Using the Lane Change Test to Investigate In-Vehicle Display Placements

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Abstract. Driving performance was measured using the lane change test (LCT). Participants followed lane change instructions presented in three locations: road signs, a head-up display (HUD), and a head-down display (HDD). To measure the participants' ability to detect ecologically-valid stimuli while viewing the displays, a peripheral detection task (PDT) with inward-moving stimuli from either side of the road was applied on half of tracks. Interacting with the HDD resulted in the poorest driving performance, and similar driving performance was found with the road signs and the HUD. Further analyses revealed that the participants' age had an effect on their performance with the display locations. The younger age group (20–24 years) drove the best with the HUD; while the older age group (26–31 years) drove the best with the road signs. PDT performance differences were not significant. Results indicate that HUDs may be a good option for displaying navigational information to drivers.

Keywords: Human factors · In-vehicle displays · Driver distraction · Navigational displays

1 Introduction

Technology has been advancing rapidly throughout our lifespans, and technologies once seen as novel are now commonplace. Since 2011, the percentage of Americans owning a smartphone has increased from 35% to 77% [1]. As smartphone capabilities and popularity have increased, so have the technologies available in modern vehicles. Unfortunately, along with these capabilities come more opportunities for distraction while driving. In 2015 alone, 3,477 people were killed in distracted driving accidents, and 391,000 people were injured [2]. While many of the capabilities available to drivers are not essential (e.g., music playlists), navigational systems are critically relied on by some drivers. It is essential that a method is found for displaying navigational information to drivers that allows them to keep their attention on the road as much as possible.

Human Capabilities. Attentional resources are limited [3], yet a portion of attention is required to safely drive a vehicle. Detriments to driving can result if a driver is interacting with a display that consumes an abundance of their attention. With reference to the limited

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resource theory of attention, attention can be distributed between tasks, and specific amounts of attention are required to complete various tasks successfully [4]. The quality of which a task can be completed may be influenced by the amount of attention devoted to it. If a task (e.g., referencing a navigation system), interferes with a concurrent task (e.g., driving), it can be presumed that both tasks are drawing from a common pool of resources. Humans can complete several tasks simultaneously if the attentional demands of the tasks are within the available resources [3]. In-vehicle interfaces, especially those that must be referenced throughout a commute, should be designed to ensure adequate resources are available for all components of the driving task.

In-Vehicle Displays. In the United States, automobile manufacturers often place displays in the center of the dashboard, down/right of the driver's line of sight. This location for a head-down display (HDD), is likely popular because it is one of the few available areas within the driver's sight, but the user must reorient their line of sight away from the road (i.e., down/right) to view the display (see Fig. 1). Furthermore, a smartphone often qualifies as a HDD when it is mounted in a vehicle, and although many users are familiar with this display placement, they must significantly shift their gaze from the road to view the display.

Fig. 1. Examples of navigational displays in modern vehicles (left: head-down display; right: head-up display) [5, 6].

A head-up display (HUD) projects content to the driver or pilot on their windshield. This placement allows the user to reference the display with only a slight shift of their gaze (see Fig. 1). Usually, a HUD is in front of the user, slightly below their line of sight, allowing the content to be visible without blocking any important out-the-window information. Additionally, content displayed on a HUD can be perceived and comprehended faster, which reduces the amount of visual attention required by the display [7, 8]. However, some notable limitations of HUDs have been reported. Some spatial disorientation has been reported by pilots when interacting with a HUD, although the pilots did not deem it to be a severe problem [9]. Additionally, HUDs can produce positive misaccommodation, in which objects in the environment appear smaller and more distant than they actually are.

Present Study. The present study compared the attentional demands when accessing navigational information from external signs, a HUD, and a HDD. Horberry and colleagues [10] found that interacting with an infotainment system on a HDD is more harmful to driving performance than having a cellphone conversation. Due to the importance of in-vehicle navigational systems, research must be completed to investigate the best options for displaying information to drivers. The effect of the placement of an in-vehicle display on a driver's ability to reference it while maneuvering the vehicle safely is an essential finding that could inform future automobile designs.

This paper is based on a Master's thesis project at California State University, Long Beach [17]. As such, the methods and results in the present report are similar to those submitted as part of the thesis to the university.

2 Methods

Participants. Twelve participants (five males, seven females) volunteered for this study. All participants were between 20 and 31 years of age (*M* = 25.25 years (yrs), *SD* = 3.31 yrs) and reported 2–15 years of driving experience (*M* = 8.17 yrs; *SD* = 4.11 yrs) [17]. Participants were divided into two groups of six for analysis purposes: Younger (20–24 yrs), and Older (26–31 yrs).

Table 1. Demographic data collected through a pre-test questionnaire [17].

Measure	Age group	Data
Age	Younger	*M* = 22.50 yrs, *SD* = 1.65 yrs
	Older	*M* = 28 yrs, *SD* = 1.79 yrs
Driving experience	Younger	*M* = 5 yrs, *SD* = 2.69 yrs
	Older	*M* = 11.33 yrs, *SD* = 2.42 yrs
Preferred GPS platform	Younger	6/6 (100.0%) Smartphone
	Older	6/6 (100.0%) Smartphone
Preferred mount location	Younger	4/6 (66.7%) Down/Right 2/6 (33.3%) Right
	Older	3/6 (50.0%) Left 2/6 (33.3%) Right 1/6 (16.7%) Other
Frequency of GPS use	Younger	2/6 (33.3%) Extremely Often 2/6 (33.3%) Often 2/6 (33.3%) Somewhat Often
	Older	2/6 (33.3%) Extremely Often 3/6 (50.0%) Often 1/6 (16.7%) Somewhat Often

Participants reported no experience interacting with a HUD for navigational information. All participants had normal or corrected-to-normal vision and had valid drivers' licenses. Participants were compensated $20–$30 for participating.

Lane Change Test (LCT). The lane change test (LCT) is a simple driving simulation that provides an empty, three-lane highway. Participants are instructed to drive down this highway at a constant speed (60 km) and change lanes when prompted by road sign cues (see Fig. 3). There are approximately 18 lane changes per track, with lane change cues appearing roughly every 150 m [11]. A dual-task paradigm was created with the LCT to measure driving performance and estimate the attentional demands of interacting with different navigation display placements.

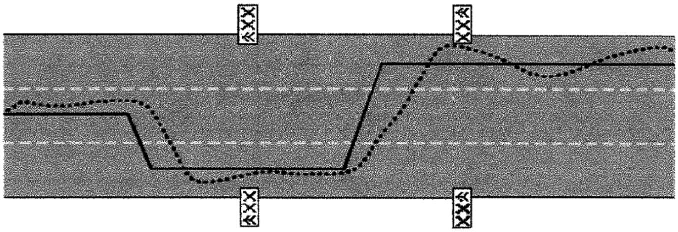

Fig. 2. Visual representation of a normative path (solid line) and a participant's path (dotted line). These paths are compared to calculate the MDev and quantify driving performance [11].

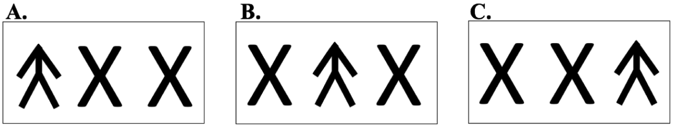

Fig. 3. Lane change cues used to instruct the participant on which lane to change to (A. left, B. middle, C. right) [11].

Driving performance was measured by the participants' mean deviations (MDev) from a normative path model throughout the track. This metric calculates the difference between the participants' path throughout the lane change and the normative path model (see Fig. 2) [11]. The difference between the paths is the area of the maneuver. Larger areas indicate poorer driving performance. The MDev measures the driver's ability to detect and respond to the lane change commands and maintain lateral control of the vehicle [12].

In the standard LCT, the lane change cues are displayed as road signs on either side of the simulated road. The present study manipulated the placement of the lane change cues between the following conditions: Road-Signs (standard LCT procedure; See Fig. 4), a simulated HUD (see Fig. 4), and a HDD on an external monitor (see Fig. 5). All three of the display locations presented identical lane change cues (see Fig. 3) [11]. In the Road-Sign condition, the cue was presented on road signs located on both sides of the road. For the HUD condition, the lane change cue was presented in the center of the projected screen approximately 5° below the participant's line of sight, the preferred location found in past studies [7, 13, 14]. For the HDD condition, the cue was displayed on a small monitor down/right of the participant, approximating the location of a vehicle's center console. The angle between the center of the steering wheel and the center of the monitor was 40.2°, slightly less than the that same angle in a 2013 Toyota Corolla (~53°; see Fig. 5).

Throughout track completion, the road sign cues were initially presented to the participant at a size of 1.6° visual angle, and as the participant approached the road signs, the size of the cues increased to 4.2°. In the HUD and HDD conditions, cues were presented at a constant size of 4.2° throughout the track. This was done to account for the differences in the display types. Between lane change cue presentations, the HUD and HDD remained visible and blank [17].

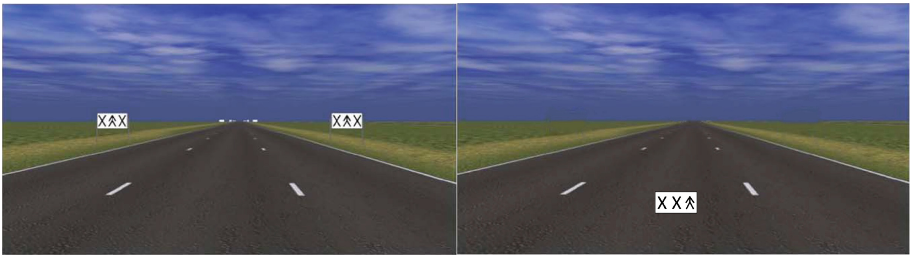

Fig. 4. Visual depictions of the LCT simulation with Road-Signs (left) and HUD (right) lane change cues [17].

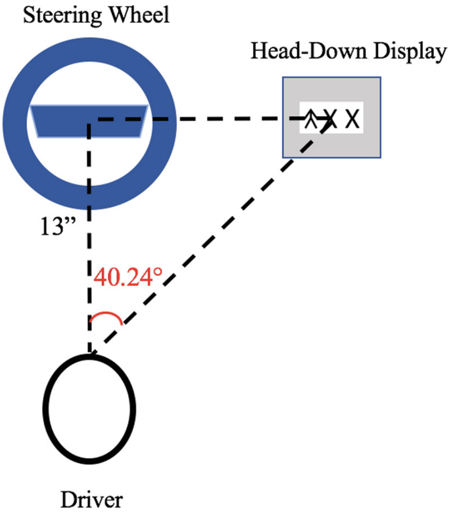

Fig. 5. Diagram of the angle of the HDD in comparison to the simulation steering wheel [17].

Peripheral Detection Task (PDT). The peripheral detection task (PDT) was employed to measure the drivers' ability to detect ecologically-valid stimuli while navigating with each display. The PDT is a validated measure of visual distraction and workload, and it is a common secondary task in driving simulation studies [15]. Participants were instructed to report when they detected a stimulus (small white circle) moving inwards from the side of the simulated road (see Fig. 6). This stimulus behavior was chosen due to its similarity to hazardous obstacles that can be encountered in normal driving, such as pedestrians or crossing vehicles [17].

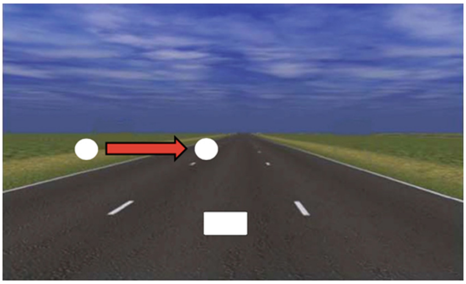

Fig. 6. Approximation of the location of the left PDT stimulus in HUD condition (Not drawn to scale; Note: Stimulus moves inward for 200 ms) [17].

Stimuli were presented on either side of the simulated road and moved inward. The stimulus was presented for 200 ms. Buttons were mounted on either side of the steering wheel (upper right and upper left), and the participants were instructed to respond to the presence/location of the stimulus with a congruent button press. Participants were able to respond without moving their hands from the wheel or compromising control of the vehicle [17].

Tracks that included the PDT had a total of 36 stimuli presented throughout the 18 lane changes. Two stimuli were presented at random between each of the lane change cues. PDT performance was calculated based on response times (RT), rate of correct responses (Hit rate), rate of missed responses (Miss rate), and rate of incorrect-locational detections (Incorrect-response rate) [17].

Experimental Procedure. This study employed a 3 (Cue Location: Road-Signs, HUD, HDD) X 2 (PDT: Absent, Present) within-subject design completed over a 2-h period, split into two 1-h sessions. The Cue location (Road-Signs, HUD, HDD) was manipulated between experimental blocks, and the presence of the PDT was counterbalanced within the experimental blocks. The participant completed 10 tracks (4 practice, 6 test) for each of the three experimental blocks (Road-Signs, HUD, HDD). The order of the experimental blocks and their conditions were counterbalanced [17].

3 Results

Driving Performance. A 3 (Cue Location: Road-Signs, HUD, HDD) X 2 (PDT: Present, Absent) X 2 (Age group: Younger [20–24 years], Older [26-31 years]) mixed design ANOVA was conducted to determine the effect of Cue location on driving performance with and without concurrent PDT. Age group (Younger, Older) was included as a between-subjects factor. A main effect of the Cue location was found, $F(2, 20) = 7.55$, $p = .004$, $\eta^2 = .43$ (see Fig. 7) [17]. A pairwise comparison was then completed to further explore this main effect. The HUD ($M = 1.19$, $SD = 0.08$) resulted in significantly better driving performance than the HDD ($M = 1.39$, $SD = 0.09$), $p = .006$. Road-Signs ($M = 1.26$, $SD = 0.07$) also resulted in significantly better driving performance than the HDD, $p = .02$. No significant difference in driving performance was found between the HUD and Road-Signs. Additionally, there was not a main effect of the presence of the PDT on MDev, $F(1, 10) = 0.49$, $p = .50$, $\eta^2 = .047$. The interaction between the Cue location and the presence of the PDT was non-significant, $F(2, 20) = 0.24$, $p = .789$, $\eta^2 = .023$.

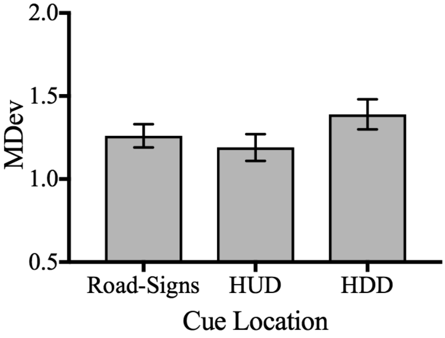

Fig. 7. Driving performance (MDev) by the placement of the lane change cue. Lower MDev scores indicate better driving performance. Errors bars represent the standard deviation [17].

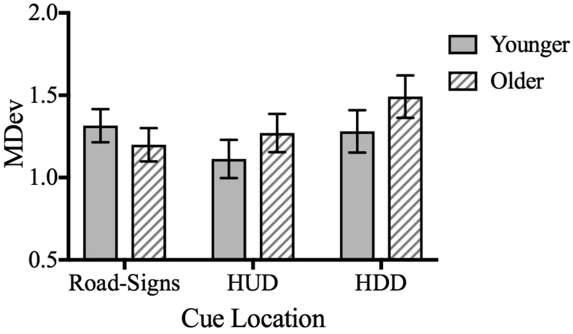

Fig. 8. Driving performance (MDev) by the placement of the lane change cue and the participants' age group (Younger: 20–24 yrs; Older: 26–31 yrs). Lower MDev scores indicate better driving performance. Errors bars represent the standard deviation [17].

A significant interaction was found between the display locations (Road-Signs, HUD, HDD) and the age group (Younger, Older), *F*(2, 20) = 5.92, $p = .01$, $\eta^2 = .372$ (see Fig. 8) [17]. The interaction found between the age group and the display location used for the lane change cue prompted further analyses. Simple effects tests were conducted for each age group to investigate the differences in driving performance with each display location. In the Younger group, a significant difference in driving performance was found between the display locations, *F*(2, 10) = 6.74, $p = .014$, $\eta^2 = .574$. Post-hoc pairwise comparisons revealed that the Younger group had significantly better driving performance with the HUD ($M = 1.11$, $SD = 0.12$) than with the HDD ($M = 1.32$, $SD = 0.12$), $p = .011$, or the Road-Signs ($M = 1.32$, $SD = 0.10$), $p = .021$. No significant difference in driving performance was found between the HDD and the Road-Signs.

For Older participants, a significant difference in driving performance between the display types was also found, *F*(2, 10) = 6.70, $p = .014$, $\eta^2 = .573$ [17]. A post-hoc pairwise comparison revealed that the Older participants performed significantly better with the Road-Signs ($M = 1.20$, $SD = 0.10$) than with the HDD ($M = 1.49$, $SD = 0.13$), $p = .005$. No significant differences were found for Older participants' driving performance between the HUD and the HDD or Road-Signs. All other interactions were non-significant.

Peripheral Detection Task. PDT performance was measured by RT, Hit rate, Miss rate, and Incorrect-response rate. The RT was averaged for all correct responses in any given condition. The Miss rate is the proportion of peripheral stimuli that the participant did not respond to. Hit rate is the proportion of correct responses to peripheral stimuli, and incorrect-response rate is based on the proportion of incorrect responses made by the participant (i.e., incongruent button-press response) [17].

Results revealed an extreme range of performance. Some participants did extremely poorly on all conditions and some did extremely well on all conditions. A two-way mixed ANOVA was completed to investigate the effect of the Cue location (Road-Signs, HUD, HDD) on PDT performance during dual-task conditions, with the inclusion of age group (Younger, Older) as a between-subject variable. Four measures of PDT performance (RT, Miss Rate, Hit Rate, Incorrect-Response Rate) were evaluated within the three display levels (Road- Signs, HUD, HDD) of the lane change cue factor and the two age groups (Younger, Older). There was no main effect of the Cue location on the participants' average RT, Miss Rate, Hit Rate, or Incorrect-Response Rate (*p*'s > .15). All interactions were also insignificant [17].

Observations and Participant Insight. At the completion of the study, a post-test questionnaire was administered. Participants were asked to report the cue display location that they felt was the easiest to interact with. The age groups reported identical display location preferences with 4/6 (66.7%) in each group reporting a preference for the HUD [17]. One of the participants reported that they "barely had to adjust [their] attention" with the HUD, and they felt that the "HDD was very annoying." Many participants stated that they felt the HUD was "easier to see" than the HDD and allowed them to keep their "focus on the road."

The remaining 33.3% of participants preferred the Road-Signs. One participant wrote that he/she felt that they "could better anticipate when to change lanes" with the

Road-Signs [17]. Another participant reported that the Road-Signs were "less distracting" and allowed them to keep their eyes on the road better than the other displays. One participant reported that the presence of the "PDT made the HDD a lot easier, because there was a rhythm." He/She stated that without the presence of the PDT, the HDD was very difficult to interact with. This final comment reveals a potential limitation of the study - the potential predictability of the PDT and lane change cue presentations.

4 Discussion

The goal of this study was to investigate the visual distraction that resulted from accessing navigational information at different display locations (Road-Signs, HUD, HDD). This study also examined the extent to which participants were able to detect peripheral stimuli while interacting with the displays. This was done to further assess the practical use of the displays in driving situations. All participants were experienced drivers and reported being practiced in following navigational system instructions while driving.

Display Location. Findings aligned with those of Burnett [16], with better driving performance when interacting with a HUD, compared to a HDD. This finding also supports the past finding that content on a HUD may be recognized faster than a HDD, as faster recognition allows for reduced visual attention taken from the road [7, 8]. All participants reported that they prefer to use their smartphone for navigation while driving, and a majority of participants reported that they prefer their smartphone mounted down/right in their vehicle (see Table 1). This mounting location is comparable to a HDD, yet none of the participants reported a preference for the HDD over the road signs and/or HUD in the present study. This finding supports the idea that driver satisfaction with a display does not mean that it is the optimum display for the purpose. Drivers may be unaware that there are superior display options.

Age and Display Location. The participants were divided into two age groups for analysis purposes: Younger (20–24 yrs) and Older (26–31 yrs). Both groups reported extremely similar frequencies of GPS use and preferred GPS platforms (see Table 1). At the completion of the study, 66.7% of participants in each age group reported a preference for the HUD over the Road-Signs and HDD. A slight difference can be found between the age groups in the preferred location of their in-vehicle GPS. All participants in the Younger group reported a preference for their smartphone mounted to the right or down/right, and only a third of the Older participants preferred these locations. It is possible that the Older group is less familiar with the HDD location, and that could have contributed to their poorer performance with that display.

The Younger group had the best driving performance with the HUD, and there was no difference in driving performance between the Road-Signs and the HDD. The Older group had the best driving performance with the Road-Signs compared with the HDD, and performance was not significantly different between the HUD and the Road-Signs. All twelve participants reported using their smartphones frequently for GPS navigation while driving. While this may be common today, in the recent past, this technology was not available, and drivers were forced to rely on less technical sources for navigational information (e.g., road signs, paper maps).

The Older group had an average of 11.3 years of driving experience while the Younger group had only an average of 5 years of driving experience (see Table 1). Although the age difference between the age groups may not seem large, 5/6 (83.3%) of the participants in the Older group have been driving for more than 10 years. Within the last decade, smartphone capabilities have increased remarkably. It is possible that many of the participants in the Older group relied on road signs for navigational information when they first began driving. Increased familiarity with road signs from early interactions while driving could be the reason for the improved driving performance from the Older participants with these cues. It is possible that the Younger group has less experience then the Older group relying on road signs for navigational information, as they have potentially been able to rely on HDDs for navigation throughout their entire driving career.

Furthermore, the Younger group's improved driving performance with the HUD could be attributed to younger individuals being more open to new, novel technologies. The participants in the Younger group have likely been exposed to evolving technology for their entire lives, increasing their acceptance technology embedded in novel locations. Increased novel interface acceptance could lead to a lack of inhibition when interacting with an innovative display location, resulting in the younger participants' improved driving performance with the HUD.

Limitations. The predictability of the PDT could be a potential limitation of this study. There were two peripheral stimuli presented between each lane change cue. This was done to prevent the PDT stimulus from overlapping with the lane change itself. It is possible that the participants were able to recognize this pattern and anticipate the cues/stimuli (i.e., lane change cue, peripheral detection, peripheral detection, lane change cue…). One participant reported that he/she felt that the predictable nature of the PDT made it easier to interact with the HDD, because he/she was able to adjust his/her attention accordingly.

A potential limitation of the methods used to create the display locations is that the Road-Signs and the HUD were presented on the same projection screen. Although the location of the HUD within the participants' visual field was valid, a HUD in real-life would be much closer to the participant than road signs in the environment. Another potential limitation lies in the fixed position of the HDD. The HDD was a small LCD screen mounted to the right of the participant on a stand. The participant was not able to adjust the HDD during the study, but the visual angle between the center of the steering wheel and the center of the display was comparable to the adjacent visual angle in a modern vehicle.

Steps were taken to ensure that unwanted variables would not impact the effect of the display location on driving performance; however, a few potential advantages of the Road-Sign over the HUD and HDD are remaining. First, the road signs were visibly approaching in the environment, giving the participant an indication of their approach. Second, the Road-Sign condition had two lane change cues, one on the right and one of the left side of the road, while the HUD and HDD conditions included only one lane change cue.

Conclusion. HUDs have been implemented in some vehicles in the past, yet research has seldom investigated their use for the presentation of navigational information to drivers. Navigational instructions can be extremely crucial in certain driving situations; therefore, a need was seen for a less distracting method for displaying this information. Most modern vehicles have a centrally-located HDD that offers navigational capabilities. The HDD used in the present study was designed to be comparable to a HDD in a modern vehicle, yet in this study, interacting with the HDD while driving resulted in the worst driving performance compared to the HUD and the road signs. The deprecated driving performance with the HDD is particularly concerning, since all participants reported that they use their smartphone (comparable to HDD) often for navigation while driving.

HUDs may be an advantageous method for displaying navigational information to drivers, especially since a majority of the participants (66.7%) preferred the HUD to the Road-Signs or the HDD. These findings indicate that HDDs are detrimental to driving performance and should not be as commonplace as they currently are. A better method is essential for displaying navigational information to drivers.

Future Research. Future studies should investigate the method for displaying content on a HUD, such as the content size and illumination. HUD use should be thoroughly evaluated prior to implementation in vehicles to ensure that the HUD does not introduce new distraction. Additionally, research should further investigate the impact of age on interactions with common and novel display placements. Furthermore, HUDs should be investigated in a more complex driving simulation. Studies should also be done to evaluate drivers' abilities to detect and react to ecologically-valid events (e.g., breaking vehicle ahead, hazard on road) while interacting with different display locations.

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