Designing In-Vehicle Message Delivery with Manual and Highly Automated Driving

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Appendices

Delivering Road Signage Information during Highly Automated Driving: A Review of Human Factors Considerations

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***Abstract*—As automated vehicles become more prevalent on roadways, it is necessary to research driver behavior during interaction with these automated vehicles. With higher levels of vehicle automation, drivers will become less engaged with the road environment. For example, how to effectively deliver information that has been traditionally shown on roadside signage is a challenge that demands a prompt answer. In this review, we summarize current knowledge on three existing domains of research: (1) the effectiveness of traditional road signage, (2) vehicle automation and human factors considerations, and (3) current design guidelines of in-vehicle information presentation. Based on the review of existing empirical studies, we identify the critical research gaps in the literature to guide the design of effective communication of road signage information in automated vehicles. We propose a framework highlighting various factors that could determine the effectiveness of in-vehicle messaging. These factors include trait-based and state-based characteristics of the driver (e.g., attentional capability, experience with technology), characteristics of the driving environment (e.g., visibility) and vehicle automation (e.g., level of automation), as well as design parameters of the in-vehicle display (e.g., information content and display format). This literature review is motivated by the need to identify the critical considerations for effective in-vehicle road signage presentation development. The intent is to provide a detailed review and analysis of knowledge gaps to inspire future research on the topic and development of in-vehicle interface designs for highly automated driving.**

***Index Terms*—Automated driving, automated vehicles, road signage, driver performance, vehicle safety, information presentation, Advanced driver assistance systems**

I. Introduction

WITH the rapid development of sensor and computing technologies, personal vehicles are now capable of collecting voluminous information on vehicle status and the road environment, as well as making proximity estimates and predicting potential driving events. Recent advances in vehicle automation have envisioned future driving without the need for drivers to attend to the road. Ford's earlier announcement to deliver high volume, fully automated vehicles by 2021 is a key example [1]. Volvo, Nissan, Honda, Toyota and BMW have all promised similar timelines (e.g., [2-5]). Federal and state legislation is also responding to this rapid technological change [6] [7]. These vehicles will be fully equipped with information systems for navigation, communication, and entertainment, resulting in a shift in information communication from driver-roadway interaction to driver and in-vehicle display interaction. For example, drivers may be less likely to read road signs and rather increasingly rely on a GPS device to notify them of a speed limit change or beginning of a school zone.

Despite decades of research on in-vehicle notification designs (see [8] for a complete review), the majority of studies have focused on presenting information that is primarily related to the driving task, such as collision warnings and navigation information. In contrast, how to effectively present information that is non-safety critical, secondary to driving but important for a trip (e.g., notifications of a rest area and local businesses), remains unexplored, especially during highly automated driving. The results of these studies that focused on the impact of using in-vehicle information systems on manual driving (e.g., [9-11]) or the effectiveness of collision warning designs (e.g., [12-14]) are informative but may not necessarily generalize to non-safety critical notifications under automated driving. This is because driver attentional processing could differ depending on the degree of relevance of the notification to the primary driving task, and drivers' levels of alertness may be lower under automated driving [15-17].

In this literature review, we aim to provide an overview of the current understanding of driver interaction with road signage and automated driving technologies as well as factors that affect driver performance including characteristics of the driver, the environment, vehicle automation, and the in-vehicle display. We discuss the research gaps in the literature to inform the design of in-vehicle messaging of road signage information under highly-automated driving conditions and propose a framework to guide further empirical investigations.

II. Road Signage and Human factors Issues

One of the most common forms of traffic control on the roadway is a road sign. Road signs utilize words, pictorial elements, or a combination of these to convey the information [18]. Although existing design guidelines were developed for signs along the road, these guidelines could still be informative to ensure the signs remain easy to read and understand when

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presented in an in-vehicle display. Sanders and McCormick [19] outlined five ergonomic principles related to the development of traffic signs, which are 1) spatial compatibility, 2) conceptual compatibility, 3) physical representation, 4) familiarity, and 5) standardization. Spatial compatibility refers to the sign's physical position and orientation in space. For example, in a right-side driving environment, a stop sign is always placed to the driver's right at an intersection. Conceptual compatibility refers to the degree in which the symbols and words present on the sign match the driver's associations. A stop sign is always octagonal, thus making people associate stopping with an octagonal shaped sign. Physical representation refers to the degree to which the content of the sign represents reality. In this case, the sign needs to accurately inform the driver about the roadway. Familiarity refers to the extent of the driver's experience with a specific sign. Some drivers may encounter signs that are not as common and may be confused as to their meaning. This lack of familiarity can be an issue if the sign is designed to serve as a warning or in cases of driving in foreign countries [20]. The last guideline is standardization, which refers to the level of consistency in the design of the signs. Shape, color, and pictorial elements should be consistent for each specific type of sign, otherwise issues with driver interpretation can arise if different sign designs are being used for the same purpose. Shinar & Vogelzang [21] found that pairing pictorial information with text on road signage presentation improved interpretation accuracy, even when the sign was unfamiliar to the driver. While the presentation of road signage on an in-vehicle display potentially allows more creative designs of this information communication and more flexibility in the time and duration of communication, visual presentation of signage should still consider these ergonomic principles to be compatible with signs on the road.

Even though drivers have a vast amount of experience with numerous types of road signage, these signs have limitations [22-23]. For example, driver awareness of a road sign can be easily affected by weather (e.g., fog vs. clear), lighting conditions (e.g., night vs. day), vegetation (e.g., tree branches covering a sign), sign legibility (e.g., font size of a street name being too small to see), and potential culture difference (e.g., foreign drivers face difficulty in understanding local signs). In addition, driver compliance with a road sign may be low even when they perceive the sign, because they do not associate the sign with a necessary action. For example, a driver may ignore the need to stop at a stop sign when there is no traffic at an intersection. A comparison across studies conducted from 1931 to 1999 on driver compliance with conventional stop signs using traffic counts revealed a sharp decline of the percentage of drivers who made a full stop at stop signs [24] (p. 2775, Table XIV; full stop from 47% in 1931 to 1% in 1996, full violation from 42% in 1931 to 97% in 1996). With higher levels of vehicle automation, drivers may not need to perform some or all aspects of the driving task, thus their visual scanning and vigilance of the road may degrade as compared to manual driving [25]. As a result, driver processing of signage on the road could be significantly limited or even eliminated. In contrast, in-vehicle messaging of signage information presents opportunities to address many of these limitations.

III. Highly Automated Driving

Many car manufacturers are releasing increasing numbers of automated vehicles (e.g., Tesla, Volvo, BMW, General Motors, Ford, and Fiat Chrysler Automobiles, just to name a few) which promise to improve safety and reduce the number of accidents and injuries that arise from manual driving [26]. The Society for Automotive Engineers (SAE) has defined six levels of automated vehicles in order to determine the capabilities of a vehicle with varying degrees of automation or driver assistance [27]. There are a number of human factors issues that go along with these new technologies. For example, among the six levels of automation, vehicles with level 2 automation can maintain lane position and adaptively control speed, but the driver would be responsible to monitor the road in order to safely respond to road hazards and determine the suitability of using certain the automated functions. With further increase in the level of automation, Level 3 vehicles can make informed decisions about driving in certain environments, but the driver would still need to be available to takeover control when the automation becomes incapable in executing the driving task. However, when the vehicle is automated, the driver is likely disengaged and therefore would need to be cued to retake control from the vehicle in part or entirely at a moment's notice [28]. Examples of Level 2 automated vehicle technologies include adaptive cruise control, active lane-keeping, and forward collision warning systems [29] [30]. These types of technologies are generally referred to as Advanced Driving Assistance Systems (ADAS). Several manufacturers have included some, if not all, of these technologies in current generations of vehicle models [31]. Some companies claim to have produced vehicles that reach Level 3 automation [32] [33]. These vehicles aim to take drivers to destinations within mapped areas as drivers tell the car where they want to go. However, the driver is still expected to be prepared to takeover control when necessary.

While higher levels of vehicle automation have the potential to ultimately reduce crashes involving driver error, there are a number of human factors concerns that have been expressed [28] [34]. These include mode confusion, error handling, overreliance, and driver underload. Mode confusion refers to the potential for the operator to misunderstand their responsibilities during automated driving. Error handling refers to where the ultimate decision authority for action rests in response to a hazard or error and whether the response of the decision authority is consistent with expectations. For example, if a driver has enabled automated vehicle controls, and there is a hazard in the road, the car may respond in a way that is inconsistent with the driver's expectations, especially if control is not ceded to the driver. Overreliance describes the issue that drivers may attempt to engage the vehicle automation as frequently as possible despite system limitations. Overreliance may lead to degradation of driver alertness and capability to handle expected situations, such as taking over vehicle control when needed. Finally, driver underload refers to the decrease of a driver's workload when automation operates the vehicle, leading to driver disengagement and boredom.

A. *Out-of-the-Loop Problem*

A major human factors concern of highly automated technologies is that these technologies would lead to reductions in situation awareness, which would result in performance decrements when drivers were required to takeover control from automated vehicle mode [35]. These decrements in driver performance during takeover could be a result of the driver being out of the loop during automated driving.

The out-of-the-loop state could result from a lack of physical interaction or cognitive disengagement with a task. When a driver is not required to control steering, acceleration, and braking, the out-of-the-loop state could arise [36]. As a result, the driver is reduced to passively monitoring the vehicle functioning instead of being actively engaged and monitoring the vehicle. In addition to the physical control loop, this problem could also appear when a driver is disengaged with the cognitive control loop [36]. In this case, the driver loses situation awareness of the current state of the vehicle either because they are not viewing the roadway or because they are disengaged from the driving task. Related to this, research on mind wandering while driving has shown detrimental driving performance as a result of cognitive disengagement [37-40]. When the driver's mind becomes disengaged from the driving task, a range of impairments on the driving performance would occur, including greater variabilities in vehicle speed [37], slower reaction time [40], reduced visual scanning of the environment [38], and poorer recognition/memory of the visual environment [39]. The physical and cognitive loops are intertwined, as physical control of a vehicle provides neuromuscular feedback to the driver, which can then be cognitively translated into heading corrections of the vehicle through adjustments in steering torque [41].

One potential method to address the out-of-the-loop problem is to schedule drivers' takeover in a predictable fashion. Merat and her colleagues compared driver performance during a takeover request under conditions where automated driving to manual driving alternated at a regular system-based interval or based on the duration of a driver's gaze being away from the road [42]. The study found that driver engagement was higher with a system-based interval as it allows expectation and preparation. When drivers expect the takeover, they are primed to start attending to the dynamic situations present inside and outside the vehicle, which allows a driver to resume control more safely. This finding begs further investigations of whether in-vehicle presentation of road signage information may serve as a cue to engage drivers with the environment regularly. Takeover performance is also critical in the discussion of in-vehicle messaging, because the driver may have to assume vehicle control to head towards a desired business destination, in which case a takeover notification and road sign presentation may be coupled

B. *Driver Engagement in Non-Driving-Related Tasks*

Several studies observed that drivers tend to engage in non-driving-related activities during highly automated driving. Due to the driver not manually operating the car, they are more likely to engage in a separate task that diverts attention away from driving [43]. Much of the work done in this area reveals some conflicting results in terms of the effects of such activity engagement on takeover performance. Some studies have found that non-driving related tasks have a similar effect to that of distracted driving during manual driving [44] [45]. Other studies, in contrast, showed non-driving-related activities to be beneficial for takeover performance [46]. For example, Miller et al. found that driver fatigue was lower when engaged in a non-driving-related task, such as watching a television show on a tablet or reading, during an automated drive [16]. Without non-driving-related tasks, drivers showed signs of drowsiness, which is dangerous in situations where a takeover is required. Clark and her colleagues examined takeover performance as drivers voluntarily engage in non-driving-related activities during automated driving [48, 49]. In general, findings from this study and others suggest that such activities did not impair driver takeover performance [47, 48], although longer activity engagement tends to be associated with slower takeover response after a notification [49]. Furthermore, regardless of the modality of the voluntarily chosen activity, participants showed consistent takeover performance [48].

Gold et al [50] found that while engagement with a non-driving-related task did not influence takeover time, it did increase the risk of collision. In addition, their study [50, 51] found that drivers have a higher risk of collision when a takeover happens with high traffic density. As it relates to drivers' consumption of road signage information, drivers who are in a highly automated vehicle may be required to resume control in order to exit the road when they need food or lodging. At exits, traffic situations become more complex due to lane and speed changes. These factors will all have some effect on driver's ability to effectively and safely assume control of the vehicle in order to arrive at a target destination.

Other work examined how non-driving-related tasks during automated driving affect workload. Miller and Boyle investigated driver performance of a non-driving-related task during automated lateral vehicle control [52]. This study assessed driver performance across eight drives over three non-consecutive days within a seven-day period. The results of the study showed that participants experienced higher workload when automation was removed, and the driver was required to resume manual control of the vehicle following experience with automated driving.

Driver performance decrements due to secondary task engagement has been a concern with increasingly complex in-vehicle technologies [53] [54], although some research show that these decrements may be mitigated by reducing the complexity of the secondary task during manual driving [53-55]. During automated driving, drivers are likely to be engaged with non-driving-related activities [49]. If such activity does not involve interacting with the in-vehicle display, the design of in-vehicle messaging should consider its potential in capturing driver attention. Cueing will be addressed later in this review, but the design of in-vehicle messaging should assume the presence of other tasks drivers may be performing to promote driver processing of the message.

C. *Driver Mistrust*

Another factor that impacts driver performance during highly automated driving scenarios is the degree of trust between the human and the machine. The nature of automated driving means that the vehicle is making decisions on behalf of the driver and as a result, the driver must trust that the vehicle is operating safely [56]. Previous work done on this topic has shown that use of simulated autonomous vehicle can result in significant physiological stress [57]. Other work has shown that driver trust of automated vehicle technologies varies depending on the type of automation in the vehicle [58]. For example, drivers tend to trust side-view assist more than active lane keeping [58]. The trust between driver and vehicle in autonomous driving is of interest because trust can determine the likelihood of a driver's usage of automation [59]. A lack of trust may result in driver's disregard of messages from automation regarding the distance to particular destinations, which would result in failure to reach those destinations. Driver trust has not been investigated with regards to non-safety related messaging, but driver trust has been shown to vary across specific Advanced Driving Assistance Systems (ADAS) [58]. Therefore, implementations should ensure that content for in-vehicle messaging regarding signage is kept up to date in order to foster and continuously calibrate driver trust in the in-vehicle messaging content.

IV. Advanced In-vehicle Displays

In-vehicle displays and in-vehicle information systems provide additional information to the driver, and as a result they can have significant effects on the behavior of drivers. The inclusion of in-vehicle information systems (IVIS) in the car increases the number of tasks that the driver must perform concurrently [60]. During manual driving, IVISs can degrade driving performance by overloading the driver, thus resulting in safety concerns [61, 62]. A previous study showed that during naturalistic observations of 100 drivers, 78% of crashes and 65% of near crashes were the result of driver distraction, of which in-vehicle technologies accounted for roughly a quarter of these events [63]. While this study was done in the context of manual driving, driver distraction due to these types of displays could also affect the ability of the driver to respond quickly to a takeover request.

Research has found that drivers tend to adapt their behavior in various ways to compensate for the presence of the IVIS in the vehicle, but these adaptations vary between being beneficial and detrimental [64-66]. One of the issues is that IVIS creates secondary tasks for the driver, which in some cases may increase the workload on the driver to the point that their ability to respond to environmental events is impacted negatively [67]. For example, IVIS displays that required manual input were shown to increase workload and were related to increased, center line crossings, and off-road accidents in a simulator study [61]. Drivers also differ in the way they interact with IVIS displays. Higher risk drivers demonstrate longer eyes-off-road times (EOR) than lower risk drivers, even when performing tasks that they rated as higher risk, such as typing in a street address during driving [68]. However, driving performance with an IVIS in the vehicle does improve with time as individuals become more proficient in the system and tends to follow the power law of practice [65].

While it is known that IVIS displays impact driver performance during manual driving, those observed performance decrements may not apply to automated driving. When the driver is not required to physically control the car during highly automated driving, the IVIS can be used for more than simply displaying navigation information or vehicle status information. A recent survey of user preferences for activities during automated driving revealed that instead of doing nothing, people prefer listening to music or entertainment, engaging in communication or productivity during an automated drive [69]. An effective presentation of messages may recapture the driver's attention from the secondary activity. The majority of the work in this area has focused mainly on messaging safety-critical information (e.g., such as a forward collision warning [13] [70]) to the driver in manual driving, as reviewed below.

A. NHTSA Guidelines for In-Vehicle Messaging

NHTSA [8] developed a series of design guidelines for driver vehicle interfaces including those for the presentation information to the driver during manual driving. The current guidelines state that messaging content needs to be designed in order to pose minimal additional workload and not obstruct a driver's ability to process information from the roadway [8]. As processing information from an in-vehicle display may occupy the same pool of perceptual and cognitive resources the driver needs to operate the vehicle, poor interface design could lead to distracted driving [71]. Specifically, the recommendations state that displays should support tasks that can be completed in sequential glances that are brief enough not to affect driving and tasks that do not require the driver to make time sensitive responses [8]. These guidelines are supported by previous work that has investigated empirical evidence on driver distraction (for a comprehensive review see [72]). During manual driving, effective messaging content needs to be informative without increasing workload, but these concerns may become more complex in automated driving given the general underload issue and sudden unexpected spike of workload in the event of a takeover.

The design of in-vehicle messaging needs to consider the three phases that take place during message presentation to the driver: extraction, recognition and interpretation [70]. Extraction relates to how easily the message can be perceived by the driver; recognition refers to the structure of the message and whether it accurately represents the information it is trying to convey to the driver; and interpretation relies on the ability of the driver to understand the message [8]. While these phases were developed in reference to driving in a manual context, they may also apply to automated driving, with an additional assumption that a driver is likely disengaged from the driving task. For example, NHTSA released guidelines for how the elements in a visual display should be presented in order to optimize these three phases of message presentation and processing. Specifically, the use of certain representation can aid in driver's processing of information. One example is the use of continuous graded displays that indicate criticality of warning via "looming" or scaled distance to show crash warnings as well as the use of symbolic or pictorial information to aid understanding without a need to read text [8]. NHTSA also recommends symbolic or iconic images to add meaning to analog displays such as a collision warning so that the driver does not need to read anything to interpret the information. Spatial information can be used to present lane change information or intersection information. Representational information such as display indicating lane to be in for a merge, can be used for scenarios when a spatial location needs to be conveyed to the driver [8]. The use of stimulus-response compatibility, or consistency between the type of display and type of information being displayed, allows these specific representations to aid in the driver's understanding of the visual display and the effectiveness of these types of display elements has been supported empirically [8] [73-74].

Another issue is the amount of information being presented in one display, which can result in display clutter if too much information is presented at once. It is generally agreed in the literature that the amount of attention devoted to the display increases with an increasing amount of clutter [75]. Pankok and Kaber extended these findings and observed that in higher workload scenarios, drivers begin to use shorter glances at the display in order to account for increased clutter on the display [76]. This has been shown to occur despite drivers not affording enough time during shorter glances to process the information. Altogether, these findings suggest that the design of in-vehicle messaging needs to pay careful attention to the imposed workload on the driver, the ability of the driver to process the information, and limit the amount of display clutter in order to assist the driver in perceiving necessary information.

B. Advanced Display Technologies

New technologies are being developed to offload some cognitive processing from driver to the vehicle in the form of Advanced Driver Assistance Systems. With automated driving, it is not easy to predict where drivers will be looking at each given moment thus the amount of information to display and how to present it becomes a more difficult question to answer. Many vehicles now include visual displays, but if the driver is disengaged from these displays, they may not be nearly as effective alone.

Head-Up Displays (HUDs) are being integrated in vehicles as part of a current trend in vehicle engineering [77]. These displays present information on the windshield of the vehicle so that it is within the driver's field of view as they gaze at the roadway [78]. These displays have shown promise in reducing eyes-off-the-road and are more effective than Head-Down Displays (HDDs) in the presentation of navigation and safety information [79]. However, a major issue is such displays absorb driver attention, taking it away from the roadway even though the road scene is generally within the visual field [67] [80, 81]. For automated driving, HUD is being considered for presenting important trip-related information [82]. So far, there is little work done as of yet to test their effectiveness in displaying information such as augmented road signs to the driver during automated driving scenarios.

Multi-modal warnings are another type of display that are becoming increasingly prevalent in vehicles with more automation and provide a potentially viable solution for providing adequate information to the driver in case of a takeover request where the driver must re-establish situational awareness of the vehicle state and the road environment [83]. There is a growing body of work investigating how best to combine modalities for more effective driver alerts and how urgency can affect driver response times during takeover [64] [84, 85]. The general findings suggest that response time for driver was better in conditions where the alert was pictorial versus text based and when the perceived urgency of the alert was increased. However, these results were observed when a threat was present in the roadway, resulting in a takeover request from the vehicle to the driver. There is little work done on how multimodal warnings affect driver processing of non-safety-critical information such as signage for food and lodging.

C. In-Vehicle Display of Roadway Conditions

With the development of highly advanced automobile technologies, such as connected vehicles, in-vehicle information systems have been proposed as a potential alternative, or supplement, to road signage [24] [86-88]. Compared to conventional signs, in-vehicle information has many advantages, such as being less susceptible to poor weather conditions and presenting messages that are tailored to traffic conditions (current and anticipatory) as well as driver information needs. For example, lodging information can be displayed more frequently to a driver in the evening than during the day. However, only a small number of studies have been conducted to guide the presentation of in-vehicle information of roadway conditions. In one study, Lee and his colleagues found that in-vehicle messages, such as warnings about "icy roadway" and "accident in lane", were much more effective when presented as redundant information, in addition to road signs, than when presented alone [64]. Caird and his colleagues examined the effectiveness of in-vehicle display of traffic light notifications and found that these notifications presented 8 to 12 seconds before arriving at an intersection reduced the frequency of drivers running yellow lights [87]. In a study by Creaser & Manser [88], drivers were provided with in-vehicle speed limit information. Although this in-vehicle presentation of information did not lead to significant improvements in driver longitudinal speed control and lane-keeping, drivers rated the in-vehicle information as favorable and helpful when following an unfamiliar route.

V. Factors that Influence the effectiveness of in-vehicle messaging

Several cognitive and engineering factors need to be taken into consideration when designing in-vehicle messaging content. Multiple factors may significantly affect the way messaging content is presented to the driver. Specifically, we address cognitive factors associated with characteristics of the driver, environment, engineering of the automated vehicle, and engineering of the in-vehicle display that might play a role in the effectiveness of message delivery. Figure 1 provides a conceptual illustration and summary of these specific factors.

The characteristics of the driver are major factors that can affect the efficacy of in-vehicle messaging during automated driving. State versus trait-based characteristics of the driver have separate effects on the driver's capabilities and their ability to perceive information on the road and are considered separately in this review. The distinction here is necessary because states can be influenced by the tendencies that result from trait level characteristics [89].

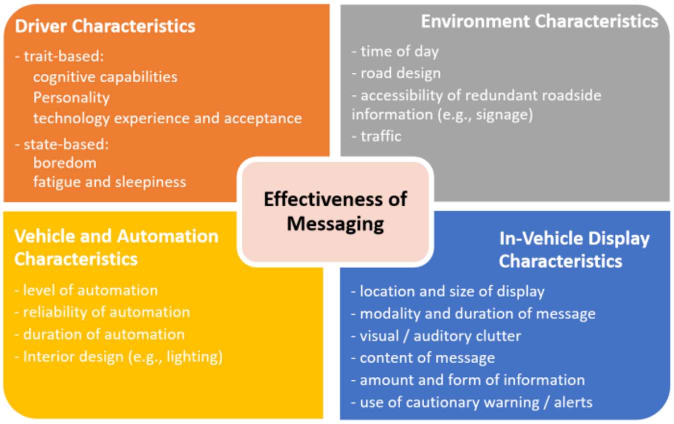

Fig. 1. A conceptual framework of factors that could influence the effectiveness of in-vehicle message delivery.

A. *Driver Characteristics*

Trait-based characteristics of a driver, such as perceptual, attentional, and cognitive capabilities, as well as personality profiles, make a driver prone to certain tendencies or states during driving [89]. For example, limited attentional resources may result in an inability for the driver to store relevant information in working memory, such as the relative speed of other cars on a highway. This lack of information can result in a safety hazard if the driver then attempts a lane change. The following section provides a review of specific trait characteristics that may affect the driver's ability to perceive and interpret in-vehicle messaging information.

1) *Visual and Auditory Perception*

Visual perception is one of the most important factors in the task of driving and has been shown to be a significant predictor of driving performance and safety [90] [91]. One major difference between automated and manual driving is that the driver's perception of visual information is altered because their attention may be focused internally to the vehicle (for a review see [92]). During manual driving, the driver is an active observer; in contract, in an automated vehicle, the driver becomes a passive observer as the person is not in direct control of the vehicle. In this passive-viewing state, the driver is likely generally disengaged from all information related to driving therefore less likely to perceive a message from the vehicle.

Auditory cues have shown significant promise for capture and divert attention to visual information that are spatially coupled with the auditory cue [93]. These findings suggest that messages presented by the vehicle will benefit from a pairing of auditory and visual information to best alert the driver that their attention needs to be diverted to the information being presented on the in-vehicle displays.

2) *Attention*

Spatial attention refers to the deployment of attention to locations in the visual field [94]. The allocation of spatial attention is affected by peripheral and central cues, which involve reflexive orienting and volitional orienting, respectively [95] [96]. During driving, an individual must direct their attention to several different locations within the vehicle in order to develop a complete picture of the status of the vehicle and travel. This process is related to automated driving because the driver may be required to reallocate attention from a secondary task to a display in the car during a takeover request. One concern is the spatial attention of older drivers who may experience decrements in vision, attention, and processing speed [97-99]. For example, older adults who have experienced falls demonstrated altered visuospatial attention during a volitional orienting task compared to those without experience of a fall [100]. As a result of decrements in attention, older drivers experience increased workload in driving [101]. Reduced spatial attention at older ages were found along the horizontal spatial extent as well as the depth axis in three-dimensional space [102].

Related to attention, driver boredom is a state characterized by decreased vigilance and overall performance decrements [103]. However, despite boredom being a state, there is work that demonstrates a trait-level characteristic of boredom proneness [104]. This characteristic refers to the amount of stimulation needed in order to prevent an individual from being bored. Boredom proneness can play a major role in automated driving since drivers are required to passively monitor the vehicle state [105]. Boredom proneness has been demonstrated to be affected by factors such as age, personality, and attitude toward driving [103]. Research on age effects in driver distraction has shown that younger drivers require higher levels of stimulation during driving and are more prone to distraction [106] [107].

To effectively design messaging content, attentional capability and boredom proneness must be considered because the messaging may fail to enter the driver's awareness or unnecessarily capture too much attention. These factors are especially important for older drivers who will need accommodations due to reduced attention capability with age-related cognitive changes. Also, drivers who are more prone to boredom may demonstrate decreased vigilance when in-vehicle messages are presented by the automation. This requires development of cues that can aid the driver in attending to the message content. Understanding of driver spatial attention under various driving and non-driving-related task conditions can also guide the presentation of in-vehicle messages.

3) *Working Memory Capacity*

One critical factor of in-vehicle messaging during automated driving is the driver's ability to process the information presented by the car. During automated driving, reduced engagement of the driver with driving task can pose some obstacles for designers. Many studies have focused on working memory as a factor that affects driver performance due to driving being a complex cognitive task [108]. Working memory is defined as the ability to hold and manipulate information while concurrently performing a task [109]. Previous results have shown that individuals who have high working memory capacity are better at maintaining cognitive control and focus during complex tasks compared to individuals who have lower working memory capacity [108] [110].

More recent work on working memory and driving has shown that high capacity novice drivers were less affected by increasing cognitive loads in driving task and performed better on lane changing [111]. In one study, participant working memory capacity predicted how quickly participants were able to identify a developing hazard scenario presented in video clips in a dual task condition and was also related to self-reported lapses in attention [108]. Similar empirical evidence has been found in another study that individuals with lower working memory capacity demonstrated more frequent instances of inattention than high capacity individuals [112].

Driver gaze behavior has also been used to show the relationship between driving performance and working memory capacity. Fixations have been shown to be an indicator of distracted driving as well as a predictor of hazard perception performance [113] [114]. Fixations on potential hazards can be interrupted by increasing the demands of a task [115]. Wood et al showed that there were significant differences in hazard perception between low and high working memory capacity groups during increased cognitive load from a secondary task [108]. Taken together, the results suggest that low capacity individuals perform worse on hazard perception performance partially because they fixate less on the hazard, which greatly reduces their ability to identify, interpret, and respond quickly to the hazard [108].

These findings point to the conclusion that in-vehicle messaging needs to be designed in a way that does not overload working memory of the driver. While automated driving does not require the driver to be actively engaged in the task of driving, the need for the driver to be ready to takeover may result in them monitoring the status of the car while also engaging in some secondary task. In-vehicle messaging and signage should be designed in such a way that the driver is able to process the information while not impairing their ability to take over control of the vehicle if need be, and individual working memory capacity should be considered.

4) *Personality*

Certain human factors studies of automated vehicles has focused on the ways in which personality traits can affect the use (or disuse) of automation. One way personality is discussed is based on the Five Factor Model developed by Costa and McCrae [4]. These factors are neuroticism, extraversion, conscientiousness, agreeableness, and openness and each have demonstrated influences on how humans interact with automation in various contexts [116] [117]. For example, neuroticism is predictive of impairment on working memory, attentional resources, and other cognitive functions [118]. These personality factors can account for a number of individual differences in task performance. In the context of automation, it has been shown that reliable automation can attenuate the effects of neuroticism during a threat detection task [117]. Personality traits may play a role in the acceptance of automated vehicle technology as well as the interaction between the driver and the technology. Specifically, personality traits have been shown to be related to mind wandering and boredom during driving [89]. While designers may not be able to develop messaging content that addresses personality specifically, it is important to be aware of the role these traits can play during initial adoption of technology and driver-vehicle interaction in general.

5) *Technology Experience and Acceptance*

The degree to which drivers engage in automated vehicle technologies may be determined in large part by their experience with and acceptance of the new technologies. For example, surveys about driver acceptance towards automated vehicle technologies has shown that drivers tend to vary in their comfort using adaptive cruise control and active lane-keeping across driving situations [119]. Specifically, drivers were more comfortable with automation during free flow traffic than in stop and go traffic scenarios [1119]. The degree to which drivers utilize these technologies is also affected by their level of experience with them, demonstrated by work showing that drivers who are used to adaptive cruise control tend to be faster at responding to event notifications during automated driving [120]. Older adults are a demographic of particular interest as they stand to benefit greatly from automated vehicle technology. Automated vehicle technology promises to vastly improve the mobility of older adults, while also improving their overall vehicle safety [121] [122]. The disparity in technology use between older and younger drivers is shown by results from a study by Clark and Feng, which found that older drivers engage in more conversational secondary tasks during automated driving while younger drivers tend to be immersed in electronic device use [49]. These findings demonstrate a gap that must be bridged to make automated vehicle technologies universally usable by everyone. For in-vehicle messaging content to be effective, this means considering individual including age differences with appropriate notification times to allow them to respond, and provide sufficient support especially at an earlier stage to promote adoption.

B. *Driver States*

Driver states are characteristics of a driver at a given moment, thus are dynamic and situational [123]. Driver states are influenced by a driver's circadian rhythm, their prior and current task at hand, and the environmental condition. Driver states that may be considered in the in-vehicle signage information delivery design include, but are not limited to, driver boredom, sleepiness and fatigue, as well as driver vigilance. Despite being separate, these state measures are often related and impact each other.

1) *Boredom*

A concern with level 3 automated driving (according to SAE taxonomy) is that the driver may become bored due to their disengagement with the driving task [104]. Part of what contributes to the state of boredom is the nature of the task during level 3 automated driving, which requires the driver to passively monitor the state of the vehicle [124]. In air traffic control, passive monitoring has been shown to contribute to operator boredom [125]. The issue is that relevant events occur infrequently and lead to periods of monotony, which then can cause boredom in the driver or operator. This is of concern because states of boredom can result in performance decrements such as slower response times and higher variability in responses [103] [126] [127]. Past work demonstrated that drivers tend to cope with boredom using approach or avoidance strategies [128]. In approach strategy, the driver may refocus their attention in order to increase the amount of stimulation they receive from the driving task; thus, they are approaching the task. Avoidance strategies are used when the driver seeks stimulation outside of the task which results in driver distraction, thus they are avoiding the task. Heslop showed that drivers tend to use avoidance strategies when engaged in the driving task resulting in driver distraction [103].

During automated driving, the driver will most likely tend towards this avoidance strategy and seek stimulation from a source other than monitoring the state of the vehicle. There is research that shows drivers who are actively monitoring automated systems demonstrate more signs of drowsiness than drivers who are engaged in secondary tasks such as reading a book or watching a video [16]. These states of boredom will increase during automated driving and must be accounted for when designing in-vehicle messaging to engage driver's attention to the message content. It is possible that proper stimulation provided by in-vehicle messaging of non-safety-related information such as logo signs may reduce the likelihood of driver boredom, a close examination is needed on whether that may offset the detrimental effect of task switching between a secondary task (e.g., sign identification) and the driving task (e.g., takeover).

2) Driver Fatigue

Driver fatigue is commonly experienced behind the wheel. Fatigue is defined as a gradual process that results in a disinclination towards effortful activity, which produces performance decrements and losses in efficiency [129]. May and Baldwin developed a taxonomy of Active Task-Related Fatigue and Passive Task-Related Fatigue, which is related to Sleep-Related (SR) Fatigue [130]. For the purposes of this review, only Active and Passive task related fatigue will be discussed because they are more directly related to the presentation of information to the driver.

Active Task-Related Fatigue is related to higher workload on the driver, which can result from higher traffic density or roadway conditions, including construction zones or adverse weather conditions [131]. In the case of active fatigue, the task demands of driving occupy a higher amount of attentional resources, leaving the driver with limited resources to perform concurrent tasks while maneuvering the vehicle safely, such as perceiving road signs. Passive Task-Related Fatigue is related to task underload, which can occur during long drives with low traffic density and minimal change in the driving environment. In the case of automated driving, the driver is more likely to be passively observing the vehicle function which will likely result in passive fatigue. Designers of automated vehicles need to take this fatigue and its effects into account when designing messaging content because performance decrements during assuming a part or the entire driving task as result of this fatigue can be dangerous.

3) Vigilance

When the vehicle is highly efficient under automated conditions, the role of the driver is reduced. The reduction in the driver's role results in a state of decreased vigilance on the driver's part because they are not in control of the vehicle's motion [105]. For example, drivers may fail to recognize and respond to hazards or roadway conditions in a timely manner when a takeover is required [13]. Control mode transitions such as the transition between automated and manual driving have a significant impact on the state of the operator, even if the driver knows when the takeover is happening [14].

Vigilance refers to the ability of an individual to maintain a state of sustained attention that allows them to detect stimuli in the environment that may be presented at random intervals [15]. Given a repetitive or monotonous task, vigilance tend to decrease over time [132-134]. This ability to maintain sustained attention during automated driving is important because the driver must be ready to respond to changes in the control state of vehicle during takeover requests or respond to in-vehicle messages.

Recent work in this area has been concerned with the driver being out-of-the-loop during the driving task (reviewed in section III.A) and subsequently lose situational awareness which is the perception, comprehension, and projection of the state of the vehicle and the state of the road environment. In a study examine how driver distraction affects manual driving performance, Kaber and his colleagues have investigated driver situational awareness under hazard conditions based on cognitive abilities and distractions present on the road [135]. Distractions have been of particular interest for researchers during driving because they introduce overloads on driver cognitive processing and form bottlenecks for the flow of information during the task of driving [136]. These investigations of situational awareness showed that distractions (engagement in a secondary cognitive activity) degraded driver situational awareness under normal and abnormal hazard conditions. Their results also showed a significant relationship between working memory performance and situational awareness along with divided attention and selective attention performance. Taken together the results of this study showed that there are several cognitive (e.g., working memory) and situational factors (e.g., travel duration) that affect the ability of the driver to maintain situation awareness and vigilance.

C. Characteristics of the Road Environment

While possible it is not directly involved in the perception of in-vehicle messaging content, the road environment itself may play significant role during the driver's interaction with automated vehicle during a takeover event following the perception of a message or alert from the vehicle to the driver. Therefore, it is necessary to consider some of the factors that the external environment may present that could affect driver performance when assuming part of the entire vehicle control. The roadway design typically influences driving performance at the maneuvering/control interaction level [137]. Specific structural features of the roadway such as lane width, road markings, and the presence of trees or buildings near the road all affect the speed a driver maintains [138-140]. In addition, the time of day can also play a role. Time of day has been shown to be a significant factor in the rate and severity of automobile crashes [141]. Nighttime driving is more dangerous than day time driving due to a number of factors that include, fatigue and circadian rhythms [142]. Another reason for this is that during nighttime driving, there is lower luminance which can affect visual processing of stimuli on the roadway and increase processing times [143]. However, it remains unclear how these variations in the road environment can affect driver interaction with automation in general, and more specifically, the transfer of control between the automation and the human driver as well as the interpretation of in-vehicle messaging during automated driving.

From an engineering standpoint, these factors need to be taken into account when providing messaging content that might result in a takeover scenario for the driver. These factors can influence the performance of the driver as they incorrectly take over control of the vehicle from the automation, thereby reducing safety. In-vehicle messaging content will need to have time-of-day settings that adjust based on luminance levels during night and day times in order to improve readability and ease of processing for the driver. Roadway structure may not be as easily addressed in terms of messaging content but should be kept in mind to design for driver safety.

D. Characteristics of Vehicle Automation

Vehicles with level 3 or 4 automation can monitor and maintain control of itself with the expectation that a human will take over control, while automated vehicle technologies fall more into levels 1 and 2 where the human is still required to maintain control of the vehicle for the most part [27]. The characteristics of this automation create a set of factors that could potentially impact the development of in-vehicle messaging content. Specifically, automation reliability will be crucial to ensuring safe and effective use of new technologies. However, increasingly reliable automation technologies come with their own pitfalls, as addressed in work on the "lumberjack hypothesis", which states that as the level of automation increases, there is an increased chance of performance impairment when automation fails [144]. However, in the context of automated driving, this hypothesis may not follow the same pattern as other technologies. This is because in levels 2 and 3 automation, the driver is disengaged from a significant part or entirely from the driving task but is still expected to takeover vehicle control in part or entirely when need, but this can create a scenario where a driver is then forced to remain vigilant for a long period of time with limited opportunities to be physically engaged in vehicle control, which, as discussed earlier, can result in driver boredom and decrements in performance [28] [105]. With a longer time elapsed since the beginning of an automated driving, driver vigilance and situational awareness will worsen thus whether vehicle automation regularly or rarely disengages is a characteristic that needs to be considered.

Another concern regarding characteristics of automation is the amount of feedback that is provided by the system. As a result of the driver being disengaged with the task of driving, recovery of control can differ in quality depending on the design of warning [49] [145] [146]. Informative feedback could potentially alleviate the negative consequences of higher levels of automation by keeping the driver apprised of information relevant to the driving task. However, in contrast, drivers may get frustrated if they are engaged in some secondary task and are interrupted by messaging notifications from the vehicle from time-to-time for no acute reason. A potential method is to establish specific messaging intervals depending the criticality of the message. However, this would require further investigation.

The inclusion of in-vehicle messaging content may serve to mitigate the side effects of automation by providing a secondary task that might prevent the onset of boredom during an automated drive, but evidence thus far is limited. The information provided by this messaging should provide helpful and informative content without resulting in increased workload on the driver in order to process that information.

E. Characteristics of In-Vehicle Display

A large amount of human factors work has been devoted to the interaction between the human and automation and between the human and the display, but the interaction among human, automation, and display altogether has not been studied as thoroughly. Based on human factors understandings of each, we start with hypothesizing some interactions.

First, Head-Up Displays (HUDs) and Head-Down Displays (HDDs) may each come with some advantages but also pose unique challenges for presenting road sign information during automated driving. Head-Up Displays (HUDs) may engage the driver quickly with the driving environment by directing attention to the road areas and result in fewer off-road fixations; however, they can overwhelm the driver with too much information, particularly during a takeover request. In contrast, Head-Down Displays (HDDs) may reduce the visual clutter but could lead to longer response time as attention is first directed to the display then moved to the road if needed. Therefore, HUDs could be more suitable to periodically engage driver with the road environment, while HDDs may be more beneficial when a longer response period is allowed (e.g., a notification well in advance). Of course, it is important to ensure consistency in interface design for a vehicle system that the same type of information should always occur at the same location, either on an HUD or an HDD. HDDs would most likely require more extensive use of cues to orient the driver's attention towards the display because it will not be co-located with the road in the same way that a HUD would be. As of this review, a comparison of HUDs and HDDs has not been done for the presentation of road sign information and remains an open question.

The combination of visual, auditory, and even haptic cues could be effective in guiding the spatial attention of the driver to the in-vehicle display. For non-safety related messaging, the use of these cues can improve the driver's processing of upcoming exits that may be of interest such as food or lodging options. Cue modalities should be tested for information presentation using HUDs and HDDs, as their pairing with display types may alter their effectiveness during automated driving.

Critically, the amount of information presented on the in-vehicle display will need to be optimized in order to improve the driver's ability to process the information being presented, and to allow the driver enough time to make a decision about whether they will need to take over control of the vehicle to divert to an exit. To this end, pictorial information paired with text tends to be more effective than just text-based information and should be prioritized on the display [21]. This can also help to reduce display clutter and increase readability. Auditory menu cues can also aid with reducing driver workload [147]. Therefore, auditory menu cues along with the visual presentation should be utilized in order to reduce driver workload. The use of auditory cues for menu navigation would aid in the orienting of driver spatial attention as well [148]. On top of this, takeover performance varies on a number of factors, as discussed earlier. Therefore, in-vehicle displays need to present information in such a way that the driver is allowed enough time to process the in-vehicle message and decide whether to react to it. The amount of time necessary for a driver to decide to take over control and divert a vehicle to an exit has not been fully explored in the current body of research, but future work on in-vehicle displays should explore this to determine a minimum interval of time necessary.

In terms of display characteristics, adopting a certain level of display clutter could be a method to maintain a proper level of alertness and engagement of the driver. This is a potential issue that needs to be addressed considering the general concern of driver underload and disengagement during automated driving. However, the level of display clutter may also need to be adjusted to the dynamics of vehicle automation status. For example, when a driver is required to takeover, the driver is likely in an overload rather than an underload condition, thus the amount of display clutter should be largely reduced. The reduced amount of attention the driver needs to allocate to processing display information would allow the driver to respond to takeover requests effectively and safely. The goal is to maintain a proper level of processing load on the driver considering the condition of the automation, the driver, and their interaction.

VI. Proposed Design Guidelines

One aim of this review is to provide a preliminary set of guidelines to design effective non-safety related in-vehicle messaging content. Previously, attempts have been made to provide ergonomic guidelines for road signage and interface design for elderly drivers [149]. NHTSA proposed a series of guidelines for in-vehicle displays, but these guidelines focus primarily on manual driving [8], whereas the conditions of automated driving could involve differing concerns from those of manual driving. As research on in-vehicle message delivery of road signage during automated driving is still in its infancy, it is important to note that the preliminary guidelines proposed here are intended to provide a general overview of how in-vehicle messaging should be designed to leverage aspects of the automation, the driver, and the interaction between the two. These guidelines are meant to be guiding the questions to ask in the context of existing knowledge rather than answers to exact designs. Table 1 provides each guideline and description as well as the supporting literature for each one.

TABLE 1
Proposed design guidelines for in-vehicle messaging content

Design Aspect	Guidelines Based on Existing Literature
Presentation of Road Signage	• Road signage should use familiar structure to external signs [19]. • Signage should be physically representative of what it is trying to convey (i.e., lane closure signs should represent a lane being closed) [19]. • Pictorial information with text is more effective for conveying sign information [21].
Example Outstanding Question	• Should the presentation of road sign information follow the standard road conventions if presented during highly automated driving?
Driver Attention	• Multimodal cues (auditory and visual) should be leveraged to guide driver attention effectively [83-85]. • Messaging cueing needs to be able to accommodate older or disabled drivers [101] [102].
Example Outstanding Questions	• Are auditory, visual, or multimodal cues most effective for presenting non-safety related information to the driver? • How do these cues need to be altered in order to accommodate older drivers when presenting non-safety related information?
Communicating Automation State	• It should be assumed that the driver is disengaged with the driving task [44]. • Indicate status of vehicle control to driver using effective cues that allow appropriate response time (i.e., whether the vehicle is in control of specific functions or not) [91][147].
Example Outstanding Questions	• How should information regarding automation state be presented to the driver? • What information does the driver need regarding the automation state?
Displaying Information	• HUDs should be leveraged to reorient driver to roadway [150]. • Displays should optimize information in order to be informative with minimal display clutter [62].
Example Outstanding Question	• Should the presentation be different for safety-critical and non-safety critical information?
Driver Interaction	• Display content should minimize driver eyes off road time such that messages are easily interpreted without requiring the driver to look off the road for extended periods of time [8]. • Visual messages and menus should allow auditory navigation as well to facilitate interaction [147].
Example Outstanding Question	• Does non-safety related information significantly impact driver eyes-off-road time?

VII. Future Research Directions

It is important to note that this limited body of research has focused on in-vehicle display of safety-critical messages. For example, Politis, Brewster, and Pollick investigated the use of multimodal displays in conveying safety critical handover of control from the automated vehicle to the driver [84]. In this study, the authors tested multimodal abstract (pictorial) or language-based warnings and compared their effects on the driver's ability to resume control of the vehicle. Delivery of non-safety-related, but trip-related, information (e.g., available local services) remains unexplored. Since driver attention varies according to the relevance of a message to concurrent tasks, the findings on in-vehicle messages of safety-related information may not generalize to messages of non-safety-critical information.

Due to the nature of previously published guidelines and supporting research focusing on manual driving, it is necessary to conduct additional research based on current proposed guidelines. Specifically, it will be important to investigate driver performance when signage is presented either on the roadway, the in-vehicle display, or both. In addition, for in-vehicle presentation, the spatial location of display should also be examined. Vehicle control, hazard response, and gaze behavior should all be considered in such investigation. At the same time, despite the non-safety related nature of logo signs, presentation of this content may have a significant effect on driver performance during a hazard scenario. Driver performance should be investigated in terms of manual driving and automated driving in order to be able to compare how automated driving specifically alters the driving scenario during presentation of this type of content. In relation to this, it is possible that signage information, which is presented in specific ways, may need to be restructured in order to aid in driver interpretation of the information during automated driving when the information is presented via an in-vehicle display.

Additional work should focus on the effects of individual characteristics (demographic, trait-based, or situational) and engagement on driver performance during presentation of messaging content. For example, aging results in a number of physical and cognitive changes that can affect driving, as noted in the previous sections. Therefore, age groups should be compared to investigate how aging affects the perception and response to non-safety related messaging content. Also noted in previous sections, automated driving can result in driver disengagement due to passive monitoring of the roadway. As such, it is necessary to investigate how drivers behave during an automated vehicle and how their ability to perceive and attend to in-vehicle messages is affected by their disengagement from the driving task.

Furthermore, future work should explore whether the current standards of road signage can be translated to an in-vehicle display or whether new organizations of exit information could improve driver performance. It is possible that the structure of current road signage should be re-evaluated for placement on the in-vehicle display. Particularly when the driver is not in control of the vehicle and not attending to information external to the vehicle. Takeover intervals for responses to non-safety related messages should be explored as well in order to determine the minimum presentation time for drivers to perceive and respond to food or lodging information.

VIII. CONCLUSION

The present review sought to provide a framework of the factors involved in delivering in-vehicle messaging content during automated driving and propose preliminary guidelines for designing such content for future investigations. It's apparent from the body of literature that not only does the automation technology need to be leveraged to effectively deliver content, but also the features of human attention and cognition, the design of messaging, as well as situational factors of the environment all need to be considered. The guidelines provided in this review are meant to aid the investigations that will benefit the development of messaging content that is safe and informative for drivers during automated driving.

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Appendix B

On-Road and In-Vehicle Delivery of Service Signs: Effects of Information Source and Age

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In-vehicle technologies for communicating information to drivers have realized increasing use in recent years. While most attention has been paid to in-vehicle displays for presenting safety-related information, such as warnings, few studies have explored communication of non-safety-related information with in-vehicle displays. This simulated driving study examined driver performance in vehicle control and sign identification, when processing service logo information from on-road signs or an in-vehicle display. Findings suggest that in-vehicle displays, on-road signage, or both allowed drivers to identify service logos with a high accuracy and a relatively low level of workload. The use of in-vehicle displays either alone or simultaneously with on-road signage produced lower speed deviations therefore better vehicle control. Age differences were observed in vehicle control as well, suggesting the need for personalization of sign messages according to individual characteristics. This study is an initial step to examine the use of in-vehicle displays for messaging service logos as an example of non-safety-related information. The study is ongoing, and findings could provide a basis for in-vehicle display and on-road sign design for non-safety-related information.

INTRODUCTION

In the past decade, in-vehicle technologies have advanced significantly; displays are becoming larger and more information is being presented in cars. There has been a push to steer the development of in-vehicle technologies in directions that improve the driving experience and road safety. For example, drivers receive warnings about road hazards and the state of vehicle systems (Birrell, Fowkes, & Jennings, 2014; Creaser & Manser, 2013; Politis, Brewster, & Pollick, 2015; Koo et al., 2015).

There is a large body of work exploring how to effectively present information on in-vehicle displays, exploring design factors such as sensory modalities of warnings, message complexity, and general workload associated with processing warning information (for a review, see Campbell et al., 2016). These efforts have been mostly focused on safety-related information such as collision warnings (e.g., Jahn, Krems, & Gelau, 2009; Politis, Brewster, & Pollick, 2015, 2017). Lee, Gore and Campbell (1999) compared the effectiveness of commands versus notifications about potential upcoming road hazards (e.g., merge left vs. lane blocked by accident) and found that command messages resulted in greater driver compliance but could reduce overall driving safety due to distraction. In addition, the study found that presenting road sign information on an in-vehicle display, without the redundant roadway sign, may lead to decreased safety as drivers allocate attention inappropriately (Lee et al., 1999). Safety-related information often requires immediate attention or immediate action; therefore, one display design priority is to capture driver attention. In contrast, non-safety-critical information, such as service logo signs, is more ambient, and communication should be less intrusive. However, there is limited knowledge on how to deliver this ambient non-safety-critical information, thus research is needed to investigate the communication of non-safety-related information through in-vehicle displays.

One example of non-safety-related information is a service logo sign. Past human factors research has primarily examined presentation of such information as part of the external road environment (Kaber et al., 2015; Zahabi et al., 2017a, 2017b). Kaber and his colleagues (2015) quantified the influence of sign type on driver glance behavior and vehicle control and found little meaningful difference between logo signs of 6 or 9 panels, and between logo signs and route guide signs. Zahabi and her colleagues (2017a, 2017b) measured driver ability to detect visual target logos on highway signs. They also provided a comparison of types of information (logo only versus logo and text) and differences in detection due to age. They found that older drivers exhibited poorer logo detection performance when exiting a highway, likely due to more conservative behavior in performing the secondary detection task and less time spent on searching for logos. These findings suggest that design of freeway ramp signage should consider driver demographics. While it may be difficult to account for driver individual differences in roadside sign design, in-vehicle displays provide a unique opportunity to tailor communication according to individual characteristics.

Despite existing understanding of human factors in on-road signage design and in-vehicle communication of warnings, there is a gap in the current literature regarding how to present signage information, such as service logos to drivers via in-vehicle displays and how this may differ among individuals. Our current and ongoing studies attempt to address this gap by examining various design factors of communicating business logo signage on-road and/or in-vehicle according to the NHTSA human factors guidelines for in-vehicle display design (Campbell et al., 2016). Based to the guidelines, in-vehicle displays should not divert driver attention away from activities that are critical for safe driving (i.e., vehicle control and hazard avoidance). Related to this, the visual display design should impose proper workload that allows drivers to complete secondary tasks with brief glances so as not to adversely affect driving. In our specific case of displaying service logo signs, the goal was to limit workload induced by in-vehicle displays such that it was not greater than the roadside signage. In the meantime, in-vehicle displays should present adequate content to enable successful decision making.

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In the current study, we compare information processing efficiency between on-road signage and an in-vehicle display in terms of driver ability to identify service logos, the imposed workload, and driver performance in vehicle control. We report preliminary findings on the effects of information source (road sign vs. in-vehicle display vs. both) as a within-subject manipulation and age group (younger vs. mid-age vs. older) as a between-subject factor. It was hypothesized that simultaneous presentation of in-vehicle and on-road business logos would lead to better performance in logo identification and vehicle control, although overall workload was expected to be higher. Driving performance was expected to be worse when logo information was presented on the in-vehicle display only. Older drivers were expected to be more susceptible to distraction with increased visual information (i.e., both road signage and displays).

METHODS

Participants

In this study, 21 participants (13 male, 8 female) were recruited from three age groups: (1) younger: drivers between 18-22 years of age (Age: M = 20.86, SD = 1.36; 4 male, 3 female; Driving Experience in years: M = 4.38, SD = 2.77), (2) mid-age: drivers between 26-65 years of age (Age: M = 34.43, SD = 12.68; 4 male, 3 female; Driving Experience in years: M = 5.21, SD = 6.48), and (3) older: drivers older than 65 years of age (Age: M = 74.00, SD = 5.56; 5 male, 2 female; Driving Experience in years: M = 31.97, SD = 28.55). All drivers reported good to excellent general health conditions, had normal or corrected-to-normal vision, and possessed valid state-issued driver's licenses at the time of study participation.

Apparatus

Driving simulator. This study utilized a high-fidelity, full motion driving simulator at North Carolina State University (FORUM8 Co. Ltd, Tokyo, Japan). Seven monitors surrounded a realistic full-size cab, providing a 315-degree field of view (see Figure 1). Drivers could interact with the simulator through a full-size wheel, a modular accelerator and a brake pedal. The full-motion simulator also allowed for synchronized motion with the virtual vehicle.

Figure 1: Setup of the Forum 8 driving simulator.

In-vehicle display. A tablet computer was integrated with the driving simulation system as an in-vehicle display. The tablet was installed on the right-hand side of the driver's seat. The size of the display (10.5-inch) was determined by a market survey as well as the assumption that the display size would continue to increase. The display incorporated basic features of common in-vehicle display systems, and the logo panel display matched the layout and format of on-road logo signs (Figure 2).

Figure 2: Screen capture of an example in-vehicle display, consisting of a mock navigation interface (left) and a logo panel sign (right).

Tasks

Simulated driving. Drivers were posed with a total of 3 driving scenarios, each with a unique setting of information source (on-road vs. in-vehicle vs. both). All scenarios presented a four-lane freeway (two-lane each direction) with 3 interchanges (and 1.5 miles of straight road section in between) followed by a 2-mile straight road. The route of simulated driving with locations of various signs is illustrated in Figure 3. All road and sign configurations were consistent with the regulations set by the North Carolina Department of Transportation and MUTCD (Federal Highway Administration, 2009). Participants were instructed to follow the speed limit while maintaining a safe following distance with a lead vehicle (time to collision = 2.5 seconds), including situations when the lead vehicle braked suddenly.

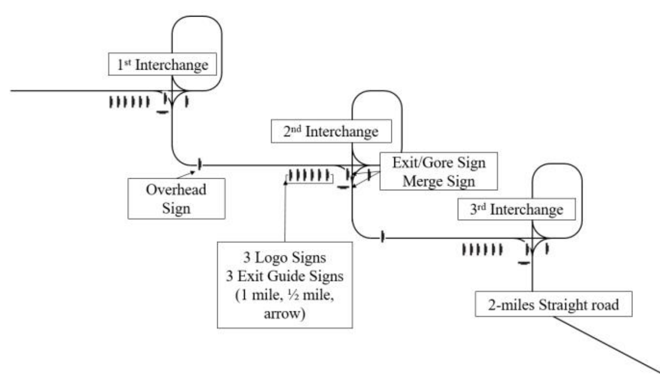

Figure 3: Scenario route map.

Logo identification task. Before each trial, two logo targets (one food and one lodging) were shown to the participants and they were asked to verbally indicate ("yes" or "no") when a logo target was seen while driving. At each interchange, one food logo sign, one lodging logo sign and one gas logo panel were displayed. Therefore, each driving scenario (with three interchanges) contained 6 relevant logo panels (3 food and 3 lodging) and only two of them contained a target. Participants were instructed to report a target logo as soon as they saw it.

Measures

Vehicle speed and lane deviation. Participants were asked to maintain their vehicle position in the right lane at all times and maintain speed as close as possible to the posted 65 mph speed limit with the only exception being use of exit ramps. Speed deviation was defined as the absolute velocity deviation from 65 mph. Lane deviation was defined as the absolute position deviation from the lane center. Driver performance was recorded during sign observation periods, which began 650 ft before passing a sign (where the sign became visible) and ended immediately after passing the sign. Periods of sudden braking by a lead vehicle were excluded from the current analysis.

Logo identification accuracy: Logo target "hits" and "false alarms" were calculated for each participant. A hit was defined as a participant correctly identifying when a target was present. A false alarm was defined as a participant reporting a target when it was actually absent.

Mental workload. The NASA TLX (Task Load Index; Hart & Staveland, 1988) was adopted to measure workload. Participants rated their perceived workload on a 100-point scale with 5-point steps in terms of six aspects: mental demand, physical demand, temporal demand, performance, effort, frustration. At the beginning of the experiment participants completed pairwise comparisons of the demand components to obtain rankings. Participants completed the ratings after each trial. The TLX was computed as a rank-weighted sum of all ratings.

Experimental design

In the current ongoing study, information source (3 levels: road sign vs. in-vehicle display vs. both) and format (2 levels: logo vs. logo plus text) were within-subject manipulations. There was one simulated drive for each combination of information source × format condition; thus, there was a total of six drives for every participant. Drives were counterbalanced in randomized order. As our data collection is still ongoing, in the current analysis, we only examined data from three simulated drives with logo only presentations. Therefore, only the information source manipulation was included in the current analysis. Driver age served as a grouping variable in the analysis. Trial number was also included in the experiment data analysis statistical model as a covariate.

Procedure

All incoming participants were first presented with an informed consent form, a demographic questionnaire, and a baseline Simulation Sickness Questionnaire (SSQ). Upon completion, participants were introduced to the driving simulator and completed two training sessions for familiarity with vehicle controls (similar to Zahabi et al., 2017) and the logo identification task. During the experiment session, each participant completed a total of six drives during which driving performance, logo identification and eye movements were recorded. After that, participants answered a set of questions regarding their opinions of signage displays and provided NASA TLX workload ratings.

RESULTS

As the study is still ongoing, here we only report preliminary findings on the effects of information source and age. Data were first screened by Cook's D method to identify any potential outliers. The influential data points were then checked against lab notes and set criteria (speed deviation > 10 mph, lane deviation > 3 ft; same procedure as in Lau & Kaber, 2017). Statistical diagnostics were then conducted, and speed deviation was log-transformed to meet the normality assumption. Mixed-model ANOVA and logistic regressions were conducted depending on the type of data. The full model examined the effects of information source and age, as well as their interaction, on the response measures. The trial number co-variate was removed from the model if it did not have a significant effect on a response measure.

Response Accuracy

Since the logo identification response data took a binary form (hit=1 vs. miss=0; false alarm=0 vs. correct rejection=1), logistic regression analysis was performed to identify condition manipulation effects on driver response outcomes. Wald's test was used to examine the effect of individual predictors (Peng et al., 2002). Participants correctly identified most target logos (hits: 90.47%), with low false alarms (FA: 2.38%). According to logistic regression analysis, neither information source (Wald $\chi^2 = 0.012$, $p = 0.99$) nor age (Wald $\chi^2 = 8.11e\text{-}6$, $p = 1$) had significant influence on hits. Similarly, neither information source (Wald $\chi^2 = 6.5e\text{-}6$, $p = 1$) nor age (Wald $\chi^2 = 7.21e\text{-}6$, $p = 1$) had significant influence on false alarms. No other factor or interaction was significant.

Workload

For the NASA TLX composite score, the mixed-model ANOVA was highly significant ($r^2 = 0.917$, $p < 0.001$). The untransformed response data met the assumptions of the ANOVA. No significant effects of information source (F[2,31] = 0.90, $p = 0.416$, $1\text{-}\beta = 0.191$), age group (F[2,31] = 0.690, $p = 0.509$, $1\text{-}\beta = 0.155$), or an interaction between the two factors (F[4,31] = 0.639, $p = 0.639$, $1\text{-}\beta = 0.185$) were found. The means scores for the younger, mid-age, and older driver groups were 43.6, 34.0, and 51.5, respectively. There were significant individual differences within age group, $F(18,31) = 11.22$, $p < 0.001$, $1\text{-}\beta = 1$. Trial number was also significant, F(5,31) = 3.13, p = 0.022, suggesting that the order of the trials played a role in the workload rating. Participants may have adapted as their exposure to the driving simulator environment increased, leading to a decrease in mental workload ratings.

The same statistical analysis was performed on mental demand ratings, given its particular relevance to the current task. The model was significant, $r^2 = 0.92$, $p < 0.001$. No significant effect of information source (F[2,31] = 1.13, p = 0.336, 1-β = 0.230) or age group (F[2,31] = 1.314, p = 0.284, 1-β = 0.262) was found. The mean mental demand ratings for the younger, mid-age, and older driver groups were 9.3, 6.9, and 10.2, respectively. Significant individual differences were observed but not accounted for by age group, F(18,31) = 12.52, $p < 0.001$. Trial number was significant, F(5,31) = 9.26, $p < 0.001$. The interaction of display type and age group was also significant, F(4,31) = 2.80, p = 0.043. Post-hoc tests (Student-Newman-Keuls) revealed that the middle age group perceived mental workload in use of on-road signs (Mean rating = 7.3) to be significantly less than the younger (M = 9.3) and older age groups (M = 10.2).

Speed Deviation

For the analysis of speed deviation, there were 252 data points collected from the experiment, and after application of Cook's Method, 0.06% data points were removed (speed above 10 mph [n = 15] and with abnormal behavior on note [n = 1]). Trial number was not significant and subsequently removed for the statistical model. Both main effects of age group (F[2,209] = 5.56, p = 0.004, 1-β = 0.851) and information source (F[2,209] = 7.45, p = 0.001, 1-β = 0.939) were found to be significant. Further analysis using Tukey HSD post hoc tests on age group demonstrated that young drivers produced significantly lower speed deviations than older drivers (Fig. 4). The Tukey HSD post hoc tests on the effect of information source showed that drivers demonstrated significantly greater speed deviations in the presence of road signs in comparison to in-vehicle displays and the combination of signs and displays (Fig. 4). There was no interaction between age and information source, F(4,209) = 0.65, p = 0.626, 1-β = 0.211.

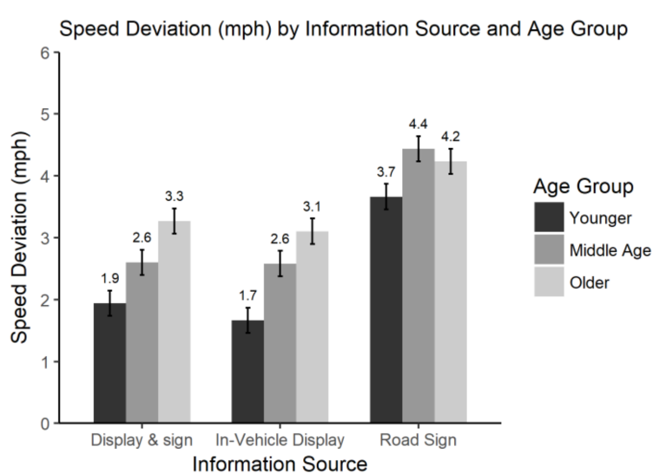

Figure 4: Speed deviation across information source conditions by age group.

Lane Deviation

For the analysis on lane deviation, there were 252 data points collected from the experiment, and after application of Cook's Method, 0.01% data points were removed (speed above 10 mph [n=1] and with abnormal behavior on note [n=2]). Trial number was not significant and subsequently removed for the statistical model. There was no significant main effects of age group (F[2, 222] = 1.81, p = 0.165, 1-β = 0.377) or information source (F[2, 222] = 1.40, p = 0.248, 1-β = 0.299). There was no interaction either (F[4, 222] = 1.04, p = 0.388, 1-β = 0.325).

DISCUSSION

Participants performed quite well on the logo identification task, showing no difference in high accuracies across conditions. This suggests that participants followed task instructions and devoted sufficient effort for target identification relative to all conditions. Further investigation into glance behavior during logo identification may provide additional insights into driver behavior and visual search strategy. Moreover, this result supported comparison of driving performance across information sources without concern for trade-offs between the primary driving task and secondary logo identification task.

Speed deviations were found to be significantly lower when the in-vehicle display was (or part of) the information source. While the question of whether speed deviations may lead to vehicle safety concerns remains unclear, the results suggest that use of in-vehicle displays may limit driver instinctive adaptive behavior to slow down during sign exposure when attention is drawn off-road, a speculation that is relevant and consistent with Lee et al (1999) which found that only in-vehicle display led to drivers' inappropriate allocation of attention. Another potential explanation is that drivers estimated longer time needed to process information from on-road signage than when using an in-vehicle display and, therefore, they slowed down more when approaching the physical roadside sign to enable longer search times. However, an intriguing finding related to this point is that participants did not report higher mental workload for the on-road sign only condition. A possible explanation of this contradiction is that participants did not consider the search task to be more effortful, as they were able to control how long they could take to process the information. Another explanation could be that NASA TLX was not sensitive enough to capture the difference. Further examination of glance behavior, coupled with vehicle control data, as part of our on-going analysis, may reveal more insights on this observation.

Results from this study also revealed no difference in target identification accuracy among age groups. These results differ from Zahabi et al. (2017a), who found degraded performance among older participants, as compared to middle age and younger groups. It is worth noting that the present study utilized a driving simulator with higher fidelity and a much larger field of view. The realistic driving environment and improved visual presentation might have compensated for the visual and motor control degradation that commonly occurs among older drivers. Alternatively, differential emphasis of one of the driving or logo identification tasks may have led to such observation. In the current study, all participants had high hit rates and low false alarm rates, suggesting that they excelled at the task. Instead of performing similarly on the driving task, as in Zahabi et al. (2017a), older drivers showed greater speed deviations when observing a sign. Consequently, there were differences among age groups in the driving task rather than in the logo identification task. This may be an indication of behavioral strategy by older drivers, as they slowed down more to accommodate processing time and effort required by the dual tasks.

CONCLUSION

In summary, the current analyses based on our existing data examined the effect of information source (on-road sign vs. in-vehicle display vs. both) on logo identification accuracy, driver vehicle control performance, and perceived workload. The study also compared three age groups (younger vs. mid-age vs. older) in the driving and target identification tasks. Results indicate that using in-vehicle displays produces comparable target identification accuracy and workload without compromising driver vehicle control performance. In fact, drivers exhibited superior speed control when in-vehicle displays were presented. This study provides support for using in-vehicle displays to present non-safety related business logo information. Older drivers showed poorer speed control (i.e., greater speed deviations) but performed comparably to middle-age and younger drivers in identifying service logos. This suggests consideration of tailoring messaging of service logo information, such as providing longer presentation times for older drivers.

Application

The findings of this study provide general guidance to manufacturers for in-vehicle display design. Given the susceptibility of road signs to environmental factors, it may be worthwhile to consider using in-vehicle displays for business logo presentation. Such an approach may better support in-vehicle secondary task efficiency and safety.

Limitations

The current study results are based on a limited sample size thus our findings should be validated with more data. It is also worth noting that the roadway scenarios had moderate traffic density (Level of Service A), and they were presented with clear weather conditions. Driver behavior might vary under more complex roadway conditions.

Future Work

Future research should examine driver glance behavior and aspects of driving performance such as hazard avoidance that may be more indicative of safety measures. Moreover, given the variety of business logo design, it is important for future studies to investigate presentation of logos with different information formats (pictorial vs. texts). Future research may also examine signage information delivery under automated driving conditions.

ACKNOWLEDGEMENT

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Appendix C

Display Non-Safety Critical Information Through In-Vehicle Displays

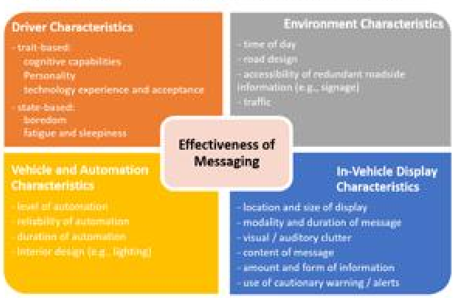
Stephen J. Cauffman[1], Mei Y. Lau[1], Yulin Deng[1], Ebony Johnson[2], Christopher Cunningham[1], David B. Kaber[2], & Jing Feng[1]
[1]North Carolina State University, [2]University of Florida

Background

- Personal vehicles are now capable of collecting large amounts of information through on-board sensors (Fagella, 2017).
- Increase in vehicle automation and in-vehicle information displays (Fagella, 2017).
- Most work has focused on presentation of safety critical information (Campbell et al., 2016).
- Need to explore methods of presentation of non-safety critical information to driver minimizing impact on performance.

Literature Review

- A review of factors influencing driver behavior and performance.
- A research framework that includes four categories of factors.
- Display types and characteristics need study.

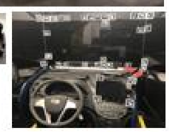


Acknowledgement This project is supported by North Carolina Department of Transportation (Grant No. 2018-26).

Current Experiment

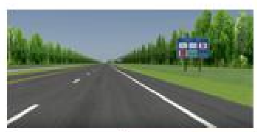
Apparatus

- Full-motion driving simulator (high fidelity motion cueing and immersive displays)
- Pupil Lab Eye Tracker
  - 200 Hz sampling frequency
  - accuracy= 0.6 degrees of visual angle
- GoPro cameras for motion monitoring



Tasks

- 6 freeway driving trials
- Each scenario includes 3 interchanges, 1.5 miles apart
- 3 logo sign targets and 1 city destination per drive (prevalence rate of 50%)



Measures

- Driving performance
  - hazard negotiation
  - lane maintenance
  - speed maintenance
- Logo target detection
- Gaze behavior
  - fixations
  - blinks
- Workload
  - NASA TLX
  - pupillometry

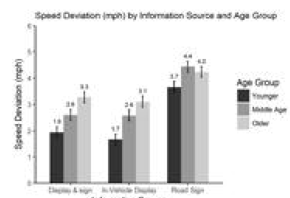
Trial	Info Source	Message Content
1	In-Vehicle Display	Logo
2		Logo+Text
3	Road Signage	Logo
4		Logo+Text
5	In-Vehicle & On road	Logo
6		Logo+Text

Hypotheses

- Increase in display/sign message content may result in increased visual workload, degraded target detection and driving performance.
- Simultaneous presentation of in-vehicle and on-road displays will support target detection but increase visual workload and degrade driving performance.

Preliminary Results

- All display conditions allowed drivers to identify service logos with a high accuracy and a relatively low level of workload.
- The use of in-vehicle display produced lower speed deviations therefore better vehicle control.
- Some age differences in speed control.



Discussion

- Identification of superior methods of non-safety critical information presentation in terms of display type and content.
- Future work will focus on logo detection performance during automated driving.

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Appendix D

On-road and In-vehicle Delivery of Non-Safety-Related Messages: How Information Source and Presentation Format Impact Drivers' Processing of Logo Signs and Hazard Response

Yulin Deng, Stephen Cauffman, Mei Ying Lau, Ebony Johnson, Azhagan Avr, Christopher Cunningham, David Kaber, Jing Feng

ABSTRACT

Newer vehicle technologies allow real-time communication of various information to drivers. Much research has focused on using in-vehicle displays for presenting safety-related information, such as warnings; while limited work has investigated communication of non-safety-related information. To fill this research gap, the current simulated driving study examined driver behavior when searching for service logos in three information source conditions: on-road sign, in-vehicle display, or a combination of both. Findings suggest that drivers identified service logos with high accuracy and relatively low levels of workload across all conditions. The majority of drivers (54.8%) preferred the on-road signs, and most of them (63.6%) would choose to use on-road signs even when logos were presented both in-vehicle and on-road. Analyses also showed that drivers are more likely to succeed in hazard negotiation and avoid collisions while service logos were presented on both on-road signs and the in-vehicle display. Comparisons among the age groups suggest that older drivers (65-85 years old) were in general less accurate in identifying target logos and reported higher workload than the younger (18-23 years old) and middle-aged (24-64 years old) groups. However, older drivers were more alert to hazards than middle aged drivers, likely due to them being more cautious and exerted more effort on the task. Older drivers also had fewer collisions and exhibited faster hazard responses, at a level of performance comparable to young drivers. Findings of this study offer insights for communicating non-safety-related information via an in-vehicle display and on-road signage.

Keywords: In vehicle display, driving, logo signs, age, hazard

Appendix D

On-road and in-vehicle displays of non-safety-related information (#20-04712)

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BACKGROUND

- In-vehicle displays are becoming more prevalent, larger in size with more information.
- Increasing information load may affect driver performance [1].
- Existing research focused on safety-related information such as forward collision or lane departure warnings [2,3].
- Less is known about delivering non-safety-related messages via in-vehicle displays.
- Attentional processing differs between safety-related and non-safety-related information.
- **The purpose of this study** is to investigate the presentation of non-safety-related road sign information on logo identification, visual behavior, and driving performance among younger, middle-aged, and older drivers.

CURRENT STUDY

Apparatus

- Full-motion Forum 8 driving simulator with immersive displays
- Pupil Lab Eye Tracker

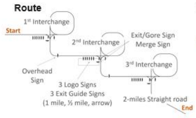
Participants

- 36 drivers; balanced across age and gender
- Younger (18-22), middle-aged (23-64), older (64+)

TASKS

- 6 freeway drives
- Each drive includes 3 interchanges, 3 logo sign targets, and 3 hazards

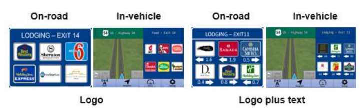
Route



Hazard negotiation

EXPERIMENTAL DESIGN

- 3 x 2 x 3 mixed factorial design
- **Information source**: on-road vs. in-vehicle vs. both
- **Information load**: logo vs. logo plus text
- **Age group**: younger, middle-aged, older



RESULTS

Logo identification

- Older drivers had fewer hits and more false alarms than younger and middle-aged groups.

Age Group	Hit	False Alarm
Younger	94.5%	1.3%
Middle	94.0%	2.0%
Older	85.5%	8.8%

Hit: correctly report a target when there was one.
False Alarm: falsely report a target when there was none.

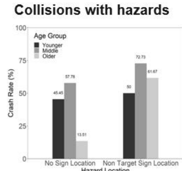
Workload (NASA TLX)

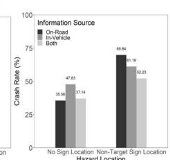
- Older drivers (49.9 out of 100 points) reported higher workload than middle-aged (35.5) and younger drivers (35.6).

Self-reported preference

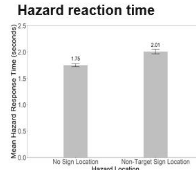
- More drivers (54.8%) preferred on-road signs.

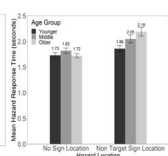
Collisions with hazards





Hazard reaction time





SUMMARY OF FINDINGS

- In-vehicle display had comparable effects on driver performance and workload as compared to on-road signage.
- Drivers had fewer collisions when redundant logo information was delivered via both the in-vehicle display and on-road signage.
- Drivers exhibit longer reaction times to hazards occurring in the presence of logo signs.
- No significant effect of information load likely due to the load difference being very small. This should not be overly generalized to other designs that impose higher loads.
- Drivers preferred on-road signage and reasoned that: on-road signage was what they were accustomed to; it allowed them to keep their eyes on the road; it was less distracting.
- Older drivers exhibited less accurate logo identification and reported higher workload than younger and middle-aged drivers.

FUTURE DIRECTIONS

- Driver visual behavior can provide insights on information processing especially when logo signs were presented via both the in-vehicle display and on-road signage.
- Studies shall investigate timing of the in-vehicle display and alternative designs such as multimodal displays.
- The design considerations should be examined in the context of vehicle automation.

ACKNOWLEDGEMENT

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References: [1] Blanco, M. et al (2006). The impact of secondary task cognitive processing demand on driving performance. *Accident Analysis & Prevention, 38*(5), 895–906. [2] Vashitz, G. et al (2008). In-vehicle information systems to improve traffic safety in road tunnels. *Transportation Research Part F: Traffic Psychology and Behaviour, 11*(1), 61–74. [3] Campbell, J. L. et al (2016). *Human Factors Design Guidance for Driver-Vehicle Interfaces* (Report No. DOT HS 812 360). Washington, DC: NHTSA. [4] Institute of Transportation Engineers. (2016). *The Traffic Engineering Handbook* (7th Edition). John Wiley and Sons.

Appendix E

Driver Hazard Response When Processing On-road and In-vehicle Messaging of Non-Safety-Related Information

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***Abstract*—With advances in vehicle technologies, more information can be communicated in real-time to drivers via in-vehicle interfaces. In-vehicle messaging can be used for safety-related information, such as warnings, as well as non-safety-related information, such as upcoming gas stations. While much research has focused on the design of messaging safety-related information, little is known about the best practice for in-vehicle messaging non-safety-related information. The current study aimed to examine how drivers process service logos – as an example of non-safety-related information – and respond to road hazards when logos are presented on: (1) an on-road sign panel, (2) an in-vehicle display, or (3) a combination of both. It was found that drivers generally identified logos with high accuracy and low workload across the presentation conditions. Driver reactions to road hazards were slower when logos were present for processing, although the number of collisions did not increase. Although the majority of drivers self-reported a preference for the on-road presentation, the simultaneous presentation of logos on-road and in-vehicle showed a benefit on driver hazard negotiation (fewer collisions). Older drivers were less accurate in identifying logos but also had fewer collisions, likely due to them being more cautious and allocating more attention to the driving task. Findings of this study provide support for use of in-vehicle presentation of non-safety-related information in addition to existing on-road signage.**

Keywords*— *in-vehicle display, driving, logo signs, age, hazard negotiation

I. Introduction

In-vehicle displays (IVDs) provide many different types of information for drivers, ranging from GPS directions to forward collision warnings [1-3]. Newer vehicle technologies support collection and communication of real-time information to drivers, such as blind spot warnings and emergency braking system warnings. Previous research has indicated that drivers rely heavily on visual presentation of information from an in-vehicle display [4]. Although more information while driving seem beneficial for performance, there are a number of associated human factors issues. In specific, driver distraction and information overload can occur [5]. In-vehicle displays can interfere with the task of driving due to visual distraction, cognitive distraction, or biomechanical interference [6]. For example, drivers found an implementation of a side view assist system to be distracting because the activation alarm was too loud [7]. Such interference results from the display demanding attentional resources similar to the task of operating the vehicle for periods of multiple seconds [8-9]. For example, if a call notification appears on an IVD, a driver's eyes may be diverted away from the roadway to the display while processing the caller information, which can result in a hazardous situation.

Much of the past work on the use of IVDs has focused on messaging safety-related information, such as alerting drivers to takeover events during automated driving or hazard warnings [10-12]. For example, the NHTSA has released a set of IVD guidelines that provide guidance on the structure and types of warnings that should be presented (see [13] for a comprehensive review). As noted in this guideline, research on driver-vehicle interfaces has predominantly focused on safety-related information, including collision warnings. Although some design guidance was also provided for non-safety-related information [13], much of these recommendations focused on ensuring that non-safety-related information does not compete

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with safety-related information. The guidelines suggest delaying non-safety-related messages to allow drivers sufficient time to process and respond to safety-related messages. However, there is limited knowledge on what design factors could influence driver processing of non-safety-related information and vehicle safety. The same is true in the specific domain of in-vehicle messaging of road signage. There is a body of literature on safety-related information presentation, such as displaying stop sign or traffic light information inside a vehicle; however, little work has examined in-vehicle presentation of non-safety related information, such as logo signs for local business and services to the driver.

There are differences between safety-related information and non-safety-related information in terms of importance to driving safety and response demand. Safety-related information requires drivers to react quickly to a warning. Research has been conducted to examine collision warning designs and concluded that warnings need to be spatially intuitive to promote rapid attention reorienting for focus on a potential collision and an immediate and appropriate response [14-15]. Similarly, studies have investigated the use of multi-modal cues to efficiently reorient driver attention to the roadway [12, 16-18]. Processing of safety-related information is often prioritized over other information. For example, to ensure a driver is aware of a school zone, a warning may be delivered with a salient visual display message (text or icon) coupled with an auditory or even tactile stimulus. In contrast, notifying drivers of a specific route alternative is of a lower safety priority and navigation messages are typically presented visually. In contrast to safety-related information, non-safety related information does not require a driver to rapidly reorient attention to the roadway and, in most cases, an immediate action is not necessary. For example, a driver on the highway may see a billboard showing an attraction at an upcoming exit. The driver can make a decision about whether to change their route to navigate to the attraction. As such, the interval to process non-safety-related information is different than that of safety-related information. The driver also may or may not choose to take the exit. With further advancements in IVDs, non-safety-related information, such as local services and attractions, could become increasingly communicated via displays.

There are several design parameters that dictate presentation of IVD content. Format, or the layout of content, can affect driver ability to locate information within the display. For example, it is recommended that messages requiring immediate detection be located within 5 degrees of the forward view of the driver [19]. The amount of content can also play a significant role, with increased complexity of messages resulting in slower response times by the driver [20]. Hoffman et al. [20] found that increasing the amount of information displayed on a text-based message resulted in fewer but longer glances to the display. More recently, Pankok and Kaber [21] found that when drivers were asked to navigate a route using an interface with low or high clutter, they attempted to utilize their expectations and knowledge of the interface to optimize visual search and avoid unnecessary information on displays. All of these findings either only address safety-related information or they address more basic questions about the nature of the in-vehicle display.

Another area of research that could provide insights for in-vehicle messaging of non-safety-related information is empirical work on how to present information on road signs. Zahabi et al. [22] conducted a study to investigate how presenting six or nine logos on a highway sign affected driver detection and how varying pictorial vs. pictorial plus text content affected a driver's ability to detect a target logo. Interestingly, drivers tended to have higher accuracy when searching for text-based targets compared to pictorial targets [22]. However, this study did not include a combination of both. Differences among age groups were also investigated revealing that older drivers, in general, adopted more conservative strategies (i.e., driving slower when approaching signs) to search for target logos in nine-panel signs compared to six-panel signs. Older drivers were also less accurate in logo recognition, as compared to younger drivers. These findings indicate that the amount of information presented on a logo sign can play a role in driver visual search behavior and younger and older drivers adopt different search strategies. However, it remains unclear whether driver processing of information displayed on roadside signs vs. an IVD would be different. As IVDs hold the potential for delivering real-time and tailored messages to drivers, there is a need to examine driver behavior with IVDs and factors that may influence message effectiveness and vehicle safety.

The main objective of the current study was to examine the impact of information source and presentation format on effectiveness of messaging non-safety-related information and vehicle safety among younger, middle-aged, and older drivers. In a simulated driving environment, information on local services was presented on roadside signs, an IVD, or both in the form of either logos or logos plus text. Unexpected hazards were presented to drivers at locations where local business information was either present or absent. Drivers were instructed to drive safely (following traffic control devices) while identifying logos for local services. Driver success in identifying business logos was the measure of message effectiveness while collision avoidance and reaction time to hazards were used as indicators of driving safety. It was hypothesized that redundant information presentation on an IVD and road signage would benefit logo identification and driving safety. Driver hazard negotiation would be compromised when processing sign information, particularly when logo and text information was present due to a higher perceptual load. In addition, differences in logo identification and hazard responses were expected across three age groups, similar to the findings of [22].

II. METHOD

A. *Participants*

A total of 36 drivers were recruited from local communities in Raleigh, North Carolina. Drivers were recruited via online advertisements as well as calls and visits to retirement communities in the area. Driver age groups were defined as younger (18-23 years), middle aged (between 24-64 years), and older (65-85 years). Participant demographic information is provided in Table 1. All participants reported being in good to excellent health and had normal or corrected-to-normal vision.

TABLE I. PARTICIPANT DEMOGRAPHICS AND SELF-REPORTED DRIVING MEASURES

		Age Groups		
Characteristics	***Participants (n = 36)***	***Younger***	***Middle***	***Older***
Age Range		18-23	24-64	65-85
Mean Age		20.92[a] (1.51)	34.48 (13.76)	73.67 (5.52)
Gender: Male | Female	18|18	6|6	6|6	6|6
Years Licensed		4.45 (2.21)	10.08 (13.34)	47.36 (23.04)

[a.] Note: the numbers in parentheses are SD for each mean

B. Apparatus

The study utilized a high-fidelity driving simulator. Seven 55-inch high-definition monitors were mounted atop a motion platform (Moog, Elma, NY) using a visualization frame and provided a 315-degree field of view of a virtual driving environment (see Figure 1a). Driving simulation software (FORUM8, Tokyo, Japan) also presented the driver's vehicle and roadway traffic. The motion platform offered 6 degree-of-freedom and motion cues synchronized with virtual vehicle control. A quarter vehicle cab with full-size controls was integrated with a 10.5-inch tablet computer mounted above the center console area (where navigation and information displays are normally mounted; Figure 1b). The tablet displayed conventional navigation information as well as business logos that matched the layout of on-road signs (Figure 2a & 2b).

(a) (b)

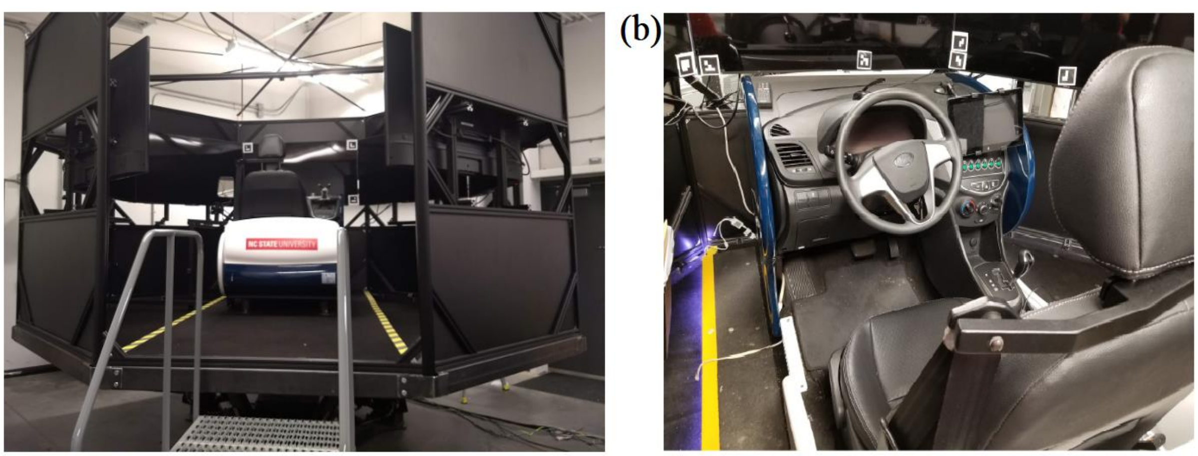

Fig. 1: (a) Forum 8 driving simulator; (b) Set up of the in-vehicle display

C. Stimuli and Measures

a) Driving: The driving simulation presented a normal freeway driving scenario with three interchanges. Each participant completed 6 test trials. Prior to driving tasks, drivers were given a target destination and they were required to take the correct exit for their destination. Their responses (through action) were recorded by experimenters. While driving, participants were asked to maintain a consistent position of the vehicle in the right lane of the freeway and maintain speed at the posted speed limit (65 mph) at all times.

b) Logo identification: Apart from driving, participants were required to look for target logos. Prior to each trial, participants were presented with logo targets (e.g., Wendy's and Motel 6). They were instructed to verbally indicate presence of logo targets ("yes" or "no") when panels were visible on signs. In each trial, six logo panels were presented with three logos randomly selected as targets and no more than one target occurred at each panel. Therefore, the target prevalence rate was 50%, making it difficult for drivers to bias their guesses. Driver verbal responses were recorded by an experimenter.

c) Hazard negotiation: The driving simulation also included situations when a lead vehicle braked suddenly (at a deceleration rate of -8.73m/s^2) and came to a complete stop within 3.4 seconds. The lead vehicle remained stopped for 10 seconds. Prior to test trials, drivers were informed of the possibility of a hazard. Hazards occurred in the presence or absence of a logo sign panel (either on-road or in-vehicle). The locations of hazards were completely randomized; thus, participants could not predict hazards. Drivers were instructed to respond to hazard by braking only. If a steering maneuver was applied, the test trial was repeated with different hazard locations.

d) On-road Signage and In-vehicle Displays: The experiment followed a full-crossed design with information source (IVD vs. on-road signage vs. both) and logo presentation format (logo vs logo + text) as manipulations. In each trial, drivers experienced a unique combination of information source and logo presentation format. To counterbalance the order of trials and control for carryover effects, presentation of trials followed a 6x6 Latin Square design.

The on-road signage was displayed through 3D models in the driving simulation, and each trial included either logo only signage (see Figure 2c) or logos with text (see Figure 2d). All road and sign configurations were consistent with regulations set by the North Carolina Department of Transportation and MUTCD [23]. The in-vehicle signage display at the tablet computer matched the logo panel layout and format of the on-road logo signs.

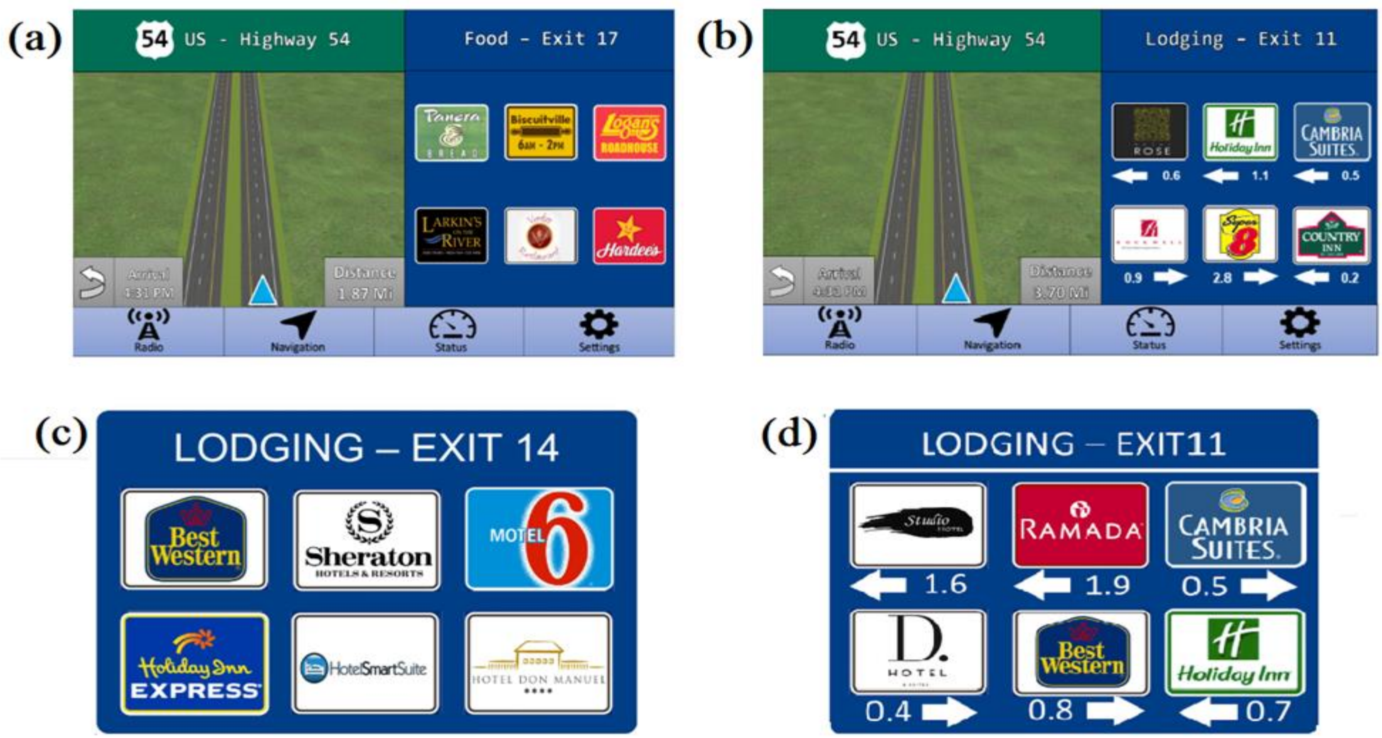

Fig 2: (a) IVD with logos; (b) IVD with logos and text; (c) On-road signage with logos; (d) On-road signage with logos and text.

e) Driver Workload: The NASA Task Load Index (TLX) was used to assess workload. At the beginning of the experiment, participants completed pairwise comparisons of demand components/rating subscales in terms of relevance to driving. Participants completed demand ratings after each trial.

f) Post-Drive Questionnaire: Participants completed a written questionnaire after all simulated driving trials. The survey included questions on driving confidence, history, and experience with information delivery methods. The survey included multiple-choice questions, open-ended questions, and ratings using a Likert scale.

D. Procedure

Subsequent to informed consent, a simulation training session allowed participants to practice maintaining vehicle control, logo target detection, and hazard negotiation with braking. The training trials required drivers to achieve: 1) an average lane deviation of less than 1.37’ [24] from the center of the right lane; and 2) an average speed deviation of 1.6 mph or less. The speed deviation criteria was established based on the performance of three Forum8 driving simulator experts. If either of these criteria was not satisfied, participants repeated the training scenario. If participant training performance remained unacceptable after three trials, his/her participation in the experiment was terminated.

After training, the NASA-TLX ranking worksheet was administered. Each participant then completed six driving trials, each of which lasted approximately 15 minutes. After each trial, the NASA-TLX worksheet was administered to assess mental workload experienced by drivers. Before and after the training session, and between every other test trial, the Simulator Sickness Questionnaire [SSQ; 25] was administered to assess participant motion sickness-like symptoms. Participants were given 5-minute breaks between trials and 10-minute breaks between every other trial. None of the 36 participants involved in this study exhibited simulation sickness symptoms or voluntarily withdrew from the study for any other reason. Upon completion of all test trials, participants completed the post-drive questionnaire.

III. Results

A. Logo Identification

If a target logo was present on a panel and a participant responded with a “yes”, a target “hit” was recorded. If the response was “no”, a target “miss” was recorded. If a target logo was absent from a panel and a participant responded with a “yes”, a “false alarm” was recorded. If the response was “no”, a “correct rejection” was recorded. For logo identification, we only analyzed driver responses to panels when hazard were not present. This approach ensured that results for on-road signs vs.

IVDs were not affected by hazard detection and hazard avoidance maneuvers. Table 2 presents the logo identification performance across panel conditions for the three age groups.

A contingency table analysis was conducted to assess participant hit and false alarm rates. The analysis revealed a significant age effect on target detection accuracy. Older drivers were less likely to produce "hit" responses than middle-aged and young drivers ($\chi^2(2) = 9.903$, $p = 0.0017$) but were more likely to produce "false alarms" ($\chi^2(2) = 12.355$, $p = 0.0021$). There were no significant effects of source of information or presentation format.

TABLE II. TARGET IDENTIFICATION PERFORMANCE (HIT RATE / FALSE ALARM RATE) ACROSS INFORMATION SOURCES AND PRESENTATION FORMATS AND BY AGE GROUPS

Source	**Information Source**					
	On-Road Signage		***In-Vehicle Display***		***Both***	
Format	Logo	Logo + Text	Logo	Logo + Text	Logo	Logo + Text
Younger	96% / 0%	91% / 0%	*88% / 4%*	*100% / 0%*	*96% / 0%*	*96% / 4%*
Middle-Aged	83% / 4%	97% / 0%	96% / 0%	96% / 4%	96% / 0%	96% / 4%
Older	81% / 6%	83% / 13%	83% / 13%	91% / 13%	83% / 4%	92% / 4%

B. Driving Performance

As described earlier, during hazard negotiation, a lead vehicle suddenly braked, came to a complete stop within 3.4 seconds, and remained stopped for 10 seconds afterwards. We examined driver performance during the 13.4-second time-window to identify any effects of age, hazard location, information source, presentation format, and factor interactions. The current analyses focused on hazard exposure in the absence of any sign and hazards when non-target signs were present. A total of 318 observation periods were examined.

Analyses were run using a statistical model with predictors including information source (IVD, on-road sign, both), presentation format (logo, logo + text), hazard location (sign absent, sign present), and age group (younger, middle-aged, older), as well as the resulting two-way, three-way, and four-way interactions. When needed, the three-way and the four-way interaction were pooled in the error term to ensure sufficient degrees of freedom. Trial number and gender were initially included in the model as covariates and were later removed due to a lack of significance.

a) Collisions with Hazards: Collision rate was calculated as the percentage of collisions occurring among the total number of hazard exposure periods. The full factorial model was significant ($\chi^2(68) = 163.100$, $p < 0.0001$) for all exposures. A Chi-Square Effect Likelihood Ratio test revealed main effects of age group (young M = 48.2%, middle-aged M = 66.7%, older M = 43.3%; $\chi^2(2) = 37.716$, $p < 0.0001$) and information source (on-road sign M = 55.6%, IVD M = 55.8%, both M = 47.4%; $\chi^2(2) = 7.185$, $p = 0.0275$). The two-way interaction of hazard location by age group was significant ($\chi^2(2) = 13.895$, $p = 0.0010$) revealing a much greater difference among hazard locations for older drivers (Figure 3a). The interaction of hazard location by information source was also significant ($\chi^2(2) = 10.338$, $p = 0.0057$) with a much greater difference between the sign present and absent conditions when service logos were communicated via on-road signs in the trial (Figure 3b). The main effect of presentation format and its interactions were not significant.

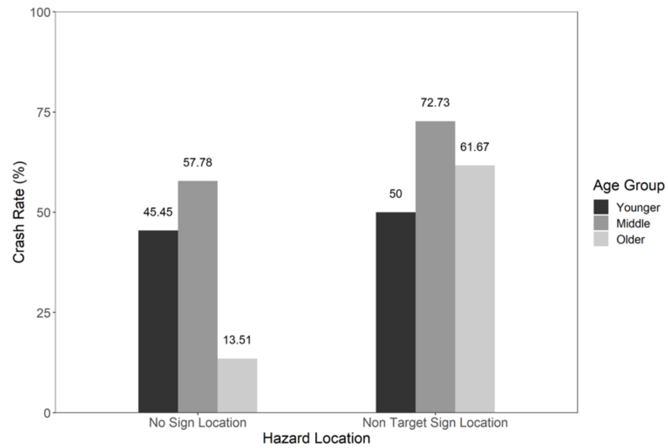

Fig. 3a: Crash Rates by Hazard Location and Age Group

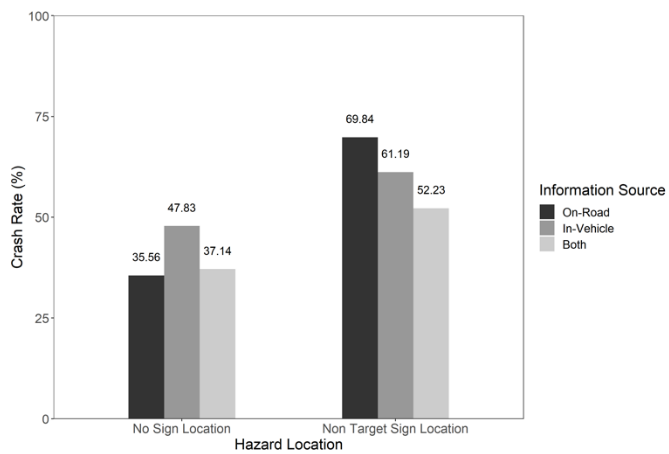

Fig 3b: Crash Rates by Hazard Location and Information Source

b) Hazard Reaction Time: Reaction time was calculated as the time from the start of a hazard (i.e., when the lead vehicle began braking) to the time when a participant consciously reacted and braked hard, defined as a deceleration value of -3.048m/s^2 or greater. This deceleration value is comparable to decelerations observed in driver reactions to yellow lights, according to the Institute of Transportation Engineers [26]. For the reaction time analysis, the 318 hazard exposure periods were grouped according to the occurrence of a collision: (1) those in which a driver successfully braked and avoided a collision (n = 149); and (2) those in which a driver failed to react and crashed into the lead vehicle (n = 169).

For the first group avoiding hazards by braking, two outliers were excluded from the dataset and 147 other observations were analyzed. Regarding the statistical model, the four-way interaction was pooled in the error term to ensure sufficient degrees of freedom for analyze the other lower-order interactions and main effects. The only significant main effect was the hazard location ($F(1,84) = 8.29$, $p = 0.0051$, $1\text{-}\beta = 0.8121$). Tukey's HSD post-hoc test on hazard location revealed drivers to exhibit longer reaction times to hazards occurring in the presence of signs (M = 2.01 s) in comparison to hazards occurring at locations without signs (M = 1.75 s). Aside from the main effects, there was a significant two-way interaction of hazard condition by age group ($F(2,84) = 3.86$, $p = 0.025$, $1\text{-}\beta = 0.9979$; see Figure 4). No other main effects or interactions were statistically significant.

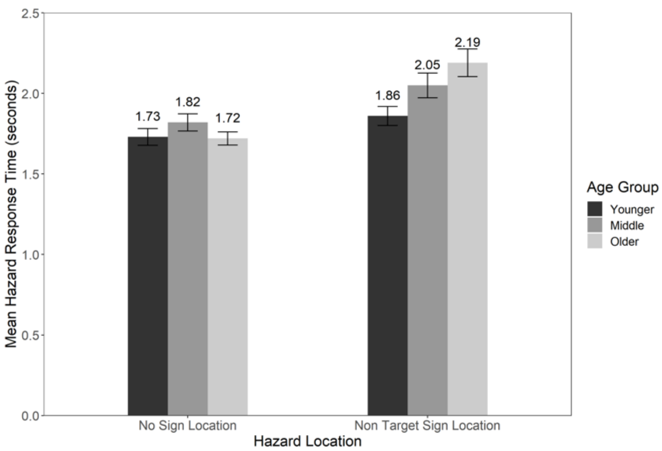

Fig. 4: Hazard Response Time by Hazard Location and Age Group.

For the second group of hazard exposures in which drivers failed to react in time to avoid a collision, the three-way and four-way interactions were pooled in the statistical model error term to ensure sufficient degrees of freedom for analyze the other lower-order interactions and main effects. However, none of the main effects or interactions proved to be significant in effect.

C. *Workload*

For the NASA TLX composite score, the mixed-model ANOVA was significant ($r^2 = 0.856$, $p < 0.0001$). The untransformed response data met the assumptions of ANOVA. There were significant differences between age groups, $F(2, 53) = 68.829$, $p < 0.001$, $1\text{-}\beta=1$. Post-hoc tests (Student-Newman-Keuls) revealed that the older drivers perceived workload to be significantly higher (Mean composite score = 49.9) than the middle (M = 35.5) and young age groups (M = 35.6). Trial number was also significant, $F(5, 53) = 7.547$, $p < 0.001$, $1\text{-}\beta = 0.999$. Post-hoc tests (Student-Newman-Keuls) showed that the NASA TLX composite score for Trial 1 was statistically higher than Trials 3-6. In other words, as exposure to the driving simulator environment was extended, there was a significant decrease in the NASA TLX composite score (cognitive workload). After being exposed in one or two test trials, participant workload appeared to plateau.

D. *Participants Preference and Ratings of Logo Sign Delivery*

In the post-drive interview, participants were asked which method of message delivery they preferred. It was observed that 16.1% of participants had no preference, 54.8% of participants preferred the on-road message delivery, and 29% of participants preferred the in-vehicle message delivery. Participants were also asked which delivery method they utilized when both methods were made available during simulator test trials. It was observed that 63.6% of participants used the on-road display, 33.3% of participants used the IVD, and 3% of participants used both displays equally.

IV. Discussion

On the basis of the inferential statistics, the IVD was found to have comparable effects on driver performance and workload, as compared to on-road signage. While using both on-road signage and the IVD, drivers are more likely to successfully negotiate hazards and avoid collisions while looking for business logos. However, the majority of drivers preferred the traditional on road signage delivery method, and tended to use on road signs even when both display types were available. Results from this study also revealed differences in driver behavior among age groups. Older drivers exhibited less accurate target identification and reported higher perceived workload than younger and middle-aged groups. In contrast, older drivers demonstrated superior hazard negotiation. Older drivers were more alert to hazards than middle aged drivers, as indicated by fewer collisions and shorter hazard reaction times, and were comparable in performance to younger drivers.

Although research generally suggests that crash risks increases with increasing age beyond 65 years, older drivers in this study had fewer collisions than middle-aged drivers, particularly when signs were absent and they could concentrate on the driving task. In addition, middle-aged drivers took much longer to respond to a hazard than younger and older counterparts. It is possible that the middle-aged drivers were overly confident in their driving capabilities relative to the simulated hazard scenarios. We observed no group differences in maximum brake input. Consequently, it is likely that the delayed reactions of the middle-aged drivers led to collisions occurring quite quickly once a hazard was recognized and this, in turn, produced a greater number of collisions.

One explanation for older driver high hazard negotiation performance is that they generally focused more on the driving task than the other two age groups and they consistently prioritized performance of the driving task over the logo identification task. This prioritization is consistent with our previous findings [22, 27] indicating that older drivers tend to have different ratios of misses and false alarms depending on the safety-criticality of a target. This observation could be an adaptive strategy of older drivers. In general, all of these age group differences suggest the need for tailored design of IVDs for delivery safety-related and non-safety-related information for drivers of different age.

Several additional findings have implications for the design of logo sign displays. First, there was a main effect of hazard location on hazard reaction time such that drivers were much more likely to have a collision when a hazard took place when a sign was present (either presented on-road, on the IVD, or both). This is perhaps not surprising as drivers had to perform the additional task of processing sign information when it was present. What is more interesting is the finding of a greater difference between sign present and absent conditions when service logos were communicated using on-road signage (Figure 3b). The lower collision rate at the sign absent location in the on-road signage condition than in the IVD condition suggests that drivers tend to be more successful in avoiding collisions when they knew that they had to process information from on-road signage. This is likely due to them paying more attention to the road during the drive when sign information were available on-road. However, when a hazard took place in the presence of a sign, the on-road signage impaired the driver more on their ability to avoid a hazard. One possible explanation is that drivers spent longer time looking for logos at the on-road signage as compared to the IVD. Further examination of eye movement data is needed to verify this speculation. It was also observed that the presentation format (logo vs. logo+text) did not have a significant effect on collision rate. It may be due to the slight difference in information load between the two formats. The current result suggests that at least with a small amount of additional text below the logo for driver processing does not lead to a higher collision risk. Second, drivers preferred on-road signage and reported relying more on it when both information sources were available. Participants reasoned that they preferred on road signage because: it is what they were accustomed to; it allowed them to keep their eyes on the road; and it was less distracting. Familiarity and prior experience with on road signage could have contributed to the preference bias.

Future research and analyses should extend the method and conditions of the current study. Although eye tracking measures were recorded during this study, due to space limitations the results are not presented in this report. Eye tracking measures may provide valuable information, especially when logo sign information is delivered simultaneously via an IVD and on-road signage. Participants self-reported the information source that they relied on when both logo signs and the IVD were available. Eye tracking measures would provide an objective assessment of driver attentional allocation and workload.

In the present study, the IVD was designed to match the on road signage. Future studies should explore alternative designs, such as multimodal and/or head-up displays of signage information. Furthermore, the current study focused on business logo signage, which is one type of non-safety-related information. Future efforts could be devoted to investigating other non-safety-related information, such as destination guide signs. In particular, with rapid advances in vehicle automation, future drivers will likely rely more on IVDs and more information will be presented through such interfaces. Further research should be conducted to investigate how to effectively deliver various forms of non-safety-critical information under different levels of vehicle automation.

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Driver Visual Behavior and Vehicle Control with In-Vehicle and On-Road Deliveries of Service Logo Signs

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Manuscript prepared based on Phase 1 findings from project NCDOT RP 2018-26: On-road and In-vehicle Delivery of Non-Safety-Related Messages: How Information Source and Presentation Format Impact Driver' Processing of Logo Signs and Hazard Response.

Abstract

With the advances in vehicle technologies, more information is communicated in real-time to the driver via an in-vehicle interface. In-vehicle messaging may deliver safety-related information such as warnings as well as non-safety-related information such as an upcoming gas station. While much research has focused on the design of messaging safety-related information, little is known about the best practice in in-vehicle messaging safety-unrelated information. This study investigated the effects of information source and load on driver signage logo identification, glance behavior, and vehicle control among younger, middle-aged and older drivers. The logos were presented on: (1) an on-road sign panel, (2) an in-vehicle display, or (3) a combination of both, with half of the drives showing logo only, and the other half of the drives showing logo plus additional text. The general findings support the use of in-vehicle displays, especially when it is presented simultaneously with on-road signs. In-vehicle displays did not lead to higher workload or more visual distraction, and that simultaneous presentations resulted in slightly better speed control. The findings also showed minimal negative impacts from increased information load. Significant age group differences were found that older drivers performed less well in signage identification, vehicle control, as well as having longer glances to logo information suggesting design considerations should be made to accommodate specific driver characteristics.

Keywords: vehicle control, glance behavior, logo signs, on-road signage, in-vehicle display, driving safety

1. Introduction

In-vehicle technologies are growing at an ever increasing rate. As of 2016, electronics accounted for approximately 40% to 75% of the total value of a vehicle (Kun, Boll, & Schmidt, 2016). With this increase in technologies inside the vehicle also comes advancements in the ways information is communicated from the vehicle to the driver. In-vehicle displays can provide a wealth of information to the driver such as entertainment, navigation directions, or even safety warnings about upcoming hazardous situations (Blanco, Biever, Gallagher, & Dingus, 2006; Vashitz, Shinar, & Blum, 2008). Although the general intention of in-vehicle information was to improve driver awareness, the rapid increase in the amount and types of information raise a number of human factors challenges that need to be examined with research.

This study focused on a specific type of information that is the presentation of road signs via in-vehicle displays. Road signs are a form of traffic control devices, that convey information such as changes in speed limits, changes in the structure of the roadway, or even alerting the driver to potentially hazardous conditions (Roess, Prassas, & McShane, 2011). As most research of in-vehicle display design focused on the presentation of safety critical information such as warnings, there has been little work done to investigate how this information might be presented to the driver. Previous studies have examined sign presentations that indicate changes in the road condition (Caird, Chisholm, & Lockhart, 2008; Creaser & Manser, 2013; Lee, Gore, & Campbell, 1999; Lee, Young, & Regan, 2009). For example, Creaser and Manser (2013) investigated driver compliance with speed limit signs when the speed change notification was presented in-vehicle. The study showed no differences in participants' response to speed change regardless of whether an in-vehicle presentation of signs was present or not. However, most studies only focused on one form of signs that is the safety critical form, very little is known about how to present other forms of road signs. A major consideration that the presentation of this type of information does not compromise the safety of the driver on the road.

This follows along with a strong push to develop in-vehicle displays that do not compromise safety. NHTSA released display guidelines for in-vehicle visual displays that focus on the structure, size, and types of information that should be used based on previous empirical findings (Campbell, Brown, Graving, Richard, Lichty, Sanquist, Bacon, Woods, Li, Williams, & Morgan, 2016). One major concern of in-vehicle displays is that they can contribute to driver distraction, which can be due to tasks involving the in-vehicle display utilizing the same pool of cognitive resources that are required for the task of driving (Lee, Young, & Regan, 2009). Workload is another major concern of in-vehicle displays as the increased amount of information may add increased workload on the driver (Theeuwes, 2012). In-vehicle displays can help reduce workload on the driver in certain scenarios, such as when the display is functioning as a GPS, however, if the driver needs to change the location they are travelling to, then the action of modifying the location can increase workload (Theeuwes, 2012). These concerns and the NHTSA guidelines are representative of a strong push to improve improve driving safety when using in-vehicle displays. To motivate our specific research questions and research methods, in the following sections, we review relevant literature on in-vehicle displays of on-road signage information, driver attentional processing of safety-related and non-safety-related information, and the methods to quantify driver safety.

1.1 In-vehicle displays vs. on-road signage (maybe as an individual section or integrated into the general background)

A major advantage of in-vehicle displays is that it provides needed signage information in the event of reduced visibility of road signs due to weather conditions, such as rain (Tiffin & Kissling, 2005). Lee, Gore, and Campbell (1999) found that in-vehicle messages were more effective at alerting drivers to unsafe road conditions when presented as redundant information. In-vehicle displays may also provide additional alerts to drivers. Caird, Chisholm, and Lockhart (2008) found that when an in-vehicle display alerted a driver to a pending traffic light change 8-12 seconds prior to the change, drivers were significantly less likely to run yellow lights. In-vehicle displays can also be calibrated to present information based on specific factors such as time of day. For example, during an evening drive on the highway, the in-vehicle display may present lodging information more frequently to the driver than other pieces of information.

Despite these advantages of in-vehicle displays, there are several challenges posed by implementing in-vehicle displays during manual driving. One major issue with in-vehicle displays is that they can create additional secondary tasks that add additional workload on the driver along with the task of driving, which can then degrade driving performance (Lee et al., 2008). Another issue is that in-vehicle displays can increase the duration of eyes-off-road (EOR) time (Naukjoks & Newcomb, 2014). This was found to be especially true for drivers who scored as being higher risk compared to lower risk drivers. Eye-off-road is problematic because the driver may miss potential hazards or changes in traffic, which could result in crashes. In another simulator study, in-vehicle displays that required manual control inputs was shown to increase driver workload and resulted in increased centerline crossings as well as crashes (Yordanov & Hussein, 2010).

In order to mitigate the disadvantages and realize the potential benefits of in-vehicle displays, the content must be designed to take into account three phases of processing that occur during message presentation to the driver; extraction, recognition, and interpretation (Campbell, Richman, Carney, & Lee, 2004). These three phases encapsulate the time it takes the driver to perceive, process, and understand the message, respectively, and need to be accommodated when presenting information via the in-vehicle display. Another challenge is that the display needs to be designed in such a way that reduces visual clutter, which can increase the time needed for the driver to perceive the message. Horrey and Wickens (2004) found that the presence of a Heads Down Display (HDD) resulted in slower response times to hazard events. The study, however, investigated driver performance with in-vehicle displays when performing a phone number entry task and did not include any form of road signage information on the displays. The amount of information present on the display is also a major concern because it can take the driver longer to process relevant information from the display. Peng, Boyle, Ghazizadeh and Lee (2013) found that increasing the amount of ambient text present on the display also increased the duration of EOR times for the driver. Each of these concerns presents a potential design challenge for safe presenting content via an in-vehicle display to the driver.

1.2 Driver information processing: safety-related messages vs. non-safety related messages

In NHTSA's design guidelines for in-vehicle displays (for a complete review, see Campbell et al., 2016). These guidelines are concerned with safety-related issues regarding in-vehicle displays, but there are some notable differences between safety-related and non-safety related messages. First, the two types of messages demand different levels of attention in the overall goal to prioritize driving safety. Safety-related information such as a forward-collision warning or a lane deviation warning often alert the driver to unsafe situations and require immediate attention and proper action. Designing these messages that they will capture driver attention is necessary. In contrast, in a case where information is not safety-related, there is not as much of a need to induce immediate exogenous attentional capture which could lead to driver distraction (Lee, Young, & Regan, 2009). Second, safety-related messages also need to be as simple and direct as possible in order to facilitate driver perception and understanding of the alert, allowing them to respond to hazards with sufficient time. Following this guideline, increased amounts of text and increased complexity icons may not be desirable as they result in increased glance duration, higher variance in glance duration, and the overall number of glances as well as increasing visual search times for icons (Hoffman, Lee, McGehee, Macias, & Gellatly, 2005; McDougall, Tyrer, & Folkard, 2006). In contrast to safety-related information which is typically time-locked with critical events, non-safety related information is not generally not time-locked and the message may be more elaborated with further details for a driver to make a decision. For example, a message about a restaurant at an upcoming exit that is still 2 miles away does not require the driver's immediate response but the driver may want to know if any specific promotion may be going on at the restaurant. There has been little work done on the dynamics of non-safety related information presented via in-vehicle displays. As such, this presents a gap in the literature that merits further investigation.

1.3 Driving safety measures to quantify the impacts of in-vehicle displays

Various measures have been used to assess the impacts of in-vehicle displays on driving safety; these include lateral and longitudinal vehicle control, hazard detection and response, task-relevant information processing, driver visual behaviors, and workload Vehicle control typically includes lateral and longitudinal measures. Lateral vehicle control measures are generally in reference to a driver's ability to maintain lane position (Peng, Boyle, & Lee, 2014). An example of this approach is to take the standard deviation of the driver's lateral deviation from the centerline of the lane (Peng, Boyle, & Lee, 2014). Longitudinal measures are related to vehicle speed and braking events, such as the driver's ability to maintain a speed limit (Yan, Xiang, Wong, Yan, Li, & Hao, 2018). Both of these types of measures have been commonly used in previous research (Caird, Johnston, Willness, Ashbridge, & Steel, 2014; Liu & Lee, 2006; Fitch et al., 2013; Zahabi et al., 2017a).

Driver information processing is another commonly used class of variables to quantify driver performance on particular tasks. For example, previous studies have measured drivers' ability to recognize logos on a sign (Zahabi et al., 2017a; Zahabi et al., 2017b). Responses for driver information processing can be categorized as hits, false alarms, and misses. This secondary task measure is important to reflect driver effort in performing the task and prioritization in various driving conditions.

Driver visual behavior is also commonly collected as an indicator of driver attention, particularly when evaluating sources of potential driver distraction. In the literature, visual behaviors have been used to evaluate driver preferences for information layouts on in-vehicle displays (Olaverri-Monreal, Hasan, Bulut, Korber, & Bengler, 2014), driver distraction during secondary tasks (Kaber, Liang, Zhang, Rogers, Gangakhedkar, 2012), and driver interaction with in-vehicle devices (Peng & Boyle, 2015). Specifically visual behavior measures include glance durations for each area of interest (AOI), and general eyes-off-road (EOR) time, which is when the driver's gaze is diverted from the roadway (Kaber et al., 2012; Peng & Boyle, 2015). Both measures are informative of the level of distraction of an in-vehicle display.

Hazard response is an important measure for investigating driver distraction. In simulated drives, hazards are programmed to allow drivers a specific time interval to respond. Horrey and Wickens (2004) used a 2.5-3.0 second interval for the participant to apply the brake in response to a hazard event. The time between the presentation of a hazard and driver brake response is referred to as the Brake Response Time (Yan, Xiang, Wong, Yan, Li, & Hao, 2018). This measure has been used previously in several studies the cell phone distraction while driving (e.g., Al-Darrab et al., 2009; Charlton, 2009).

Driver workload is another variable that is of interest when evaluating in-vehicle displays because the additional information presented to the driver along with the information that is already present on the roadway may cognitively overload the driver. The NASA Task Load Index (TLX) is the most common subjective measure of workload. This instrument allows participants to self-report workload along six factors; mental demand, physical demand, frustration, performance, effort, temporal demand (Hart & Staveland, 1988). For example, Jahn, Krems, and Gelau (2009) used the NASA TLX was used to assess changes in cognitive demands when using in-vehicle information systems and found that training with an in-vehicle information system at standstill can reduce the amount of cognitive demand on the participant during a driving task.

1.4 The current study

The purpose of this study is to investigate the presentation of non-safety related information via an in-vehicle display during manual driving between younger, middle, and older age drivers. This study will use a combination of driver performance, information processing, visual behavior, hazard response, and workload in order to compare the traditional presentation of non-safety related information (signs on the side of the roadway) to the presentation of this information through an in-vehicle display. It is hypothesized that: 1) simultaneous presentation of in-vehicle and on-road displays may support logo identification but lead to higher workload; 2) increase in displayed content may result in increased workload, degraded logo identification, longer glance durations thus poor driving performance; 3) the effects may differ across different age groups.

2. Material and methods

2.1 Participants

Eighteen participants (9 males, 9 females) were recruited from three age groups, including: (1) younger drivers (19-22 years of age), middle-aged drivers (23-64 years of age) and older drivers (65 years of age or older). Descriptive statistics on driver age and experience are shown in Table 1.

Table 1. Age and driving experience of participants.

Age Group	**Age Statistics (yrs.)**	**Driving Experience (yrs.)**
Younger	M = 21.17, SD = 1.17	M = 4.00, SD = 1.79
Middle-aged	M = 46.83, SD = 11.99	M = 29.33, SD = 13.26
Older	M = 73.33, SD = 5.28	M = 52.17, SD = 16.17

Each age group included 6 participants with balanced gender. Every participants had normal or corrected-to-normal vision, possessed a valid state-issued driver's license, had at least 1 year of driving experience, and reported as in good to excellent general health at the time of participation. Participants were recruited on the campus of a large land grant university and local communities.

2.2 Apparatus

2.2.1 Lab setting

The experiment took place in a lab that was used exclusively for driving simulator research. The space included the simulator motion platform, vehicle cab, visualization frame and control center. The lab space has no windows, so artificial, overhead lighting was used as the primary source of lighting before, during, and after the driving trials.

2.2.2 Simulator

The simulator is a high-fidelity, full motion system. The vehicle cab is a full-size model of a Hyundai vehicle cockpit. Participants interacted with the simulator through a full sized steering wheel, modular accelerator and brake pedal. The simulator includes eight surrounding monitors that provide a 365 degree field of view. The virtual driving environment was simulated using the Forum8 UCWinRoad software (Tokyo, Japan). The simulator allowed for synchronized motion with the virtual vehicle (Figure 1a).

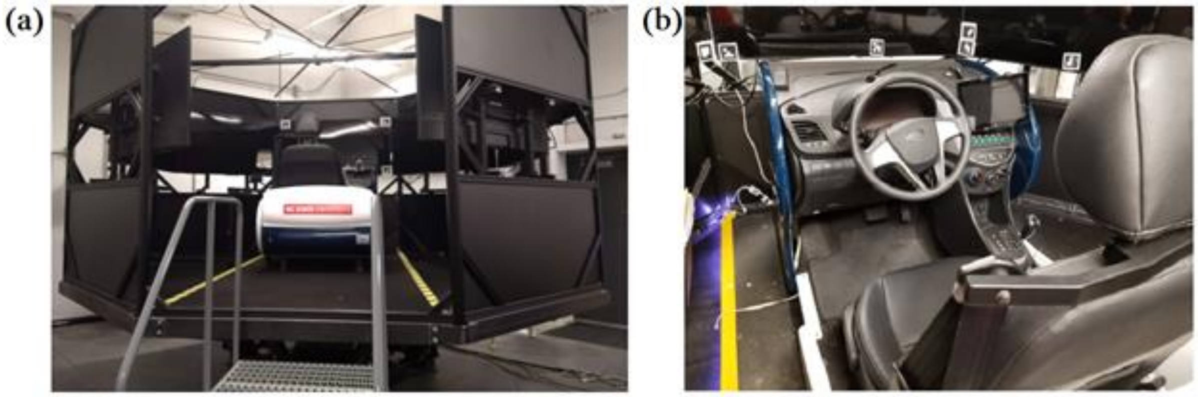

Figure 1. (a) The simulator setup; (b) Setup of the in-vehicle display.

2.2.3 In-vehicle display

A 10.5-inch tablet computer was used as an in-vehicle display (Figure 1b). The size of the display was determined based on a market survey of commercial vehicles as well as the assumption that the size of in-vehicle displays would continue to increase in the future. The tablet was integrated with the driving simulation system. It incorporated basic features of common in-vehicle display systems and presented logo panel signs that matched the layout and format of on-road logo signs.

2.2.4 Eye tracker

A Pupil Labs Pupil Core eye tracker was used for this experiment. This device is a head mounted eye tracker with two eye cameras and one world camera. The eye cameras have a sampling frequency of 200 Hz while the world camera has a maximum sampling frequency of 120 Hz. The camera scene field of vision is 100 degrees.

2.2.5 NASA TLX and Questionnaires

The NASA Task Load Index (TLX), including pre-trial and post-trial questionnaires, was delivered using paper and pencil/pen.

2.3 Tasks and Measures

2.3.1 Driving task and performance

Each participant completed a total of 6 simulated drives. Each drive presented a normal freeway driving scenario with three interchanges. Participants were given sufficient practice allowing them to become familiar with the simulator and were instructed to drive safely by maintaining a proper lane position, adhering to the posted speed limit (65 mph), as well as being vigilant at all times and respond properly whenever a road hazard occurs. To increase the task fidelity, drivers were presented a scenario that they were travelling to a particular destination. Prior to each simulated drive, a target destination was provided and the drivers were required to take the target exit for their destination. Their responses (through action) were recorded by experimenters. Driving measures included vehicle control performance such as speed and lane deviation and driver hazard negotiation performance including crash rate and break reaction time.

2.3.2 Logo identification task and performance

In addition to the driving task, participants were instructed to look for target logos while driving. Before each simulated drive, participants were presented with two logo targets (e.g., Wendy's and Motel 6). They were instructed to verbally indicate the presence of logo targets ("yes" or "no") when a logo panel was visible. At each interchange, there were three logo panels, with one for food, one f
or lodging, and the other for gas information. Target logos were selected from the food and lodging panels; thus in each trial, there were six relevant logo panels (i.e., food or lodging). Three logos were randomly picked as targets (no more than one target occurred at each panel). Therefore, the target prevalence rate was 50%. Driver verbal responses were recorded by an experimenter. Measures of driver logo identification included hit and false alarm rates. If a target logo was present and participant responded "yes", a "hit" response was recorded, and a "miss" response would be recorded if the response was "no". When a target logo was absent, a "false alarm" was recorded if participant reported "yes", or "correct rejection" if the participant's response was "no" to such a logo panel.

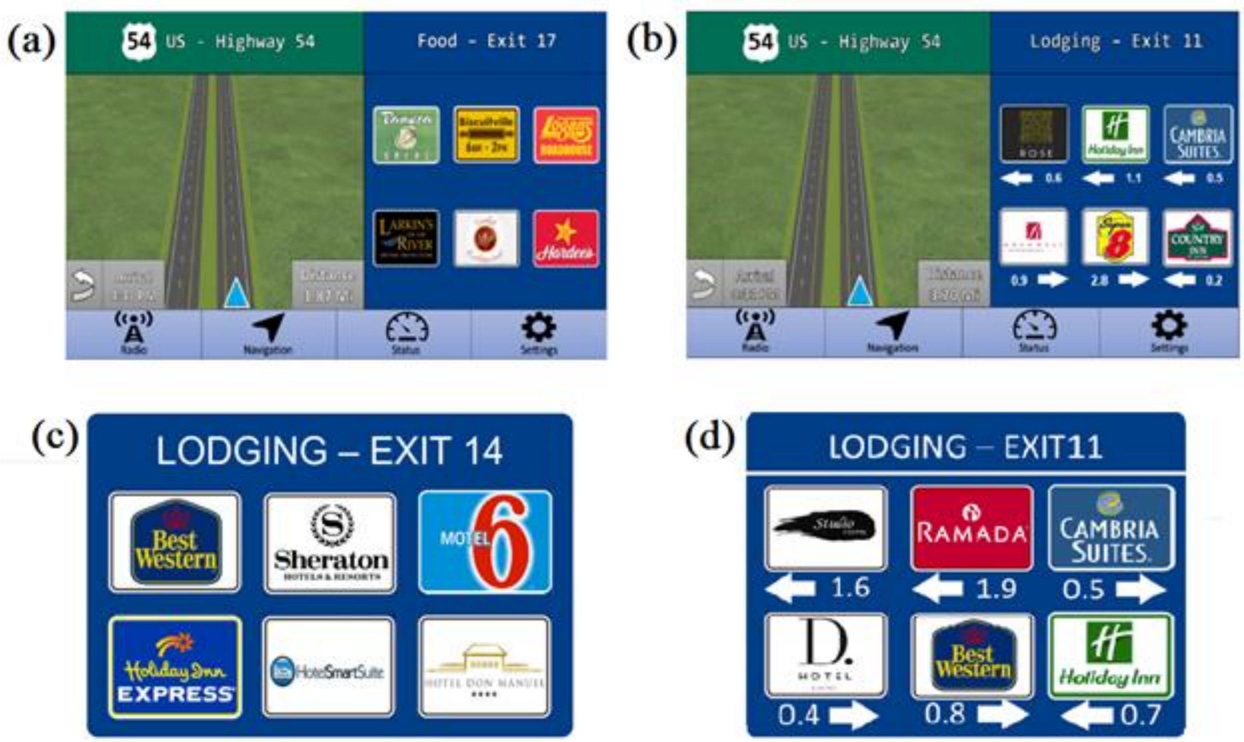

Figure 2: (a) IVD with logos; (b) IVD with logos and text; (c) On-road signage with logos; (d) On-road signage with logos and text.

2.3.3 *Glance behavior measures*

Two areas of interest (AOIs) were specified: the in-vehicle display, the on-road signage panel. A glance duration was defined as the time duration from one entry of gaze point to the following exit of gaze point from an individual AOI during an observation period (the period when a logo signs were visible to drivers). The longest single glance duration was computed for each observation period within each drive for every participant. The longest single glance duration was used to assess the visual demands when drivers process signage information.

2.3.4 *Workload measure*
The NASA TLX (Hart & Staveland, 1988) was used to measure driver workload. Participants rated perceived workload on a 100-point scale for six different demand components, including: mental demand, physical demand, temporal demand, performance, effort, and frustration. At the beginning of the experiment participants completed pairwise comparisons of these demand components to obtain rankings. Participants completed ratings after each trial. The TLX composite score was computed as a rank-weighted sum of all ratings.

2.4 Experimental design and procedure

This study followed a 2 x 3 x 3 mixed factorial design (information source x load x age). Both information source and load were within-subject manipulations, while age group served as a between-subject grouping variable. There were three levels of information source (on-road vs. in-vehicle vs. both) and two levels of information load (logo vs. logo plus text) yielding a total of six combinations of conditions. One drive represented one combination of conditions; every participant completed a total of six experimental drives. The order of the drives were counterbalanced between participants within each age group using a latin square method to control for the carry over effects. There were three age groups: younger (18-22 years), middle-aged (23-64 years), and older (65 years and above).

The entire study was conducted in a single session. First, an experimenter presented information of the study and collected participants' informed consent. Upon consent to the study, the participant was given more detailed instructions of the tasks while seated in the driving simulator with the head-mounted eye tracker calibrated. The participant then practiced maneuvering the vehicle, the logo detection task, and hazard negotiation with braking. During a practice drive, participants were asked to drive safely by maintaining appropriate lane position and speed of the vehicle. Two criteria were set up to ensure participants' familiarity with the simulator before the start of the experiment: (1) an average deviation of less than 1.37' from the center of the lane (Horrey and Wickens, 2004), and (2) an average deviation of less than 1.6 mph from the posted speed limit. The practice session repeated until a participant's performance met both criteria. However, if after three practice drives, a participant's performance still did not reach the criteria, the participation was terminated. Every participant in the current study passed the criteria before termination.

After the practice drive(s), participants completed the NASA-TLX ranking according to their experience with the practice, followed by the six experimental drives. Each drive lasted about 15 minutes. Participants were given a short break after each drive during which they completed workload ratings on the NASA-TLX sheet according to the drive they just experienced. The break was 5-minutes after an odd number drive and 10-minutes after an even number drive. The Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilenthal, 1993) was administered before and after the practice drive(s), and after every two experimental drives to continuously monitor if a participant experienced simulator sickness. None of the 18 participants in the current study reported signs of simulator sickness and completed all drives. At the end, participants reported their demographics information and opinions of various methods to deliver logo information in the post-drive questionnaire.

3. Results

3.1 Logo identification

Hits

A Chi-square analysis was conducted to assess driver target response accuracy based on "hit" responses. A significant age effect was identified (Pearson Chi-square=9.855, p=0.0072), which indicated that older drivers had less hit than younger and middle-aged group: younger - 95.83%, middle-aged - 97.22%, older - 84.72%. There was no significant differences among information sources (Pearson Chi-square=0.945, p=0.6234): in-vehicle - 90.28%, on-road - 94.44%, both - 93.06%. There was no significant effect of information load either (Pearson Chi-square=0.443, p=0.5450): logo only - 89.91%, logo plus text - 93.37%.

False alarms

A Chi-square analysis was performed on false alarm rates. Driver age was found to be significant (Pearson Chi-square=7.821, p=0.02). Older drivers (9.09%) had more false alarms than younger (0%) and middle-aged (2.86%) groups. In-vehicle display was found to produce more false alarms than on road display or the combination of on-road and in-vehicle display (Pearson Chi-square=7.23, p=0.0269): in-vehicle - 8.7%, on-road - 0%, both - 2.94%. There was no significant effect of information load (Pearson Chi-square=2.43, p=0.119): logo - 4.76%, logo plus text - 2.97%.

3.2 Visual behavior

Longest single glance durations

To compare the visual demands of various message format (in-vehicle vs. on-road vs. both) and information load (logo vs. logo plus text) across the three age groups, the longest single glance duration was computed for each combination of conditions for every participant. Therefore, in drives with only the in-vehicle display presentation or the on-road signage presentation, the longest glance duration was computed from either area of interest (AOI). In drives with simultaneous presentations on the in-vehicle display and the on-road signage panels, the longest glance duration was taken among all durations from both AOIs. An ANOVA procedure was performed to examine the effects of information source, information load, age, and their interactions. The data did not meet ANOVA normality assumption, thus a rank transformation was performed. Driver age was found to have significant effect on gaze duration ($F(2,339) = 5.2540$, $p = 0.00057$, $1-\beta = 0.8314$). Old drivers were found to have significantly longer gaze duration than young drivers.

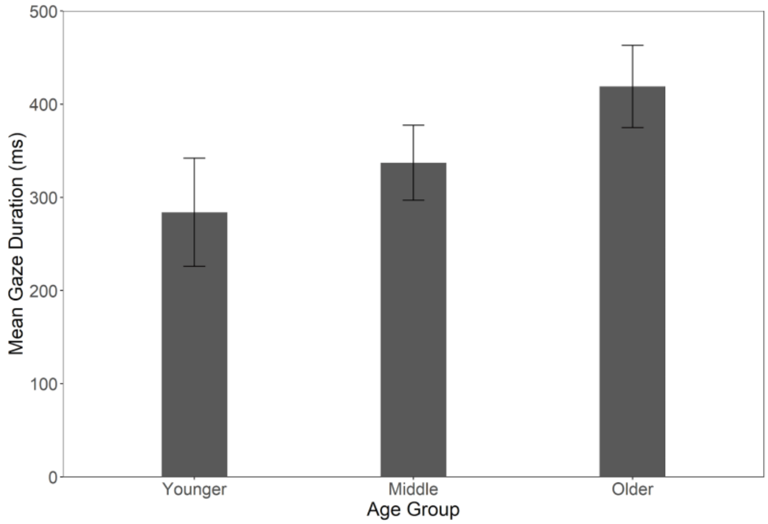

Figure 3. Longest single glance durations among age groups

The information source was not significant, but its interaction with age ($F(2,339) = 2.8138$, $p = 0.0256$, $1-\beta = 0.7658$) was significant. It appeared that older drivers had longer glances when using on-road signage compared with in-vehicle display or simultaneous presentations. Middle-aged drivers had shortest gaze duration while using on road signage. Younger drivers' gaze duration was not significantly affected by information source.

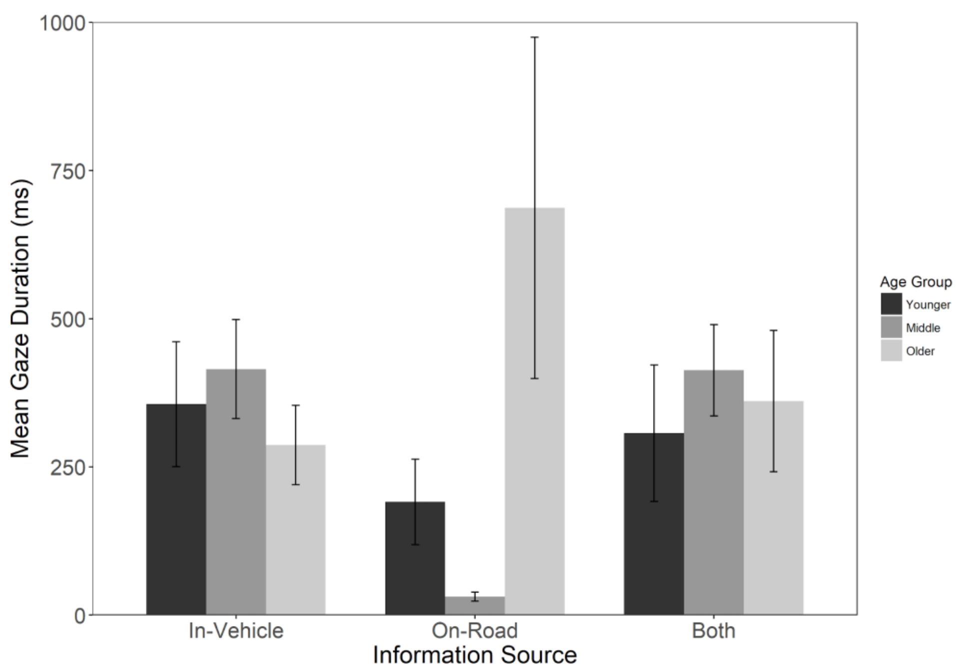

Figure 4. Longest single glance durations by information source and age group

Information load was also found to be significant ($F(1,339) = 5.7316$, $p = 0.0173$, $1-\beta = 0.6652$). Signages with logo and text information produced longer glance durations than logo only.

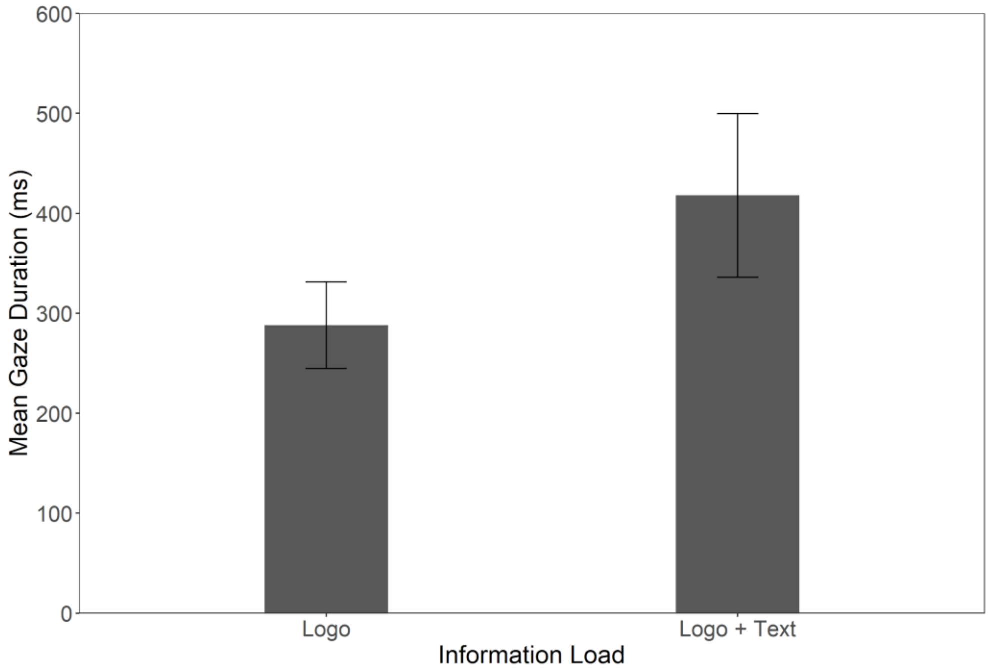

Figure 5. Longest single glance durations by information load

The second analysis investigated driver visual engagement with either information source (in-vehicle or on-road signage) when both are available. This analysis only included drives that both in-vehicle and on-road signage were displayed simultaneously. An ANOVA procedure was performed to examine the effects of information source (in-vehicle vs. on-road), information load (logo vs. logo plus text), age group (younger vs. mid-aged vs. older), and their interactions. The data again did not meet ANOVA normality assumption thus a rank transformation was performed. There was a significant effect of information source ($F(1,240)= 24.5519$, $p <0.0001$, $1-\beta = 0.9985$). Drivers had longer single glance durations on on-road signage AOI than the in-vehicle display AOI. The interaction of age group and information source was also significant ($F(2,240)= 7.0354$, $p =0.0011$, $1-\beta = 0.9257$). Glances durations on the in-vehicle display and on-road signage panels were comparable for younger drivers and older drivers, while middle-aged drivers had longer glance durations on on-road signage AOI than the in-vehicle display AOI.

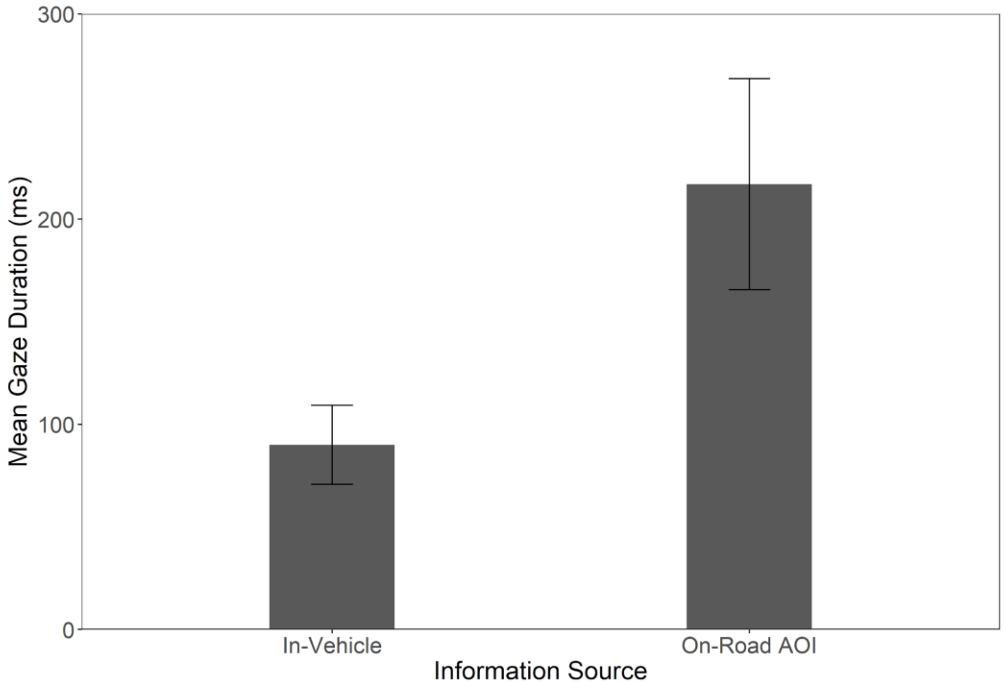

Figure 6. Longest single glance durations by information source

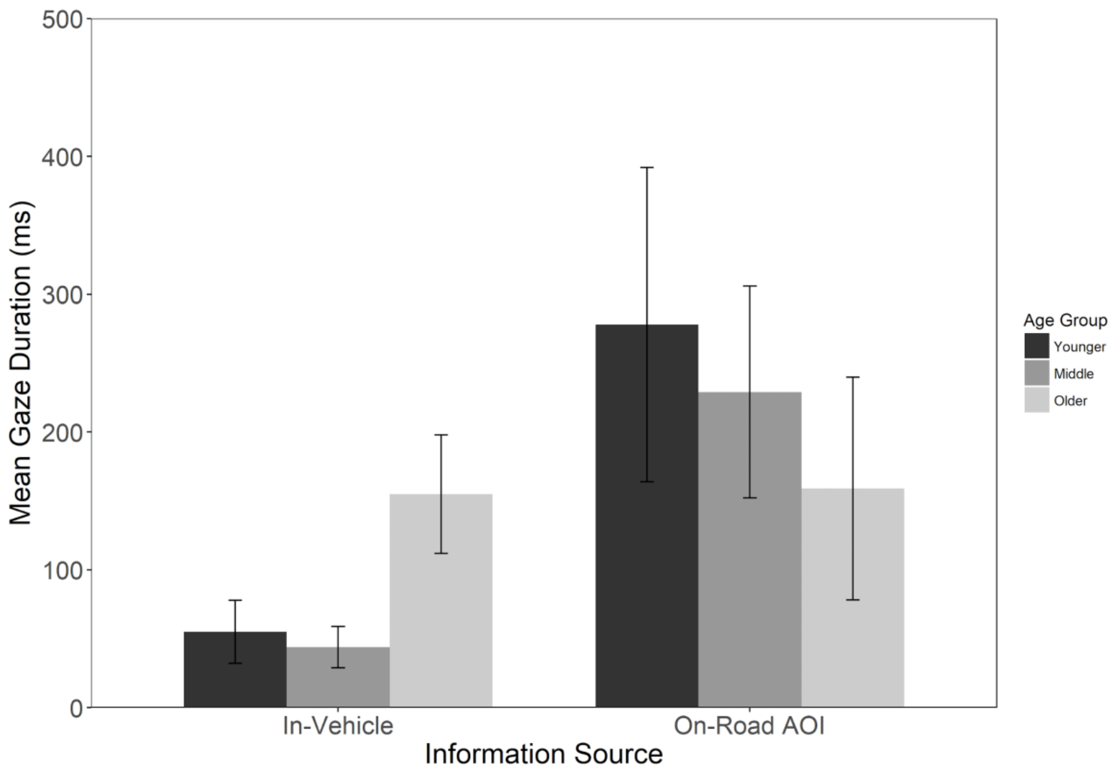

Figure 7. Longest single glance durations by information source and age group.

3.3 Vehicle control

Vehicle control performance were examined in terms of speed and lane deviation. First, the driving performance during hazard-free sign observation periods were inspected in the form of speed and lane deviation with a total of 480 observation points. As previously stated, the participants are instructed to drive in the same lane during sign observation and to maintain 65mph throughout the experiment aside from hazard encounters. Performance deviations from instructions are considered as signs of potential performance degradation or hazard mitigation technique. The hazard responses with a total of 205 observations were also analyzed. However, the obtained effect sizes suggested insufficient number for participants for hazard response measures, thus only vehicle control performance were reported here.

Speed Deviation

Speed deviation is defined as the absolute value of vehicle speed deviations from the instructed 65 mph. A log transformation was applied to the data set to meet the ANOVA test assumptions. Both main effects of age group ($F(1,458) = 18.67$, $p < 0.0001$, $1-\beta = 0.9999$) and information source ($F(1,458) = 3.44$, $p = 0.0329$, $1-\beta = 0.6444$) were found to be significant. Further application of Tukey HSD post-hoc test on age group effect found elderly driver to exhibit much higher speed deviation than the young and middle-age counterparts. As for information source effect, the Tukey HSD post-hoc test did not find any difference between the three sources, however, an application of Dunnett test shows that the simultaneous presentation of road signs and the in-vehicle display appears to produce lower speed deviation than just road signs. The remaining main effect of presentation format was not significant; however, its interaction with information source were found to be significant in the model. In particular, the Tukey post-hoc test revealed that the logo plus text presentation format caused highest speed deviation with in-vehicle display and that lowest speed deviation (greater vehicle control) was achieved by presenting logo plus text presentation format with both road sign and in-vehicle display.

Lane Deviation

Lane deviation is defined in this experiment as the absolute value of deviations from the lane center. The only significant factor found in this analysis is the main effect of age group ($F(1,458) = 26.32$, $p < 0.0001$, $1-\beta = 1.0$) where elderly drivers were found to exhibit significantly higher lane deviation than the other driver groups. All other factors in the model were found to be insignificant.

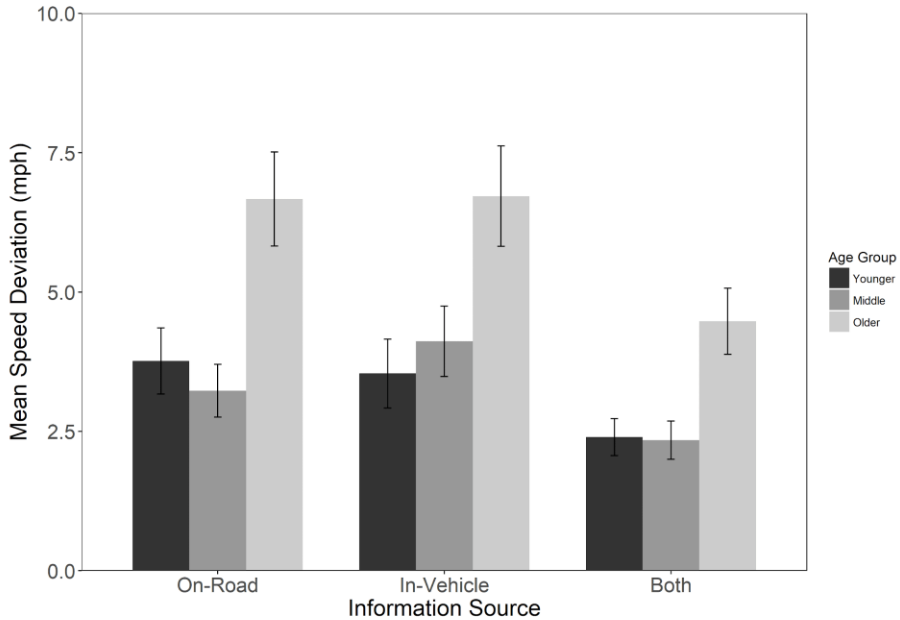

Figure 8. Mean speed deviations by information source and age group.

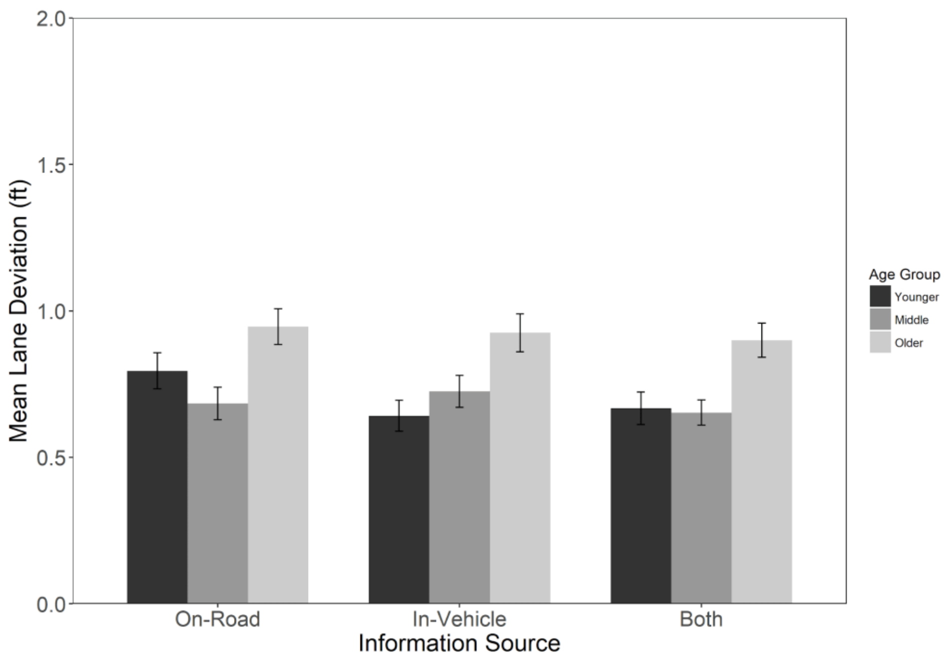

Figure 9. Mean lane deviations by information source and age group.

3.4 Workload

For the NASA TLX composite score, a mixed-model ANOVA was significant ($\square^2=0.857$, $p < 0.0001$). The untransformed response data satisfied parametric test assumptions.

There was a main effect of age group ($F[2, 37] = 11.249$, $p < 0.0001$,$1-\beta = 0.990$): younger - 33.0, middle-aged - 41.2, and older - 40.9. There were significant individual differences within age group, $F[15, 37] = 24.014$, $p < 0.001$, $1-\beta = 1.00$. and trial ($F[5, 37] = 3.820$, $p = 0.004$,$1-\beta = 0.921$) were also present. Post-hoc tests (Student-Newman-Keuls) revealed that the younger age group perceived workload to be significantly less than the middle and older age groups. Post-hoc tests also revealed that the composite TLX score for Trial 1 was significantly higher than Trials 3-6, suggesting that the driver time-on-task played a role in the workload rating.

4. Discussion

This study investigated the effects of information source and load on driver signage logo identification, glance behavior, and vehicle control among younger, middle-aged and older drivers. The general findings support the use of in-vehicle displays, especially when it is presented simultaneously with on-road signs, as it does not lead to higher workload or more visual distraction, and that simultaneous presentations resulted in slightly better speed control. The findings also showed minimal negative impacts from increased information load. However, it is important to note that the load difference between our two conditions are relatively small (i.e., one arrow showing travel direction with a number of miles below each logo). Significant age group differences were found that older drivers performed less well in signage identification, vehicle control, as well as having longer glances to logo information. The finding that simultaneous presentations led to reduced glance durations as compared to on-road signage only among older drivers also suggest a potential benefit of using in-vehicle displays. Below we discuss our specific findings with each examined factors and their implications.

Information source: in-vehicle vs. on-road vs. both
Results showed that using in-vehicle display only produced higher false alarms than using the on-road signage only or both simultaneously. It is possible that drivers were more comfortable with the familiar traditional on-road signage delivery method, which led to superior logo identification performance. Another possible explanation is that drivers perceived looking at on-road signage to be an easier and safer concurrent task than looking at an in-vehicle display while driving and monitoring hazards. Thus they may have been looking at the in-vehicle display for shorter amount of time which led to poorer identification performance. Although our current analysis of longest single glance duration did not show a significant difference between in-vehicle display only and on-road sign only conditions, further examination is needed on the mean and total glance durations as well as glance frequency. It was also found that the presentation of signage information on-road and in-vehicle concurrently resulted in lower speed deviation than just the on-road sign presentation. This finding suggests a greater amount of resources may be devoted to recognizing the sign from on-road signage panels compared to from an in-vehicle display. The workload results did not show any significant differences between the information sources (on-road, in-vehicle, or both).

Information load: logo vs. logo + text

Drivers had comparable target identification performance with two different types of information load. It appeared that the presence of text information did not affect drivers' identification of target logos. It is possible that drivers primarily focused on the pictorial content of signage for target identification thus additional text information did not pose as a source of distraction. Interestingly, the highest speed deviation resulted from the logo plus text presentation on an in-vehicle display while the lowest speed deviation resulted from the logo with text presentation when information was on-road and in-vehicle. This particular finding does not support our original hypothesis that driving performance would be negatively affected by the increased amount of information presented to the driver. Rather, simultaneous presentations may be more beneficial to when more information is to be delivered. These findings are intriguing because in general prior literature suggest more information may lead to more distraction. However, as attentional selection could happen earlier with a higher perceptual load due to more information, drivers may have benefited from earlier attentional selection and revised strategies in handling the vehicle control and signage identification tasks. It is also possible that these findings are due more to the lower sample size of 18 participants and possible technical issues within the simulator. A larger number of observations would likely match the trends seen in previous studies. On the other hand, it is possible that participants may have changed their driving strategies in order to compensate for the higher level of information presented to them. However, if this were the case, the results would show lower speed deviation across trials with logo plus text regardless of information sources. It would be prudent to conduct a replication study with a different sample to confirm these findings. The study did not find any significant differences in self-reported workload between the two information load conditions. These results do not support the hypothesis of increasing workload with a higher amount of information.

Age: younger vs. middle-aged vs. older

Older drivers had degraded target identification performance compared with young and middle aged drivers. The results were in line with prior studies suggesting older drivers experience deteriorating perception skills. The results of the vehicle control performance also revealed that there were significant differences between the age groups in terms of speed and lane deviation, such that older drivers exhibited significantly higher speed deviation compared to middle-aged and younger drivers. This could be due to age-related declines in general perceptual, attentional and motor functioning, or older drivers being less familiar with driving simulation. Older drivers also had longer durations for their longest single glances. When logo information was simultaneously available on the in-vehicle display and on-road signage panels, older drivers relied more equally between the two information sources while the other two age groups exercised much shorter glances to the in-vehicle display as compared to the on-road signage panels. The particularly longer glances by older drivers in the on-road signage only condition may explain why they used the two information sources more equally as processing information from on-road signs become more challenging with age. These findings are consistent with previous literature that older drivers experience declines in driving performance and safety. Younger drivers reporting the lowest workload compared to the other two age groups. This may be a result of younger drivers having better cognitive abilities and therefore can handle the increased presence of information but could also be a difference in self-estimation of workload rather than the experienced workload.

Limitations and future directions

There are two general limitations of the current study. First, the sample size is relatively small, and we could not obtain reliable results from the hazard response measures. However, findings from a subset of these measures have been summarized in our earlier report with a larger sample size (n = 36). Second, the current visual behavior analyses primarily focused on the longest single glance durations. While it is informative, more visual measures could be performed including the mean duration and frequency of single glances, the total duration of glances, total eyes-off-road durations, and the frequency of most unsafe eyes-off-road glances (> 2s). This line of research could lead to many future directions. One direction is to further explore the effect of information load with conditions imposing higher loads. For example, more information may be presented on the in-vehicle display with the research question on how drivers of different age groups may benefit or be impaired by such display design. Another future direction is to explore the effects of information source, information load, and age on driving performance and safety in partial or conditional automation.

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Appendix G

Driver Logo Sign Detection and Hazard Responses during Partially Automated Driving

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This study investigates the presentation of service logo information under partially automated driving. Drivers completed simulated drives with partial automation during which they had to detect target logo signs and react to hazards by taking over vehicle control when needed. Driver performance was measured in terms of sign detection rate, crash rate, and hazard response time. A number of factors, including sign information source, sign information load, and driver age group, were investigated. In general, our findings support the delivery of service logo information via in-vehicle display under partially automated driving, especially when the in-vehicle display occurred simultaneously with the on-road signage. Under this presentation condition, drivers were most accurate in detecting target logo signs, and showed little impairment from processing sign information as a secondary task when negotiating a hazard. Implications of the findings and future directions were discussed.

INTRODUCTION

Vehicles are an indispensable tool when people travel. Consequently, driving safety has been a focus of substantial human factors research. With the recent development of autonomous vehicles, there has been some speculation that more than 90% crashes related to human error could be eliminated (ITF, 2018). Many cars are now equipped with a suite of safety and driver-assistance technologies, such as adaptive cruise control, lane-keeping systems, blind spot warnings, and rear-view cameras. Although automated vehicles might be capable of sensing, collecting, integrating and processing a large volume of roadway condition information, as well as negotiating some operating situations, many domain experts still have doubts about safety. Research has indicated that such technologies can introduce additional safety risks, as the driver is disconnected from driving tasks and there may be vehicle conditions and road environments that are unmanageable by automation (Kockelman et al., 2016; Koopman & Wagner, 2017; ITF, 2018; Huang et al., 2019). Therefore, a driver may need to "takeover" vehicle control in certain hazard situations, including lost GPS signals, unclear and/or missing lane markings, construction zone entry points or road closures, and high traffic density (Körber, Prasch, & Bengler, 2018; Molnar et al., 2017). For example, with partially automated vehicles (e.g., SAE Level 2), even if a driver assistance system can perform tasks related to steering and acceleration, when roadway information is compromised, a driver may need to quickly take control to prevent an accident (Li, Blythe, Guo, & Namdeo, 2018; Litman, 2018; National Highway Traffic Safety Administration, 2017). Related to this, there are many studies that show the degree of automation can change the way humans interact with a machine system, including monitoring, action planning and execution. For example, an increase in the level of vehicle automation may lead to a decline in driver situation awareness, which could result in impaired performance under automation failures (Endsley & Kaber, 1999). Higher level automation can also increase driver boredom and drowsiness (Miller et al., 2015; Schömig et al., 2015) and reduce roadway vigilance (Saxby et al., 2013), leading to safety hazards. Driver overreliance on automation (Lee & See, 2004; Saffarian et al., 2012) and increased engagement in non-driving-related activities (Carsten et al., 2012; Merat et al., 2010) could also lead to delayed takeover responses and safety threats. Consequently, the development of automated vehicle systems demands careful consideration of how manufacturers design and develop information displays in order to limit driver distraction from the roadway and driving task and to provide alerts in the event of a need for takeover of vehicle control.

For decades, the automotive industry has developed in-vehicle displays to support driver performance and safety (Noy, 1997; Barfield and Dingus, 1998; Carsten and Brookhuis, 2005a). Displays range from gear information under manual vehicle control to roadway hazard information and vehicle states under different levels of automation (Birrell, Fowkes, & Jennings, 2014; Creaser & Manser, 2013; Politis, Brewster, & Pollick, 2015; Koo et al., 2015). In general, the amount of in-vehicle information is ever increasing, including both safety-related information such as warnings and non-safety-related information such as local services (Deng et al., 2019). It is possible that non-safety-related information could compete for a driver's limited mental resource (Wickens, 2002; Horrey et al., 2006) and, consequently, impact driver performance in dangerous situations. Previous studies have explored various characteristics of non-safety-related information presentation via on-road signage and in-vehicle displays under manual driving (Kaber et al., 2015; Deng et al., 2019, 2020; Zahabi et al., 2017a, 2017b). However, how driver performance and behavior would change with vehicle automation remains unknown.

The present study examined in-vehicle display of non-safety-related information, specifically service logo signs, under partial automation (SAE Level 2 driver assistance). Our research questions were: (1) how does the presentation of non-safety-related information impact driver responses to road hazards during partially automated driving, (2) how do such impacts differ when the information is presented either via on-road signage, an in-vehicle display, or both, (3) how does the impact change with an increase in information load, and (4) are there any age group differences on sign detection and hazard response among younger, middle-aged, and older drivers.

METHOD

Participants

Thirty-six (36) participants were recruited from the area around a Southern capital city to participate in this study. This sample was balanced across age and gender. The three age groups were younger (18-23 years), middle-aged (24-64 years) and older (65 and above years) drivers. We recruited participants via online advertisements and visits to retirement communities. Each driver was compensated $20 per hour of participation. Every participant had a valid driver's license and normal or corrected-to-normal vision and was driving regularly at the time of participation.

Design

This study followed a 2×3×3 mixed factorial design (information source × load × age). There were three age groups: younger, middle-aged, and older. Information source and load were within-subject manipulations. Information source had three levels (on-road vs. in-vehicle vs. both) and information load had two levels (logo vs. logo plus text), yielding a total of six combinations of conditions. There was one simulated drive for each combination of conditions. Every participant completed a total of six simulated drives for the experiment. A Latin square method was used to control for the carry over effects among the drives, thus the order of the drives were counterbalanced between participants within each age group.

Tasks and Measures

Simulated Drive. There were a total of six simulated drives on a standard interstate highway. Each drive involved a four lane road with three different interchanges with each interchange separated by a mile and a half of straight road. After the three interchanges there was a two mile straight road section before the end of the drive. Each drive was designed to follow the guidelines presented in the MUTCD (Federal Highway Administration, 2009). Within each drive there were five or seven hazards. Two hazards were placed at logo sign panel locations and three or five hazards were at locations where no sign was present. Among these, three hazards were presented as a result of automation failures thus a driver had to take over, while the remaining were handled by automation.

Hazard Response. Drivers' hazard response performance was measured in terms of crash rate and braking response time. Crash rate was determined as the number of times the driver collided with the lead vehicle across all hazard scenarios within each drive. Braking response time was determined by subtracting the time at which the deceleration of the vehicle reaches -3.048 m/s^2 (Institute of Transportation Engineers, 2016) by the time point where the hazard event began in the simulation.

Sign Detection. Sign detection was measured as the participant's ability to detect target logos among distractor logos as they were presented either on the roadway, the in-vehicle display, or both (Figure 1). Responses were collected by having participants respond "yes" or "no" at each sign presentation. Each response was recorded as a drive progressed and was then classified as being either correct or incorrect. Driver sign detection accuracy in each drive was measured as the percentage of correct responses in the drive.

Figure 1. Example displays of on-road signage (left panels) and in-vehicle display (right panels) for higher information load (upper panels) and lower information load (lower panels) conditions.

Procedures

Drivers were welcomed into the lab and were asked to read through and sign an informed consent form. After consenting, the drivers were asked to complete the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) in order to get a baseline measure of their current state. Drivers then provided information regarding their driving background and general health.

Every driver completed a training drive in order to familiarize themselves with the simulator. The training drive involved making a right turn at a T-intersection and then maintaining a speed of 45 mph while maneuvering on road. After this training, participants were given two more training drives specifically involving driving on a straight highway at 65 mph with a braking hazard present at the end of the drive. The first training drive was done under manual driving conditions and allowed the participants to become familiar with the sign detection task. The second training drive was done under partially automated driving conditions with the vehicle handling speed control and lane position. This drive allowed participants to acclimate themselves to the vehicle automation. The automation handled the hazard in the second training drive as well. After the two training drives, participants completed pairwise comparisons for the NASA TLX (Hart & Staveland, 1988).

Drivers then began the six highway drives. Each drive was approximately 15 minutes in duration and drivers were asked to keep their eyes on the road even when the automation handled vehicle control. The drivers stated "yes" or "no" for each blue sign that was presented to them to respond whether or not they saw the target logos they were provided at the beginning of each trial. After each drive, participants completed NASA TLX ratings. After the first three drives, participants were given the Simulator Sickness Questionnaire to ensure they were not experiencing any symptoms. After finishing the drives, drivers were given a post-drive questionnaire that asked them to provide feedback on their preferences for the different sign presentations. Once they had completed the questionnaire, they were compensated for participation.

RESULTS

Sign Detection

A driver's response to the sign detection task was coded as either a correct or incorrect response, which results in a dichotomous outcome variable. There were 1332 sign responses collected and of these, 47 responses could not be used due to technical or recording issues, thus a total of 1285 responses were included in the analysis. As such, a logistic regression model was conducted with the predictors being information source (on-road, in-vehicle, or both), information load (logo, logo plus text), and age group (younger, middle-aged, and older). The overall model was significant (χ^2 = 32.55, p < .01). There were significant main effects for information load, source, and age. For information load, the results showed that during logo plus text conditions, drivers were significantly less likely to provide a correct response (β = -1.42, p < .01; logo only – 94%, logo plus text – 98%). The results also showed that during on-road only presentations (β = -1.69, p < .01) and in-vehicle only presentations (β = -1.40, p < .01) drivers were significantly less likely to give a correct response as compared to when logo information was presented on both (on-road – 94%, in-vehicle – 95%, both – 99%). The age differences revealed that older drivers (β = -1.07, p < .01) were less likely to provide a correct response than middle-aged drivers (older – 94%, middle-aged – 98%), while younger drivers and middle-aged drivers were not statistically different (β = -.20, p > .05; younger – 97%).

Crash rate

Crash rate was computed as the frequency at which the driver's vehicle collided with the lead vehicle during hazard events within the drives. For this analysis, all hazards were included for a total of 1257 crash observations. A logistic regression analysis of crash outcome (coded as a dichotomous variable; crash, non-crash) was conducted. The factors included sign presence (present or absent), information source (on road, in-vehicle display, or both), information load (logo or logo plus text), and age group (younger, middle-aged, or older). The results showed that drivers were more likely to crash during a hazard event when a logo sign was present (β = -1.45, p < .05; sign present – 36, sign absent – 24), and when the logo information was delivered via on-road signage (β = .67, p < .05; on-road – 22, in-vehicle – 18, both – 20). There were no significant main effects for age groups or information load for the crash rate (younger – 27, middle-aged – 17, older – 16; logo only – 29, logo plus test – 31). Figure 2 shows the differences between the sign presentation conditions between sign present and sign absent conditions. There were also no significant interactions.

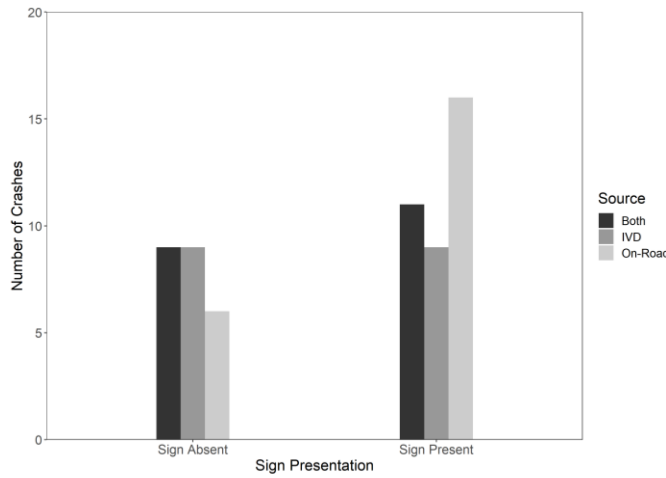

Figure 2. Crash rates by sign presentation and information source.

Hazard Response Time

Driver braking response time, was computed as the difference in time between when the hazard event began and when the participant manually decelerated to a rate equal to or more than -3.048 m/s^2 , which has been used in prior studies involving braking response time (Institute of Transportation Engineers, 2016). For this analysis, only manually handled hazards were analyzed and were split based on whether a crash had occurred or not. Cook's D was then used to identify outliers in the data. Two observations were removed due to meeting the Cook's D criteria. This resulted in a total 1208 observations where the automation failed during the hazard.

A mixed factorial ANOVA was conducted to determine differences in braking response time for sign presence (sign present, sign absent), information source (on-road, in-vehicle, both), information load (logo, logo plus text), and age group (younger, middle-aged, older). The results showed significant main effects for sign presence [F(1,1172) =25.17 p < .05] and information source [F(2,1126) = 3.03, p < .05]. The main effects for information load and age group were non-significant (logo only – 2.30s, logo plus test – 2.27s; younger – 2.34s, middle-aged – 2.19, older – 2.31). A Tukey HSD post hoc test was conducted to explore the significant effects of sign presence and information source. The results showed that drivers took longer to take over (i.e., longer braking response time) when logo signs were present (M = 2.43 s) than when there is no sign (sign-present – 2.43s, sign-absent – 2.21s). For information source, driver hazard response time was the slowest when logo information was only presented on the in-vehicle display. They were slightly faster with on-road presentation, and the fastest when the information was presented on both simultaneously (on-road – 2.30s, in-vehicle – 2.45s, both – 2.13s).

Aside from the main effects, there was a significant two-way interaction between sign presence and information source [$F(2, 1172) = 3.44$, $p < .05$] such that when a logo sign was present, on-road and in-vehicle presentation resulted in the slowest response times (Figure 3). When a logo sign was present and delivered via both the in-vehicle display and on-road signage, the braking response times were similar to when no-sign was present.

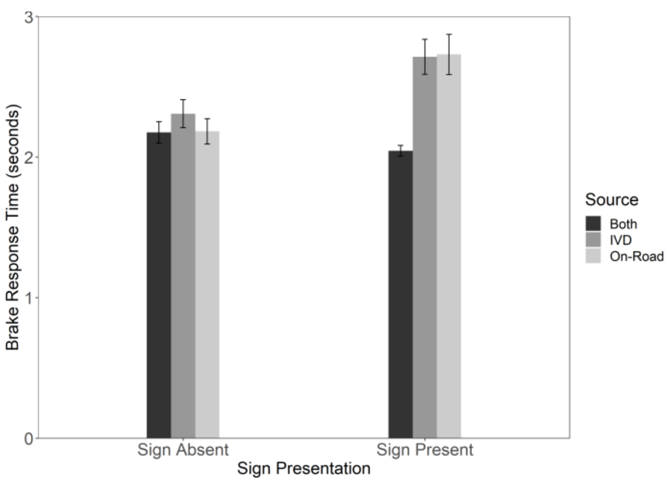

Figure 3. Brake response time by sign present or absent and information source. Error bars represent +/- 1 standard error of the mean.

DISCUSSION

Implications of the Current Findings

The purpose of this study was to investigate the presentation of non-safety-related sign information, specifically service logo signs, on driver performance during partially automated driving. Driver performance in sign detection and hazard responses was examined. Our results suggest a general cost of processing service logo information as drivers tend to crash more and have slower response times to a hazard when a logo sign was present as compared to when there was no sign. However, such cost was alleviated when information was presented via both on-road signage and an in-vehicle display. Under this condition, drivers' sign detection was the most accurate and their response times to hazards were the fastest and were indifferent from their response times when no sign was present. In contrast, the on-road presentation condition led to the most crashes. In general, older drivers were less accurate in sign detection but performed equally well on hazard responses as compared to younger and middle-aged drivers.

The presence of a sign was associated with more crashes as sign processing was an additional task to drivers. This dual-task cost on hazard response time suggests a general distraction effect of processing logo sign information under partially automated driving as compared to sign absent conditions. In-vehicle presentation and simultaneous presentations both in-vehicle and on-road were found to be associated with fewer crashes. Driver response time to hazards were also the fastest when logo sign information was available via both sources. Taken together with the finding that drivers were also more accurate in sign detection under this condition, these results suggest no trade-off between the driving task and sign detection task, but rather a benefit of deliverying logo information via both the in-vehicle display and on-road signage. Under this simultaneous presentation condition, sign processing may be supported by drivers' visual search strategies. According to our experiment observation notes, some drivers may have used in-vehicle display as a cue for timing of attentional allocation to on-road signs. Further examination of this speculation is needed with analyses of driver glance behavior.

In this study, we found that older drivers were in general less accurate in sign detection, but they were not worse than younger and middle-aged drivers on hazard response. This finding is consistent with our prior results comparing older drivers to younger age groups on sign detection and manual driving performance (Deng et al., 2020). We speculate the finding is a result of a trade-off between the sign detection task and driving task with older drivers prioritizing driving more than sign detection.

Limitations and Future Directions

There were several limitations to this study. First, the in-vehicle display was very basic showing static images mimicking a navigation info system. Real world in-vehicle displays will likely present more information and in a dynamic fashion. A second limitation is that the middle-aged driver group covered a much broader set of age range (24-63 years) than the other two age groups. As a result, there may be more heterogeneity within the middle-aged group and future studies could aim to construct more age groups within this middle-aged range. Finally, this study also only focused on partial automation. The results may be different for higher levels of automation such conditional automation.

A next step for this study is to examine driver glance behavior with signage and when negotiating road hazards. This investigation is necessary in order to understand how simultaneous presentations supported driver sign detection and hazard responses. Another next step would be expanding the current focus to other non-safety-related information. With rapid increase of in-vehicle display size and available vehicle automation functions, drivers will handle fewer driving tasks but face more non-safety-related in-vehicle information. How this information plays a role in driver attention and performance under various levels of vehicle automation is an important issue to explore.

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