Head-up displays improve off-road glance, perceived workload, situation awareness, and secondary-task performance and are preferred with the in-vehicle gesture interaction system

Yusheng Cao, Lingyu Li, Jiehao Yuan, Myounghoon Jeon[a]

[a] Mind Music Machine Lab, Virginia Tech, Blacksburg, Virginia, 24060, USA

ARTICLE HISTORY
Compiled January 27, 2024

ABSTRACT

In-vehicle infotainment systems can cause various distractions, increasing the risk of car accidents. To address this problem, mid-air gesture systems have been introduced. This study investigated the potential of a novel interface that integrates a Head-Up Display (HUD) with auditory displays (spearcons: compressed speech) in a gesture-based menu navigation system to minimize visual distraction and improve driving and secondary task performance. The experiment involved 24 participants who navigated through 12 menu items using mid-air gestures while driving on a simulated road under four conditions: HUD (with, without spearcons) and Head-Down Display (HDD) (with, without spearcons). Results showed that the HUD condition significantly outperformed the HDD condition in participants' level 1 situation awareness, perceived workload, menu navigation performance, and system usability. However, there were trade-offs on visual fixation duration on the menu, and lane deviation. These findings will guide future research in developing safer and more effective HUD-supported in-vehicle gesture interaction systems.

KEYWORDS
Gesture interaction, In-vehicle infotainment systems, Heads-up display, Auditory Display, Spearcons, Visual Distraction

1. Introduction

Car accidents are one of the leading causes of death worldwide, and many research aims to reduce their incidence. In-vehicle interfaces, such as navigation displays and media players, can distract drivers, increasing the risk of accidents. Solutions include designing user-friendly interfaces, like voice-activated controls, and equipping vehicles with sensors that detect driver distraction. Continued innovation in this field is crucial to enhancing road safety.

Over the past decade, gesture-based interactions have been implemented in in-vehicle infotainment systems (IVISs) as a means of reducing the need for drivers to perform unnecessary bodily movements while engaging in secondary tasks, such as adjusting the air conditioning temperature, navigating, and controlling the radio and music. Research has indicated that gesture-based systems are associated with lower levels of distraction and bodily movement when compared to traditional touch-based interactions. Furthermore, studies have demonstrated that gesture-based systems can reduce drivers' workload and minimize the frequency of glances directed toward the interface. (Graichen et al. 2019; Sterkenburg et al. 2019).

However, the multiple resources theory suggests that when individuals are required to perform dual tasks that utilize the same resource, their performance will be compromised (Wickens 2002). When using gesture-based interactions while driving, the driver must rely on the same manual and visual resources, potentially degrading driving performance.

Moreover, research has demonstrated that auditory feedback has been effective in reducing driver distraction (Shakeri et al. 2017). Using non-visual modalities can mitigate the risk of accidents by limiting the competition for visual attention for dual tasks (National Academies of Sciences, Engineering, and Medicine and others 2015). Sterkenburg et al. (2019) showed that the gesture-based interface combined with well-designed auditory feedback could improve drivers' performance for both driving and menu selection tasks. However, Sterkenburg et al. (2019) also stated that auditory feedback alone is not enough to avoid all unnecessary glances away from the road. The drivers cannot stop themselves from seeing the menu on the center console because they might not fully trust the auditory-only display. Thus, they instinctively seek a visual aid in such circumstances (Sterkenburg et al. 2019). Furthermore, Shakeri et al. (2017) suggested that visual scanning is one of the sources of dual-task interference. The division of the visual attention to the road and the visual feedback for gesture interactions from Head-Down Displays (HDD) will be a factor, which will make qualitative distinctions because they are not placed within the useful field of view (UFOV) (4 - 30 degrees) but 'head field.' (>30 degree) instead (Shakeri et al. 2017). The Head-up Display (HUD) enables drivers to keep their focus within the useful field of view (UFOV) by projecting key information onto a transparent surface. This allows drivers to easily switch their focus between the HUD and the road ahead without much distraction. As the HUD is transparent, it does not obstruct the driver's view of the road, enabling them to stay aware of forward traffic while receiving important information. Therefore, the HUD will be an effective tool for improving driver safety and situation awareness on the road.

1.1. *Research Questions*

In this study, a combination of auditory (spearcons) and visual feedback (HUD) was used to improve performance and user experience of a gesture interaction system, while also eliminating the need for unnecessary off-road glances. By using the HUD as a visual aid for both gesture interactions and traffic situations, users can easily switch their focus between the HUD and the road, without needing to move their heads to search for relevant information. To investigate the effects of HUD and spearcons on gesture-based interactions in vehicles, we posed the following research questions.

RQ1: How do the visual types (Head-Up Display vs. Head-Down Display) affect participants' situation awareness, performance in driving and gesture interactions, and subjective perception?

RQ2: How does the presence of an auditory display (spearcons vs. no spearcons) affect participants' situation awareness, performance in driving and gesture interactions, and subjective perception?

RQ3: How do visual and auditory display types interact with each other?

2. Related Work

2.1. *In-vehicle Gesture Interaction*

Researchers have investigated gesture interaction in various areas, including finding the best hand gesture for both primary (Xu 2006; Manawadu et al. 2016) and secondary tasks (May et al. 2014; Sterkenburg et al. 2019). There are multiple ways of designing in-vehicle gesture interaction systems. The first research direction is 'direct mapping with functions,' meaning each gesture represents a specific vehicle function (May et al. 2014). The second approach uses the traditional graphical user interface design guidelines, employing the 'WIMP' (window, icon, menu, and pointer) paradigm. Based on Jacob et al. (2008), they could make the window, icon and menu remain the same (they can be visible on HDD or HUD), but instead of using the touch screen or mouse as a pointer, they chose to use a mid-air hand position (Sterkenburg et al. 2019). However, this type of gesture system design has some major drawbacks: Sterkenburg et al. (2019) showed that compared to other conditions (auditory feedback only, visual feedback only), a combination of visual feedback and auditory feedback showed higher workload and less eyes-on-road time. Despite those major drawbacks, it showed faster secondary task completion times and was preferred by the participants. This implies that participants prefer more visual feedback when it is available (Sterkenburg et al. 2019). To complement visual feedback, researchers have explored auditory feedback (Sterkenburg et al. 2019) or haptic feedback (Shakeri et al. 2018). But little research has successfully reduced the eyes-off-the-road time and increased both the secondary task performance and user preference. Moreover, little work has attempted to improve visual feedback per se to enhance the overall performance and user experience (e.g., reducing the visual angle between the road and the IVIS). In the present study we investigated hand-gesture interactions combining HUD and auditory feedback to reduce unnecessary glances off the road and improve driving and menu navigation performance, compared to traditional HDD.

2.2. *Head-Up Display (HUD)*

Head-up Displays (HUDs) have shown to outperform traditional Head-down Displays (HDDs) in many occasions. It causes less distraction, facilitates smoother transitions, and enables faster responses to unanticipated road events under low and high driving load (Gish and Staplin 1995; Liu and Wen 2004; Oh et al. 2016; Sojourner and Antin Sojourner and Antin; Liu 2003). The HUD has shown to be effective in displaying important traffic warnings, such as lead vehicle (Plavšic et al. 2009; Alves et al. 2013; Charissis and Papanastasiou 2008; Park and Kim 2013) and pedestrian warnings (Currano et al. 2021; Park and Kim 2013), which fall under the category of hazard warnings. Most HUDs are located in front of the windshield, providing a clear view for the driver. Furthermore, research has suggested that modifying the content of the HUD can significantly improve a driver's situation awareness. However, previous studies have indicated that drivers have mostly passively reacted to the information presented on the HUD and have not actively interacted with it. Shakeri et al. (2017) stated that visual scanning is one of the sources of dual-task interference. Taking Sterkenburg et al. (2019)'s research as an example, there are two visual focal points in their gesture menu navigation research with HDD. One is on the road for driving while the other is the visual feedback of the gesture system. Those two points are placed separately so that they are larger than the driver's applicable field of view (UFOV)

(4 - 30 degree). In the present study we used HUD as a visual feedback source for the in-vehicle gesture interaction system because drivers prefer visual feedback over auditory feedback (Sterkenburg et al. 2017b), and the HUD can provide more complex information efficiently with less attention transfer time from the road. The HUD can put two visual sources within drivers' useful field of view, reducing the need to switch visual focus points while performing driving and mid-air gestures simultaneously (Shakeri et al. 2017). Therefore, using the HUD is expected to make the gesture interaction process easier and safer.

2.3. *Auditory Display*

Jason et al. found that an auditory-only menu system took more time for drivers to navigate (Sterkenburg et al. 2017b). However, adding auditory displays in addition to visual displays can reduce eyes-off-road time and encourage drivers to focus more on the road, similar to HUD (Sterkenburg et al. 2017b). According to Lucas (1994), both auditory icons (Belz et al. 1999) and earcons (Blattner et al. 1989) require extensive learning to reach the optimum results. Therefore, we considered text-to-speech and spearcons ("Speech-based Earcons") (Walker et al. 2006) as potential auditory display types based on the learnability factor. However, since driving is a time-sensitive work, text-to-speech is not considered because it takes a relatively longer time than spearcons (Walker et al. 2006). Using spearcons (Walker et al. 2006) allowed the user to get more condensed information from the system without the risk of misunderstanding. In the previous experiment, the result suggested that spearcon is the most user-friendly to use and provides the most accurate auditory feedback (Tabbarah et al. 2023). Compared to auditory icons and earcons, spearcons led to significantly better navigation efficiency, accuracy and learning rate (Walker et al. 2013). Thus, we used Spearcons as auditory feedback for the current study.

2.4. *In-vehicle Situation Awareness*

Situation awareness (SA) is critical for maintaining safety in a dynamic task environment (Endsley 1988), such as driving. SA involves understanding the surrounding environment, including the vehicle's position, potential hazards, and predictions of changes (Gugerty and Tirre 1997). There are three levels of SA: level 1 SA involves being aware of what is happening in the environment or locating the hazard in the environment. Level 2 SA involves comprehension of the current situation which is understanding the significance of the hazardous elements in the environment. Level 3 SA involves projection of future status which is predicting what will happen in the near future. Various research projects have shown different methods to improve SA, including spatialized warning sounds (Gang et al. 2018), HUDs like equipment (Calhoun et al. 2005), and highlighting interest areas with high-density information. The HUD has shown great potential in improving SA by making warning signs more salient to drivers (McDonald 2016). LED lights placed under the windshield have also been shown to improve SA. We aim to implement a gesture interaction system using HUD as a source of virtual feedback to improve drivers' SA (Sterkenburg et al. 2017a).

3. Unique Contribution

This research contributes valuable insights into driver situation awareness (SA) and performance, focusing on the use of Heads-Up Displays (HUDs) for in-vehicle gesture-based menu navigation. It provides practical guidance for future designs of in-vehicle gesture interactions and HUD interfaces. The study highlights the effects of different feedback mechanisms, such as visual and auditory cues, on drivers' SA and their ability to perform secondary tasks while driving. These findings offer theoretical and practical implications for enhancing the safety and efficiency of in-vehicle systems, pointing towards the need for carefully designed HUD and gesture interaction systems in future automotive technologies.

4. Experiment

4.1. *System Design*

4.1.1. Gesture Interaction Design

The gesture system in this experiment was based on Sterkenburg et al. (2019). It consisted of four gestures: the activating gesture to start the system, the selecting gesture to choose a menu item, the switching menu gesture to navigate between menu pages, and the tapping gesture to select a menu item. Participants needed to grab a fist for activation, hover their hand horizontally or vertically for selection, perform a swiping for switching between menu pages, and tap for selection of an item. We evaluated participants' menu navigation performance using a gesture interaction system. The time taken to make correct selections after the given commands was recorded, with selections taking longer than 25 seconds considered ”selection failures” and left blank. We also recorded the number of successful selections.

4.1.2. Visual Feedback Design

The gesture-based in-vehicle menu navigation system provided three user interfaces (UI) on both the HDD and HUD: standby, interact, and warning.

The standby UI featured a standard menu grid with a gray background (Note that this UI is not a variable in the present study). It appeared on the HUD when the gesture interaction system was not activated. The gray background on the HUD enhanced transparency, allowing participants to see the road more clearly. The menu grid remained white, providing a visual anchor for menu location.

Upon performing the activation gesture (making a fist), the standby UI transitioned to the interact UI to provide visual feedback in response to the gesture. The gesture interaction system activated, and the interact UI displayed a two-by-two grid, with each element representing a selection. As participants moved their hands, the UI highlighted their current selection by changing the UI grid menu background to red, indicating the hand's position relative to the UI element. Meanwhile, a sound corresponding to the menu item identified the highlighted UI element. After a successful swipe gesture, the UI would replace the menu option set, accompanied by a swipe sound. Subsequently, participants would perform a select gesture, and a confirmation sound would play.

The warning UI monitored driving scenarios while the participant interacted with the UI or drove. If a potential hazard, such as a pedestrian crossing or an emergency vehicle appeared, the warning UI would replace the current UI to alert the driver to react. In cases where the warning UI replaced the interact UI, the selection procedure would be halted.

A pre-programmed speech prompt would present a command, requiring the participant to select one randomly specified item within the menu. The system recorded the participant's performance using the gesture system, assessing their accuracy and speed.

4.1.3. Auditory Feedback Design

We used the spearcon (Walker et al. 2006) generator software to transfer the menu item text-to-speech to spearcon audio files with compression ratio of 70% (software default setting). In both auditory conditions, we used an auditory icon for the swipe trigger indicator (short wind pass sound) to differentiate those auditory displays from the spearcons. Also, earcons were used for the warning sound for hazards (siren sound) and the selection confirmation sound (two isolated musical notes with increasing pitch polarity).

4.2. *Equipment*

A medium-fidelity driving simulator, the NADS-MiniSim (college of engineering 2022), was employed to simulate driving scenarios. This simulator featured three 50-inch Sony displays covering a 120-degree horizontal field of view, a steering wheel, an adjustable seat, gas and brake pedals, and stereo speakers. A custom Heads-up Display (HUD) device was positioned between the display and the steering wheel, constructed using an acrylic board with a partial reflection coating. An Apple iPad Pro 12-inch served as the source of the visual display, allowing participants to view the iPad's image while simultaneously seeing through it to observe the simulated environment (see Figure 1a).

All voice commands were generated using the online text-to-speech web application, Natural Reader (to speech online 2022). Participants' gaze fixation was captured with the Tobi Pro Glasses 2, an eye tracking device (Group 2022). Hand tracking was facilitated using a Leap Motion hand tracking camera, which was positioned on the side of the simulator (ultraleap 2022).

The HUD was handcrafted in the lab using a transparent acrylic board mounted between the driving station and the monitor. A one-way reflective film was applied to the acrylic board, creating a HUD-like reflection where drivers could see through it and the reflection in another direction.

4.3. *Participants*

Twenty-four participants (7 females; M = 26 years; held a driver's license for 7 years, drove 8.8 times per week) were recruited for this experiment and compensated 15 dollars each. The power analysis resulted in a sample size of 23, and we recruited 24 participants. The Institutional Review Board approved the experimental protocol, and participants provided written consent before each experiment. To be eligible for the study, participants were required to (1) have a valid driver's license, (2) be an active driver for at least one year, (3) and be between 18 - 45 years old.

4.4. *Experimental Design*

This study adopted 2 (HDD or HUD) (Figure 1b) by 2 (Sound (with Spearcons) or No sound) within-subjects factorial design. Each participant was asked to drive through four different driving scenarios. Each auditory display representing each menu item was played when the item was ready to be selected. In the no-sound condition, the system played no sound to indicate which menu item is currently selected (the select and swipe sounds remained).

	scenerio1	scenerio2	scenerio3	scenerio4
p1	HUD with sound	HUD without sound	HDD with sound	HDD without sound
p2	HDD without sound	HUD with sound	HUD without sound	HDD with sound
p3	HDD with sound	HDD without sound	HUD with sound	HUD without sound
p4	HUD without sound	HDD with sound	HDD without sound	HUD with sound
...	...	...	...	...
p24	HDD without sound	HDD with sound	HUD without sound	HUD with sound

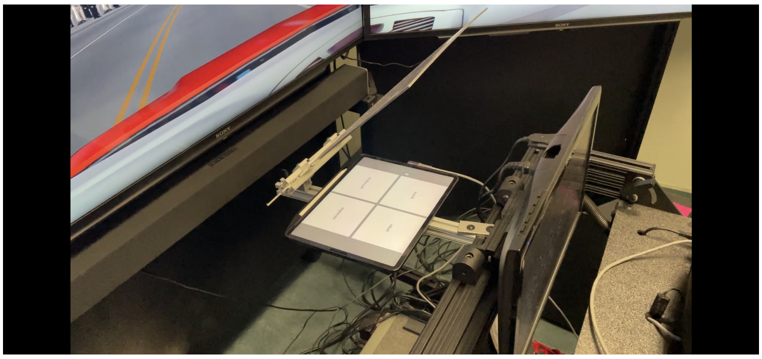
Table 1. Scenerio Design

4.4.1. Task

Participants were instructed to maintain a safe following distance from a lead vehicle throughout the driving scenarios. Every 30 seconds, a voice command prompted them to use the gesture-based menu navigation system to select a specific menu item within the given time. Participants were instructed to remain aware of traffic conditions and respond to hazards during the experiment.

4.4.2. Procedure

Participants first completed an IRB consent form, a demographic questionnaire, and a pre-questionnaire regarding motion sickness (which included a variety of motion sickness symptoms and required participants to rate them on a scale of one to ten). Following this, all participants were asked to undergo a simulator sickness check by driving in a test scenario (containing all possible driving behaviors and different simulated environments compared to the actual testing scenario) on the driving simulator for five minutes. Afterward, participants completed a post-questionnaire on motion sickness (the same set of questions as the pre-questionnaire). By comparing the ratings and participants' self-reports, we determined whether the participants experienced simulator sickness. Those who did not experience motion sickness after a simulator sickness check were allowed to proceed. Participants then watched a tutorial video and became familiar with the gesture-based menu navigation system. In the practice session, participants were able to try to search for menu items multiple times to minimize the learning effect. They completed driving scenarios with different auditory/visual feedback conditions and were asked to maintain distance from a lead vehicle and react to hazards. All driving scenarios contained the same amount of straight lanes, curve lanes and the same number of merge to the other lane. The order of the four conditions was counterbalanced. During driving in each condition, participants had to select specific menu items, and 15 voice commands were generated for this purpose. To ensure data consistency and analysis, a pre-programmed speech prompt was used to limit the choice of menu layers and randomize the specific menu item. Each driving scenario lasted around 6 minutes, and hazard warnings interrupted the participants' driving and selection process. Participants were not supposed to respond to the hazard



(a) The HUD Setup

(b) HUD vs HDD

(c) Hazard Warning: Pedestrian Ahead!

Figure 1. The Experiment Setup

but the screen was blacked out. Then, they filled out the Situation Awareness Global Assessment Technique (SAGAT) (Endsley 1988) questionnaire. In addition, subjective measures were collected via questionnaires, including the System Usability Scale Brooke (1996) , and NASA-TLX (Hart 2006). Objective measures included eye gaze data and driving performance data. After completing all four conditions, participants provided feedback and were compensated. The experiment lasted around 1.5 hours.

5. Results

A repeated-measures ANOVA (Sthle and Wold 1989) was conducted to determine if there were any differences among the four conditions. Situation awareness data collected by the SAGAT questionnaire (Appendix. A) (Endsley 1988) would determine the level of situation awareness during driving in different conditions. The NASA-TLX (Hart 2006) was used to determine participants' workload for each condition. The gesture system analyzed the task performance for gesture interaction data by comparing the participants' accuracy and time. We examined the time difference in different focus areas using the eye-tracking data collected (on-road, off-road, HUD, HDD). The driving performance data were stroed in the driving simulator. Data collected by System Usability Scale (SUS) Questionnaire would show the user preference of the system.

5.1. *Situation Awareness*

For level 1 SA, data were extracted from questions 1, 3-5 from the to make sure that participants located the source of the hazard. For level 2 SA, data were extracted from questions 2 and 6 to make sure that participants fully understood the current situation. For level 3 SA, data were extracted for the last two questions to make sure that participants had right predictions of the future. All the correct answers were marked with a score 1 and incorrect answers were marked with a score 0. Results were analyzed with a 2 (Visual types) x 2 (Sound types) repeated measures ANOVA model fit. There was a statistical difference for level 1 SA (Figure 2).

Average of Situation Awareness

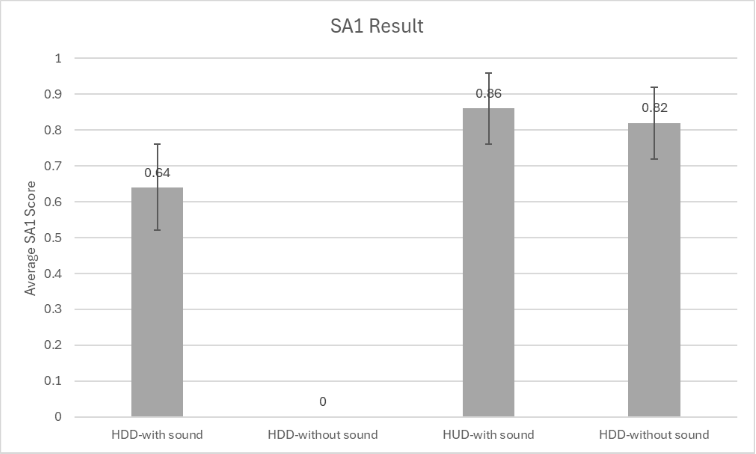


Figure 2. Situation Awareness Result

The results of the ANOVA model fit indicated that there is a statistically significant difference between visual ($F(1, 21) = 56.39$, $p < .001$, $\eta_p^2 = 0.35$) and sound feedback

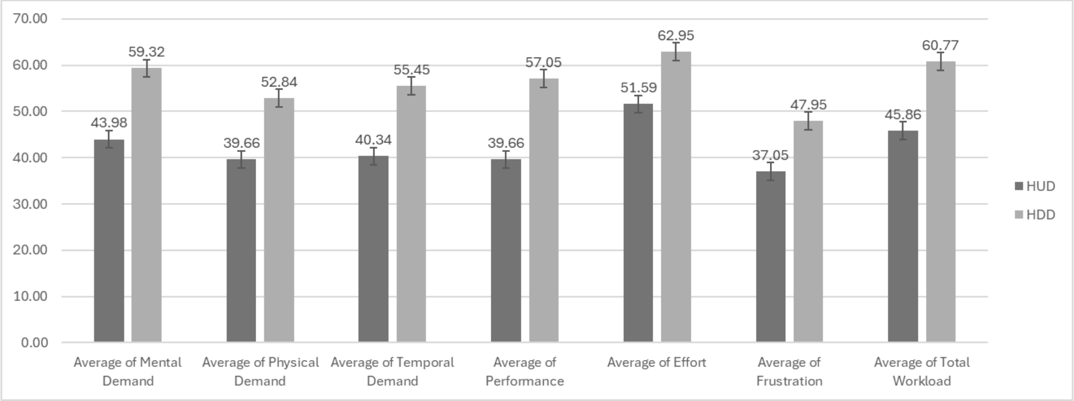


Figure 3. NASA-TLX result

types ($F(1,\ 21) = 31.71$, $p < .001$ $\eta_p^2 = 0.19$), as well as their interaction ($F(1,\ 21) = 17.31$, $p = 0.0004$, $\eta_p^2 = 0.15$), on the SA level 1 score (perception level of situation awareness) (Figure 2). HUD with sound ($Mean = 0.86$, $SD = 0.35$) had the highest SA1 score, followed by HUD without sound ($Mean = 0.82$, $SD = 0.39$), HDD with sound ($Mean = 0.64$, $SD = 0.49$), and HDD without sound ($Mean = 0$, $SD = 0$, all failed the test). However, there were no significant differences among the conditions for SA levels 2 and 3.

5.2. *Workload*

The NASA-TLX data were analyzed with a 2 (Visual types) x 2 (Sound types) repeated measures ANOVA. Results showed that HUD outperformed HDD in a statistically significant way for all sub-scales and overall workload: Mental demand ($F(1,\ 21) = 11.1332$, $p < 0.0031$, $\eta_p^2 = 0.87$), HUD ($Mean = 43.98$, $SD = 22.61$) vs. HDD ($Mean = 59.32$, $SD = 17.27$); Physical Demand ($F(1,\ 21) = 8.78$, $p < 0.0064$, $\eta_p^2 = 0.91$), HUD ($mean = 39.65$, $SD = 21.65$) vs. HDD ($mean = 52.84$, $SD = 21.03$); Temporal Demand ($F(1,\ 21) = 8.47$, $p = 0.0084$), HUD ($mean = 40.34$, $SD = 23.58$) vs. HDD ($mean = 55.45$, $SD = 21.45$); Performance (reverse scale) ($F(1,\ 21) = 36.34$, $p < 0.0001$, $\eta_p^2 = 0.89$), HUD ($mean = 39.66$, $SD = 24.38$) vs. HDD ($mean = 57.05$, $SD = 23.13$) (Note that performance is a reverse scale); Effort ($F(1,\ 21) = 8.78$, $p < 0.0064$, $\eta_p^2 = 0.94$), HUD ($mean = 51.59$, $SD = 22.97$) vs. HDD ($mean = 62.95$, $SD = 22.13$); Frustration ($F(1,\ 21) = 5.21$, $p < 0.0330$, $\eta_p^2 = 0.88$), HUD ($mean = 37.05$, $SD = 25.2$) vs. HDD ($mean = 47.95$, $SD = 25.32$); and Overall($F(1,\ 21) = 14.05$, $p = 0.0012$, $\eta_p^2 = 0.84$), HUD ($mean = 45.86$, $SD = 19.5$) vs. HDD ($mean = 60.77$, $SD = 15.22$). There was no main effect between sound types, and there was no interaction effect between visual types and sound types.

5.3. *Menu Navigation Performance*

Participants' menu navigation performance was collected by the gesture interaction system. Time for each individual selection was recorded. Time between the end of the command and the participant's successful selection of the right menu item was measured. If the participant did not select the right item in 25 seconds, the system considered it "selection failure" and the record was left blank. Accuracy for each individual scenario was calculated afterwards. The menu navigation time and accuracy data were analyzed using repeated measures ANOVA. No significant difference was found in the average accuracy among conditions (around 85% correct). Results showed a statistically significant difference between visual types $F(1{,}23.05) = 8.2$, $p = 0.0088$, $\eta_p^2 = 0.96$. The result shows that participants took less average time using HUD (*Mean* = 8.9, *SD* = 4) than using HDD (*Mean* = 10.66, *SD* = 5.2). There were no main effect of sound types $F(1{,}21.14) = 3.73$, $p = 0.067$ and no interaction effect between visual types and sound types $F(1{,}21.8) = 2.34$, $p = 0.1406$.

Figure 4. Menu Navigation Performance Result

5.4. *Eye Tracking Data*

Tobii eye tracker (Group 2022) provided three types of data based on the area of interest (AOI) we defined: Menu and road. Tobii eye tracker provided eye movement types (fixation, saccade, and eyes not found), gaze event duration (ms), and AOI hit point. Based on those data we categorized AOI hit into: selecting (eye focus on HDD/HUD for selecting, considered as distraction), driving (eye focus on road), or in-between (eyes moved rapidly between the menu and road, considered as distraction). The data were analyzed using repeated measures ANOVA. There were statistically significant differences for selecting and in-between driving and selecting.

5.4.1. Selecting Fixation

A repeated measures ANOVA showed a statistically significant difference between visual types $F(1{,}15.91) = 32.07$, $p < 0.001$, $\eta_p^2 = 0.06$. However, there was no main effect of sound types ($F(1{,}10.19) = 0.0317$, $p = 0.8622$) and the interaction effect between visual types and sound types ($F(1{,}15.7) = 0.1988$, $p = 0.661818$). Based on the result (Figure 5), When fixation gaze occurred during menu selection, participants spent more time on HUD (*mean* = 1755579.50, *SD* = 110421.81) compared to HDD (*mean* = 23342.38, *SD* = 22869.66)

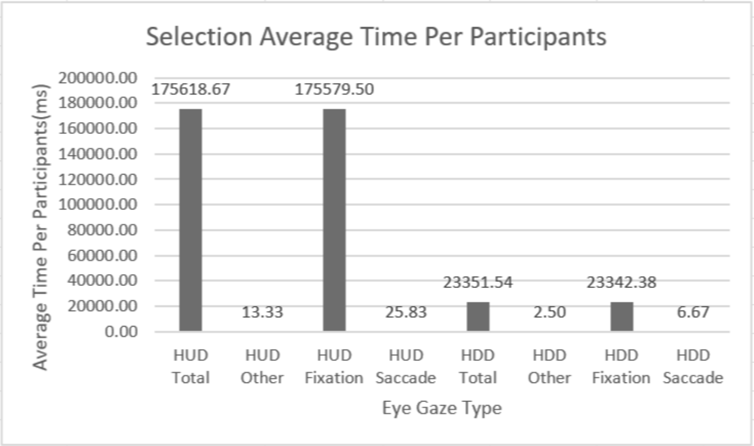


Figure 5. Selecting Fixation time Result

5.4.2. In-Between Saccade

After filtering out all the in-between data (gaze area of interest is neither on the road nor on the HDD/HUD) in which eye movement type is saccade, we analyzed them with repeated measures ANOVA. Results showed a statistically significant difference between visual types $F(1,16.77) = 53.35$, $p < 0.001$, $\eta_p^2 = 0.02$. However, there were no main effect of sound types ($F(1,17.48) = 3.51$, $p = 0.0777$) and the interaction effect between visual types and sound types ($F(1,15.84) = 4.01$, $p = 0.0629$). Based on the result (Figure 6), using HDD had (*mean* = 47780.83, *SD* = 1071.38) longer average saccade gaze time per occurrence compared to using HUD (*mean* = 12342.5, *SD* = 1198.72) in between driving and selecting.

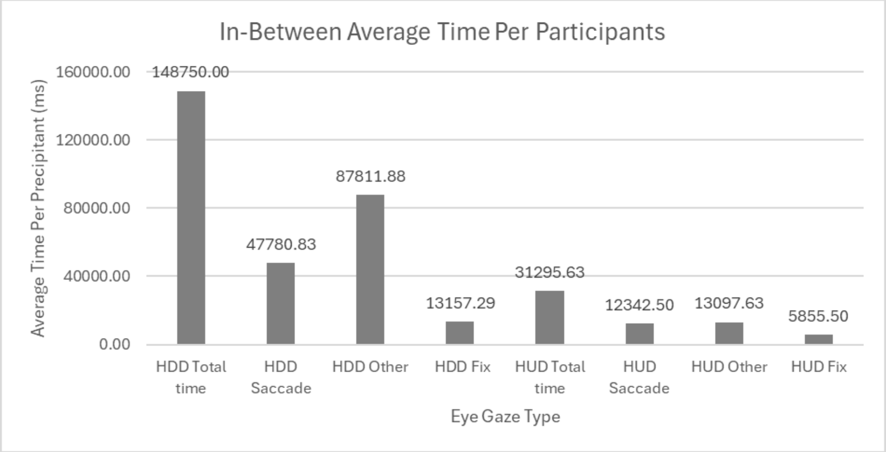


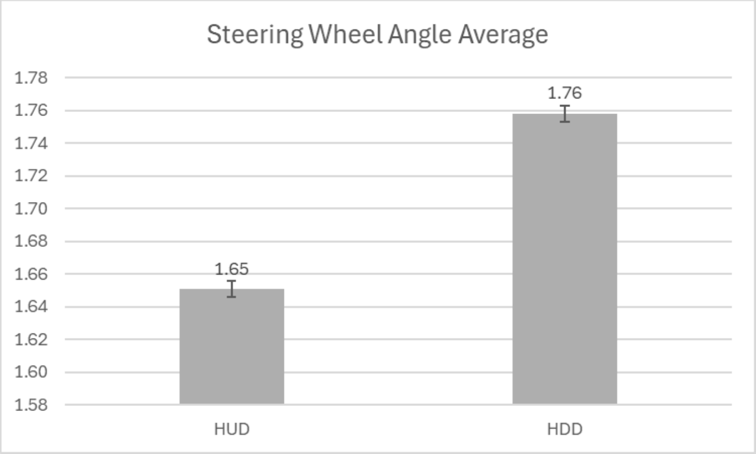
Figure 6. In-Between Saccade time Result

5.5. *Driving*

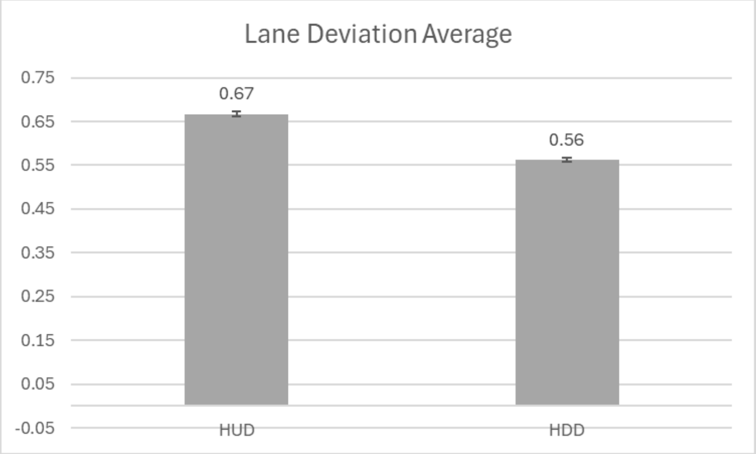
NADS-MiniSim (college of engineering 2022) provided data for each scenario: brake pedal force (lb), steering wheel angle, steering wheel torque (lb), collisions, bumper to bumper distance (ft), time to collision (s), and lane center offset (ft). After fitting in repeated measures ANOVA model, steering wheel angle and lane center offset showed statistically significant differences.

5.5.1. *Steering Wheel Angle*

Steering wheel angle measured how much participants turned the steering wheel. A repeated measures ANOVA showed a statistically significant difference between visual types $F(1{,}22.57) = 5.54$, $p = 0.0277$, $\eta_p^2 = 0.03$. There were no main effect of sound types ($F(1{,}23.68) = 0.0001$, $p = 0.9910$) and interaction effect of visual types and sound types ($F(1{,}23.22) = 0.22$, $p = 0.6417$). HUD ($mean = 1.65$, $SD = 4.79$) had lower average steering wheel angle compared to HDD ($mean = 1.76$, $SD = 3.15$) (Figure: 7a).



(a) Steering Wheel Angle Average



(b) Lane Deviation Average

Figure 7. Driving Data Result

5.5.2. *Lane Deviation*

Lane center offset measured how much participants drove away from the center of the road. By putting all data to repeated measure ANOVA model, results showed a statistically significant difference between visual types $F(1{,}23.24) = 9.71$, $p = 0.0048$, $\eta_p^2 = 0.03$. There were no main effect of sound types ($F(1{,}23.33) = 0.32$, $p = 0.58$) and interaction effect of visual types and sound types ($F(1{,}23.3) = 0.69$, $p = 0.41$). HUD ($mean = 0.67$, $SD = 0.95$) had higher lane deviation compared to HDD (*mean*

= 0.56, *SD* = 0.97) (Figure: 7b). Combined with the steering wheel angle result, it is reasonable to infer that even though drivers might maintain stable control on the steering wheel when using HUD, they might not sufficiently adapt to the curve or so.

5.6. *System Usability Scale (SUS)*

The participants were asked to fill out the SUS questionnaire (Appendix. B) for each condition. The results were analyzed using a repeated measures ANOVA. Visual types had a statistically significant result $F(1{,}22.65) = 20.02$, $p = 0.0002$, $\eta_p^2 = 0.87$. There were no main effect of sound types $F(1{,}20.77) = 1.54$, $p = 0.27$ and no interaction effect between visual types and sound types $F(1{,}16.54) = 0.0068$, $p = 0.93$. The result shows that HUD (*mean* = 68.85, *SD* = 19.44) had higher system usability than HDD (*mean* = 53.8, *SD* = 19.76).

6. Discussion

This experiment aimed to increase the overall in-vehicle secondary task performance and user experience as well as driving safety by implementing a gesture-based menu navigation system which integrated a HUD and auditory displays. HUD decreased perceived workload, enhanced menu navigation performance and increased system usability, but showed trade-offs in eye movements and driving performance (RQ1). The presence of spearcons alone did not independently affect dependent measures (RQ2), but contributed to increase level 1 situation awareness when HUD was employed (RQ3).

6.1. *Situation Awareness*

The situation awareness results suggest that both visual types and sound types affect level 1 SA. It means that HUD works better than HDD, with sound working better than without sound. HUD with sound condition resulted in the best level 1 SA and HDD without sound condition resulted in the worst level 1 SA. There was no difference in the results of levels 2 and 3 SA among the conditions. The HUD was placed in a similar location as in Yang et al. (2018), which provided a similar feature and increased driver SA. Our result is in partial agreement with Gang et al. (2018)'s work which revealed that spatialized warning sounds increased drivers' SA. However, in their research, all levels of SA were increased. The difference might be caused by the application of the spatialized warning sounds in their research. Our results indicate that even though the participants had a good situation perception, visual and audio feedback in our design might not help them properly comprehend the current situation and predict corresponding actions based on that, even though the HUD UI paused the gesture menu ahead of the hazard occurred and replaced it with the warning. Thus, our SA results confirm that even though lower level SA is a necessary condition for the higher level SA, it is not a sufficient condition for higher level SA (Endsley 1988). More advanced approaches (e.g., spatial sounds about hazards) need to be implemented to increase all levels of SA.

6.2. *Workload*

From all the workload factors (mental demand, physical demand, temporal demand, performance, effort, frustration, and overall workload), HUD showed statistically significant differences compared to HDD. However, there were no significant differences between sound and no sound conditions, which shows contradictory results with Sterkenburg et al. (2017a). Our system shared a similar gesture system design with their research. Their visual and audio combinations (same as our experiment's HDD with sound condition) showed significantly lower workload than the visual-only condition (same as our experiment's HDD without sound condition). However, in the present experiment, there was no significant difference between with and without sound conditions. Villalobos-Zúñiga et al. (2016) suggest that using HUD will significantly reduce workload. Taken together, we can cautiously infer that when a sufficient visual display is given, drivers' workload can be reduced, regardless of the presence of auditory cues.

6.3. *Menu Navigation Performance*

For the menu navigation gesture performance, there was no statistically significant difference in selecting accuracy among conditions. The results are in agreement with Sterkenburg et al. (2017a), which also shows that there is no difference in menu selection accuracy between conditions. However, the menu navigation time results show that there was a significant difference between visual conditions but not between sound conditions. There was also no interaction effect between visual and sound conditions. The results show that HUD had a shorter menu navigation time than HDD, and thus, better performance than HDD. Sterkenburg et al. (2017a)'s results demonstrated that with visual feedback, gesture performance was better than non-visual feedback. This result is also in agreement with Villalobos-Zúñiga et al. (2016)'s results, which showed that the HUD condition had better performance compared to the HDD condition. However, these findings suggest that the observed good performance in the secondary task may be a result of compensatory behavior for the primary driving performance. Indeed, HUD showed significantly larger lane deviations than HDD. Therefore, it may be more meaningful to discuss drivers' performance in the secondary task together with their performance in the primary task.

6.4. *Eye Tracking Data*

The eye-tracking data showed interesting trade-offs. During the menu navigation, the participants using HUD had a longer fixation time on the menu than those using HDD. In the meantime, the participants using HDD had more saccades between driving and selecting. These results matched with Metz et al. (2011)'s discussion point: drivers take the demands of the driving task into account and try to distribute available resources in a way that preserves driving safety. HUD was placed within the user's useful field of view, but HDD was not. Therefore, when using HUD, the participants might have thought that they could shift their visual attention quickly between HUD and the road, and thus, they stayed longer time on the menu for better menu selection performance (i.e., shorter selection time mentioned above).

When using HDD, participants had to move their head to see the menu, which could cause them to divert their attention away from the road and feel unsafe. Therefore, participants using HDD tended to have a shorter fixation duration on the menu and switch their visual focus between the road and HDD more frequently, because they prioritized driving safety over menu selection performance.

However, this strategy led to longer menu selection times, indicating that participants may have had difficulty comprehending the menu items and had poor overall performance. Furthermore, the overall saccade time spent on HDD in between driving and selecting was longer, leading to more distraction and potentially unsafe driving.

Furthermore, it is important to note that the results of this experiment cannot directly show that the longer fixation duration during menu selection with HUD causes visual distraction, as there may be other factors at play. However, the potential for HUD to divert the driver's attention and may create a tunnel vision effect highlights the need for further research to investigate the potential safety risks associated with the longer fixation duration during menu selection with HUD.

6.5. *Driving Performance*

Based on the results, HUD demonstrated more stable steering operations compared to HDD. However, in lane deviation, HUD showed a higher average center offset which might mean that when the lane situation changes (e.g., vehicle entering a curve), the participants maintained going straight and slowly adjusted the vehicle position. This could be attributed to the participants' prolonged focus on the HUD menu and fewer short glances towards the road. The presence of sound did not have any effects on driving performance, which is in agreement with Sterkenburg et al. (2017a) who also found the presence of sound had no significant difference for lane deviations. However, Villalobos-Zúñiga et al. (2016) showed that HUD significantly improved the lane deviations when compared to HDD. However, in their research, they had no detailed descriptions of their driving scenarios. Therefore, the difference might come from the different scenarios. Even though both HUD and HDD showed the trade-offs in driving performance, the SA results showed that when the participants used HUD, their SA (at least level 1) towards the hazards was improved, which means that the participants could locate potential emergency hazards quickly. Therefore, the longitudinal safety might be better secured with HUD. However, in situations where the environmental changes were gradual (such as entering a large curve), the participants might have failed to notice the changes. Taken together, both HUD and HDD have limitations, so further improvements are necessary to enhance driving safety.

6.6. *System Usability Scale (SUS)*

There was a significant difference between visual conditions for the system usability scale. HDD had a mean of 53.8 and HUD had a mean of 68.85. Based on the SUS score category, HDD belongs to Grade D (Poor), and HUD belongs to Grade C (Okay). While HUD has demonstrated advantages in level 1 situation awareness and performance in secondary tasks, their effectiveness and user-friendliness may vary depending on the specific system design and user group. Therefore, it is essential to evaluate the system design comprehensively and consider various factors to determine its level of user-friendliness.

6.7. *Theoretical Implications*

6.7.1. Visual Feedback and Situation Awareness

According to our SA result, HUD had a significant improvement in the participants' level 1 SA compared to HDD. This result is in partial agreement with the McDonald (2016) and Wang et al. (2020), which showed that HUD improved drivers' overall SA from level 1 to level 3. The different experimental setup might have caused this distinction. To make the comparison consistent in the current study, both HUD and HDD provided the same warning sign (just a warning, not indicating what it is and where the source of the warning is). But in literature, the past attempts used a more advanced visual approach to improve driver SA with the capability to show where the drivers are supposed to pay attention. For example, Yang et al. (2018) used LED to point to the right direction. Calhoun et al. (2005) highlighted the interest area. McDonald (2016) indicated where the landmark is. With the hazard's spatial information, HUD will be able to improve even higher levels of SA. With a more specific way of highlighting (e.g., text note, color change), the system will enable the driver to respond to the hazard even faster.

6.7.2. Auditory Display and Situation Awareness

Based on the results, it was also found that the presence of sound had a significant influence on level 1 SA, but not on other levels. This confirms that without auditory feedback, the driver's ability to analyze the current situation tends to be worse. This finding is consistent with previous research that showed that visual feedback alone is not sufficient to improve the driver's overall SA, and that a visual-auditory in-vehicle warning system is more effective than unimodal feedback (Ju et al. 2022). However, other related research that investigated the use of 3D sound cues found that the other levels of SA were also improved (Wang et al. 2017; Gang et al. 2018). These findings also suggest adopting spatial auditory feedback about the hazard location can be good future improvement direction.

6.7.3. Driving and Secondary Task Performance

The use of HUD with sound in gesture-based menu navigation presents both advantages and disadvantages. When using HUD, drivers can have better secondary task performance, less workload, and increased system usability. However, this may lead to a false sense of safety, because the drivers may believe that they could correct errors in time when an accident is about to happen. Furthermore, with HUD switching visual focal points between the road and HUD can take longer. Although HUD allows the drivers to see through and monitor traffic, they spend more time staring at it while using the gesture system, leading to longer fixation time and increasing the risk of missing gradually appearing hazards. While they may notice jaywalking pedestrians with their peripheral vision, they may not detect other hazards that require more focus, such as their vehicle off-center or entering a curve. Thus, the transparent feature of HUD may not necessarily help the driver drive better, especially during intense activities like selecting a menu item. Also, the longer duration of distraction may cause drivers to notice the source of the hazard but fail to predict what will happen and plan how they are supposed to respond to it.

On the other hand, the use of HDD tends to allow drivers to do more defensive driving, while it leads to worse secondary task performance, higher workload, and lower system usability. Our participants compensated for their eyes-off the road behavior by reducing the fixation time on the menu system, while increasing the overall short glances and rapidly switching between the menu and the road to ensure driving safety. This approach would work only when the drivers have a correct assessment of the current situation. However, HDD caused more body movements and distractions in general, so the results showed that drivers had significantly lower level 1 SA with HDD, indicating that HDD can help them neither be aware of the environment nor perform secondary tasks well. Therefore, a balance needs to be struck between the use of HUD and sound to achieve optimal results in gesture-based menu navigation.

6.8. *Guidelines for future research*

In this study, the use of a HUD and spearcons in conjunction with gesture-based interactions was found to have the potential for increasing driver safety, particularly in improving gesture selection and partial situation awareness. However, it also revealed that the current HUD with sound feedback design may still not be optimized and resulted in visual distractions that negatively impacted driving performance, specifically in lane-keeping. Future research in this area should focus on addressing the identified issues. For instance, by designing HUD displays that are tailored to the position of the HUD, drivers can be presented with specific information that enhances their overall SA. This may include using different elements, such as colors, icons, or text, to convey different information or prioritize complex information. The size of the HUD is another factor to investigate as a larger HUD provides more information but also creates more visual distraction. Therefore, it is essential to determine how to maintain driving safety while presenting a large amount of information on the HUD. The sound, spearcon, used in this study was selected based on the ease of learning but can be further improved. Future research should explore different layers of sounds (e.g., spatial sounds for the hazards) that have different information densities depending on the context. The future study can include more complex driving scenarios and real-life situations that may further explore the system's effectiveness in more diverse contexts. Finally, improving the gesture interaction system's direction and interaction logic is necessary to ensure that it works seamlessly, and so drivers can interact with the system more effectively and efficiently without causing distractions or compromising driving safety.

7. Limitations

In the present experiment we used the leap-motion camera for hand tracking, but it was inconsistently performed due to variations in hand shapes, sizes, and colors. A more accurate camera or tracking system will improve gesture detection-related outcomes and may affect users' workload and system usability measurements. We also used a small sample size for SAGAT data, which can be improved with more pauses. The HUD size was made consistent with the HDD size for comparison, but real-life HUDs are typically smaller, potentially affecting the results.

8. Conclusion

Using a gesture interaction system can improve the overall driving experience, but ensuring its safe use requires appropriate visual and sound feedback. This experiment introduced a HUD to improve driver situation awareness, driving performance, and gesture-based menu navigation. The results showed that HUD improved level 1 situation awareness and gesture menu selection but compromised lateral driving performance. Sound improved level 1 situation awareness, but had no significant influence on driving or menu selection performance. The experiment highlights the potential of a well-designed HUD for in-vehicle gesture interaction, although optimizing such interactions remains a niche area of research. The experiment may not have produced the most optimal system yet but provides a useful illustration of the potential of a well-designed HUD for in-vehicle gesture integration.

References

Alves, P. R. J. A., J. Goncalves, R. J. F. Rossetti, E. C. Oliveira, and C. Olaverri-Monreal (2013). Forward collision warning systems using heads-up displays: Testing usability of two new metaphors. *2013 IEEE Intelligent Vehicles Symposium (IV)*.

Belz, S. M., G. S. Robinson, and J. G. Casali (1999). A new class of auditory warning signals for complex systems: Auditory icons. *Human factors 41*(4), 608–618.

Blattner, M. M., D. A. Sumikawa, and R. M. Greenberg (1989). Earcons and icons: Their structure and common design principles. *Human–Computer Interaction 4*(1), 11–44.

Brooke, J. (1996). Sus: a “quick and dirty’usability. *Usability evaluation in industry 189*(3).

Calhoun, G. L., M. H. Draper, M. F. Abernathy, M. Patzek, and F. Delgado (2005). Synthetic vision system for improving unmanned aerial vehicle operator situation awareness. In *Enhanced and Synthetic Vision 2005*, Volume 5802, pp. 219–230. SPIE.

Charissis, V. and S. Papanastasiou (2008). Human–machine collaboration through vehicle head up display interface. *Cognition, Technology & Work 12*(1), 41–50.

college of engineering, I. (2022, may). minisim.

Currano, R., S. Y. Park, D. J. Moore, K. Lyons, and D. Sirkin (2021). Little road driving hud: Heads-up display complexity influences drivers’ perceptions of automated vehicles. *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*.

Endsley, M. R. (1988). Situation awareness global assessment technique (sagat). In *Proceedings of the IEEE 1988 national aerospace and electronics conference*, pp. 789–795. IEEE.

Gang, N., S. Sibi, R. Michon, B. Mok, C. Chafe, and W. Ju (2018). Don’t be alarmed: Sonifying autonomous vehicle perception to increase situation awareness. In *Proceedings of the 10th international conference on automotive user interfaces and interactive vehicular applications*, pp. 237–246.

Gish, K. W. and L. Staplin (1995). Human factors aspects of using head up displays in automobiles: A review of the literature.

Graichen, L., M. Graichen, and J. F. Krems (2019). Evaluation of gesture-based in-vehicle interaction: User experience and the potential to reduce driver distraction. *Human Factors: The Journal of the Human Factors and Ergonomics Society 61*(5), 774–792.

Group, T. (2022, may). Tobii pro glasses 2 - discontinued.

Gugerty, L. and W. Tirre (1997). A pc-based driving simulator for assessing situation awareness. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Volume 41, pp. 895–895. SAGE Publications Sage CA: Los Angeles, CA.

Hart, S. G. (2006). Nasa-task load index (nasa-tlx); 20 years later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting 50*(9), 904–908.

Jacob, R. J., A. Girouard, L. M. Hirshfield, M. S. Horn, O. Shaer, E. T. Solovey, and J. Zigelbaum (2008). Reality-based interaction: A framework for post-wimp interfaces. In *Proceed-*

ings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '08, New York, NY, USA, pp. 201–210. Association for Computing Machinery.

Ju, U., L. L. Chuang, and C. Wallraven (2022). Acoustic cues increase situational awareness in accident situations: A vr car-driving study. *IEEE Transactions on Intelligent Transportation Systems 23*(4), 3281–3291.

Liu, Y.-C. (2003). Effects of using head-up display in automobile context on attention demand and driving performance. *Displays 24*(4-5), 157–165.

Liu, Y.-C. and M.-H. Wen (2004). Comparison of head-up display (hud) vs. head-down display (hdd): driving performance of commercial vehicle operators in taiwan. *International Journal of Human-Computer Studies 61*(5), 679–697.

Lucas, P. A. (1994). An evaluation of the communicative ability of auditory icons and earcons. Georgia Institute of Technology.

Manawadu, U. E., M. Kamezaki, M. Ishikawa, T. Kawano, and S. Sugano (2016). A hand gesture based driver-vehicle interface to control lateral and longitudinal motions of an autonomous vehicle. In *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, pp. 001785–001790.

May, K. R., T. M. Gable, and B. N. Walker (2014). A multimodal air gesture interface for in vehicle menu navigation. In *Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '14, New York, NY, USA, pp. 1–6. Association for Computing Machinery.

McDonald, Z. (2016). *Augmented Reality HUDs: Warning Signs and Drivers' Situation Awareness.* Rochester Institute of Technology.

Metz, B., N. Schömig, and H.-P. Krüger (2011). Attention during visual secondary tasks in driving: Adaptation to the demands of the driving task. *Transportation research part F: traffic psychology and behaviour 14*(5), 369–380.

National Academies of Sciences, Engineering, and Medicine and others (2015). Analysis of naturalistic driving study data: Safer glances, driver inattention, and crash risk.

Oh, H. J., S. M. Ko, and Y. G. Ji (2016). Effects of superimposition of a head-up display on driving performance and glance behavior in the elderly. *International Journal of Human-Computer Interaction 32*(2), 143–154.

Park, H. and K.-h. Kim (2013). Efficient information representation method for driver-centered ar-hud system. In *International Conference of Design, User Experience, and Usability*, pp. 393–400. Springer.

Plavšic, M., M. Duschl, M. Tönnis, H. Bubb, G. Klinker, et al. (2009). Ergonomic design and evaluation of augmented reality based cautionary warnings for driving assistance in urban environments. *Proceedings of Intl. Ergonomics Assoc.*

Shakeri, G., J. H. Williamson, and S. Brewster (2017). Novel multimodal feedback techniques for in-car mid-air gesture interaction. *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.*

Shakeri, G., J. H. Williamson, and S. Brewster (2018). May the force be with you: Ultrasound haptic feedback for mid-air gesture interaction in cars. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '18, New York, NY, USA, pp. 1–10. Association for Computing Machinery.

Sojourner, R. J. and J. F. Antin. Journal of the human.

Sterkenburg, J., S. Landry, and M. Jeon (2017a). Eyes-free in-vehicle gesture controls. *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct.*

Sterkenburg, J., S. Landry, and M. Jeon (2017b). Eyes-free in-vehicle gesture controls: Auditory-only displays reduced visual distraction and workload. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*, AutomotiveUI '17, New York, NY, USA, pp. 195–200. Association for Computing Machinery.

Sterkenburg, J., S. Landry, and M. Jeon (2019). Design and evaluation of auditory-supported air gesture controls in vehicles. *Journal on Multimodal User Interfaces 13*(2), 55–70.

Sthle, L. and S. Wold (1989). Analysis of variance (anova). *Chemometrics and Intelligent Laboratory Systems 6*(4), 259–272.

Tabbarah, M., Y. Cao, A. Abu Shamat, Z. Fang, L. Li, and M. Jeon (2023). Novel in-vehicle gesture interactions: Design and evaluation of auditory displays and menu generation interfaces. In *Proceedings of the 15th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, AutomotiveUI '23, New York, NY, USA, pp. 224–233. Association for Computing Machinery.

to speech online, T. (2022, may). Free text to speech: Online, app, software, commercial license with natural sounding voices.

ultraleap (2022, may). Leap motion controller.

Villalobos-Zúñiga, G., T. Kujala, and A. Oulasvirta (2016). T9+hud: Physical keypad and hud can improve driving performance while typing and driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, Automotive'UI 16, New York, NY, USA, pp. 177–184. Association for Computing Machinery.

Walker, B. N., J. Lindsay, A. Nance, Y. Nakano, D. K. Palladino, T. Dingler, and M. Jeon (2013). Spearcons (speech-based earcons) improve navigation performance in advanced auditory menus. *Human Factors 55*(1), 157–182.

Walker, B. N., A. Nance, and J. Lindsay (2006). Spearcons: Speech-based earcons improve navigation performance in auditory menus. Georgia Institute of Technology.

Wang, J., W. Wang, P. Hansen, Y. Li, and F. You (2020). The situation awareness and usability research of different hud hmi design in driving while using adaptive cruise control. In *International Conference on Human-Computer Interaction*, pp. 236–248. Springer.

Wang, M., S. L. Lyckvi, C. Chen, P. Dahlstedt, and F. Chen (2017). Using advisory 3d sound cues to improve drivers' performance and situation awareness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, CHI '17, New York, NY, USA, pp. 2814–2825. Association for Computing Machinery.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical issues in ergonomics science 3*(2), 159–177.

Xu, D. (2006). A neural network approach for hand gesture recognition in virtual reality driving training system of spg. In *18th International Conference on Pattern Recognition (ICPR'06)*, Volume 3, pp. 519–522.

Yang, Y., B. Karakaya, G. C. Dominioni, K. Kawabe, and K. Bengler (2018). An hmi concept to improve driver's visual behavior and situation awareness in automated vehicle. In *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, pp. 650–655.

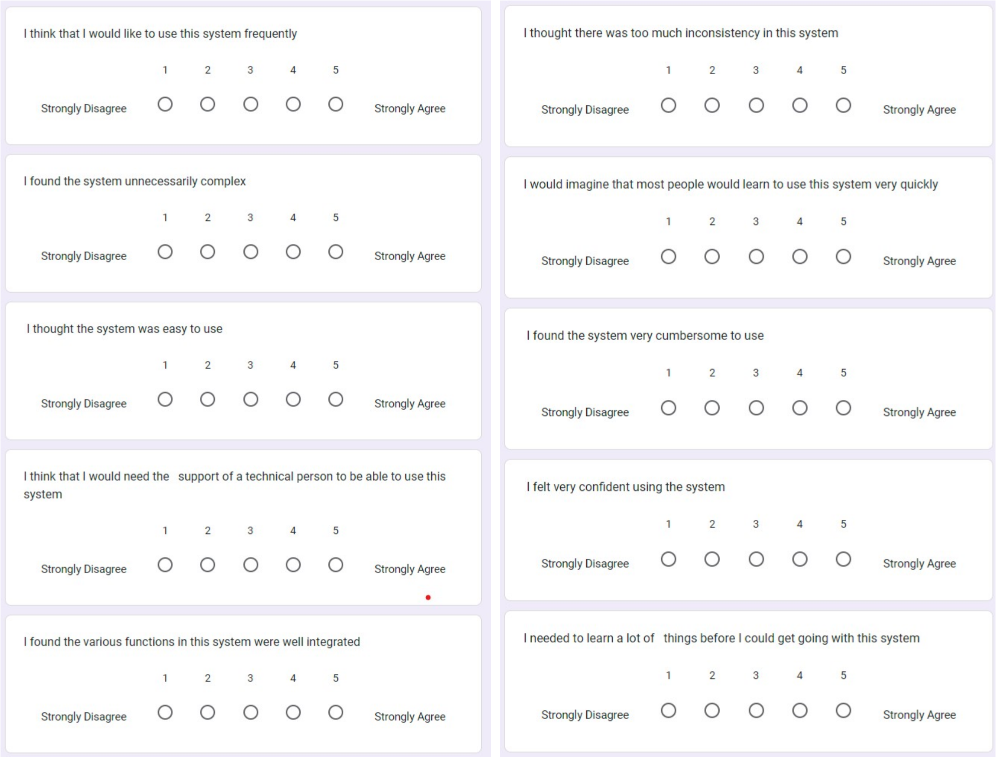
supported Questionnaire

Appendix A. SAGAT

SAGAT Situation Awareness Questionnaire

1. What elements of interest do you see on the screen?
2. What do these elements tell you about the current situation(are you safe or in danger)?
3. What vehicles did you notice around you?
4. What buildings did you notice around you?
5. How many pedestrians do you see on the screen?
6. What is currently happening in the scenario?
7. What do you think will happen next?
8. What do you think you need to do next?

Appendix B. SUS Questionnaire



I think that I would like to use this system frequently

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I found the system unnecessarily complex

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I thought the system was easy to use

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I think that I would need the support of a technical person to be able to use this system

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I found the various functions in this system were well integrated

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I thought there was too much inconsistency in this system

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I would imagine that most people would learn to use this system very quickly

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I found the system very cumbersome to use

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I felt very confident using the system

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

I needed to learn a lot of things before I could get going with this system

1 2 3 4 5

Strongly Disagree ○ ○ ○ ○ ○ Strongly Agree

Figure B1. SUS Questions