

Can Augmented-Reality Head-Up Display Improve Driving Performance on Monotonous Drives?

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Abstract

Although driving is a complex and multitask activity, it is not unusual for drivers to engage simultaneously in other nondriving related tasks using secondary in-vehicle displays (IVIS). The use of IVIS and its potential negative safety consequences has considerably been investigated over the years. However, with the advent and advance of in-vehicle technologies such as augmented-reality head-up displays (AR HUDs), there are increasing opportunities for improving secondary task engagement and negative safety consequences. In this study, we aim to understand the effects of AR HUD low cognitive load tasks on driving performance on monotonous driving. Adapting NHTSA's driver distraction guidelines, we conducted a user-study with twenty-four gender-balanced participants that performed secondary AR HUD tasks of different durations while driving in a monotonous environment using a medium-fidelity driving simulator. We performed a mixed-methods analysis to evaluate driver's perceived workload (NASA-TLX), lateral and longitudinal driving performance. Although we found that drivers subjectively perceive AR HUD tasks to be more cognitive demanding and more distracting than driving not performing any tasks; AR tasks resulted in improved driving performance. Conversely, the duration of the secondary tasks had no measurable impacts on performance which suggests that the amount of time spent on tasks has no negative or positive implications on driving performance. We provide evidence that there are potential benefits of secondary AR task engagement; in fact, there are situations in which AR HUDs can improve driver's alertness and vigilance.

Keywords

Augmented Reality, Head-Up Display, Distracted Driving

Introduction

Driving can often be monotonous. Naturalistic driving data indicates that when drivers are insufficiently stimulated while driving, they may become drowsy [1]. This phenomenon can occur in low demand driving environments since the driver experiences a limited number of tasks. Drowsy driving accounted for 2.3 to 2.5 percent of all fatal crashes and 1.9 – 2.1 percent of overall injury crashes nationwide from 2011 to 2015 [2]. In 2015, 824 fatalities and 90,000 of 6.3 million crashes were due to drowsy driving. The National Motor Vehicle Crash Causation Survey also reports seven percent of drivers include fatigue as a factor in the crash [3]. In addition to drowsiness and fatigue, distracted driving – primarily related to secondary in-vehicle displays (IVIS), such as cellphones or GPS - accounts for 15% of injury crashes and 9% of fatal crashes in the United States in 2017 [4]. Another driving safety risk is boredom, defined as a “state of relatively low arousal and dissatisfaction, which is attributed towards an inadequately stimulating environment” [5]. Boredom and fatigue can have similar consequences in driving, including difficulty with attention and cognitive deficits [6].

Although extensive research has been conducted to demonstrate the harmful effects of using secondary in-vehicle displays while driving (distracted driving, fatigue), not much attention has been given to the potential benefits of using them to reduce driving risks. Emerging technologies, such as an augmented-reality head-up display (AR HUD), provide unique opportunities to design novel approaches that complement existing driving safety strategies. AR HUDs allow graphical information to be displayed into the windshield in the driver’s forward field view. This means the driver can access information in their field of view while using peripheral vision rather than through a traditional head-down display in which the driver needs to look away from the road to get information needed.

In this paper, we aim to investigate whether AR HUDs can go from a foe to a friend: “*Can Augmented-Reality Head-Up Display Improve Driving Performance on Monotonous Drives?*” Rather than demonizing in-vehicle display technologies as a threat to road safety by distracting drivers, we want to investigate if they can be seen as an untapped opportunity for road safety, e.g., by incorporating low-cognitive secondary tasks to the driving activity in monotonous environments.

Objectives

In this paper, we aim to investigate whether AR HUD display interfaces could be used to improve driver engagement with the driving task in monotonous environments. We defined a monotonous environment as an environment in which the road is long, straight, and with no upcoming traffic present. In this situation, the cognitive load of the primary task (driving) is low, and therefore, the driver is more likely to become drowsy, distracted, and even fatigued. We hypothesize that by introducing a secondary visual task of low cognitive load, there is a potential to improve drivers’ engagement, which will result in better driving performance. In this study, driver’s performance was evaluated in terms of the standard deviation of lane position, average headway, and standard deviation of speed. By comparing performance measures between environments in which drivers used an AR HUD to perform secondary tasks and environments in which no secondary task was present (baseline), we aim to determine if engagement in the secondary tasks could improve driving performance.

Additionally, we used the NASA Task Load Index (TLX) questionnaire for measuring subjective mental workload of drivers when performing tasks. We believe that by introducing secondary visual tasks, drivers will perceive a higher mental load demand compared to baseline environment. Therefore, we formulate the following hypothesis:

- *H1: Driving performance will be better when drivers perform secondary AR HUD tasks*
- *H2: Subjective mental workload will be higher when drivers perform secondary AR HUD tasks*

Methods

Participants

Following the NHTSA’s driver distraction guidelines [4], we recruited a sample of twenty-four participants counterbalanced by gender. Two participants’ data were removed due to driving simulator sickness resulting in a total of twenty-two participants in the final sample (11 males and 11 females). Eighteen participants were right-handed, one ambidextrous, and four left-handed. While 17 of 22 had prior experience with driving automatic, the rest drove a

manual stick shift. The average age of participants was 22.36 years old ($SD=2.84$), and the average driving experience was 5.32 years ($SD=2.63$ years). Nine participants shared experience with factory-fitted center console displays, a few of which could be used for texting, calling, and GPS functions. Twelve participants did not have in-vehicle displays.

Equipment

This study was conducted in a fixed-base, medium-fidelity driving simulator in the COGNITIVE Engineering for Novel Technologies (COGENT) Lab at Virginia Tech [7]. Participants drove the front end of a 2014 Mini Cooper automobile with a Pioneer Cyber Navi HUD with conformal AR graphics capabilities. The area of the HUD measured 780x260 pixels with a 15-degree field of view. The AR HUD provides AR graphics overlayed into the exterior computer graphics generated driving environment. The VR content for the driving simulator is provided through MiniSim (software developed by the University of Iowa National Advanced Driving Simulator Research Center). Eye-tracking data and participants' glance behavior were monitored through SensoMotoric Instrument (SMI) eye-tracking glasses using the software iView eye-tracking glasses 2.6. We used eye-tracking glasses to make sure participants were looking at the HUD while performing secondary tasks.

Experimental design

We used a within-subject experimental design study in which each participant had a total of two drivers. The display style (*baseline*, *HUD*) condition was randomized in order to mitigate potential order effects. In the HUD condition driving, participants performed a secondary task concomitant with the primary driving task. In the baseline condition, participants drove through our simulated environment and did not perform secondary tasks. During each drive, the participants were exposed to four task durations (20,30,40,50 seconds) with three repetitions in a randomized order (see Figure 1 for experimental design overview).

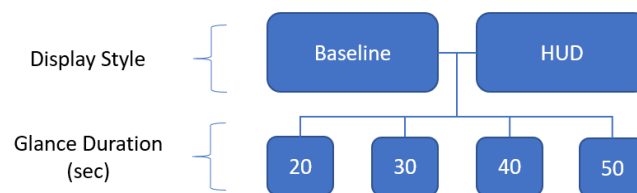


Figure 1: Overview of experimental design

Primary Driving Task

In the driving simulation, participants performed a car following task in which a lead car was positioned on the right side of the road. US driving laws were followed and the start and end position was consistent as the right lane of the road. There are no other vehicles in the eye line of the driver in these simulations. The driving scenario was designed in accordance with NHTSA's driver distraction guidelines for simulator studies [5]. The guidelines recommend the lead car maintains a constant speed on a straight road with no traffic. This reflects a monotonous and long drive. Participants were instructed to travel at a constant speed of 55 mph and to maintain a safe distance from the lead vehicle.

Secondary Task

Participants were measured on their performance in the primary task of driving the vehicle in tandem with a secondary glance task. The secondary task was a random letter reveal presented on the HUD, as shown in Figure 2. In this task, a single letter changes rapidly in a manner such that the participant cannot isolate a single character until the generator pauses and a target letter is displayed. To capture sustained glances the target letter was reveal every 2 to 5 seconds and the pauses were varied between 0.5 and 1 second. The duration between the pauses was short enough to maintain the participants' attention but long enough to allow them to comprehend the target letter. At each pause, participants were instructed to read the letter out loud. This is what was used to measure accuracy of the secondary task. Also, eye-tracking recordings were reviewed to check that participants were engaged in the secondary task and not looking away.

Procedures

The experimental procedure for this experiment was approved by Virginia Tech's ethics review board. All participants submitted a demographic survey using Qualtrics. Participants could adjust the driving simulator to their own comfort, and the HUD was calibrated such that AR random letter graphics were located at the same location regardless of the participants' specific seat adjustments. The participant was allowed to engage in a practice drive to understand the driving simulator, car, and secondary tasks. The secondary task, a letter reveal task, was explained in depth. Participants were instructed to read the target letters aloud whenever they felt a pause. This practice drive lasted for at least 5 minutes, and participants' understanding of the letter reveal task in-tandem with comfort driving was ensured. Motion sickness was monitored between each drive using a questionnaire. If a high level of motion sickness was measured, participants were encouraged to take a break and were given the option to withdraw from the study. Withdrawn participants were given a fifteen-dollar compensation for time spent on study, and their data was removed. Each data collection drive lasted between twelve to fifteen minutes. On completion of the drive, the NASA task load index (TLX) questionnaire was used to measure the perceived workload. Upon completing the study, all participants filled out the post-trial consent form and were compensated with 15 dollars for their time.

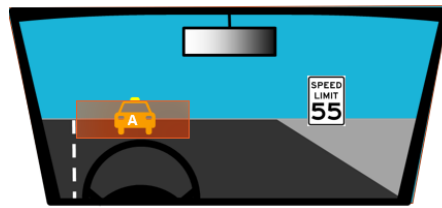


Figure 2: Letter Reveal Task

Analysis

An ANOVA mixed-effects model was used to account for the difference between the participants. The participants' perceived workload was measured using the NASA TLX questionnaire. The raw scores were averaged and used to measure driver workload. Vehicle control was measured both laterally and longitudinally. Lateral analysis of vehicle control was done using the standard deviation of lane position (SDLP), and longitudinal analysis was done through standard deviation of speed and average headway between the vehicle and lead vehicle. The driving data was analyzed during the time at which the participant would be performing secondary tasks.

Results

NASA Task Load Index (NASA-TLX)

A significant effect of condition was found on mental demand ($p < 0.000$), physical demand ($p < 0.023$), temporal demand ($p < 0.000$), effort ($p < 0.000$), distraction ($p < 0.000$), and overall average ($p < 0.000$). No significant effect of condition was found for performance or frustration. The NASA-TLX data shows that participants feel that performing secondary using a HUD is generally more distracting and mentally demanding than performing no tasks.

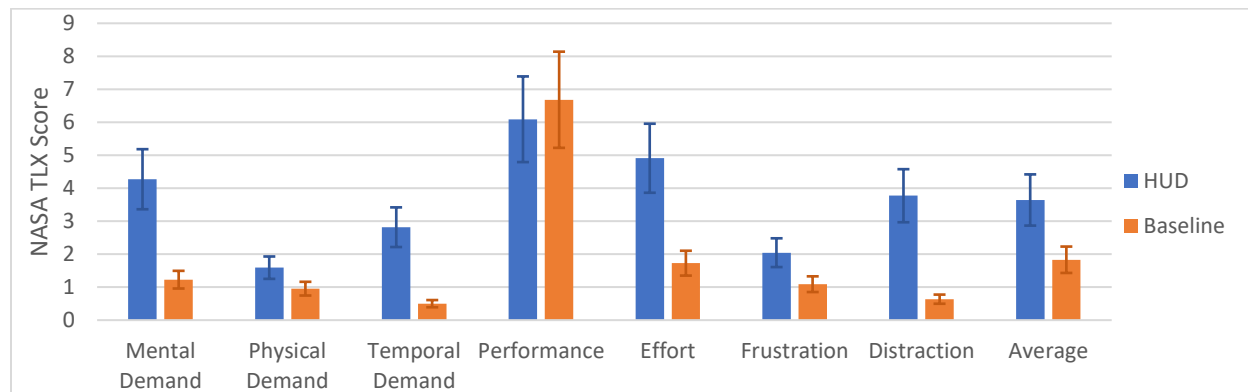


Figure 3: NASA TLX sub-scores on a scale of 0 to 10 (low to high demand). Error bar uses 1 SEM.

Driving Performance

Standard Deviation of Lane Position (SDLP)

We found a main effect of duration ($F(3) = 4.67, p < 0.003$), and condition ($F(1) = 23.87, p < 0.000$) on SDLP. Table 1 and Table 2 display the Bonferroni post-hoc results for the main effects. Means that do not share the common letter are significantly different.

Table 1: SDLP Bonferroni post-hoc for duration

Duration	N	Mean	Grouping
40	132	0.964409	A
50	132	0.938480	A
20	132	0.855027	A B
30	132	0.790761	B

Table 2: SDLP Bonferroni post-hoc for condition

Condition	N	Mean	Grouping
Conventional-Baseline	264	0.976088	A
Conventional-HUD	264	0.798251	B

Standard Deviation of Speed

We found a main effect of condition ($F(1) = 31.42, p < 0.000$) on Standard Deviation of Speed. Table 3 displays the Bonferroni post-hoc results for the main effect. Means that do not share the common letter are significantly different.

Table 3: Standard Deviation of Speed Tests Bonferroni post-hoc for condition

Condition	N	Mean	Grouping
Conventional-HUD	264	2.41958	A
Conventional-Baseline	264	1.54402	B

Average Headway

We found a main effect of condition ($F(1) = 20.26, p < 0.000$) on Average Headway. Table 4 displays the Bonferroni post-hoc results for the main effect. Means that do not share the common letter are significantly different.

Table 4: Average Headway Bonferroni post-hoc for condition

Condition	N	Mean	Grouping
Conventional-HUD	264	193.849	A
Conventional-Baseline	264	163.235	B

Discussion

This paper begins to investigate the possible positive effects of using AR HUD secondary tasks to improve driving performance while on monotonous roads. We hope this study will start the discussion on whether emerging technologies have the potential to go from foe to a friend. Instead of only extensively investigating potential adverse effects of secondary in-vehicle displays, we believe there are many opportunities and situations in which they could be used as an aid to improve road safety.

Driving Performance

We found the SDLP to be higher for glance durations of 40, 50, and 20 seconds compared to a glance of 30 seconds. However, based on post-hoc analysis, there is no statistical difference in these results. Therefore, we suggest that for secondary tasks of similar cognitive load to the task used in this study, task duration has no effect on driving performance. We also found that when drivers performed secondary tasks using the AR HUD, their driving performance - in terms of SDLP - was better than the baseline condition (no secondary task present). Therefore, we fail to reject hypothesis 1 “*Driving performance will be better when drivers perform secondary AR HUD tasks*”. Two

factors that could explain this result: cognitive load and gaze concentration. While driving, performing secondary tasks increased the cognitive load required from participants – amount of working memory resources being used – therefore, SDLP improved. Other studies have isolated a similar pattern where participants experience a moderate cognitive load, and lane-keeping performance is enhanced compared to baseline driving performance [8]. In addition to this, since the secondary tasks are directed towards the center of the road (see figure 2), this induces the gaze concentration-effect when the glance area is focused on the road ahead and fewer glances are made toward off-path locations. The effect has been previously noted to improve the lateral control of vehicles when performing secondary tasks when compared to the baseline drive [8].

Additionally, we found the standard deviation of speed to be higher during the AR HUD drives, indicating a higher variation of speed while using HUD. Although deviation of speed is higher for the HUD condition, it does not necessarily mean that drivers adopted unsafe behaviors in this situation. When performing secondary tasks, drivers tend to adopt compensatory behaviors (i.e., decrease speed when additional cognitive load is introduced), and thus, our finding is consistent with real-life environments. Similar behaviors are perceived when traffic becomes heavier or during rain and snow.

Finally, participants were instructed to maintain a safe distance from the lead car. Participants maintained a larger average headway during HUD drives compared to the baseline drives. Previous studies have also shown that drivers tend to adopt longer headway behavior when performing a visual secondary task concomitant with the primary driving task [9]. Higher average headway does not necessarily mean poorer driving performance. Drivers adopt compensatory behaviors to stay within their standard of safe distance behavior. Lastly, since the increase in cognitive load had been reported to cause degrading effects in event detection performance when driving, inattention blindness and cognitive tunneling should be further investigated to gain a better understanding of the implications of the AR HUD design [10].

Conclusion

Can AR HUD Low cognitive Load Tasks Improve Driving Performance on Monotonous or Long Drives? Although we found that drivers subjectively perceive AR HUD tasks to be more cognitively demanding and more distracting than driving not performing any tasks; AR tasks resulted in improved driving performance. Therefore, we suggest that there is a potential for secondary tasks to improve driving performance, and this area should be investigated further.

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