

Evaluation of Forward Collision Warning System Visual Alert Candidates and SAE J2400

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ABSTRACT

Forward Collision Warning (FCW) systems are intended to alert drivers when they may be at risk of a rear-end crash with a vehicle directly ahead unless they take immediate action. A forward collision visual alert (FCVA) is recommended as part of a multi-modality FCW system crash alert approach also including auditory and/or haptic crash alert components. SAE J2400 recommends that a conventional dashboard location shall not be used for the FCVA, since such an alert may distract the driver from the crash threat ahead (instead of helping the driver visually orient toward the crash threat). This research examined the merit of this recommendation by examining the effectiveness of instrument panel, head-up display, and (vehicle-centerline) top-of-dashboard FCVA candidates. In this static on-road study, 49 subjects (20-70 years old) made rapid judgments on the presence and nature of scene changes over two successive forward scene exposures controlled by a visual occlusion window. Scenes consisted of full-scale "pop up" vehicle and pedestrian targets. During the occluded period between scene exposures, drivers performed an "eyes-off-road" visual distraction task (located at either a center console or left side mirror location) until the window opened or they received a FCVA (which signaled them to abort the

distraction task and prepare for an imminent window opening). Additional trials were conducted involving only alert detection. Results for the change detection and alert detection trials indicated that the overall time savings benefit for the larger HUD and top-of-dashboard alert types examined relative to the instrument panel alert type was 120 and 160 ms, respectively. A follow-on eye movement time-course analysis suggests that the benefits of these alert types have different underlying mechanisms. Overall, these results support the SAE J2400 recommendation advising against the use of instrument panel FCVAs and should be used to further refine FCVA-related SAE J2400 recommendations.

INTRODUCTION

Forward Collision Warning (FCW) systems are intended to alert the driver when they may be at risk of a rear-end crash with a vehicle directly ahead unless they take immediate action. In response to a FCW system alert, the driver must quickly decide if the alert signifies an actual rear-end crash threat or a "cry wolf" false alarm, so that they can execute any necessary crash avoidance maneuver in a timely and appropriate manner (Automotive Collision Avoidance System Field Operational Test Final Program Report, 2005).

A forward collision visual alert (FCVA) is recommended as part of a multi-modality FCW system crash alert approach also including auditory and/or haptic (e.g., seat vibration, brake pulse) alert components Kiefer et al., 1999). The FCVA is well-suited for helping to explain non-visual FCW alerts, and also provides an important redundant source of crash alert information. This redundancy has particular relevance if the driver does not perceive non-visual FCW alerts. For example, the driver (particularly an older driver) may fail to perceive an auditory FCW alert either due to hearing impairments or competing noises from either inside or outside of the vehicle.

With respect to recommending a FCVA location, Kiefer et al. (1999) argue the FCVA should be positioned in a manner such that it conveys the direction of the potential crash threat and facilitates (or attracts) the driver to visually orient toward the forward roadway (rather than toward the head-down, instrument panel (IP), dashboard area). Potential obscuration of FCVAs located in the IP area by the hands and/or steering wheel is also of potential concern (Lind, 2007). Consistent with this FCVA location recommendation, Society of Automotive Engineers (SAE) Recommended Practice J2400, entitled "Human Factors in Forward Collision Warning (FCW) Systems: Operating Characteristics and User Interface Requirements", states that a conventional dashboard location shall not be used for the visual warning since it may distract the driver from the hazard ahead (Society of Automotive Engineers, 2003). Furthermore, SAE J2400 recommends that the FCVA should be positioned to fall within a 10° cone from the driver's line-of-sight and states that this implies the FCVA should be positioned at either a Head-Up Display (HUD) or top-of-dashboard location. It should be noted that SAE J2400 does not address other important "attention-getting" characteristics of FCVAs (e.g., display size, luminance, flash rate), which should be designed in such a manner that enhances FCVA effectiveness without interfering with the driver's ability to use other safety-relevant information in the forward scene.

Empirical research supporting the SAE J2400 FCVA location recommendation is lacking, particularly in an automotive context. The Lind (2007) fixed-based driving simulator study examined drivers' ability to detect and quickly respond to candidate HUD (a string of horizontally-aligned red light-emitting diodes), top-of-dashboard/high head-down display (HHDD), and instrument panel FCVAs while detecting one of five signs. These signs were presented randomly at the left mirror, right mirror, center console, or rear inside mirror locations. Results indicated that the HUD alert elicited 140-180 ms faster alert detection times relative to the IP and HHDD alerts examined. In addition, IP alerts were less likely to be detected than HUD alerts.

Although these results generally support the SAE J2400 FCVA display location recommendation, there are important limitations to the Lind (2007) study. First, since forward crash threats were not presented, one cannot assess any potential impact that the FCVAs examined may have had on appropriate decision-making and responses to safety-relevant events in the forward scene (e.g., to a lead vehicle braking event). Second, the sign detection distraction task employed by Lind (2007) may not be representative of the types of tasks which lead to rear-end conflicts in terms of both task difficulty and pre-crash eye movement behavior (i.e., a quick series of scans at various locations around the vehicle rather than having the eyes dwell longer at a given location). The location of the drivers' eyes at FCVA onset was not reported in the Lind (2007) study.

In summary, further quantification of the effects of candidate HUD, HHDD, and IP FCVAs merit evaluation under more safety-relevant driving situations. The current study used a change detection paradigm in a novel, realistic context to test the effects of various FCVA types with younger, middle-aged, and older participants. If safety-relevant changes in the forward traffic scene are not detected (e.g., a change in lead vehicle location or brakelight status), then the ensuing appropriate response (e.g., hard braking) may not occur, which could lead to a rear-end crash.

In the current static on-road study, subjects made rapid judgments on the presence and nature of scene changes over two successive forward scene exposures controlled by a large-scale visual occlusion window (e.g., a vehicle approached with activated brakelights). Safety-relevant changes in the forward scene were created using specially-designed "pop up" full-scale vehicle and pedestrian targets. During the occluded period between scene exposures, drivers performed an "eyes-off-road" visual distraction task (located at either a center console or left side mirror location) until the window opened or they received a FCVA (which signaled them to abort the distraction task and prepare for an imminent window opening). Following a surprise trial at the end of these change detection trials (where a "new" type of change was introduced), additional "alert detection only" trials were conducted combining the visual distraction task with a FCVA detection task. The primary goal of the study was to determine the extent, if any, to which candidate HUD, HHDD, and IP FCVA types influenced change detection and alert detection performance. In addition, the results of this study were intended to be used as further input to refine FCVA-related SAE J2400 recommendations.

METHOD

PARTICIPANTS - The 24 males and 25 female study participants were distributed almost evenly across the younger (range=20-30, M=22.4 years), middle-aged (range=40-50, M=45.4 years; this group had 9 females instead of 8) and older age groups (range=60-70, M=64.5) tested. Participants were required to sign an informed consent statement before undergoing any experimental procedures. The entire experiment lasted from 2 to 3 hours, and subjects were paid \$20.00 per hour for their participation.

VEHICLE AND INSTRUMENTATION - Participants were seated in the driver seat of a 2006 Cadillac STS during all experimental trials. The car was outfitted with all of the equipment necessary to execute the experimental trials, including data acquisition, experimental control, and experimental-distraction control devices.

The data acquisition equipment consisted of face, forward, over-the-shoulder, and display-centered views collected at 30 Hz. These views were multiplexed into a single video image and stamped with a video frame number. This video was combined with audio from the vehicle cabin (recorded via a microphone) and synchronized with the subject response data (collected at 10 Hz) from the experimental trials.

The experimental trials required software control of a visual occlusion window device, experimental targets (subsequently referred to as “pop-up” targets), and a collection of FCVA displays. The experimental control system also received, recorded, and responded to activation signals from two independent (left/right) push-button wands, which were used by participants to respond to the experimental trials. Progression of the experimental trials was controlled by the in-vehicle experimenter via a lap station keyboard and display. As shown in Figure 1, the occlusion window was located outside of the car, in front of the seated participant (see Kiefer, Cassar, Flannagan, & Jerome (2005) for a more detailed description of the visual occlusion window device.)



Figure 1. The position of the visual occlusion window device in front of the test vehicle.

Three separate pop-up target types were used for this study: an adult (male) pedestrian scaled to a 95th percentile standing height (Kroemer, 1989); a 5-year old child (female) pedestrian scaled to a 5th percentile standing height (Centers for Disease Control and Prevention, 2002), and the rear-end of a 2000 Chevrolet Impala scaled to actual dimensions (Figure 2). The car pop-up target was outfitted with fully-functional red LED brakelights. The vehicle pop-up targets were positioned directly in front of the experimental vehicle in a static arrangement at either a 100, 200, or 300 foot (or 30.5, 61.0, and 91.4 m, respectively) distance. The pedestrian targets occurred at either a 100 or 300 foot distance on either the left or right edge of the imaginary lane occupied by the test vehicle and the pop-up target vehicle. Pedestrian targets were included in the study to provide some added complexity to the participant's decision making, and to explore any general impact that the FCVA type may have on forward scene change detection.

Activation of the pop-up targets was achieved via compressed air, which forced the target upright from their resting state position (i.e., flat at a small offset from the ground) within 1.5 sec of activation. Targets automatically returned to their resting state when the compressed air was removed.



Figure 2. The full-scale adult (male) pedestrian, child (female) pedestrian, and vehicle pop-up targets used to create scene changes. (For clarity, targets are not shown to scale).

The experimental control system also activated one of five possible FCVA candidates, as required by the experimental trial being conducted (see Figure 3 and Table 1). These FCVA types chosen for this study were considered to be “production representative”; given vehicle packaging considerations and current industry practice for FCVA displays (see Figure 4). Each of the FCVAs were flashed at 4 Hz with a 50% duty cycle, given evidence of benefits of dynamic aspects of warnings on detection speed (Gros, Greenhouse, & Cohn, 2005).

Table 1. Description of FCVAs used in the experiment.

Display Name	Description	Location ¹	Luminance	Size (Visual Angle, Vertical X Horizontal)
HUD-10	Reflected HUD consisting of a strip of 10 horizontally-aligned RED light-emitting diodes (LEDs) positioned at driver centerline. This display was intended to closely match the display used in the Lind (2007) study.	3° look-down angle, driver-centerline	1250 cd/m ² , measured from the display reflection	0.65° X 9.68°
HHDD-4	Four-cavity, vehicle-centerline HHDD reflected off the base of the windshield. This display consisted of two amber and one red indicators (used for Front Park Assist) and one red FCVA telltale.	21.2° offset angle, a 7.4° look-down angle, and a 20.2° look-over angle	300 cd/m ² (amber), 200 cd/m ² (red and FCVA)	0.65° X 3.20° (~33% of the area for the HUD-10 alert)
HHDD-1	Same as HHDD-4 except only the FCVA cavity was illuminated.	21.2° offset angle, a 7.4° look-down angle, and a 20.2° look-over angle	200 cd/m ²	0.65° X 0.80° (~25% of the area for the HHDD-4 alert, ~8% of the area for the HUD-10 alert)
HUD-1	Same as HUD-10 except the display was masked such that the size of the visible strip of red light was equivalent to the visual angle covered by HHDD-1.	3° look-down angle, driver-centerline	1250 cd/m ² , measured from the display reflection	0.65° X 0.80°
IP-1	An “add-on” red FCVA telltale was located within the IP.	20.6° look-down angle, driver-centerline	250 cd/m ²	0.65° X 0.80°

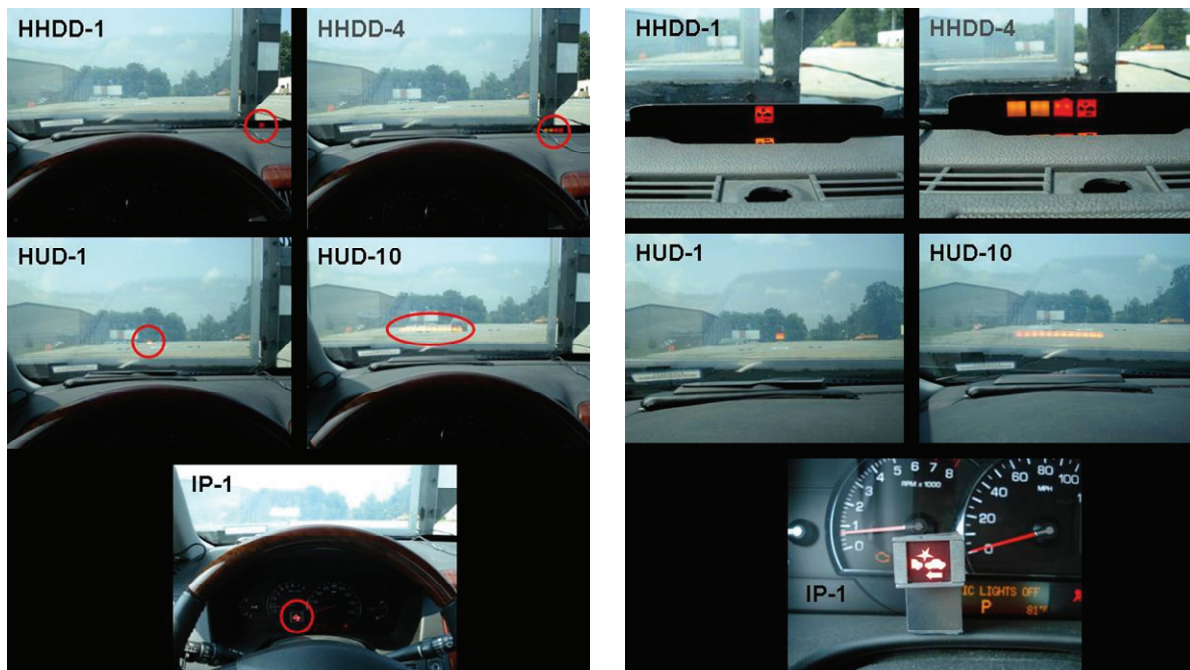


Figure 3. Driver-perspective views (shown on left) and corresponding close-up views (shown on right) for each of the forward collision visual alert (FCVA) candidates examined. These candidates are circled in the driver-perspective view.

The visual stimuli associated with the Surrogate Reference Task (SuRT) were used as the “eyes-off-road” visual distraction task (Rognin, Alidra, Val, Lescaut, & Chalandon, 2007). As shown in Figure 5, this task was presented on LCD screens positioned at either the front center console or left side mirror location. Figure 5 also provides an illustration of the difficulty of the visual distraction task. Participants were asked to quickly indicate whether the left or right of the screen contained the slightly larger circle within a field of otherwise similar circles, and express their choice via voice commands issued to a headset microphone. Participants were instructed to use the commands “one” and “two” when reporting that the slightly larger circle occurred on left and right side of the screen, respectively. One second after participants verbally responded with their choice, the laptop controlling the presentation of the visual distraction stimuli moved to a different trial screen, in which it remained until a voice command (“one” or “two”) was received. Say-Now™ voice recognition software was used to recognize the driver’s verbal responses. It should be noted that this “eyes-off-road” visual distraction task was used in the current experimental context purely for the purposes of creating a self-paced, continuous visual distraction task. Thus, performance on this task was not analyzed, and it is assumed that participants’ performance on this task remained stable across the various experimental conditions examined.

PROCEDURE - In addition to falling within the appropriate age group ranges required for the study, participants had to satisfy certain predetermined health constraints and were required to have normal (or

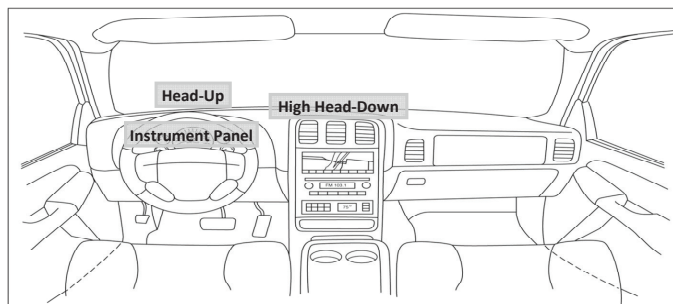


Figure 4. Current automotive industry practice for head-up display (HUD), instrument panel (IP) display, and high head-down display (HHDD) forward collision visual alert (FCVA) locations.



Figure 5. Center console (shown on left) and left side mirror (shown in the middle) visual distraction task locations. A sample visual distraction task stimulus (derived from the Surrogate Reference Task or SuRT) is shown on right. Drivers were required to verbally indicate which half of the screen contained a larger circle (indicated here with an arrow).

corrected-to-normal) vision and hearing. If participants passed the screening procedure and were still interested in the experiment, they were scheduled for an experimental session.

Upon arrival at the test facility (the Virginia Tech Transportation Institute), participants read and signed an informed consent form and completed a Snellen visual acuity test, Vistech™ visual contrast test, Ishihara test for color vision, and a Useful Field-of-View test (UFOV™, Ball & Owsley, 1992). Participants also completed a pre-experimental questionnaire requesting information on their demographics and the technology available in their personal vehicle.

Participants were then accompanied to the experimental test vehicle, where they were seated and instructed to adjust the seat, mirrors, and steering wheel as desired. If the participant reported that the IP-1 alert was obscured by their preferred hand/steering wheel position (which was estimated after the study by experimenters to have occurred for roughly seven participants), drivers were instructed to change the positioning of their hands and/or steering wheel to enable viewing of the IP-1 alert.

Each experimental trial was structured such that, at the start of the trial, the participant looked toward the forward scene. Next, the occlusion window was opened to reveal to the participant the first forward scene exposure (or look), which lasted for one second. The occlusion window then closed for either 2.5, 3.0, 3.5, or 5.0 seconds, with this closing duration varying on a trial-by-trial basis.

During this occlusion period, the participant was instructed to perform the visual distraction task, where the location of this task (either at the center console or left side mirror) was held constant for a block of trials. The participant was asked to continue performing the visual distraction task until either the FCVA was activated (which occurred on 30.3% of the trials) or the occlusion window opened (which occurred on the