarily a continuum and can be thought of as five discreet states (no vehicle detected, vehicle detected, caution, approaching imminent, and imminent), the "vehicle detected" icon should communicate that a vehicle is detected rather than the fact that the driver is safe.

Maintaining a consistent color on the HUD when no threat was present conforms more closely with the design axiom of "display by exception". Given that "vehicle detected" is not an inherently urgent state, the representing icon should be less salient to the driver, so that it can be ignored (when desired). In the absence of a cautionary or warning state, the HUD will present a monochromatic display, however, when attention is demanded, amber or red color will appear.

As a direct result, the introduction of a different color will be more salient. Figure 4.1 displays the final selection of the FCW icons.

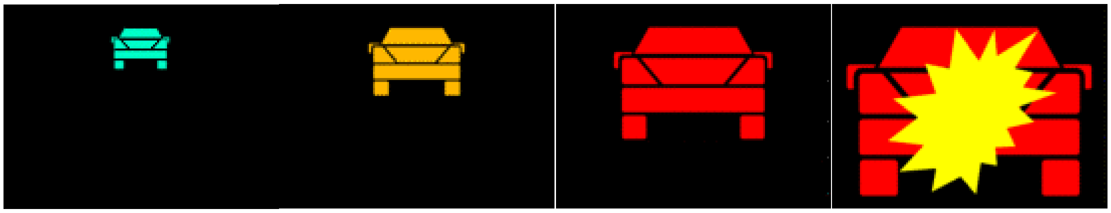


Figure 4.1. Final selection of the FCW display. From left to right the icons mean "vehicle-detected", "caution", "approaching imminent", and "imminent". When no vehicle is detected, this display is blank. The imminent icon will flash at 4 Hz.

4.2 Display moding and messages

Decisions on display moding were based on the combined reasoning of the human factors group rather than on paper-and-pencil studies involving multiple participants. It was decided that because of the inherent engineering complexity, it was not expected that participants could gain a sufficiently complete understanding of the FCW and ACC systems on which to base their decisions. Instead the design criterion was unanimous human factors agreement between the group participating in the human factors decision making for the ACAS FOT.

Figure 4.2. The distinction between ACC-not-engaged (left) and ACC-engaged (right). The right half of each display contains three elements: the alert-level icon at the top, the message line in the middle, and the gap/warn setting line at the bottom. When ACC is engaged, the set speed text will display by default and the gap (as opposed to warn) setting is displayed at the bottom.

The DVI layout is displayed in Figure 4.2 for the ACC-not-engaged and ACC-engaged conditions. In addition to observing the natural vehicle throttle control cues during the ACC-engaged state, the driver can observe that ACC is engaged by noticing the set speed text and the solid gray blocks between the gap/warn display vehicles, as opposed to the radar waves. Whereas the number of radar waves and distance between the two car icons represent the six different sensitivity settings for the FCW system, the number of blocks and distance between the two car icons represent the six different headway settings for the ACC system,. The set speed text is the only cyan text that can appear on the text line, so the presence of the set speed text should be salient to the driver.

The other messages (and their associated meanings) that can appear on the set speed line are “Dirty Radar” (the radar is obstructed, reducing the reliability of the ACC/FCW system, and needs to be cleaned), “Heavy Rain” (heavy rain is reducing the reliability of the ACC/FCW system), “Slippery” (the cool temperature suggests that the roads may be slippery and so the FCW algorithm will assume a more cautious friction coefficient), “Sharp Curve” (the radar is unable to detect what is around the curve, so use caution), and “Speed too fast” (the vehicle is traveling beyond the range of the radar). The messages “Driver Control Required” (the ACC-system has automatically been disengaged, so driver control of the vehicle is now required), and “Malfunction” (ACC/FCW system failure) will simultaneously occupy both the text and gap/warn setting lines.

Because a single line is being used to provide several different possible messages, the messages were prioritized according to the order displayed in Figure 4.3. A single type of message can assume more than one priority, assuming a higher priority if it has just been detected, or a lower priority if it is older information. To avoid driver annoyance, only some of the messages are accompanied with an audible tone (a pair of 50-ms 3000-Hz tones, separated by 20 ms of silence). The entire right side of the HUD will be blanked when a “FCW Inactive” message is broadcast over the CAN interface and during the first week of the FOT (when only conventional cruise control is available). “FCW Inactive” occurs when the vehicle speed is less than 25 mph and when the driver applies the brake. The text and gap/warn setting lines will be blanked when the imminent alert level is reached.

Malfunction	-When present (+audio)
Driver Control Required	-When ACC is automatically disengaged until brake or gas pedal (+audio)
	-When FCW Inactive, Malfunction, or imminent alert present
SET: 100 MPH	-When or set speed changed (or ACC is engaged) in last 2 s
Sharp Curve	-When present
Speed Too Fast	-When detected in the last 10 s
Dirty Radar	-When detected in last 10 s and not active in past 15 min (+audio)
Heavy Rain	-When detected in last 10 s
Slippery	-When detected in last 10 s and not yet activated (retry until >= 2 s activation)
Dirty Radar	-When present
SET: 100 MPH	-When ACC engaged
Speed Too Fast	-When present
Heavy Rain	-When present

Figure 4.3. Priorities for the text line messages. Visual display of messages will be accompanied with audio, where indicated.

When the driver is in park, the text line will cycle through "Dirty Radar" (plus audio), and "Slippery" when these messages are present. Each message will display for 2 s and loop continuously. The audio accompanying "Dirty Radar" will only play only once in this sequence. The gap/warn setting will also be displayed and adjustable when the vehicle is in park.

4.3 Audio System

To avoid the delays associated with communicating with the radio over the Class 2 vehicle bus, an additional speaker and amplifier were added to the vehicle to play the ACC/FCW system sounds. The 4-ohm 3-inch mid-range speaker was placed in front of the driver seat so that the sound would appear to emanate from a frontal direction. The DVI will mute the radio during the imminent alert level and play the imminent alert tone through the added amplifier and speaker, keeping the Class 2 communication to a minimum. Half a second after the imminent tone has played, the DVI system will un-mute the radio. To avoid unnecessary annoyance, the radio will not be muted during the message audio. The audio messages for the ACAS FOT system were set to play at 75 dBA.

4.4 Steering wheel button remapping

Figure 4.4 displays the configuration of the steering wheel buttons in the prototype vehicle. To make room for the gap/warn addition to the steering wheel, the temperature button (inner right) was removed. Given that the outer buttons are easier to manipulate than the inner buttons, the seek button (outer left) was moved to the position that the temperature button had previously occupied (inner right), to allow the gap/warn button to occupy the outer left position. Because the volume control is the most frequently used function, its location was preserved on the outer right location. As required by the ACC system, the “ACC on/off” and the “SET/RESUME” buttons remained in the same position. Buttons in the prototype vehicle are labeled according to the new arrangement.

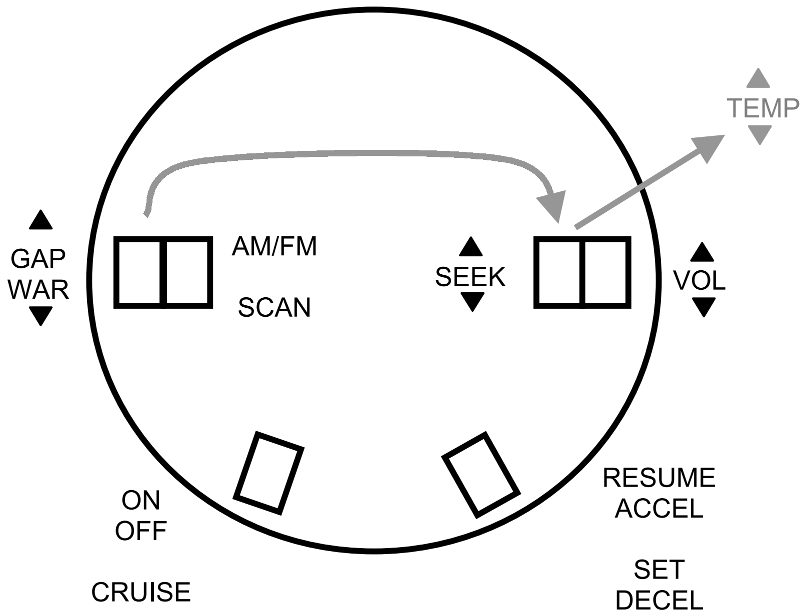


Figure 4.4. Steering wheel button layout. The rectangles represent where the buttons are located on the steering wheel. The temperature button was removed and the seek button replaced it. The gap/warn setting button was placed where the seek button had been.

5. CONCLUSION

The two experiments revealed that the scale stimulus component of the forward collision warning displays was both ineffective and poorly accepted by drivers. Whether combined with a looming stimulus or standing alone, the scale stimulus provided no observable benefit to the driver braking performance. The salience and natural mapping provided by the “looming” stimulus appeared to be a far more effective candidate for forward collision warning displays. Perhaps the failure to adhere to the design axiom of “display by exception” was a contributing factor that undermined the performance of the scale displays. The scale background was present even in the absence of a lead vehicle, perhaps perceptually masking the change to a cautionary or warning state. This may have also contributed to the poor driver-acceptance ratings of the displays containing a scale stimulus.

The “looming” stimulus appeared to be effective for communicating the urgency of the forward target to the driver. Displays with two or more changes in vehicle icon size exhibited an observable reduction in brake reaction time. Most participants seemed to favor displays with two or more changes in vehicle icon size, with all twelve participants ranking either the two-stage or looming display as their first or second choice. There was some evidence to suggest that younger participants may prefer simpler displays, such as the single-stage display. For this reason, the ACAS FOT program adopted a three-stage display that can emulate a single-stage display if the most aggressive warning sensitivity setting is selected. Although this research was suggestive that driver preferences vary significantly across age groups, because the sample size was so small, this observation should be verified with a much larger sample size in future research.

REFERENCES

Dingus, T. A., McGehee, D. V., Manakkal, N., Jahns, S. K., Carney, C., & Hankey, J. M. (1997). Human factors field evaluation of automotive headway maintenance/collision warning devices, *Human Factors, 39*(2), 216-229.

Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., and Shulman, M. (1999). *Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems*, Report under contract DTNH22-95-H-07301. Washington, DC: National Highway Traffic Safety Administration.

Lerner, N., Kotwal, B., Lyons, R., & Gardner-Bonneau, D. (1996). *Inappropriate alarm rates and driver annoyance*, Report under contract DTNH22-91-07004. Washington, DC: National Highway Traffic Safety Administration.

Lerner, N., Dekker, D., Steinberg, G., & Huey, R. (1996). *Preliminary human factors guidelines for crash avoidance warning devices*, Report under contract DTNH22-91-07004. Washington, DC: National Highway Traffic Safety Administration.

Mortimer, R. G. (1988). Rear-end crashes. In G. A. Peters & B. J Peters (Eds.), *Automotive Engineering and Litigation*, Vol. 2 (pp. 275-306). New York: Garland Law Publishing.

Schiff, W. (1965). Perception of impending collision: A study of visually directed avoidance behavior. *Psychology Monographs: General and Applied, 79* (Whole No. 604).

Smith, M. R. H., Flach, J. M., Dittman, S. M., & Stanard, T. (2001). Monocular optical constraints on collision control, *Journal of Psychology: Human Perception and Performance, 27*, 395-410.

Wickens, C. D., Gordon, S. E., & Liu, Y. (1998). *An Introduction to Human Factors Engineering*. New York: Addison-Wesley Educational Publishers Inc.

APPENDIX A
Experiment 1 Questionnaire

1. Did the lead-vehicle-braking event at the end of the trial surprise you? (answer yes or no)
2. Did you notice a visual alert on the HUD during the lead-vehicle-braking event? (answer yes or no)
3. Were there letters or an icon or both?
4. If you saw letters, what word or words did they spell?
5. If you saw an icon, please describe the icon (colors and shapes)?
6. If you saw an icon or letters did they flash or remain constant?
7. Did you notice an auditory alert (answer yes or no)?
8. Was there a seat-vibration accompanying the alert (answer yes or no)?
9. If so, please describe the sensation (what did it feel like?).
10. If you felt a seat-vibration, do you think that it helped you to react safely (answer yes, no, maybe)?
11. If you felt a seat-vibration, was it overly annoying (answer yes, no, maybe)?
12. Describe what this icon means/indicates to you?

13. If you saw this icon on your HUD, what action (if any) would you take?
14. If so, how soon would you take this action?

    A. Immediately | B. In a few seconds | C. Sometime before ending the drive |

    D. Immediately after ending my drive | E. When it is convenient

15. During the period before the sudden braking event, was the timing of the car-following display (if you experienced it):

    A. Far Too Early | B. Too Early | C. Just Right | D. Too Late | E. Far Too Late

16. During the sudden braking event, was the timing of the collision warning alert (if you experienced it):

    A. Far Too Early | B. Too Early | C. Just Right | D. Too Late | E. Far Too Late

Please indicate the extent to which you agree with the following statements for the display that you just experienced. Use the numbering scale below to make your responses. Record your answers on the scoring sheet.

Strongly Disagree	Moderately Disagree	Perhaps Disagree	Perhaps Agree	Moderately Agree	Strongly Agree
1	2	3	4	5	6

17. This is a good method for presenting car-following and collision-warning information to drivers.

18. Using this method, changes of display-state would be clearly detectable.

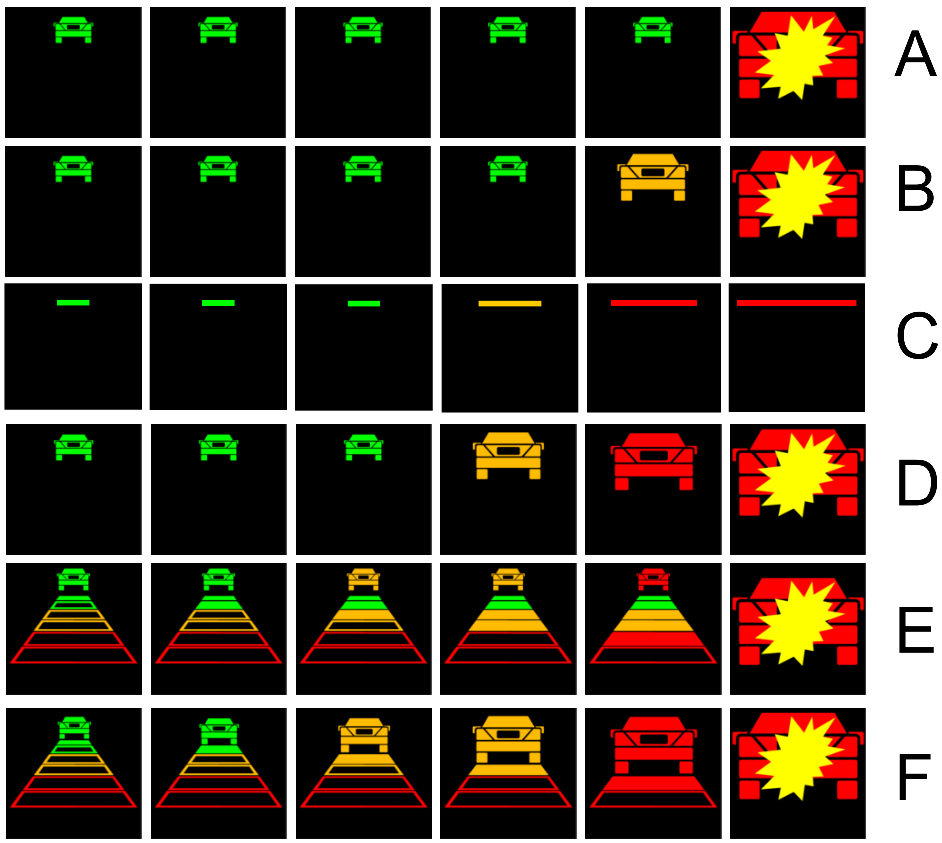
19. This method could clearly tell me that I am in danger and need to react immediately.

20. This method would NOT startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement.

21. This method would NOT interfere with my ability to make a quick and accurate decision about the safest driving action to take (brake, steer, brake and steer, do nothing).

22. This method would get my attention effectively if I was distracted and not concentrating on the driving task.

23. This method would be annoying.



24. Rank the above displays from your MOST to LEAST preferred.

25. Rank the above displays from MOST to LEAST discriminable [change of state is likely to be noticed].

26. Rank the above displays from MOST to LEAST understandable.

27. Rank the above displays from MOST to LEAST startling [likely to cause you to blink, jump, or make a rapid reflex-like movement].

28. Rank the above displays from MOST to LEAST interfering [likely to interfere with you ability to make a quick and accurate decision about the safest driving action to take (brake, steer, brake and steer, do nothing]

29. Rank the above displays from MOST to LEAST attention-getting [likely to get your attention immediately if you were distracted and not concentrating on the driving task.]

30. Rank the above displays from MOST to LEAST annoying.

APPENDIX B

Experiment 1 ANCOVA AND ANOVA Tables

Brake-reaction-time

SOURCE	SS	df	MS	F	p <
Corrected Model	33.061	8	4.133	36.810	0.0000
Intercept	24.544	1	24.544	218.619	0.0000
THEO	22.736	1	22.736	202.512	0.0000
Display type	3.674	7	0.525	4.675	0.0002
Error	7.971	71	0.112		
Total	548.243	80			
Corrected Total	41.032	79			

Required deceleration at 50 percent braking

SOURCE	SS	df	MS	F	p <
Corrected Model	2.939	8	0.367	3.077	0.005
Intercept	13.668	1	13.668	114.463	0.000
THEO	1.214	1	1.214	10.166	0.002
Display type	2.338	7	0.334	2.797	0.013
Error	8.478	71	0.119		
Total	53.991	80			
Corrected Total	11.417	79			

Subjective measures for different dependent variables (DV)

DV	SOURCE	SS	df	MS	F	p <
Good	Between Groups	10	6	1.667	1.270	0.284
	Within Groups	82.7	63	1.313		
	Total	92.7	69			
Discr.	Between Groups	13.09	6	2.181	1.369	0.241
	Within Groups	100.40	63	1.594		
	Total	113.49	69			
Under.	Between Groups	31.57	6	5.262	4.722	**0.000**
	Within Groups	70.20	63	1.114		
	Total	101.77	69			
Startle	Between Groups	6.57	6	1.095	0.512	0.797
	Within Groups	134.70	63	2.138		
	Total	141.27	69			
Interf.	Between Groups	3.37	6	0.562	0.471	0.827
	Within Groups	75.20	63	1.194		
	Total	78.57	69			
Att.-get.	Between Groups	39.94	6	6.657	3.960	**0.002**
	Within Groups	105.90	63	1.681		
	Total	145.84	69			
Annoy	Between Groups	7.60	6	1.267	0.938	0.475
	Within Groups	85.10	63	1.351		
	Total	92.70	69			

APPENDIX C

Experiment 2 Questionnaires

Questionnaire used after each trial (absolute judgments)

Initials	Display	Block

A **nuisance alert** is an alert activation error that is not connected to the presence of the lead vehicle.

strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree
1	2	3	4	5	6

In the last 4 minutes:	Answer
1. How many nuisance alerts did you experience?	
2. The nuisance alerts were tolerable	
3. This display would assist me in the task of maintaining safe headway	
4. This display would assist me in avoiding collisions with the lead vehicle.	
5. This display is overly annoying	
6. This system would distract me from the driving task	
7. I would buy this warning system for my vehicle if it were reasonably priced	

In the last 4 minutes:	Answer
1. How many nuisance alerts did you experience?	
2. The nuisance alerts were tolerable	
3. This display would assist me in the task of maintaining safe headway	
4. This display would assist me in avoiding collisions with the lead vehicle.	
5. This display is overly annoying	
6. This system would distract me from the driving task	
7. I would buy this warning system for my vehicle if it were reasonably priced	

In the last 4 minutes:	Answer
1. How many nuisance alerts did you experience?	
2. The nuisance alerts were tolerable	
3. This display would assist me in the task of maintaining safe headway	
4. This display would assist me in avoiding collisions with the lead vehicle.	
5. This display is overly annoying	
6. This system would distract me from the driving task	
7. I would buy this warning system for my vehicle if it were reasonably priced	

Note. At the time “Nuisance Alert” was thought to be synonomous with “False Alarm” so the term “Nuisance Alert” here actually means “False Alarm”. The above form was used for each display and participants recorded their answers in one section every trial.

Questionnaire used after the conclusion of all trials (relative rankings)

Initials

1. Rank the 4 displays (A, B, C, D) from most to least **understandable:**

Most	2nd Most	3rd Most	Least

2. Rank the 4 displays (A, B, C, D) from most to least **attention-getting:**
[likely to get your attention immediately if you were distracted from driving]

Most	2nd Most	3rd Most	Least

3. Rank the 4 displays (A, B, C, D) from most to least **distracting:**
[likely to attract your attention away from the driving task]

Most	2nd Most	3rd Most	Least

4. Rank the 4 displays (A, B, C, D) from most to least **annoying:**

Most	2nd Most	3rd Most	Least

5. Rank the 4 displays (A, B, C, D) from most to least **preferred:**

Most	2nd Most	3rd Most	Least

6. Did you notice any **seat-vibration** associated with the alert?	

7. Rate the **urgency level** communicated by the **sound** [indicate below]

far too urgent	too urgent	slightly too urgent	slightly not urgent enough	not urgent enough	not nearly urgent enough

8. Rate the **timing of the transitions** between display levels [indicate below]

far too early	too early	slightly too early	slightly too late	too late	far too late

Use this scale for questions 9 through 12

strongly disagree	disagree	slightly disagree	slightly agree	agree	strongly agree
1	**2**	**3**	**4**	**5**	**6**

9. The **seat-vibration** enhanced the display	
10. The **seat-vibration** made the display more annoying	
11. If I had this display in my vehicle, I would want **seat-vibration** to accompany the alert	
12. I would turn off the **sound** if this alert system was in my vehicle	

APPENDIX D

Experiment 2 ANOVA Tables

SOURCE	MEASURE	SS	df	MS	F	p <
DISPLAY	ANNOY	31.441	3.000	10.480	7.414	0.001
DISPLAY	AVOID	11.759	3.000	3.920	1.235	0.314
DISPLAY	BUY	39.978	3.000	13.326	4.650	0.009
DISPLAY	DISTR	20.842	3.000	6.947	4.648	0.009
DISPLAY	HDWY	9.185	3.000	3.062	1.041	0.389
DISPLAY * AGE	ANNOY	14.375	3.000	4.792	3.390	0.031
DISPLAY * AGE	AVOID	28.264	3.000	9.421	2.968	0.048
DISPLAY * AGE	BUY	38.444	3.000	12.815	4.472	0.010
DISPLAY * AGE	DISTR	11.000	3.000	3.667	2.453	0.083
DISPLAY * AGE	HDWY	31.486	3.000	10.495	3.568	0.026
DISPLAY * NFA	ANNOY	0.302	6.000	0.050	0.128	0.992
DISPLAY * NFA	AVOID	0.727	6.000	0.121	0.814	0.563
DISPLAY * NFA	BUY	0.156	6.000	0.026	0.268	0.950
DISPLAY * NFA	DISTR	0.216	6.000	0.036	0.317	0.925
DISPLAY * NFA	HDWY	0.690	6.000	0.115	0.706	0.646
DISPLAY * NFA * AGE	ANNOY	0.417	6.000	0.069	0.176	0.982
DISPLAY * NFA * AGE	AVOID	1.194	6.000	0.199	1.337	0.255
DISPLAY * NFA * AGE	BUY	0.222	6.000	0.037	0.382	0.888
DISPLAY * NFA * AGE	DISTR	0.250	6.000	0.042	0.367	0.897
DISPLAY * NFA * AGE	HDWY	0.972	6.000	0.162	0.996	0.437
Error(DISPLAY)	ANNOY	42.410	30.000	1.414		
Error(DISPLAY)	AVOID	95.236	30.000	3.175		
Error(DISPLAY)	BUY	85.972	30.000	2.866		
Error(DISPLAY)	DISTR	44.840	30.000	1.495		
Error(DISPLAY)	HDWY	88.236	30.000	2.941		
Error(DISPLAY*NFA)	ANNOY	23.694	60.000	0.395		
Error(DISPLAY*NFA)	AVOID	8.931	60.000	0.149		
Error(DISPLAY*NFA)	BUY	5.819	60.000	0.097		
Error(DISPLAY*NFA)	DISTR	6.806	60.000	0.113		
Error(DISPLAY*NFA)	HDWY	9.764	60.000	0.163		
Error(NFA)	ANNOY	9.861	20.000	0.493		
Error(NFA)	AVOID	2.514	20.000	0.126		
Error(NFA)	BUY	3.569	20.000	0.178		
Error(NFA)	DISTR	2.861	20.000	0.143		
Error(NFA)	HDWY	2.903	20.000	0.145		
NFA	ANNOY	1.043	2.000	0.522	1.058	0.366
NFA	AVOID	0.668	2.000	0.334	2.658	0.095
NFA	BUY	0.270	2.000	0.135	0.757	0.482
NFA	DISTR	0.080	2.000	0.040	0.280	0.758
NFA	HDWY	0.113	2.000	0.056	0.388	0.683
NFA * AGE	ANNOY	0.583	2.000	0.292	0.592	0.563
NFA * AGE	AVOID	1.028	2.000	0.514	4.088	0.032
NFA * AGE	BUY	0.333	2.000	0.167	0.934	0.410
NFA * AGE	DISTR	0.083	2.000	0.042	0.291	0.750
NFA * AGE	HDWY	0.250	2.000	0.125	0.861	0.438

Note. "SOURCE" refers to the independent variable, whereas "MEASURE" refers to the dependent variable. "NFA" refers to the number-of-false-alarms.

DOT HS 809 462
May 2002

U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
People Saving People
www.nhtsa.dot.gov