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Head-Up Displays and Distraction Potential

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16. Abstract

Head-up displays (HUDs) present opportunities and challenges for mitigating driver distraction. HUDs may improve safety by reducing the time required to view driving-related information relative to a traditional head-down display (HDD). However, because the HUD is in the driver's field of view, drivers may fixate on it and fail to perceive events in the environment. This study used 48 participants in the dataset and investigated driver use of a HUD, an HDD, and an aftermarket, phone-based display by measuring visual behavior during public road driving. Additionally, participants completed a task that used the displays to assess reactions to a surprise event on the Virginia Smart Road. Results showed participants had faster glances to a HUD when drivers were asked to read driving information; however, drivers were more likely to glance at the HUD than other displays while driving. While driving on a closed test track, drivers were asked to fixate on their assigned display (HDD, HUD, or aftermarket display) during a surprise event (an object dropped in the road). Reactions with the HUD were no faster than the HDD or aftermarket display while fixating on displays.

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Glossary of Terms

ANOVA – analysis of variance

ARHUD – augmented reality head-up display

Cognitive capture – A situation when attention is drawn to one task at the expense of another.

CI – confidence interval

CL – confidence limit

DAS – data acquisition system

EOD – eyes-on-display

EOR – eyes-off-road

HDD – head-down display

HMI – human-machine interface

HUD – head-up display

HUD benefit time – A time period during which the HUD improves the driver’s ability to see events in the forward scene and avoid consequences that compromise traffic safety.

IRB – institutional review board

OBD-II – On-Board Diagnostics port

RQ – research question

SD – standard deviation

VTTI – Virginia Tech Transportation Institute

Executive Summary

This report for the Head-Up Displays (HUDs) and Distraction Potential Study, National Highway Traffic Safety Administration comes under contract DTNH22-11-D-00236, Task Order 0019.

Background

An automotive head-up display (HUD) is a device that projects driving-related information — speed, rpm, navigation information — in a driver's field of view so the driver does not have to look down at the dashboard and away from the road. Typically, the HUD projects the information onto the windshield (in some cases via a combiner lens on the dashboard), with a focus depth from 2.5 to 4 meters. HUD technology presents both opportunities and challenges for mitigating driver distraction. On one hand, reduction of the distance the eyes need to travel between the road and a display (as well as the necessary focal depth adjustment) can reduce the time required to view a display relative to a traditional head-down display (HDD) in the instrument cluster. This benefit has been termed the "HUD benefit time window" (Kiefer, 1998a). However, HUD technology also has some drawbacks that may lead to visual and cognitive distraction.

The main objective of this project was to determine whether HUD technology changes the driver's ability to process information about the forward road scene and respond to crash-imminent situations. A supporting objective was to identify surrogate measures of distraction similar to eyes-off-road (EOR) time appropriate for drivers using a HUD or an HDD in different driving situations (i.e., on public roads or on a test track). Five primary research questions (RQs) defined the scope of the project.

> RQ1: Identify the main visual distraction issues involved with using HUD versus HDD human-machine interfaces.
>
> RQ2: Identify metrics that are sensitive to potential distractions resulting from using a HUD versus an HDD.
>
> RQ3: Determine whether a surrogate measure of distraction increases when drivers use candidate HUD systems.
>
> RQ4: Identify any unintended consequences associated with HUD systems.
>
> RQ5: Describe potential minimum performance specifications for HUD systems and their advantages and disadvantages.

The present work was not intended to determine the causes of cognitive capture with HUDs, but rather to determine how cognitive capture changes driver response to a traffic scenario requiring immediate driver response.

Methods

Participants

Forty-eight drivers 20 to 35 years old or 50 to 65 years old, participated in the study. Each age group consisted of 13 males and 11 females. All participants had normal or corrected-to-normal vision to the legal minimum of 20/40, normal color vision, and passed a basic hearing test.

Vehicles

The vehicle used for this project was a 2010 Buick LaCrosse equipped with a HUD installed by the original equipment manufacturer (OEM), an OEM-installed HDD in the instrument cluster, and an aftermarket smartphone display in a holder attached to the windshield. It was instrumented with a data acquisition system to record several camera views (forward roadway, close-up of the driver's face, foot-well, and wide angle of the driver's face). A camera mounted on safety glasses recorded the driver's perspective.

A vehicle designed to look like a Virginia Department of Transportation work truck was the lead vehicle used in the study. It was equipped to drop a box onto the roadway from a mechanical apparatus installed underneath the vehicle (see Procedures).

Displays

The figure below shows the three displays used in the study: the OEM HUD, the OEM HDD, and an aftermarket smartphone app display.

OEM HUD (Left), OEM HDD (Center), and Aftermarket Display (Right)

The HUD was the 2010 Buick LaCrosse OEM HUD. The two-dimensional image was optically focused at 2.5 meters, just beyond the vehicle's hood. The mean look-down angle for the OEM HUD was approximately 4 degrees with a standard deviation of 1.42 degrees. The display presented vehicle speed in mph, cardinal direction of travel, current gear selection, and external temperature.

The HDD was the OEM HDD. The two-dimensional image was presented in the instrument cluster behind the steering wheel. The mean look-down angle for the OEM HDD was approximately 29 degrees with a standard deviation of 1.69 degrees. The displayed content included vehicle speed, cardinal direction, and ambient temperature.

The aftermarket display was a vehicle information application displayed on a smartphone mounted in a cradle attached to the vehicle windshield. Although a smartphone presented the content, the participant was not asked to interact with the smartphone in any way. This display was intended to replicate the display conditions of a variety of aftermarket devices and applications (e.g., navigation systems or other vehicle information displays), and not smartphone use per se. The aftermarket display had a mean look-down angle of approximately 14 degrees, with a standard deviation of 1.40 degrees. The application displayed vehicle and general information including vehicle speed (calculated from GPS), trip distance in miles, cardinal direction of travel, altitude, average speed, current time, and temperature.

Procedures

Each participant test session took place on public roads and the highway section of the Virginia Smart Road, a 2.2-mile controlled test track.

The public road component consisted of drivers following the lead vehicle along the route shown on the map below. Each participant completed the route three times. Participants were assigned a different display condition during each lap. When not assigned, the HUD and aftermarket displays were removed/disabled; however, the HDD was always visible. Each lap was approximately 20 miles and took approximately 30 minutes. Participants were asked about the cardinal direction of travel and their current speed (each question was treated as a task) six times (three speed and three direction questions) during each lap. Lap 1 and Lap 2 both started and ended in the parking area at the Virginia Tech Transportation Institute. After completing the third lap, participants proceeded directly onto the highway section of the Smart Road. In addition to the tasks, periods of "just driving" were also sampled during each loop in order to have a baseline measure of eye glance behavior with each display. Video-based classification of eye-glance behavior was performed for sampled periods of just driving and for each task conducted on public roads.

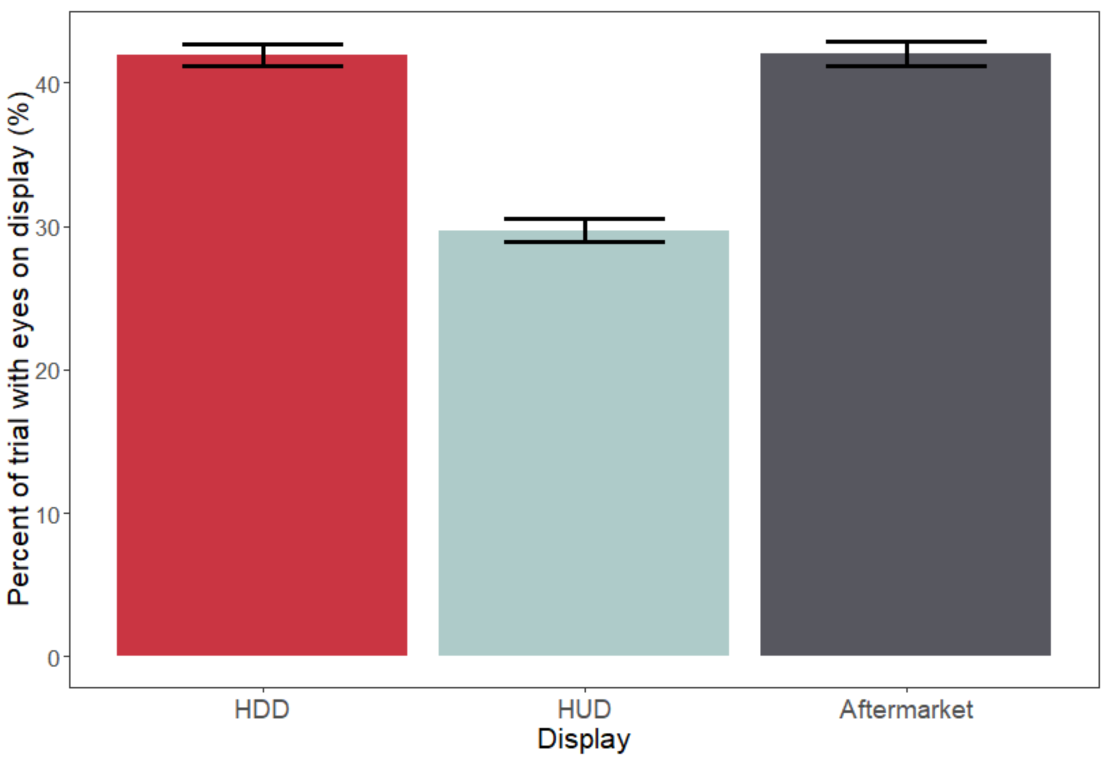
Twenty-Mile Divided Highway Course in Blacksburg and Christiansburg, Virginia

Participants followed the lead pickup truck onto the highway section of the Smart Road using the live connector ramp. The Smart Road live connector offers gated access from US-460 Business to the test track, allowing for a seamless transition from public roads.

While on the Smart Road, the experimenter asked drivers to perform a task with the assigned display that was "too hard to be performed on public roads," read the display silently, and then report the eighth character in the display. Note that the accuracy and duration of this task was not recorded; rather, the task was implemented to draw visual and cognitive attention to the display. The attention required to complete the task created cognitive capture with the display that would likely not be present without the task (i.e., increased attention to the display that reduced attention to the forward roadway). This task was intended to approximate a "worst-case scenario" that could be generalized across display types. Unknown to the driver, the lead vehicle then dropped a cardboard box at the command of the in-vehicle experimenter while the participant was performing the task (or just driving if assigned to the non-task condition). The event type was also a "worst-case" approximation, as it was relatively low contrast and difficult to see with peripheral vision alone. Drivers' responses to the surprise event were measured as time to look forward from the task display (gaze response time) and reaction time (brake response time or swerve response time). After completion of the surprise event, drivers were debriefed about the study, and the experiment session ended.

Results and Discussion

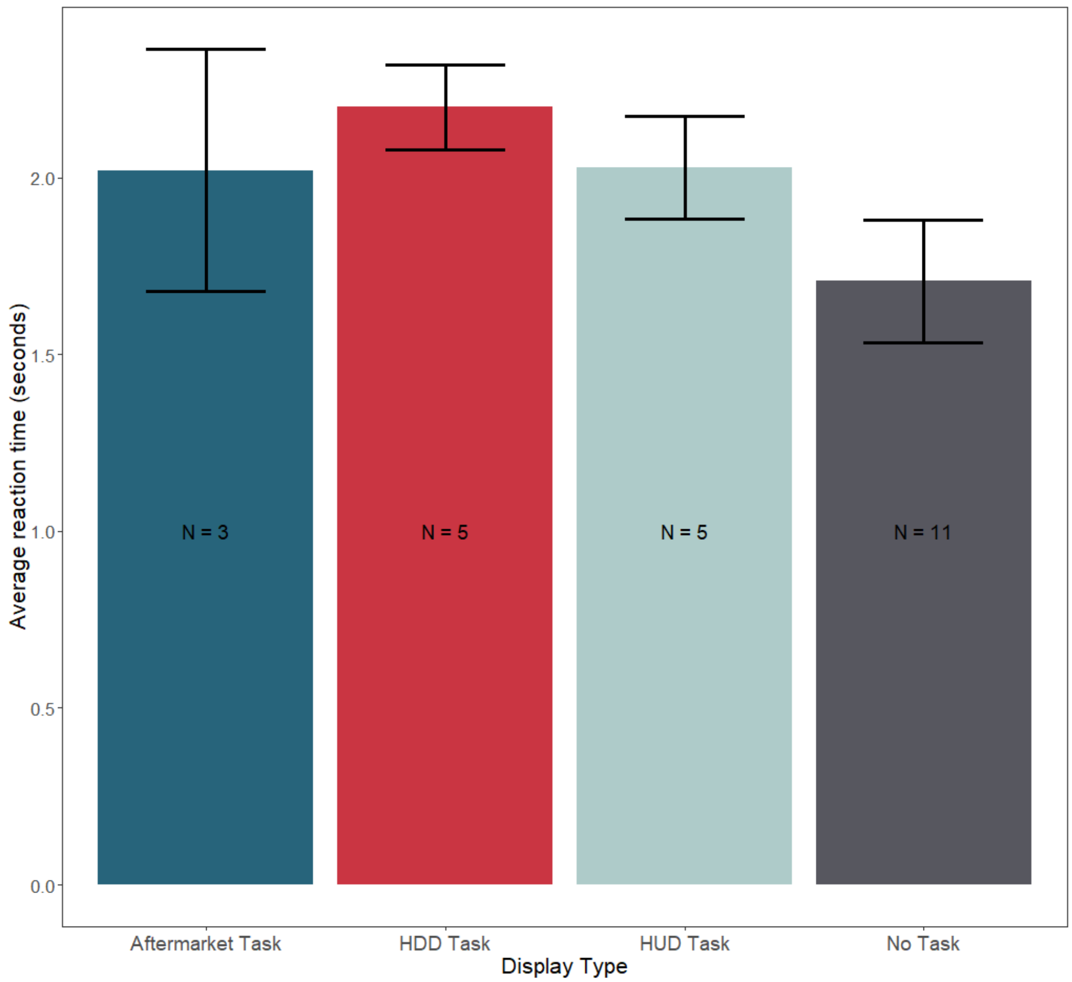
When asked to read driving information (vehicle speed or cardinal direction of travel), drivers on public roads had less eyes-on-display (EOD) time during tasks conducted with the HUD compared to other displays. The chart below shows this relationship. This result supports the concept of the HUD benefit time window (i.e., glances to the HUD are faster than to the HDD or other displays; Kiefer, 1998b).



Percentage of EOD Time in Tasks Performed With Each Display Type

Although there was less EOD time with a HUD, during sampled instances of “just driving” on public roads, the HUD showed a significantly higher percentage of EOD time (11% EOD) as opposed to the other displays (EOD of 5.8% for HDD and 7.8% for aftermarket), suggesting that drivers were more likely to glance or dwell on the HUD during normal driving compared to other displays. However, the total dwell time was less than 2 seconds overall, indicating that even though drivers were more likely to glance at the HUD while driving, the HUD used in the study was not a distraction in and of itself.

Regarding reaction times, the figure below shows the average reaction time in seconds to the surprise event for each display and for the no-task condition. Reaction time was significantly faster when drivers were not asked to read the display (i.e., just driving) compared to when they were asked to perform the fixation task. There were no differences in surprise event reaction times among the display tasks; focusing on the HUD was just as distracting as the other displays.



Mean Reaction Time to the Surprise Event for Each Display Task and No-Task Conditions. N Indicates the Number of Participants (Out of 12) Who Reacted to the Event

The HUD design tested in the present study did not appear to distract drivers unless they were specifically asked to perform a task that required them to focus on the display (i.e., read the display in order to report the eighth character). During public road tasks, all EOD times were less than the 2-second threshold included in the NHTSA distraction guidelines (81 FR 87656, 2016). However, when participants were asked to read a specific character, it made no difference that the HUD was positioned higher in the driver's field of view in terms of driver responses. Many participants in the HUD condition (as with the HDD and aftermarket condition) failed to notice that the box had been dropped in the roadway, let alone respond appropriately. This, along with the finding that the HUD drew the participants' gaze, suggests that future HUD systems should be carefully designed to avoid the driver's cognitive capture. HUD designers should use caution when designing HUDs to display on a larger field of view or in a higher field of view, such as an augmented reality HUD system that is projected onto the forward roadway. As the results of this study show, distraction from a task performed with a HUD system that creates cognitive capture may have negative consequences similar to distraction from an HDD or aftermarket display.

Limitations

One potential limitation of the results is the possible novelty of a HUD to the participants. It is certainly possible that this study was a participant's first exposure to a HUD. In this case, "novelty" could account for higher EOD during periods of just driving (e.g., Kiefer, 1991; Ward & Parkes, 1994). Given that novelty was not the focus of the study, visual behavior observed during "just driving" circumstances could be different if drivers were more familiar with the HUD. However, it is unlikely that novelty would account for participant responses to the surprise event, and as such, the conclusions regarding cognitive capture are still valid.

The displays used in the study could be considered another limitation. Although efforts were made to structure tasks to ask about information that was available on all display types, each display did present different information types. Furthermore, the complexity of information in all the displays was relatively low; other than the cognitive capture created by asking participants to count the characters in the displays, it is difficult to generalize the overall level of distraction caused by the displays used in the study. Finally, this limitation in display types extends to the study of focal depth. It is noted that the experimental approach did not explicitly address the question of focal depth specifically with HUDs of different focal depths. Technological limitations, including the lack of availability of aftermarket HUDs at the time of the study, did not allow this condition to be tested. Again, it is unlikely that focal depth would change participant responses to the surprise event when distracted.

1. Introduction

Background

An automotive HUD is a device that projects information — temperature, speed, rpm, navigation information — so that the driver does not have to look down at the instrument panel and away from the road. Typically, the HUD projects the information at a focus depth between 2.5 and 4 meters using a reflective surface (typically the windshield or a secondary lens mounted on the dashboard, i.e., a combiner lens). HUD technology presents both opportunities and challenges for mitigating driver distraction. On one hand, the reduction of the distance that the eyes need to travel between the road and a display can minimize the amount of time required to view a display relative to a traditional head-down display (HDD) in the instrument cluster. This benefit has been termed the "HUD benefit time window" (Kiefer, 1998b).

Originally developed for aviation, HUDs have been used in automotive applications for several decades. The first commercial automotive HUD became available on the Oldsmobile Cutlass Supreme in 1988. Human factors issues associated with HUDs have been a topic of study since then. NHTSA sponsored a literature review on HUDs (Gish & Staplin, 1995) that introduced the hypothesis that HUDs cause "cognitive capture," which they define in terms of the HUD's possible effects on selective attention, divided attention, and switching attention between the HUD and road. The full definition of cognitive capture from Gish and Staplin is as follows:

> **Cognitive capture:** Typically used to refer to the inefficient attentional switching (from HUD, to primary task) when using HUDs. This may result in missing external targets, delayed responses to external events, and/or asymmetrical transition times (longer to switch from HUD-to-external visual processing than vice versa). In effect, the HUD acts as an attentional "trap" that draws information processing resources to the HUD and slows/degrades processing of external events.

A short review of sources of distraction is included here as a direct response to RQ1 (see below). Driver distraction is a vast topic, and distractions can come from many sources. For the purposes of this project, the definition of distraction is adapted from NHTSA's guidelines (81 FR 87656, 2016). Driver distraction is defined as a specific type of inattention that occurs when drivers divert their attention away from the driving task to focus on another activity. In the present work, the potential distraction sources are in-vehicle displays. As noted in NHTSA's published guidelines, driver distraction can affect drivers in different ways and can be broadly categorized into the following types (note that a task may involve one, two, or all three of these distraction types).

- Visual distraction: Tasks that require the driver to look away from the roadway to visually obtain information.
- Manual distraction: Tasks that require the driver to take one or both hands off the steering wheel to manipulate a control, device, or other non-driving-related item.

- Cognitive distraction: Tasks that require the driver to avert mental attention away from the driving task.

In the present work the primary distraction issue is that a driver focuses visual and cognitive attention on the HUD at the expense of attention to the forward roadway, defined previously as "cognitive capture." In their review of human factors in automotive HUDs, Gish and Staplin (1995) describe cognitive capture as an effect of several factors, such as driver attention, driver perception, and the complexity of information presented in the HUD. Regardless of the source, the outcome is generally the same: decreased scanning of the external road scene (compared to scanning without a HUD). This may prevent drivers from perceiving events in the environment, such as an object on the road or a braking lead vehicle. Humans have difficulty simultaneously processing two displays overlaid on each other (Neisser & Becklen, 1975). In addition to cognitive capture, a HUD that has too many components may clutter the driver's visual field, including obscuring the driving scene (Gabbard et al., 2014). Visual clutter may be reduced via design choices (e.g., limiting information that is displayed; transparency of HUD displays), but even a well-designed HUD has the potential to occlude important information from the forward roadway, in particular if the driver has adjusted the HUD too high in the visual field.

Summarizing their review, Gish and Staplin (1995) concluded that both the benefits and drawbacks of HUD use are relatively minor, a view that has subsequently been supported by additional research. When measuring eyes-on-display (EOD) time, Ablaßmeier et al. (2007) found that during normal driving situations, the gaze retention period, which is EOD plus eye movement time, was less for HUDs than for typical HDD displays. When warnings were presented on a redundant HUD, participants showed faster responses, as opposed to when warnings were spread out across other displays (Normark et al., 2009). Burnett and Donkor (2012) report that these response times are moderated by the complexity of the display. Additional investigations of how HUDs may influence driver reactions have also been conducted, specifically driver reactions to engine overheating warnings (Liu & Wen, 2004), in which HUDs were shown to speed responses to the warnings. As these unexpected events were warnings, and not an event in the forward roadway, the question of whether or not HUDs may delay a driver's response to on-road situations was not directly addressed. More recently, Park and Park (2019) reviewed research and market projections from the intervening years, again confirming that the benefits and drawbacks of HUD use are relatively minor.

Still, based on market research the prevalence of automotive HUDs will likely continue to increase (ABI Research, 2015). At the same time, the complexity of information presented in automotive HUDs is also likely to increase, particularly as driving automation and advanced driver assistance systems become more widespread. For example, HUDs may show additional information about the status of advanced driver assistance systems, such as adaptive cruise control settings, alerts, or other information. In addition, prototype, promotional, and other pre-production HUDs that have wider displays, project information beyond 6.7 meters, or incorporate augmented reality (ARHUDs) have been publicized (e.g., 2021 Mercedes-Benz S Class; Mercedes-Benz (n.d.)).

Before the deployment of more complex HUD systems, more information is needed to understand driver distraction with HUDs compared to other displays. For example, how would the level of distraction from a HUD compare with the level of distraction from an HDD in the instrument cluster or an aftermarket display on a smartphone? The present study is an investigation of "worst-case" cognitive capture during the performance of a distracting task that requires the use of these three display types.

Research Questions

The main objective of this project was to determine whether HUD technology changes the driver's ability to process information about the forward road scene and respond to crash-imminent situations. A supporting objective was to identify surrogate measures of distraction similar to eyes-off-road (EOR) time for drivers using a HUD versus an HDD in different driving situations. Five research questions defined the scope of the project.

RQ1: What are the main visual distraction issues that can arise when using a HUD versus an HDD human-machine interface?

RQ2: What metrics are sensitive to potential distractions resulting from using a HUD versus an HDD?

RQ3: Does a surrogate measure of distraction increase when drivers use candidate HUD systems?

RQ4: What are the unintended consequences, if any, associated with HUD systems?

RQ5: What are the potential minimum performance specifications for HUD systems? What are the advantages and disadvantages of HUDs?

The goal of the present work was not to determine the causes of cognitive capture with HUDs, but rather to determine the effects: how cognitive capture changes the driver's response to a traffic scenario requiring an immediate response.

2. Approach

This chapter presents the methodology, procedures, and experimental design for the on-road evaluation of HUDs and HDDs.

Participants

A total of 48 drivers completed the study. This sample size was selected to exceed the minimum sample size based on a priori power analyses using best estimates of response time differences (alpha = .05, power = .8; estimated reaction time difference 0.5 seconds, SD = 0.3 seconds). Participants were recruited from two different target age groups as requested by NHTSA: 20 to 35 years old and 50 to 65 years old. Each age group consisted of 13 males and 11 females.

All participants had normal or corrected-to-normal vision to the legal minimum (in Virginia) of 20/40, normal color vision, and were able to pass a basic hearing test. The hearing test was to ensure participants could hear and understand instructions from the experimenter. Participants were recruited from the local population in the New River Valley of Virginia. Recruiting material, including advertisements, are included in Appendix A. All study material, procedures, and recruiting material were approved by the Virginia Tech Institutional Review Board. See Appendix B for an example of the information sheet and informed consent document used in the study. Limited demographic information was collected; Appendix C includes the demographic questionnaire used in the study.

Vehicles

Study Vehicle

The vehicle used for this project was a 2010 Buick LaCrosse. Figure 1 shows interior and exterior views of the vehicle. The LaCrosse used in this study includes a HUD installed by the OEM. Two experimental conditions consisted of tasks performed with a HUD or HDD. A third experimental condition used an aftermarket display: a vehicle information app on a smartphone. When testing the aftermarket display and the HDD (see below), the OEM HUD was disabled. The HDD was active in all three conditions.

Figure 1. Exterior (Left) and Interior (Right) Images of the 2010 Buick LaCrosse

A data acquisition system was installed in the study vehicle. The following data elements were captured by the DAS in the study.

- *High-definition view* of the driver's face and eyes (see Face Camera section for further description).

- *Non high-definition camera* wide-angle views of the forward roadway and the foot well, a wider view of the driver's face (these images are split to fit into one quadrant), and video taken from the driver's vantage point via camera-mounted safety glasses worn by the driver (Figure 2). These cameras recorded at a rate of 15 frames per second.

- *Data from accelerometers* (longitudinal and lateral forces) collected on 3 axes at 10 Hz.

- *Data from forward radar* (headway to a lead vehicle).

- *Data from lane tracker collecting machine vision* estimates of the vehicle's distance to existing lane markings; although lane tracking data was not used for analysis in this report, it appears in the upper right quadrant of Figure 2 via red and blue markings overlaying the lane lines on the road.

- *Vehicle network data from the on-board diagnostics port* (such as vehicle speed, throttle application, and brake application).

- *Data from GPS* technology (the vehicle's location) collected at 1 Hz.

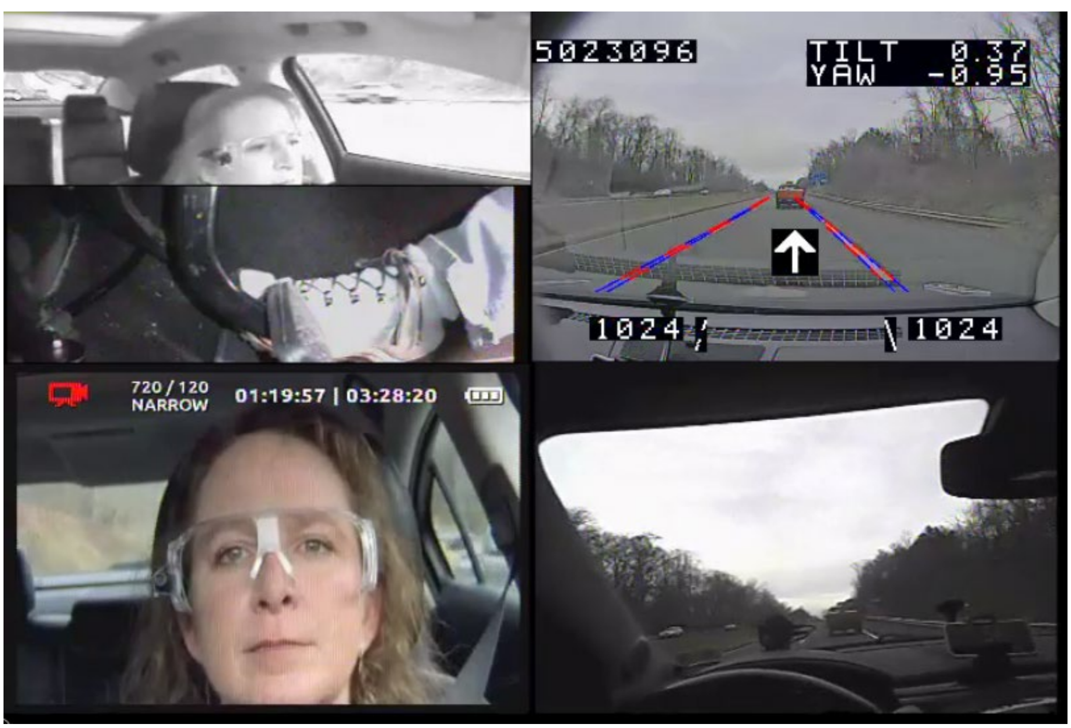


Figure 2. Camera Views Collected by the DAS

Face Camera

A GoPro HERO3+ Silver camera (https://gopro.com/content/dam/help/hero3plus-silver-edition/manuals/UM_H3PlusSilver_ENG_REVB_WEB.pdf) assembly captured close-up video of the participant's face and eyes at 720p resolution. The camera was wired into the vehicle's DAS and time-synched with vehicle data and DAS video at 15 frames per second. The camera was further modified (similar to Figure 3) to accept a zoom lens using the "Ribcage" system from Back-Bone (Figure 3, www.back-bone.ca/). This setup provided a way to adjust for driver height and seat position while still providing higher-resolution video to facilitate manual eye-glance reduction.

Figure 3. The Modified GoPro Camera With Attached Zoom Lens

Displays

The HUD used was the OEM HUD on the 2010 Buick LaCrosse (Figure 4), which was selected because it was a vehicle in the Virginia Tech Transportation Institute fleet that contained a HUD. The two-dimensional image was optically focused at 2.5 meters, which gives a fixation distance approximately in front the vehicle's hood. Across all participants, the mean look-down angle for the OEM HUD was approximately 4 degrees with a standard deviation of 1.42 degrees. The approximate look-down angle was measured for each participant by measuring their eye height from the ground, which allowed for calculation of the angle using standard trigonometric functions to determine the approximate look-down angle. A button to the left of the steering wheel controlled the HUD's brightness, adjusted the HUD's height, and disengaged the HUD altogether. As shown in Figure 4, the display presented vehicle speed (in mph), cardinal direction of travel, current gear selection, and external temperature. Note that the camera used to capture the HUD image also captured the HUD display emitter; this is an artifact and is not typically visible to drivers (the square "blur" on the right side of Figure 4).

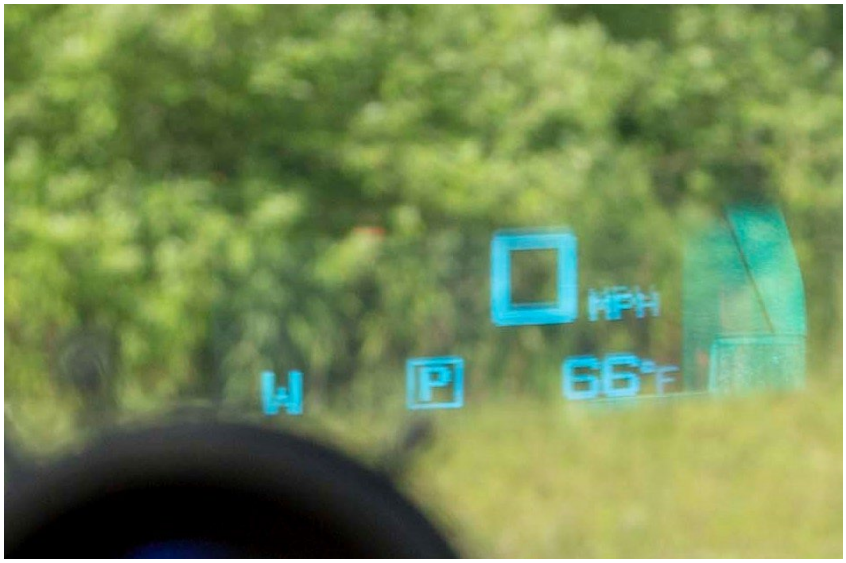


Figure 4. The 2010 Buick LaCrosse HUD – The Square Image on the Right of the Display Is the Display Projector as Captured by the Camera and Not Typically Visible to the Drivers

The HDD used was the OEM HDD on the 2010 Buick LaCrosse (Figure 5), which presents a two-dimensional image in the instrument cluster behind the steering wheel. The mean look-down angle for the HDD was approximately 29 degrees with a standard deviation of 1.69 degrees. The HDD presented vehicle speed, cardinal direction, current gear selection, and engine rpm.

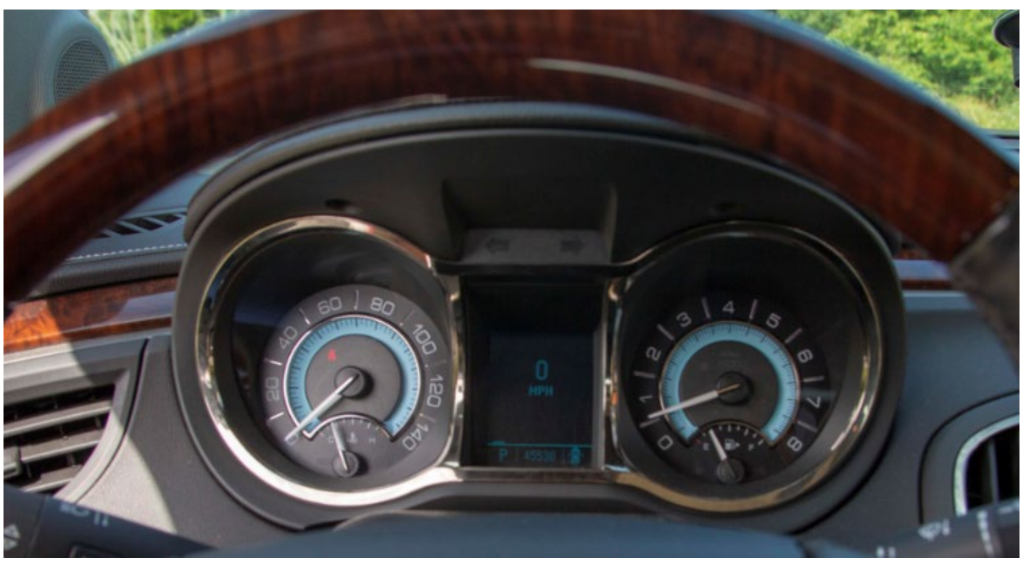


Figure 5. The 2010 Buick LaCrosse HDD

It should be noted that the original research plan was to include an aftermarket HUD device; however, any eligible device was either discontinued or no longer supported by the manufacturer at the start of study data collection. Instead, an aftermarket display was selected that approximated the information that would be displayed on an aftermarket HUD device. The aftermarket display was a smartphone-based vehicle information application (Figure 6). The smartphone was mounted in a cradle attached to the vehicle windshield. Although the display was presented on a smartphone, the participant was not asked to interact with the smartphone in any way. The features displayed were representative of a wide variety of aftermarket devices and applications (e.g., navigation systems or other vehicle information displays), and not smartphone use per-se (e.g., visual manual interaction with a phone). The aftermarket display had a mean look-down angle of approximately 14 degrees, with a standard deviation of 1.40 degrees. The application displayed vehicle and general information, including vehicle speed (calculated from GPS), trip distance in miles, cardinal direction of travel, altitude, average speed, current time, and temperature.

Figure 6. Dashboard-Level Aftermarket Display

Lead Vehicle

The lead vehicle was an orange pickup truck with roof-mounted safety lights similar to a Virginia Department of Transportation truck (Figure 7). Researchers instructed the participants to follow the lead vehicle throughout the study (both on public roads and also while driving on the highway section of the Virginia Smart Road). As shown in Figure 8, when triggered by a laptop, the modified truck dropped a small cardboard box onto the roadway to serve as a surprise event. This event occurred on the highway section of the Virginia Smart Road once for each participant. This event type was considered a "worst-case" approximation, as the box was relatively low contrast and difficult to notice with peripheral vision alone.

Figure 7. Lead Vehicle Used in the Experiment

Figure 8. Participant Perspective of the Cardboard Box Dropped From the Lead Vehicle (Box Circled in Red)

Following Vehicle

During the public road portion of the study, a third vehicle (Figure 9), also driven by a researcher, followed the participant vehicle. This vehicle served as a blocking vehicle to prevent public road traffic from inadvertently following the study vehicles through the live connector into the test track area. The vehicle was equipped with a lighting display (Figure 10) to direct any non-study traffic around the test track entrance.

Figure 9. Following Vehicle Used During Public Road Portion of the Experiment

Figure 10. Lighting Display in the Trunk of the Following Vehicle

Procedures

Arriving participants were greeted and taken to a private screening room for the initial informed consent process. Then they were tested for normal vision, as well as for determining dominant eye. Recording the dominant eye assisted in the video-based reduction of visual behavior. Participants provided general demographic information via questionnaire (see Appendix C). Researchers then led participants to the experimental vehicle and oriented them to the controls. They then allowed participants to adjust the seat position and mirrors. Once a participant had adjusted the seat, the experimenter measured participant eye-height in order to calculate look-down angle for that participant.

To minimize the potential of the HUD to obscure the forward roadway, the initial OEM HUD setup was adapted from Kiefer (1998a). The HUD was first adjusted as low as possible, and then raised just to the point that it was in the participant's field of view. Typically, this would give the appearance of the HUD appearing just above the front hood. No explicit countermeasures were undertaken to minimize any novelty with the HUD.

Each test session took place on public roads and the highway section of the Virginia Smart Road, a 2.2-mile controlled test track. The variables associated with each part of the procedure are discussed below in the Experimental Design section.

Public Road Component

The public road component of the procedure consisted of drivers following the lead vehicle along the route shown in Figure 11. Each participant completed the route three times, once for each display. At the start of each lap, researchers provided instructions to the participant for the particular display to be used during the lap. The HUD and aftermarket displays were removed or disabled when not in use; however, the HDD was always visible to participants. Laps were approximately 20 miles and took approximately 30 minutes to complete. Researchers asked the participants about the vehicle's current cardinal direction of travel and its current speed (each question was treated as a task) six times (three speed and three direction questions) during each of the three laps. Each question consisted of a one-word prompt ("speed" or "direction"). Portions of each lap in which participants were not asked a question were used to sample "just driving" with each display. Lap 1 and Lap 2 started and ended in the parking area at VTTI. After completing the third lap, participants proceeded directly onto the highway section of the Smart Road.

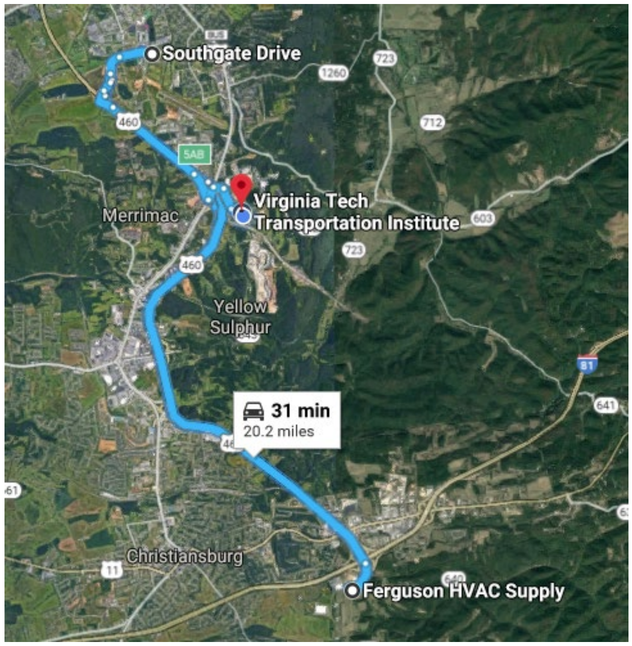


Figure 11. Twenty-Mile Divided Highway Course in Blacksburg and Christiansburg, Virginia

Smart Road Component

Participants followed the lead pickup truck onto the highway section of the Smart Road using the live connector ramp from US-460 Business. The Smart Road live connector is a gated connection from US-460 Business to the Smart Roads, allowing for a seamless transition from public roads to the controlled-access research facility.

Figure 12 approximates the participant's perspective, including the OEM HUD, while following the lead vehicle. Note that this image was captured during study development; in order to include the HUD in the image, it was higher in the field of view that would be typical during data collection. On the Smart Road, the in-vehicle experimenter asked drivers to perform a task with the assigned display "that is too hard to be performed on public roads," to read the display and report the eighth character. During this task, participants were also instructed to follow the lead vehicle at a 2-second headway at a target speed of 40 mph. This task requires both visual and cognitive attention to count the characters in the display, at the expense of attention to the forward roadway. This is consistent with the definition of cognitive capture from Gish and Staplin (1995). Unknown to the driver, the lead pickup truck dropped a cardboard box at the command of the in-vehicle experimenter while the driver was performing the task (or just driving if assigned to the non-task condition). Driver responses to the surprise event were measured as time to look forward from the task display (gaze response time) and reaction time (brake response time or swerve response time). After completion of the surprise event, the experimenter debriefed the drivers about the study, and the experiment session ended.

Figure 12. Participant's Perspective Following Lead Vehicle on the Smart Road, With OEM HUD

Experimental Design

The study implemented a different experimental design for each portion of the experiment (public road versus Smart Road). The design employed a three-level, one factor, within-subject design with the factor of display type (OEM HUD, aftermarket display, and HDD) during the public road portion. Display order was fully counterbalanced across the 48 participants. The Smart Road portion of the study employed three levels of display type and two levels of task type (task present versus just driving). Display type was assigned randomly such that 12 participants performed the distraction task during the event with each display, and 12 were just driving participants (four participants from each display condition).

Dependent Variables

The primary dependent variables were task duration and EOD time, as determined via frame-by-frame video reduction. Trained data reductionists at VTTI conducted data reduction. For public road tasks, participant eye-glance location was classified into one of three categories: "on road," "on display," or "other off road." Drivers performed three tasks for each display type: vehicle speed and cardinal direction of travel (public roads).

Data reduction sampled drivers' visual behavior during the public road scenario in between display tasks. Six samples per display of just driving were selected to serve as a baseline condition. Visual behavior was analyzed as total EOD time (the sum of EOD time during the sample) and as a proportion of EOD time (the ratio of EOD time to EOR time during the sample).

Dependent variables for analysis of data collected on the test track included response times to the surprise event triggered while drivers were reading the display in the HUD, HDD, and aftermarket display conditions. A fourth group who experienced the surprise event consisted of the subset of participants who were not asked to perform the reading task with the display (i.e., just driving). This baseline condition included equal numbers of HUD, HDD, and aftermarket display participants. The dependent variables for driver response were gaze response time (time to look forward from the display) and the start of the driver's intervention (initiation of swerve maneuver or braking response). Note that performance on the character counting task was not included as a dependent measure.

3. Results

For convenience to the reader, the research questions once again are as follows:

RQ1: What are the main visual distraction issues that can arise when using a HUD versus an HDD human-machine interface?

RQ2: What metrics are sensitive to potential distractions resulting from using a HUD versus an HDD?

RQ3: Does a surrogate measure of distraction increase when drivers use candidate HUD systems?

RQ4: What are the unintended consequences, if any, associated with HUD systems?

RQ5: What are the potential minimum performance specifications for HUD systems? What are the advantages and disadvantages of HUDs?

Per RQ1, the literature suggests that the primary distraction issue of interest is cognitive capture, which was assessed via driver visual behavior and driver response to the surprise event. RQ2 and RQ3, concerning metrics, were assessed via driver visual behavior. Visual behavior was analyzed by comparing both percentage of EOD and total task time during each epoch on public roads (task and just driving). Cognitive capture was tested during the surprise event scenario while the driver was distracted by the character counting task. Thus, driver reaction times were obtained in a "worst-case" scenario of cognitive capture by a HUD.

On-Road Visual Behavior

The analysis of driver task behavior focused on two metrics.

1. Percentage Time on Display: The percentage of time that the participant's eyes were on the display during the task.

2. Total Task Time: The total amount of time in seconds that the participant took to complete the task.

With these metrics, this analysis consisted of four a priori planned statistical comparisons (note that while gender was included in the statistical models, it was not part of the planned comparisons).

1. Whether tasks performed with the HUD differed significantly from tasks performed with the HDD or aftermarket device;

2. Whether HUD, HDD, or aftermarket tasks conducted on public roads differed significantly from samples of "just driving";

3. Whether age group interacted with display condition; and

4. Whether just driving samples (no tasks) differed by display condition.

For the first two questions, a main effects longitudinal statistical model was fit with display type, as well as the experimental design variables of age group, gender, display order (e.g., the overall sequence of displays), and display number (first, second, or third in the sequence). For the third question, the interaction of age group and display type was also included in the statistical model. For the fourth, only driving tasks were used, but were distinguished by which display was present during the lap.

Statistical significance of differences between display tasks was assessed only if the overall test of display task type was significant at an alpha of $p < 0.05$. If the p value was less than 0.05, comparisons between HUD and HDD, as well as between HUD and aftermarket, were assessed in all cases, while comparisons between all three and just driving were assessed only in percentage of time on display, since total just driving time examined was pre-chosen and not random. In comparisons without the just driving condition, the two comparisons with HUD and other displays were assessed with a Bonferroni-corrected p value of 0.025. In cases with the three just driving comparisons, the total set of five comparisons was assessed with a Bonferroni-corrected p value of 0.01.

Statistical significance of an interaction between task type and age group was also assessed as significant at alpha < 0.05. If significant, individual comparisons between age groups within different task types were assessed at a Bonferroni-corrected p of 0.017 without just driving and 0.013 with just driving.

The statistical model accounts for several participant observations, and thus not all observations are independent. Additionally, the model accounts for the fact that participants had several observations for each task type, and thus not all observations of the same task type are independent. To account for these facts, random intercept and task type terms were fit. Other correlation structures considering time dependency were considered but not selected due to either non-estimable or non-parsimony (too many parameters to estimate). Model assumptions were also checked on the scaled residuals.

The analysis results are included below. Analyses for both percentage of EOD time and total task time were conducted and were complementary. A plot is included for total EOD time; otherwise, only analyses for percentage of EOD time are included here. Additional analyses for total task time are included in Appendix D.

EOD Time

Total EOD times for tasks with the display are shown in Figure 13. For all display tasks, the total EOD observed was less than 2 seconds, a critical threshold for driver distraction (81 FR 87656, 2016).

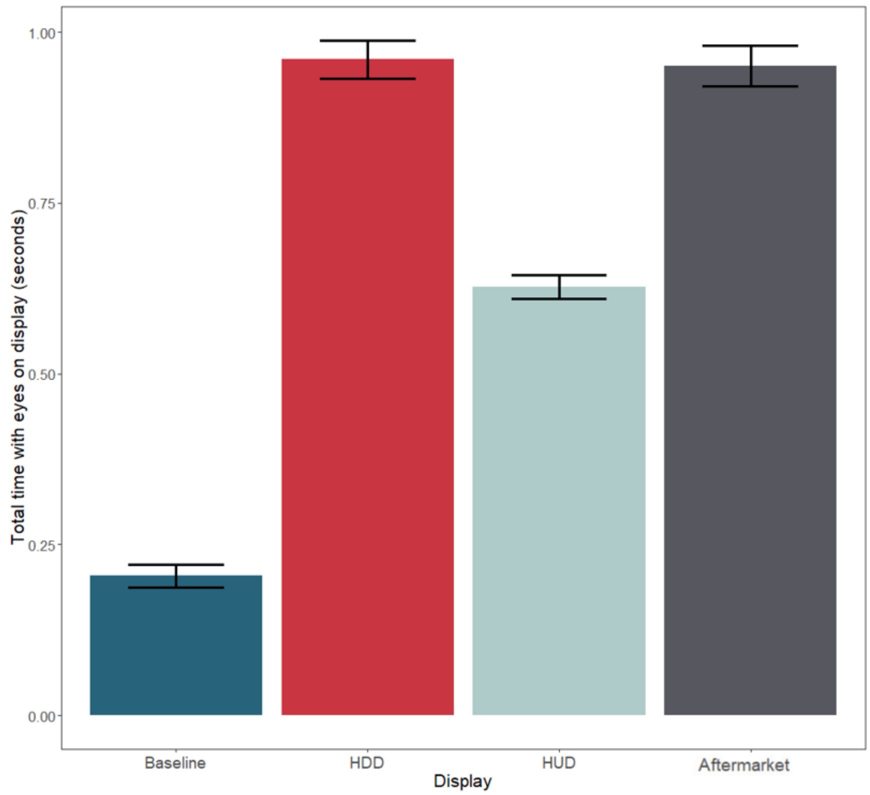


Figure 13. Mean EOD Time for Each Display Task and the Average Baseline Observed When Just Driving – Error Bars Represent +/- One Standard Error

Percentage time EOD differed significantly among the display types, $F(3, 139) = 288.76$, $p < 0.001$. Specifically, participants looked at the display a significantly smaller percentage of the time during the HUD tasks than they did during the HDD or aftermarket tasks. Additionally, participants looked at the display a significantly larger percentage of time during all display tasks than during samples of just driving. Table 1 provides the mean percentage EOD time by display type, as well as lower and upper confidence levels (CLs). Table 2 provides the comparison results, with mean difference, lower and upper CLs, and *t* and *p* values. Figure 14 shows a plot of this comparison.

Table 1. Mean Percentage Time on Display by Task Type With Lower/Upper CLs

Task Type	Mean	Lower CL	Upper CL
HUD	29.8	27.4	32.1
HDD	42	39.6	44.3
Aftermarket	42	39.7	44.3
Just Driving	8.3	6.1	10.4

Table 2. Comparison Results for Difference in Percentage Time on Display

Task Type	Comparison	Mean Difference	Lower CL	Upper CL	*t*	*p*
HUD	HDD	-12.2	-15.0	-9.4	-9.4	<0.001
HUD	Aftermarket	-12.3	-15.0	-9.5	-8.7	<0.001
HUD	Just Driving	22.5	18.8	24.2	16.0	<0.001
HDD	Just Driving	33.7	31.0	36.4	25.1	<0.001
Aftermarket	Just Driving	33.8	31.1	36.4	25.1	<0.001

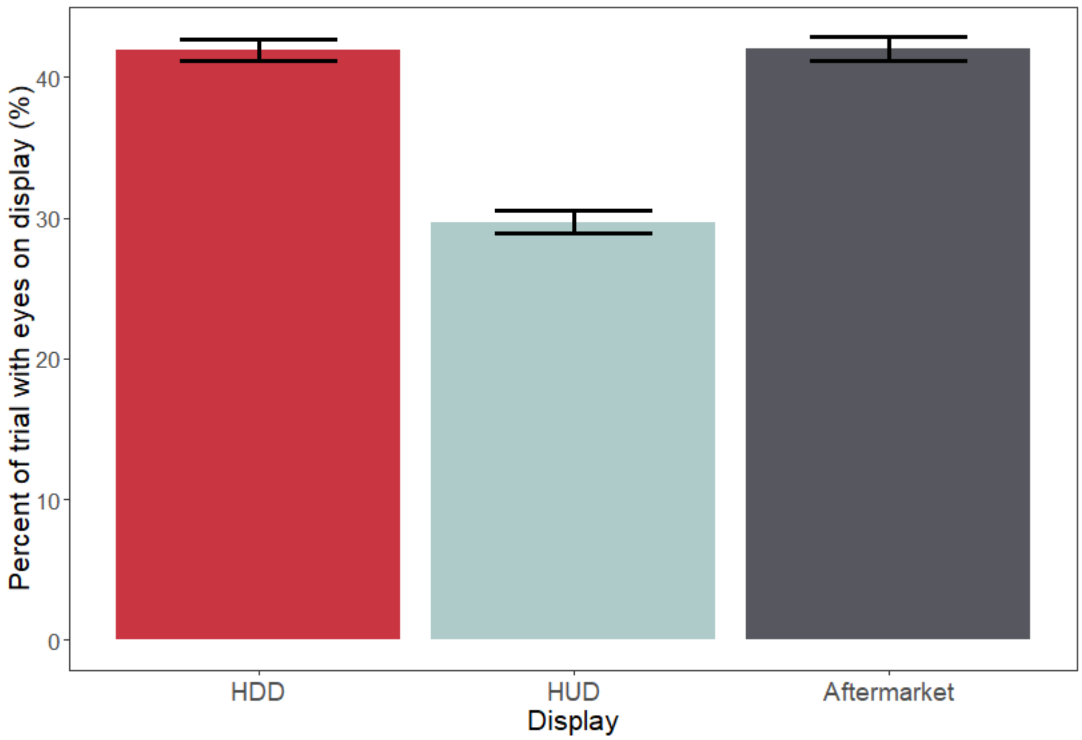


Figure 14. Percentage of Trial With Eyes on Display During Driving-Related Tasks

Task type and age group also interacted significantly, $F(3, 136) = 2.76$, $p = 0.045$. However, comparisons between individual task types did not reach statistical significance for either age group. As such, there is inadequate statistical significance to interpret any age differences between displays per RQ4.

Participants had significantly different percentage EOD time during samples of just driving depending on which display was present, $F(2, 381) = 5.86$, $p = 0.003$. Specifically, participants spent a significantly longer percentage of time looking at the display when HUD was present than when HDD was present. *Table 3* provides the mean percentage EOD time during just driving tasks by task type, as well as lower and upper CLs. Table 4 provides the comparison results, with mean difference, lower and upper CLs, and *t* and *p* values. Figure 15 shows a plot of this comparison.

Table 3. Mean Percentage Time on Display During Just Driving by Task Type With Lower/Upper CLs

Task Type	Mean	Lower CL	Upper CL
HUD	11.0	8.8	13.3
HDD	5.8	3.6	8.1
Aftermarket	7.8	5.5	10.0

Table 4. Comparison Results for Difference in Percentage Time on Display During Just Driving

Task Type	Comparison	Mean Difference	Lower CL	Upper CL	*t*	*p*
HUD	HDD	5.2	2.2	8.2	3.4	0.001
HUD	Aftermarket	3.2	0.3	6.3	2.1	0.033

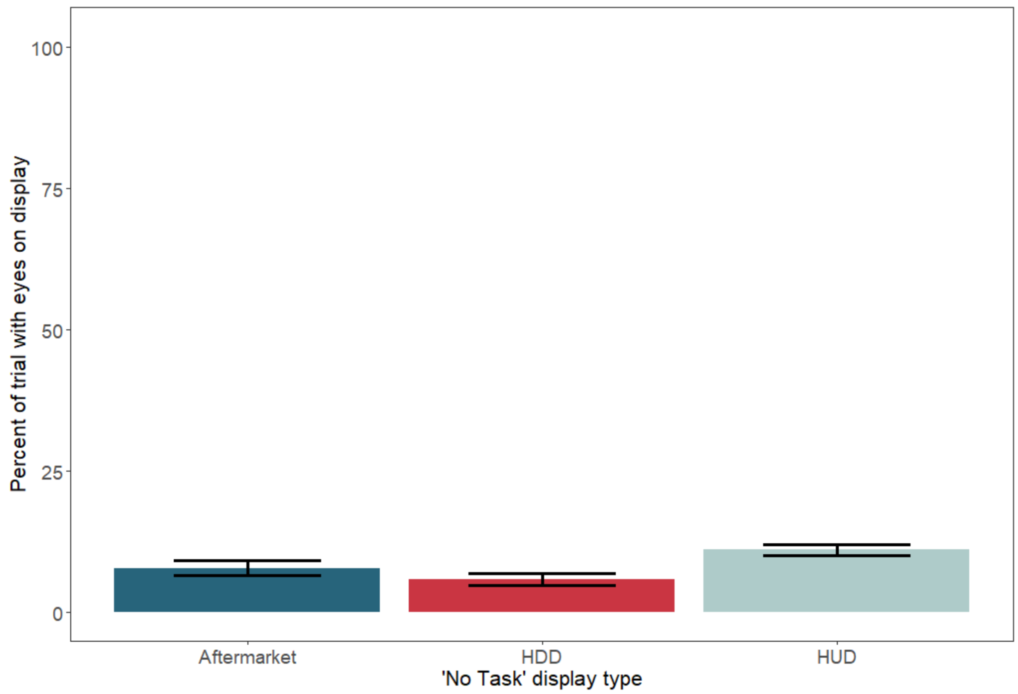


Figure 15. Percentage of EOD Time for Just Driving Samples

Total Task Time

Total task time did not differ significantly among the displays, $F(2, 91.9) = 1.75$, $p > 0.05$. Additionally, there was no significant interaction between display type and age group, $F(2, 89.8) = 0.75$, $p > 0.05$. Table 5 provides the mean total display time by display type, as well as lower and upper CLs.

Table 5. Mean Total Task Display Time in Seconds by Display Type With Lower/Upper CLs

Display Type	Mean	Lower CL	Upper CL
HUD	2.19	2.11	2.28
HDD	2.28	2.20	2.37
Aftermarket	2.25	2.16	2.33

Summary of On-Road Visual Behavior Results

Drivers' visual behavior was significantly different when using a HUD display compared to other display types. Per RQ2, when drivers were asked to report driving-related information using the HUD (29.8% EOD time during the task), the surrogate measure of EOD time was lower compared to the other display types (42% EOD time during the task). Times to complete the tasks, however, showed no differences among display types. Per RQ3, EOD time was higher in the HUD condition (11%) for samples observed during just driving when compared to both HDD (5.8%) and aftermarket (7.8%) displays.

Surprise Event Analysis

Analysis for the surprise event (box dropped from lead vehicle) included reaction time (driver releases accelerator pedal or begins to steer around the box) and time to look forward (driver looks up from the display) as determined during video based review of the driver.

Reaction Time

Task type comparison. The data set was analyzed first for differences in task reaction time based on display compared to no task using analysis of variance (ANOVA). Average reaction time did not significantly differ among the four display conditions, $F(3, 20) = 1.37$, $p > 0.05$. Table 6 shows the average reaction times with 95% confidence interval (CI) bounds for each display type.

Table 6. Average Reaction Time Among Task Display Types

Task Type	Mean Reaction Time (seconds)	95% CI Lower Bound	95% CI Upper Bound	Number of Reactions	Percentage Who Reacted (out of 12)
No task/Just driving	1.71	1.32	2.09	11	92%
HUD task	2.03	1.62	2.43	5	42%
HDD task	2.20	1.87	2.53	5	42%
Aftermarket task	2.02	0.54	3.5	3	25%

Age group comparison. To verify the results were not an artifact of driver age, average reaction time was compared between age groups. There was no significant difference in reaction time for the older driver group compared to the younger driver group across all task types. A summary of the data, by age group, is shown in Table 7.

Table 7. Summary of Reaction Times, by Age Group

Age Group	Mean Reaction Time (seconds)	95% CI Lower Bound	95% CI Upper Bound	Number of Reactions	Percentage Who Reacted (out of 24)
Older	1.84	1.44	2.23	11	46%
Younger	1.98	1.73	2.23	13	54%

Age group and task type interaction. The interaction of age group and display type was not statistically significant, $F(7, 16) = 1.215$, $p \geq 0.05$. Table 8 summarizes the mean reaction times and 95% CI bounds for the groups formed by the interaction of age group and task type. Figure 16 shows a plot of this comparison.

Table 8. Summary of Reaction Times, by Age Group and Task Type

Age Group	Task Type	Mean Reaction Time (seconds)	95% CI Lower Bound	95% CI Upper Bound	Number of Reactions
Older	No task	1.61	0.86	2.36	6
	HDD task	1.98	0.48	3.49	2
	HUD task	1.89	*	*	1
	Aftermarket task	2.36	1.83	2.89	2
Younger	No task	1.82	1.32	2.32	5
	HDD task	2.34	1.78	2.91	3
	HUD task	2.06	1.48	2.65	4
	Aftermarket task	1.34	*	*	1
** Indicates that there were not enough observed reactions (n = 1) to calculate standard deviation and create a confidence interval.*					

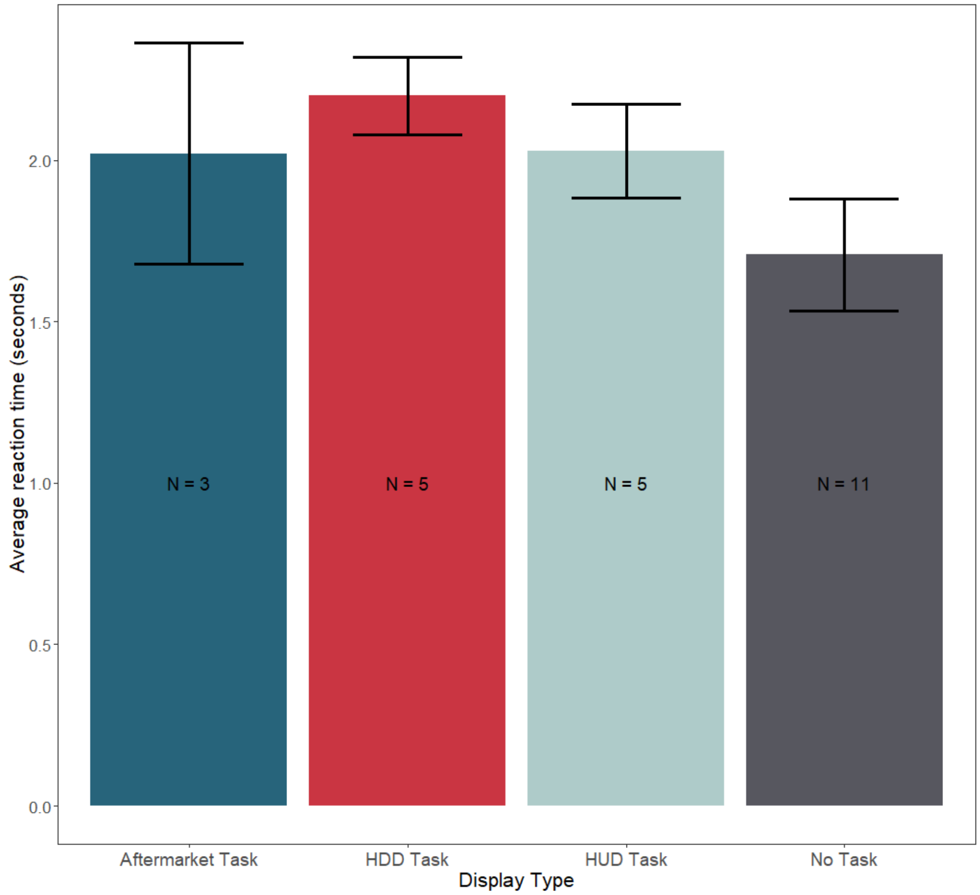


Figure 16. Average Reaction Time in Seconds for Each Display With a Task, and No Task – N Indicates the Number of Participants Who Reacted in That Condition and Error Bars Represent +/- One Standard Error

Survival Analysis of Reaction Times

ANOVA tests for reaction time include only 24 of 48 data points, as only 24 participants reacted. To account for this, survival analysis was performed on average reaction time. Survival analysis is used to model "time-until-condition" data. In this case, time until a steering or braking reaction or time until looking forward was used for all participants who did react, and the full trial length was used for all of those who did not react. Given that the experiment had a fixed ending period, this means that these subjects are considered to have gone through the duration of the trial without reacting, and hence their reaction time is the trial length. These data points are known as "censored" data in survival analysis, and they represent a participant reaching the end of the event without reacting. Note that right censored data are still included in the analysis; their reaction value is input as the total trial length.

A Kaplan-Meier survival curve was fit for each variable of interest (Figure 17), and the data were grouped by display type and age. A Kaplan-Meier survival curve uses time as the explanatory variable and the probability that a random participant is still "alive" as the response variable. Note that this implementation of the analysis is somewhat opposite of a traditional survival curve approach, where "survival" is the desired outcome. In the present implementation, "death" means that the participant has reacted. As such, the *y*-axis in Figure 17 shows the probability of a reaction rather than the probability of survival. Once the survival curves were fit, a log-rank test was used to compare survival curves for groups of interest and determine whether the curves are significantly different from one another.

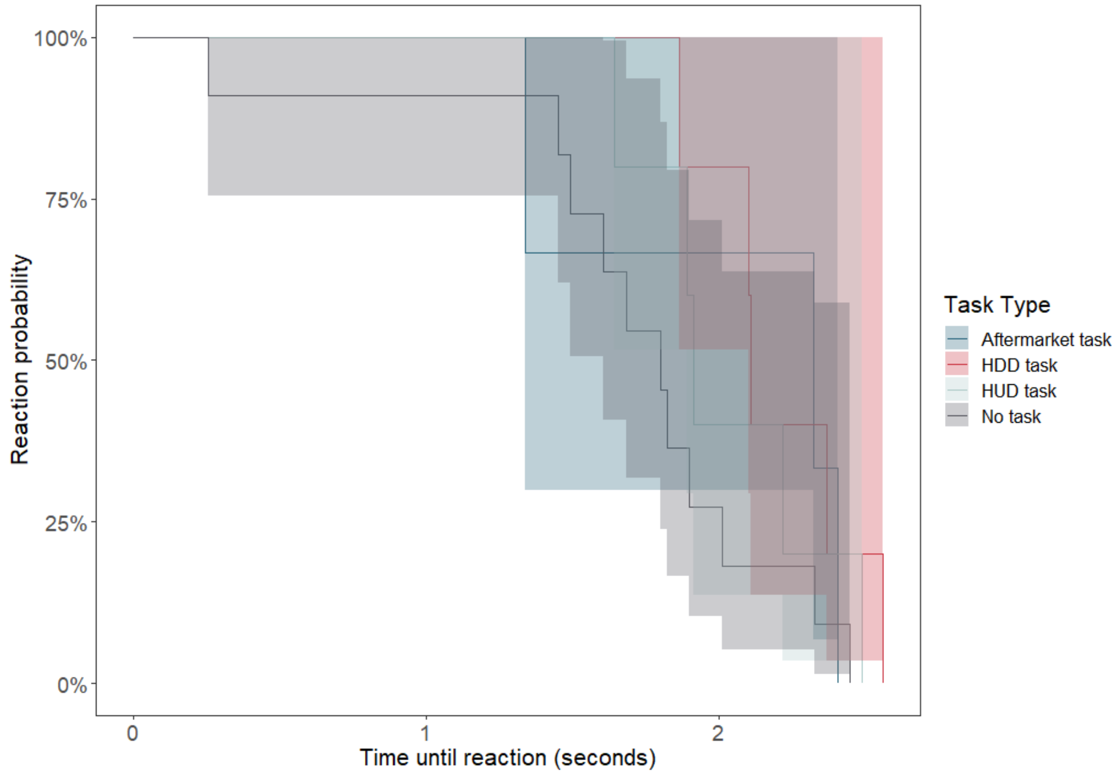


Figure 17. Kaplan-Meier Survival Curve Plot for Each Display Task Condition and the No-Task Condition

Reaction time to swerve or brake in response to the surprise event was analyzed for differences among task types and between age groups. Display tasks showed a significant difference in survival curves between just driving and all other task types ($\chi^2 = 22.9$, $p < 0.001$). There were no significant differences in response time among types of display ($\chi^2 = 0.9$, $p > 0.05$). Reaction times were not significantly different between age groups ($\chi^2 = 3.8$, $p > 0.05$).

Time to Look Forward Analyses

Task type. During the surprise event, the no-task condition differed significantly from all of the task display conditions in time to look forward, $F(3, 36) = 29.87$, $p < 0.001$. Table 9 summarizes the mean time to look forward in each display condition, and Figure 18 shows a plot of these mean times. Table 10 presents the average time difference comparisons between display conditions.

Table 9. Summary of Average Time to Look Forward, by Task Display Type

Task Display Type	Mean Time to Look Forward (seconds)	95% CI Lower Bound (seconds)	95% CI Upper Bound (seconds)	Number of Participants Who Looked Forward	Percentage Who Looked Forward (out of 12)
No task/Just driving	0.01	-0.01	0.03	12	100%
HUD task	2.26	1.78	2.74	11	92%
HDD task	1.98	1.47	2.50	9	75%
Aftermarket task	1.93	1.16	2.70	8	67%

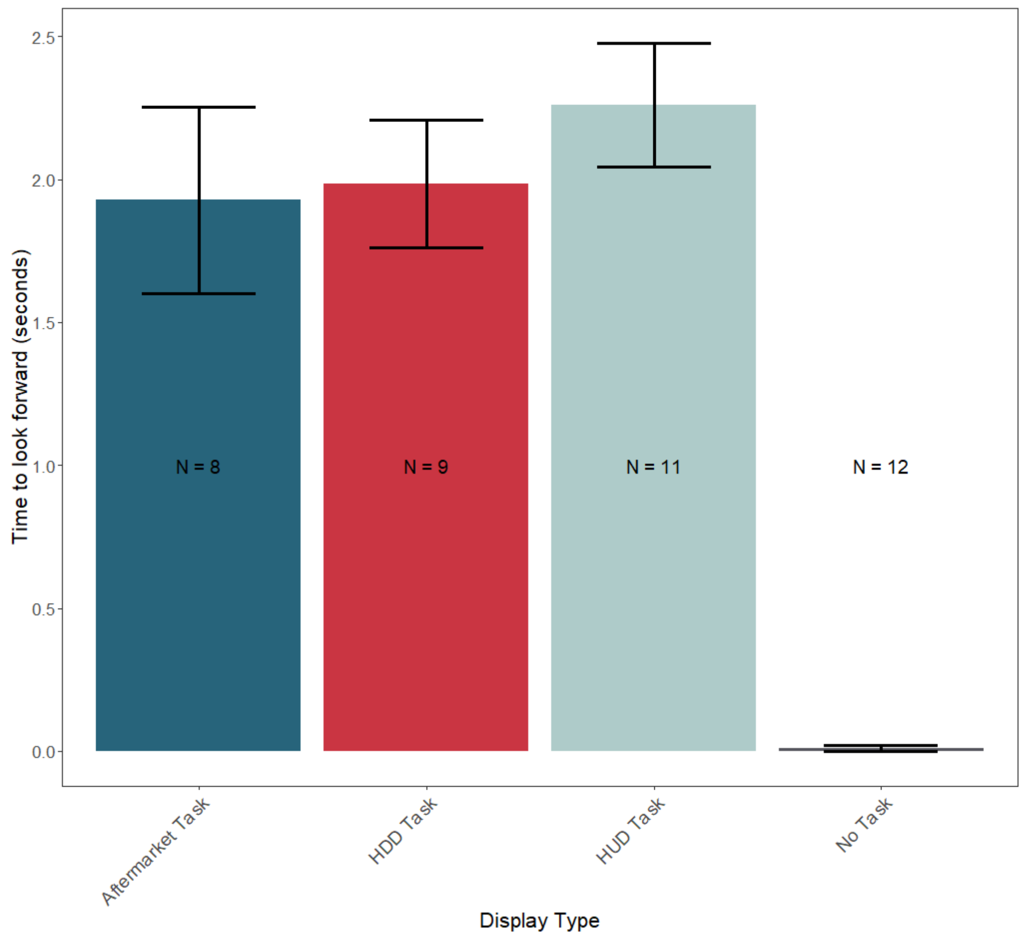


Figure 18. Time to Look Forward (in Seconds) for Each Display Task and No-Task Conditions

Table 10. Comparisons of Average Time to Look Forward for the Different Task Types, Just Driving Condition Included

Task Display Type	Comparison	Mean Difference (seconds)	95% CI Lower Bound (seconds)	95% CI Upper Bound (seconds)	*p*
HDD	Just driving	1.97	1.22	2.73	<0.0001
HUD	Just driving	2.25	1.53	2.97	<0.0001
Aftermarket	Just driving	1.92	1.13	2.70	<0.0001
HUD	HDD	0.28	-0.50	1.05	0.77
Aftermarket	HDD	-0.06	-0.89	0.77	0.99
Aftermarket	HUD	-0.33	-1.13	0.47	0.68

Participants in the just driving condition had significantly different average times to look forward from participants assigned to the other three task display conditions (HUD task, HDD task, aftermarket task, $p < 0.001$). Essentially, participants who were just driving were already looking forward at the initiation of the surprise event. There were no significant differences among display tasks, $F(2, 25) = 0.532$, $p > 0.05$.

Age group comparisons. Time to look forward was also analyzed for differences between age groups. The two age groups did not differ significantly, $F(1, 38) = 0.137$, $p > 0.05$. Table 11 shows the mean time to look forward by age group.

Table 11. Summary of Mean Time to Look Forward, by Age Group

Age Group	Mean Time to Look Forward (seconds)	95% CI Lower Bound	95% CI Upper Bound	Number of Participants Who Looked Forward	Percentage Who Looked Forward (out of 24)
Older	1.53	0.95	2.10	19	79%
Younger	1.39	0.88	1.90	21	88%

4. Summary and Conclusions

The primary goal of this project was to determine whether HUD technology changes the driver's ability to process information about the forward road scene and respond to crash-imminent situations. A supporting objective was to identify surrogate measures of distraction similar to EOR time for drivers using a HUD versus an HDD or aftermarket display in different driving situations.

The following key points summarize the results of the study:

- Glances to the HUD were faster than to the other displays when drivers obtained driving-related information (speed and direction). Overall task time was the same for all displays.

- Drivers showed a tendency to glance at the HUD during samples of just driving (although supplemental analysis results presented in Appendix D of this report show that the average glance duration was less than 2 seconds.)

- When asked to read from the display, reaction times to the surprise event were equally slow when using the HUD as compared to other display conditions.

Conclusions per the research questions are further summarized below.

Identify metrics that are sensitive to potential distractions resulting from using a HUD versus an HDD.

The current study was successful in identifying a measure of EOD time that was sensitive to HUD use versus other displays. EOD time was sensitive to changes in display type while on public roads, both during just driving conditions and when drivers were asked for driving-related information contained in the display. Specifically, EOD time was shorter when performing driving-related tasks with the HUD compared to other displays.

Determine whether a surrogate measure of distraction increases when drivers use candidate HUD systems.

Surrogate measures of distraction were observed to increase during HUD use. EOD time was longer during samples where the HUD information was displayed while participants were just driving, indicating that drivers' eyes were drawn to the HUD. However, the total glance time during these portions was less than 2 seconds, an important guideline for distraction. This finding further adds to those observed in previous work from Ablaßmeier et al. (2007). Ablaßmeier et al. reported that gaze retention times (as measured by an eye tracker) were lower for HUD displays during test track driving compared to HDD displays. The present results do not show this result during just driving samples. However, Ablaßmeier et al. did not separate gaze results between "tasks" and "just driving" as was done in the present work. This may account for the discrepancy.

When performing a distracting task (namely, reading the eighth character from one of the displays), participants' reaction times to the surprise event did not differ significantly among display conditions. This indicates that focusing on a HUD was just as distracting as looking away from the forward roadway at the HDD or aftermarket display.

Identify any unintended consequences associated With HUD systems.

As noted above, the HUD condition showed a significantly greater percentage of EOD time while just driving than the HDD and aftermarket display conditions. This suggests that eyes were drawn to the HUD display when it was available more than to the other displays. It is noted that the HUD may have been novel to the participants in the study, and the study did not include an orientation period with the HUD, which could account for the results seen here.

Describe potential minimum performance specifications for HUD systems and their advantages/disadvantages.

The HUD system tested is a typical conformal display that has been available to consumers in some form for several years. This type of design did not appear to distract drivers unless they were specifically asked to perform a task that required them to focus on the display (i.e., read the display character by character). During the public road tasks, all EOD times were less than the 2-second threshold identified in the NHTSA distraction guidelines (81 FR 87656, 2016). The tested HUD system was advantageous in terms of glance time when accessing information; drivers had less EOD time compared to the HDD and aftermarket displays.

The type of display did not affect participants' response to the surprise event. Many participants (5 of 12) in the HUD condition failed to notice that the box had been dropped in the roadway, let alone respond appropriately. Participants in the HUD condition were more likely to look forward than drivers in the other conditions; however, the overall reaction patterns observed were similar to other conditions in which participants were asked to count characters in the display. Combined with the finding that the HUD drew participants' gaze during public road driving significantly more than the other two displays. Specifically, designers might note that fixation on a HUD did not have a performance benefit in this study compared to fixation on other display types. Furthermore, considerations should be given if a HUD is designed to display on a larger field of view or in a higher field of view, such as an ARHUD system that is projected onto the forward roadway through a larger portion of the windshield. Again, as the results of this study show, distraction from a HUD system that creates cognitive capture can have negative consequences that may be similar to any non-driving task that draws eyes from the forward roadway.

Limitations

One potential limitation of the results is the possible novelty of a HUD to participants. It is certainly possible that this study was a participant's first exposure to a HUD. In this case, "novelty" could account for higher EOD during periods of just driving (e.g., Kiefer, 1991; Ward & Parkes, 1994). Given that novelty was not the focus of the study, visual behavior observed during just driving circumstances could be different if drivers were more familiar with the HUD. However, it is unlikely that novelty would account for participant responses to the surprise event, and as such the conclusions regarding cognitive capture are still valid.

The display used in the study could be considered another limitation. Although efforts were made to structure tasks to ask about information that was available on all display types, each display did present different information types. Furthermore, the complexity of information in all the displays was relatively low; other than the cognitive capture created by asking participants to count the characters in the displays, it is difficult to generalize the overall level of distraction caused by the displays used in the study. Finally, this limitation in display types extends to the study of focal depth. It is noted that the experimental approach did not explicitly address the question of focal depth specifically with HUDs of different focal depths. Technological limitations, including the lack of availability of aftermarket HUDs at the time of the study, did not allow this condition to be tested. Again, it is unlikely that focal depth would change participant responses to the surprise event when distracted.

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Appendix A: Advertisements and Screening Material

Sample Advertisement

Wanted for Research Study

The Virginia Tech Transportation Institute (VTTI) is seeking individuals who:

- are 18 years old and older
- have a valid U.S. driver's license

- Drive our Research Vehicle on Public roads & the Smart Road during daytime hours
- Total participation time: 1 visit, lasting approximately 2 hours
- This project pays $70 for full participation
- Your data will be kept strictly confidential

If you are interested in learning more,

Please contact us at: [redacted] or email, drivers@vtti.vt.edu
Reference "the Top Gun Project" in your message

All inquiries welcome!

Virginia Tech
Transportation Institute

www.vtti.vt.edu

HUD Distraction Screening Form

Note to Researcher:
Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding suitability for this study.

Introductory Statement:
After prospective participant calls or you call them, use the following script as a guideline in the screening interview.

Hello. My name is _____ and I'm with the Virginia Tech Transportation Institute, here at the Smart Rd, in Blacksburg, VA. We are currently recruiting people to participate in a research study. This study involves participating in one session lasting approximately two hours during daytime hours.

VTTI is working on a project on the use of Head-Up Displays for the National Highway Traffic Safety Administration. As part of this project, we are asking people to help evaluate some new technology and drive our research vehicle, which is a Buick LaCrosse, on both public roads as well as the Smart Road, which is our closed to the public test track. The vehicle is instrumented with data collection equipment, including video cameras which will record you while you are in the vehicle.

This study has a few parts to it. First, we would ask you to complete some paperwork; then perform a simple vision and hearing test. Second, you will receive an orientation on Head-Up Displays. A Head-Up Display projects an image onto the windshield and it appears about 6.5 feet in front of the driver. The display shows information about the vehicle, such as current speed. You will then be given an orientation of the research vehicle, and you will drive to US-460 and proceed along a predetermined route. Once the public road portion is completed, we will proceed back to VTTI, to our test track, the Smart Rd. An experimenter would be with you at all times. This project pays $70..

If you are interested in possibly participating, I need to go over some screening questions to see if you meet all the eligibility requirements of this study. Any information given to us will be kept secure and confidential.

Do I have your consent to ask the screening questions?
If yes, continue with the questions. If no, then thank him/her for their time and end the phone call.

1. *Do you have a valid U.S. driver's license?*
   - ☐ Yes If yes, how long have you had a license?____________________
   - ☐ No

2. *What is your current age?* _______________(Stop if not 18 years or older)

3. *Are you a U.S. Citizen*?
   - ☐ Yes
   - ☐ No

   If not a U.S. Citizen: Do you have a green card?
   - ☐ Yes
   - ☐ No

4. *Are you willing to provide your Social Security # should you participate, as required by the University? (explain they will be asked to complete a W-9 if they ask why)*
   - ☐ Yes
   - ☐ No

   Please note that for tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number to receive payment for participation in our studies. Or if a VT employee they may provide their VT employee #.

5. *Are you able to drive an automatic transmission vehicle without assistive devices or special equipment?*
   - ☐ Yes
   - ☐ No

6. *How often do you drive per week (on average)? How many days/week?* _______________

7. *Have you ever been in a driving study or any experiments at the Virginia Tech Transportation Institute? If "yes," please briefly describe the study.*
   - ☐ Yes ____
   - ☐ No *(Cannot have been in a type of surprise study)*

8. *Have you had any moving violations in the past 3 years? If so, please explain.*
   - ☐ Yes ____
   - ☐ No

9. *Have you been involved in any auto accidents in the past 3 years? If so, please explain.*
   - ☐ Yes ____
   - ☐ No

We need to ask a few questions about your medical history…

10. Do you have a history of any of the following medical conditions? If yes, please explain.

    a. *Neck or back pain or injury to these areas*
       - ☐ Yes____
       - ☐ No

    b. *Head injury, stroke, or illness or disease affecting the Brain*
       - ☐ Yes____

☐ No

c. *Heart condition (cannot be current heart condition, which limits their activity)*

☐ Yes____

☐ No

d. *Current respiratory disorder or condition which requires oxygen*

☐ Yes____

☐ No

e. *Epileptic seizures or lapses of consciousness within the past 12 months*

☐ Yes____

☐ No

f. *Chronic migraines or tension headaches (more than 1/mo during the past year)*

☐ Yes____

☐ No

g. *Inner ear problems, dizziness, vertigo, or any balance problems (current)*

☐ Yes____

☐ No

h. *Uncontrolled diabetes*

☐ Yes____

☐ No

i. *Have you had major surgery in the past 6 months?*

☐ Yes____

☐ No

j. *Are you taking any substances on a regular basis which could impair your motor skills or your ability to drive?*

☐ Yes____

☐ No

11. (*Females only*) *Are you currently pregnant*? (*if "yes," politely inform the participant:* while being pregnant does not disqualify you from participating in this study, you are encouraged to talk to your physician about your participation to make sure that you both feel it is safe. If you like, we can send you a copy of the consent form to discuss with your physician. *Answer any questions*)

☐ Yes

☐ No

12. *Do you have normal, or corrected to normal, hearing and vision? If no, please explain.*

☐ Yes

☐ No ____

13. *For this study, you will be asked to drive without sunglasses. Will this present a problem should you be eligible to participate?*

- ☐ Yes
- ☐ No

Do you wear eyeglasses that tint or darken in the sunlight (while seated in a vehicle)?

- ☐ Yes __________
- ☐ No ___________

14. *Are you comfortable reading, writing, and speaking English?*

- ☐ Yes
- ☐ No

15. *Are you currently employed in the design, engineering, or development of automotive-related technologies?*

- ☐ Yes
- ☐ No

Appendix B: Information Sheet and Informed Consent Document

Information Sheet

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Information Sheet for Participants in Research Involving Human Subjects

Title of Project: Top Gun
Investigators: Sheldon Russell, Josh Radlbeck, Thomas Champagne, Zach Crane, and Shane McLaughlin

I. The Purpose of this Research/Project

The purpose of this project is to study the use of Head-Up Displays. A Head-Up Display is a form of display technology that projects an image onto the windshield of a vehicle, in the forward view of the driver. For example, vehicle speed may be projected onto the windshield, as pictured below. The Head-Up Display is circled.

We are asking you to assist us with this study. If you participate you will be asked to drive a passenger vehicle on public roads as well as on our test track while performing tasks involving Head-Up Displays. The results from this study will be used to improve the design and safety of Head-Up Displays.

II. Procedures

During the course of this experiment you will be asked to perform the following tasks:

1. Read this Information Sheet and sign it if you agree to participate.

2. Complete a W-9 form.

3. Show your valid driver's license.

4. Complete a vision test.

5. Complete a short demographics questionnaire.

6. Drive a passenger vehicle at normal highway speeds on US-460 for about 12 miles, while following an experimenter in a separate vehicle. During the drive, you will be asked to perform tasks that require reading information from the Head-Up Display (such as read current speed) while driving. An experimenter will sit in the passenger's seat while you are driving and provide instructions throughout the public road portion. A video recording with audio will be made to allow for later analyses.

7. Wear safety glasses that have a camera mounted to them in order to record your perspective while driving. The safety glasses have had the lenses removed and are designed to fit over prescription eyeglasses.

8. Afterwards we will proceed to the test track and complete six test trials. Five of the test trials will include performing tasks that require reading information from the Head-Up Display (such as read current speed and read cardinal direction) while driving.

We are not evaluating you or your performance in any way. You are helping us evaluate new technology. Any opinions you have will only help us do a better job of designing the systems. Therefore, we ask that you perform to the best of your abilities. Any feedback that you provide is very important to this project. The experiment will last about 2 hours.

III. Risks

There are risks or discomforts to which you may be exposed in volunteering for this research. They include the following:

1. The risk of an accident normally associated while driving a passenger vehicle under normal operating conditions.

2. Possible fatigue due to the length of the experiment.

3. The risk of accident while viewing displays used in the experiment.

4. The risk of driving an unfamiliar vehicle on a test track at 35 mph.

5. The risk of events that require evasive maneuvers, such as swerving or hard braking. Braking forces are not expected to exceed .5g.

While the risk of participation in this study is considered to be no more than that encountered in everyday driving, if you are pregnant you should talk to your physician and discuss this information sheet with them before making a decision about participation.

Please be aware that events such as conditions on the public road, equipment failure, changes in the test track, stray or wild animals entering the road, and weather changes may require you to respond accordingly. The appropriate response may or may not involve rapid deceleration or acceleration.

In the event of an accident or injury in a vehicle owned or leased by Virginia Tech, the vehicle liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit. For example, if you were injured in a vehicle owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by this policy.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, worker's compensation does not apply to volunteers; therefore, if not in the vehicle, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses. For example, if you were injured outside of the vehicle owned or leased by Virginia Tech, the cost of transportation to the hospital emergency room would be covered by your insurance.

The following precautions will be taken to ensure minimal risk to you:

1. You may take breaks or decide not to participate at any time.
2. An experimenter will be present in the passenger's seat. We ask that you drive as you would normally drive.
3. On public roads, we will not ask you to exceed the posted speed limit.
4. On public roads, the lead vehicle driver you will be asked to follow is a VTTI employee that has been trained on the experiment protocols and procedures.
5. On the test track, we will not ask you to exceed 35 mph.
6. The driver of the other experimenter vehicle present on the test track is a VTTI employee that has been trained in test track procedures and protocols.
7. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
8. You are required to wear a seat belt restraint system while in the passenger vehicle.
9. The vehicle is equipped with a fire extinguisher and first aid kit.
10. A pre-trip inspection has been performed on the vehicle prior to your test session.

11. The experimenter will end the experiment if inclement weather occurs. This includes any weather that results in the use of the windshield wipers, wet or icy road surfaces, and reduced visibility due to fog.

12. You do not have any medical condition that would put you at a greater risk, including but not restricted to neck/spine injury, epilepsy, balance disorders, and lingering effects of head injuries and stroke.

13. In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room. You may elect to undergo examination by medical personnel in the emergency room.

IV. Benefits of this Project

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study may contribute to the improvement of in-vehicle systems.

V. Extent of Anonymity and Confidentiality

The data being collected in this experiment includes:

1. Personal information, including Social Security Number. This is personally identifiable information. This is required for payment purposes and is not for use in any analysis, nor will it be reported in any way.

2. Video recordings collected during the experiment. These recordings will include video recorded from your perspective via head mounted camera, video of your face, and will include audio. This data is personally identifiable.

3. Driving measures, such as following distance, GPS data, lane keeping, and vehicle speed: These are collected by recording instruments in the vehicle. This data will not be personally identifiable.

We will treat all of the data gathered in this experiment with confidentiality by separating your name from the data and replacing it with a number (e.g., Driver 001). It is possible that the Institutional Review Board (IRB) or study sponsor may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

All video and other data recorded in this study will be stored in a secured area at Virginia Tech. Access to the data files will be under the supervision of the Principal Investigator and lead VTTI researchers involved in the project. All data will be encrypted at the time of data collection and will be decrypted only for approved analyses. It is possible that, after data collection is complete one copy of study data will be transferred to the project sponsor (the U.S. Department of

Transportation) for permanent storage and oversight. Please note that they will follow the same procedures for protecting participant confidentiality.

Authorized project personnel and authorized employees of the research sponsors will have access to the study data that personally identifies you or that could be used to personally identify you. As explained below, other qualified research partners may also be given limited access to your driver, vehicle, and driving data, solely for authorized research purposes and with the consent of an IRB. This limited access will be under the terms of a data sharing agreement or contract that, at a minimum, provides you with the same level of confidentiality and protection provided by this document. However, even these qualified researchers will not be permitted to copy raw study data that identifies you, or that could be used to identify you, or to remove it from the secure facilities in which it is stored without your consent.

The sponsor of this project, NHTSA, may publicly release data, in final reports or other publication or media for scientific, educational, research or outreach purposes. Additionally, NHTSA may be required to release data due to Freedom of Information Act (FOIA) or other Open Government Initiative request. Data will not be released in raw form. Any data released under FOIA will not be linked to your name or contact information, and any personally identifying information will be redacted, edited, or removed. This includes editing of video and or audio files to remove personally identifying information if necessary.

VI. Compensation

You will be compensated $70 for your full participation. If the session ends early for any reason, you will be paid the rate of $30 per hour, rounded to the nearest ½ hour. All compensation, whether for the full amount of $70 or any partial amount, will be issued using a pre-loaded MasterCard. Please allow up to 1 full business day for activation of the card. Once activated, this card cannot be used past its expiration date. The issuing bank will also begin deducting a monthly service fee of $4.50 after three months of inactivity. Expected participation time will be for one visit, lasting approximately two hours.

If compensation is in excess of $600.00 dollars in any one calendar year, then by law, Virginia Tech is required to file Form 1099 with the IRS. For any amount less than $600.00, it is up to you as the participant to report any additional income as Virginia Tech will not file Form 1099 with the IRS.

Also, you will be asked to provide researchers with your social security number for the purposes of being paid for your participation. For tax recording purposes, the fiscal and accounting services office at Virginia Tech (also known as the Controller's Office) requires that all participants provide their social security number to receive payment for participation in our studies.

VII. Freedom to Withdraw

Participants in this study are free to withdraw at any time. There is no penalty for withdrawing. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty. If you choose to withdraw while you are operating the vehicle on public roads, please inform the experimenter of this decision and he/she will direct you to return to VTTI and safely park the test vehicle. If you choose to withdraw while you are operating the vehicle on the test track, please inform the experimenter of this decision and he/she will direct you off of the test track and have you safely park the test vehicle.

VIII. Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained. This form is valid for the period listed at the bottom of the page.

IX. Subject's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.
3. To wear your seat belt while operating the vehicle.
4. To abstain from any substances that will impair your ability to drive.
5. To obey traffic regulations when on public roads, including the posted speed limit.
6. To adhere to the 35 mph speed limit on the test track, and maintain safe operation of the vehicle at all times.
7. To treat the driving task as the primary task and perform other tasks only when it is safe to do so.

X. Participant's Acknowledgments

Check all that apply:

☐ I am not under the influence of any substances which may impair my ability to safely participate in this experiment.
☐ If I am pregnant, I acknowledge that I have either discussed my participation with my physician or that I accept any additional risks due to pregnancy.
☐ I do not have a history of neck or back injury or pain.
☐ I do not have uncontrolled diabetes.
☐ I do not have advanced osteoporosis.
☐ I do not have a history of a heart condition.
☐ I have not have had any major surgery in the last 6 months.
☐ I have not had an epileptic seizure or lapses of consciousness within the past 12 months.

☐I do not have chronic migraines or tension headaches.
☐I will inform the experimenter of any concerns or questions I have about this study.

XI. Consent to Use Video/Audio Data for Research Reporting Purposes

Digital video cameras will be used to record you while driving, including your face. These digital video files could be used to clarify the experimental methods and to help report findings at technical conferences and other presentations. These video files may also be shown to the research sponsors who may use the video/audio data, which will not be linked to your name or contact information, in final reports or other publication or media for scientific, educational, research or outreach purposes. We are asking your permission to show portions of video displaying your image when useful for research reporting purposes and as specified by the research sponsor.

XII. Questions or Concerns

Should you have any questions about this study, you may contact the Principal Investigator or the Project Manager:

Sheldon Russell	srussell@vtti.vt.edu	[redacted]
Shane McLaughlin	smclaughlin@vtti.vt.edu	[redacted]

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the Virginia Tech Institutional Review Board at irb@vt.edu or [redacted].

XIII. Participant's Permission

I have read and understood the Information Sheet and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

Participant's Name (Print)   Signature   Date

Experimenter's Name (Print)   Signature   Date

Informed Consent Document

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: Head-Up Display and Distraction Potential
Investigators: Sheldon Russell, Josh Radlbeck, Thomas Champagne, Zach Crane, and Shane McLaughlin

I. The Purpose of this Research/Project

We apologize for not being able to tell you the additional purpose of this research prior to your participation. The purpose of this study is to examine the distraction potential of Head-Up Displays.

We deliberately created a situation where the vehicle you were asked to follow would drop an object in the road, requiring an evasive maneuver. The dropping of the object was coordinated to occur as you took your eyes off of the forward roadway. This was done to test if reaction times are different when using Head-Up Displays when compared to Head-Down Displays. All drivers were in communication during the event to ensure safety. Furthermore, the object was an empty cardboard box and would pose little to no safety risks if a collision were to occur.

The results of this study will contribute to our understanding of how Head-Up Displays can benefit or distract drivers. This understanding will provide improvements in future system design and guidelines.

Your performance in this test trial is not an indication of your driving ability. We ask that you do not talk about the details of this study to others after your participation because this may invalidate future data that may be collected.

At this point you are free to end the experiment. If you would like to leave, we can drive you back to the Institute and compensate you for your time. However, if you are willing to continue, we have some additional questionnaires that we would like for you to complete. All data collected up to this point will be included in our analysis if you decide to continue.

Please initial one of the following:

_______ I do not want to continue.

_______ I would like to continue.

Please initial one of the following:

_______ I give my voluntary consent for the data that was collected so far and will be collected to be used in the analysis for this research project.

_______ I *do not* give my voluntary consent for the data that was collected so far to be used in the analysis for this research project.

All other aspects of the earlier information sheet you signed, including risks, benefits, safety precautions, use of video for presentations, and your responsibilities, continue to apply to the remainder of this experiment.

II. Questions and Concerns

Should you have any questions about this study, you may contact the Principal Investigator or Project Manager:

Sheldon Russell	srussell@vtti.vt.edu	[redacted]
Shane McLaughlin	smclaughlin@vtti.vt.edu	[redacted]

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the Virginia Tech Institutional Review Board at irb@vt.edu or [redacted].

III. Participant's Permission

I have read and understood the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. **If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.**

Participant's Name (Print)   Signature   Date

Experimenter's Name (Print)   Signature   Date

Appendix C: Demographic Questionnaire

Virginia Tech Transportation Institute
HUD Questionnaire

General Information:

Date: ______________
Gender: ______________
Age: ______________

1. Are you left or right handed? *Left*______*Right*___________
2. Are you left or right eye dominant (result of test)? *Left*______*Right*___________

Driving History:

1. At what age did you receive your driver's license?
   ____

2. Please estimate the following:

   a. Hours driven per week: ______________________________

   b. Miles driven per week: ______________________________

Appendix D: Supplemental Results

The original intention of the project was to identify a method to determine or manipulate the driver's focal distance to near or far displays. This is due to a potential drawback with HUD use due to focal depth. Displays with a focal depth of less than 6 meters require visual accommodation to allow drivers to focus on them. This distance is related to human 'optical infinity' or the furthest point of foveal focus for the human visual system. Older drivers may have difficulty viewing these displays, because they may have difficulty with visual accommodation. Therefore, they may take more time to visually focus and read displayed information compared to younger drivers (Gish & Staplin, 1995).

Due to delays related to approvals required from the Office of Management and Budget, HUD displays of different focal depths could not be implemented in the experiment as test conditions. Although the present study included displays at different focal depths, no practical differences were observed based on focal depth. A statistically significant interaction was observed between older and younger drivers for the aftermarket and HDD displays. However, no individual comparisons were statistically significant. Again, the displays used in this study did not allow for a robust comparison of focal depth; limited availability of aftermarket HUD devices due to delays in the OMB approval process prevented the research team from fully investigating the effects of focal depth.

This remainder of this appendix presents additional results not affecting the overall conclusion of the study or interpretation of the research questions.

Total EOD

Total time on display differed significantly between the task types, $F(2, 92.2) = 39.60$, $p < 0.0001$. Specifically, participants spent less time looking at the display during HUD tasks than they did during HDD tasks and aftermarket tasks. Note that just driving tasks are not included in this analysis because the total task time was preset and not random. Table D-1 provides the mean total time on display by task type, as well as lower and upper CLs. Table D-2 provides the comparison results, with mean difference, lower and upper CLs, and *t* and *p* values.

Table D-1. Mean Total Time on Display by Task Type With Lower/Upper CLs

Task Type	Mean	Lower CL	Upper CL
HUD	0.63	0.57	0.70
HDD	0.96	0.90	1.03
Aftermarket	0.96	0.89	1.02

Table D-2. Comparison Results for Difference in Total Time on Display

Task Type	Comparison	Mean Difference	Lower CL	Upper CL	*t*	*p*
HUD	HDD	-0.3	-0.4	-0.2	-7.8	<0.0001
HUD	Aftermarket	-0.3	-0.4	-0.2	-7.6	<0.0001

Task type and age group also had a significant interaction, $F(2, 90) = 5.86$, $p = 0.0040$. Specifically, older participants spent a significantly longer amount of time looking at the HDD display and aftermarket display, but there was no significant age group difference for the HUD display. Table D-3 provides the comparison results, with mean difference, lower and upper CLs, and t and p values.

Table D-3. Age Group Comparisons for Total Time on Display

Task Type	Comparison	Mean Difference	Lower CL	Upper CL	*t*	*p*
HUD	Older vs. Younger	0.02	-0.11	0.15	0.33	0.7429
HDD	Older vs. Younger	0.28	0.15	0.40	4.3	<0.0001
Aftermarket	Older vs. Younger	0.24	0.11	0.37	3.7	0.0003

Participants had significantly different total time on display during just driving tasks depending on which display was present, $F(2, 381) = 5.77$, $p = 0.0034$. Specifically, participants spent a significantly longer time looking at the HUD display than the HDD display. Table D-4 provides the mean percentage time on display during just driving tasks by task type, as well as lower and upper CLs. Table D-5 provides the comparison results, with mean difference, lower and upper CLs, and t and p values.

Table D-4. Mean Total Time on Display During Just Driving by Task Type With Lower/Upper CLs

Task Type	Mean	Lower CL	Upper CL
HUD	0.27	0.22	0.33
HDD	0.14	0.09	0.20
Aftermarket	0.19	0.14	0.25

Table D-5. Comparison Results for Difference in Total Time on Display During Just Driving

Task Type	Comparison	Mean Difference	Lower CL	Upper CL	*t*	*p*
HUD	HDD	0.13	0.05	0.20	3.4	0.0009
HUD	Aftermarket	0.08	0.01	0.16	2.1	0.0336

Age Group and Task Type Interaction Results

The interaction between age group and task type was significant, $F(7, 32) = 13.97$, $p < 0.0001$. While there is no difference for the no-task condition between the older and younger age groups, there are several differences that are significant. Table D-6 summarizes the mean time to look forward by age group and task type. Because there are so many comparisons to make, *Table D-7* only summarizes the significant interactions. Any age group and task type combinations not in Table D-7 were found not to be statistically significant.

Table D-6. Summary of Mean Time to Look Forward by Age Group and Task Type

Age Group	Task Type	Mean Time to Look Forward (seconds)	95% CI Lower Bound	95% CI Upper Bound	Number of Participants Who Looked Forward
Older	No task	0.02	-0.03	0.77	6
	HDD task	1.77	0.64	2.90	4
	HUD task	2.64	1.86	3.41	5
	Aftermarket task	2.16	1.31	3.00	4
Younger	No task	0	0	0	6
	HDD task	2.15	1.33	2.97	5
	HUD task	1.95	1.24	2.66	6
	Aftermarket task	1.70	-0.28	3.67	4

Table D-7. Significance of Comparisons Between Age Groups and Task Types

Age/Task Type	Comparison	Mean Difference (seconds)	95% CI Lower Bound (seconds)	95% CI Upper Bound (seconds)	*p*	Significant
Younger, no task	Older, no task	-0.02	-1.20	1.15	1.00	No
Younger, HDD task	Older, no task	2.13	0.90	3.36	<0.001	Yes
Younger, Aftermarket task	Older, no task	1.68	0.36	2.99	<0.001	Yes
Younger, HUD	Older, no task	1.92	0.75	3.10	<0.001	Yes
Older, HDD task	Older, no task	1.75	0.44	3.06	<0.001	Yes
Older, HUD task	Older, no task	2.61	1.38	3.84	<0.001	Yes
Older, Aftermarket task	Older, no task	2.14	0.82	3.45	<0.001	Yes
Younger, HDD task	Younger, no task	2.15	0.92	3.38	<0.001	Yes
Younger, Aftermarket task	Younger, no task	1.70	0.39	3.01	<0.001	Yes
Younger, HUD	Younger, no task	1.95	0.77	3.12	<0.001	Yes
Older, HDD task	Younger, no task	1.77	0.46	3.09	<0.001	Yes
Older, HUD task	Younger, no task	2.64	1.40	3.87	<0.001	Yes
Older, Aftermarket task	Younger, no task	2.16	0.85	3.47	<0.001	Yes

To summarize the results of the several comparisons, all comparisons that were made with a no-task condition (older or younger) were found to be significant. All other comparisons were not significant. These results are like the results comparing time to look forward between the task types: the no-task condition is significantly different from the others; the other conditions are not significantly different from one another. Similarly, the analysis based on age group showed that age groups do not have significantly different average times to look forward. This is evidenced by comparison of the younger, no task and older, no task conditions (there is almost no difference) and the fact that all participants in the older group, no matter their task type, are significantly different from both the older, no task conditions and younger, no task conditions. In addition, younger participants average times to look forward, regardless of display type, are significantly different from both older–no task, and younger–no task, conditions. This indicates that differentiating between older and younger drivers does not necessarily provide more or less information about the average time to look forward.

Time to Look Forward Survival Curve Analysis

Time to look forward was analyzed for differences between the task types and age groups. Task type showed significant differences in time to look forward between the four task types, including just driving ($\chi^2 = 41.5, p < 0.0001$), but not between the HUD, HDD, and aftermarket tasks with the just driving data removed ($\chi^2 = 0.8$, $p = 0.7$). Age group average times to look forward were not significantly different from one another with ($\chi^2 = 0.3$, $p = 0.6$) or without ($\chi^2 = 1$, $p = 0.3$) including the just driving data.

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