Evaluating Distraction and Disengagement of Attention from the Road

Valentine Nwakacha[1], Andy Crabtree[1], and Gary Burnett[2]

[1] Mixed Reality Laboratory, University of Nottingham, Nottingham, UK
{vqn,axc}@cs.nott.ac.uk
[2] Human Factors Research Group, University of Nottingham, Nottingham, UK
Gary.Burnett@nottingham.ac.uk

Abstract. Drivers use sat nav for navigation assistance but research links sat nav with risk of distraction [10]. Visual and cognitive workload can be increased as drivers divert their attention from the road [1, 8]. Mitigating such risks is vital and head-up displays (HUDs) can be beneficial [9]. HUDs present images on the windshield to reduce diversion of drivers' attention from the road. This paper presents a driving simulator experiment which examined how 30 participants behaved with three navigation interfaces; novel virtual car HUD, arrow HUD and sat nav to outline potential benefits of the virtual car HUD over the arrow HUD and sat nav. Distraction-related data (speed, headway, lane position and peripheral detection) were gathered. The findings showed participants were better at navigation performance and peripheral detection with the virtual car HUD. Subjective data showed participants rated the virtual car HUD easiest to use, least distracting and most preferred interface.

Keywords: Driver distraction, head-up display, user interface design.

1 Introduction

The market for In-Vehicle navigation systems has risen significantly since the first commercial satellite navigation system (sat nav) for vehicles was arguably designed by Steven Lobbezzo [5]. Sat navs are useful as they can track the location of vehicles on the route and provide turn-by-turn navigation instructions using audio and visual mechanisms [4]. The typical sat nav is mounted on the dashboard as shown in Fig. 1a but alternative designs can be placed on the windshield as shown in Fig. 1b.

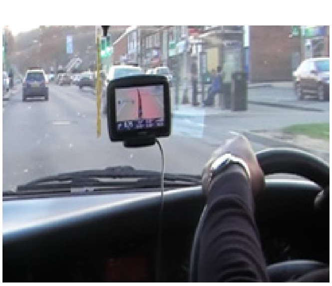
(a)  (b) 

Fig. 1. a) Dashboard-mounted sat nav b) Windshield-mounted sat nav

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According to a 2007 Gallup survey for the European Union (EU), 35% of the EU citizens (which accounts for approximately 159 million people) currently use or intend to purchase a sat nav [6] (even though these figures will undoubtedly have risen since then). Despite their benefits, there are several pitfalls which have been associated with sat nav use while driving. Research highlights that they are a potential source of distraction [10] which can cause vehicle drivers to disengage their attention visually (eyes-off-the-road) and/or cognitively (mind-off-the-road) [2]. Studies in [7] have shown that drivers can fail to detect the changes on the road when glancing at head-down displays (i.e. sat nav) which can increase the risk of crash. Significant attention has been directed towards the design of head-up displays which research has outlined can deal with the issues involving drivers disengaging their attention from the road. Head-up displays present virtual images on the windshield so that drivers can reduce the diversion of their attention from the road [3] when perceiving instructions. In essence, head-up displays can reduce the shift in the locus of work for obtaining the required instructions from the road. The possible outcomes are reduction in the driver's visual and cognitive workload, increase in visual awareness of events on the road and reduction in the response times to any change.

In this paper, a novel virtual car head-up display concept is proposed as an alternative to current navigation systems (sat nav and arrow head-up display) for presenting the required turn-by-turn navigation instructions during navigation to vehicle drivers. The virtual car head-up display is a novel multimodal interface that can be projected on the windshield to present drivers with visual and sound practices which are employed in regular driving (e.g. following vehicles, turning and indicating direction of turn with sound). The virtual car image appears embedded on the road in front of drivers as a lead vehicle to reduce the shift of the driver's visual attention from the road. The integrated indicating sound prompts drivers to know when a turn is about to be made. This is beneficial for enhanced turn anticipation, preparation and execution.

Furthermore, the virtual car head-up display uses its two states (the active and inactive states) so that drivers can safely control their vehicle movement without the need to be continually engaged with it. The active state is the state where the virtual car image provides drivers with the navigation instructions at the turning points e.g. indicating and turning at junctions. The inactive state is the state where the virtual car image remains in a forward, idle position which indicates to drivers that no turn actions need to be taken. It is proposed that the inactive state can be very useful for reducing the driver's visual workload (glancing away from the road to the navigation interface) and cognitive workload (translating instructions from the virtual car to the road) with the interface. The predicted outcome is the ability for drivers to quickly detect and respond to changes which occur on the road.

The virtual car head-up display was evaluated along with the arrow head-up display and sat nav by 30 participants in a desktop driving simulator to identify the extent to which each of the interfaces could cause participants to disengage their attention from the road. More so, the potential benefits of the virtual car head-up display over the arrow head-up display and sat nav were sought. The arrow interface was projected on the windshield and used only visual symbols (the arrow symbol and written information e.g. street name, direction of the next turn and estimated distance to the turn) to present participants with instructions for better turn anticipation, preparation and execution. The aerial map view of the dashboard-mounted sat nav was complimented by spoken commands which participants had to listen to, process in bits and execute sequentially in order to follow the route. The sat nav also presented participants with other information (current street name, next turn direction and estimated distance to the turn) on the visual interface for better turn anticipation, preparation and execution.

2 The Experiment Overview

The three navigation interfaces evaluated in the experiment are shown in Fig. 2.

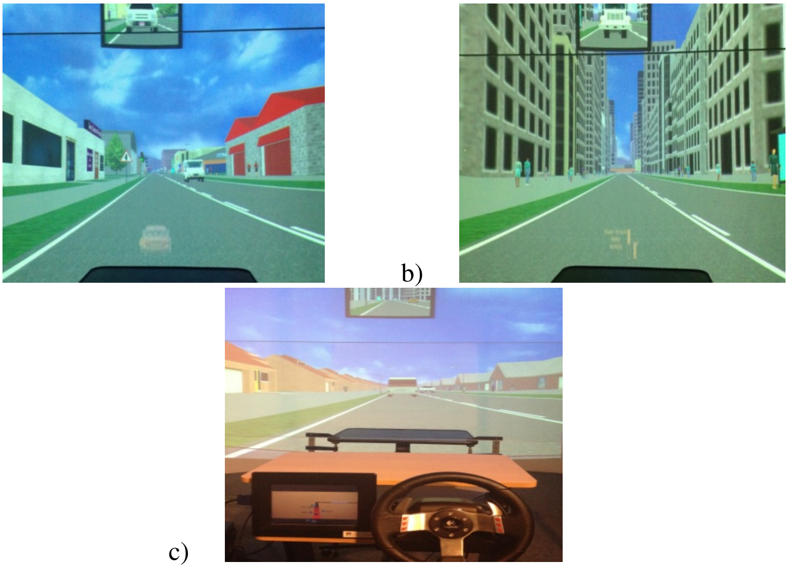


Fig. 2. a) Virtual car HUD b) Arrow HUD c) Sat nav

The hardware setup comprised of an interconnected game steering wheel and pedals system for controlling the movement of the vehicle on the simulated road. The STISIM software was used to design the simulated environment for the drives. The head-up display interfaces (Fig. 2a and b) were projected on an improvised windshield (perspex glass) from a monitor that was located about three meters in front of the participants. The sat nav interface (Fig. 2c) was located one meter in front of the participants on the dashboard. Two video recorders were placed around the participants to capture data on their driving behavior. The first recorder was placed at a 45° angle in front of the participants at a distance of about three meters away to capture their eyes and head movements during the tasks. The second recorder was placed at the rear of the simulator room and recorded the visual behavior of the participants.

Thirty participants (twenty males and ten females, average age: 27.8 years) who were residents in Nottingham took part in the experiment. They each had a valid UK driver's license with driving experience of at least one full year. The participants were divided into three groups of ten and a counter-balanced format for each group of participants with the navigation interfaces was adopted as shown in Table 1.

Table 1. Format for participant groups and interface use in the drives

Group no.	1^{st} drive interface	2^{nd} drive interface	3^{rd} drive interface
1	Virtual car HUD	Arrow HUD	Sat nav
2	Arrow HUD	Sat nav	Virtual car HUD
3	Sat nav	Virtual car HUD	Arrow HUD

The participants carried out three tasks in each of the drives; driving, navigation and peripheral detection. The driving task involved safely controlling the vehicle movement on the road using the steering wheel and pedals. The navigation task involved following the correct turns to reach the destination by using one navigation interface per route. The peripheral detection task involved detecting the appearance of an attention symbol (an arrow that randomly appeared on the left/right side of the road scene shown in (Fig. 3a and b)) on five different occasions; three of which occurred when navigation instructions were provided.

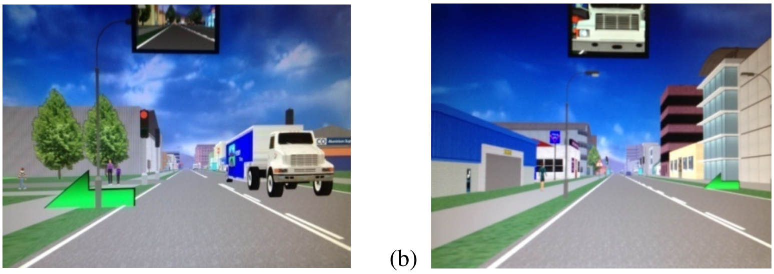
(a) (b)


Fig. 3. a) Attention symbol on the left b) Attention symbol on the right

The peripheral detection task was directly linked with hazard awareness which was considered a vital aspect of knowing the potential perceptual tunneling effect with each interface [7]. The participants were required to press a button on the steering wheel when they detected the appearance of the attention symbol. The participants were initially required to take a test drive to familiarize with the driving simulator controls. There was no data collected or navigation interface used. During the main drives, a within-subject design was employed with the experimental conditions counter-balanced. Several distraction-related data were collected, for instance, in the driving task, speed, lateral lane position and headway to lead vehicles were recorded. In the navigation task, the number of correct turns taken was recorded for navigation performance. Also, glance frequency and durations away from the road were recorded. In the peripheral detection task, reaction times and success rates for detecting the attention symbol were recorded for the potential visual tunneling behavior with each navigation interface. After each drive, the participants filled out a NASA-TLX questionnaire, providing responses based on their experience with the navigation interface used. The information provided in the questionnaire included the physical and mental demand, driving performance, ease of use, level of distraction and overall preference.

3 The Key Findings

A repeated measures ANOVA (Analysis of Variance) with Sphericity assumed for variables measured showed a statistical difference for the speed values with the navigation interfaces ($F(2,58) = 130.39$, $p<0.05$). Bonferroni post hoc tests revealed differences in the mean speed and variation comparing the virtual car head-up display and sat nav (29.5 ± 0.9 vs. 27.5 ± 1.0 mph) ($p = .00$). A higher mean and variation was obtained with the arrow head-up display (32.3 ± 1.2 mph) ($p = .00$) as shown in Fig. 4. The lowest speed values recorded with the sat nav suggested the possibility that the participants may have found the tasks more difficult to carry out with the sat nav. For the lateral lane position, the test showed that there was no significant difference in the mean values for the navigation interfaces ($F(2,58) = 0.8$, $p>.00$). Bonferroni post hoc tests revealed no significant difference in the lateral lane position with the sat nav (8.5 ± 0.22 feet) when compared with the virtual car head-up display (8.4 ± 0.17 feet) ($p = .485$) and arrow head-up display (8.5 ± 0.18 feet) ($p = 1.00$) as shown in Fig. 5. It was concluded that change of navigation interface had no significant impact on participants' lane keeping behavior.

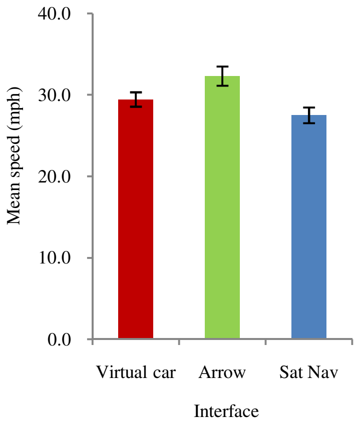


Fig. 4. Mean speeds

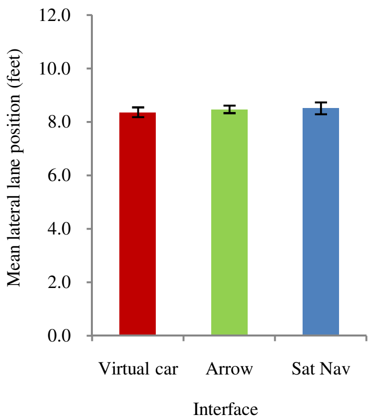


Fig. 5. Mean lateral lane positions

For the headway, there was a statistical difference between the navigation interfaces ($F(2,58) = 41.37$, $p<0.05$). The Bonferroni post hoc tests revealed a significant difference in the mean and variation values comparing headway to the lead vehicles with the head-up displays (186.4 ± 67.0 vs. 279.1 ± 63.44 feet) ($p = .00$).

Also the mean headway and variation comparing the virtual car head-up display and sat nav (186.4 ± 67.0 vs. 167.1 ± 125.9 feet) (p = .00) differed. The arrow head-up display and sat nav headways and variations also significantly differed (279.1 ± 63.4 vs. 167.1 ± 125.9 feet) (p = .00) as shown in Fig. 6. The higher headway value for the arrow head-up display was attributed to participants presumably requiring visual acuity to read information on the windshield thus leaving bigger gaps to the lead vehicles. The sat nav had the least impact on headway as no visual interface was on the windshield to engage with. More so, participants could choose to only listen to the audio instructions if desired. The arrow head-up display was thus associated with a higher risk of increasing the headway allocated to vehicles in front when compared with the virtual car head-up display and sat nav.

For the navigation performance, the participants took all the correct turns with the virtual car and arrow head-up displays which indicated an average success rate of 100%. With the sat nav, the participants missed one turn on average which indicated an average success rate of 80% as shown in Fig. 7. Since the head-up displays information were projected on the windshield, it was assumed that this helped to reduce the visual scanning process to obtain the navigation information needed to take the correct turns. The angular displacement of the sat nav from the driver's visual field meant that participants often glanced away from the road to obtain the visual navigation instructions which impacted on their ability to correctly take the turns on the route. It was concluded that the head-up displays were able to support better navigation performance than the sat nav. Also, the participants did not glance away from the road scenery while driving with the head-up displays. However, with the sat nav, an average of 42 glances (min 17, max 75) was recorded for drives with a mean time of 7 minutes. The mean glance duration for the participants was 1.5s (min 0.5s, max 2s).

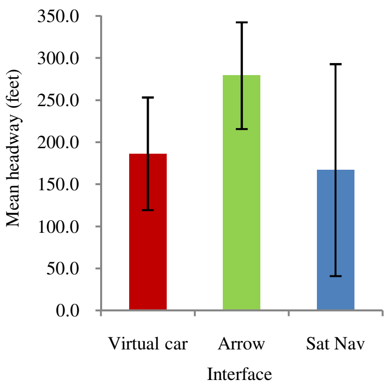


Fig. 6. Mean headways

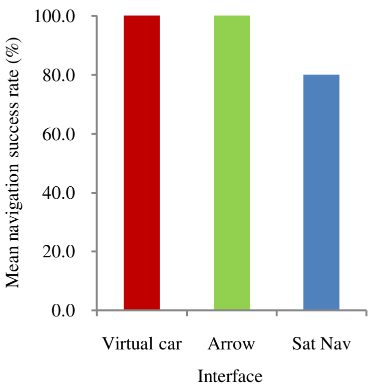


Fig. 7. Mean navigation success rates

The mean button pressing times after detecting the attention symbol in the peripheral detection task was 1.14s for the virtual car head-up display, 1.23s for the arrow head-up display and 1.3s for the sat nav as shown in Fig. 8. The faster reaction times to pressing the button after detecting the attention symbol recorded with the virtual car head-up display was attributed to the fact that participants did not have to continuously engage with the interface which allowed them to divert their attention towards attending to other tasks. It was concluded that the virtual car head-up display supports faster detection of critical events on the road than the arrow head-up display and sat nav. The average success rates in the peripheral detection task were 98% for the virtual car head-up display, 96% for the arrow head-up display and 94% for the sat nav as shown in Fig. 9. The head-up displays allowed participants to have a good visual awareness of the road scenery and were associated with higher rates for detecting the attention symbol when compared with the sat nav. Also, it was identified that participants were less occupied with attending to the virtual car head-up display due to the inactive state thus allowing for better detection of the attention symbol when compared with the arrow head-up display and sat nav. It was therefore concluded that the virtual car head-up display has the ability to support better detection of hazardous situations than the arrow head-up display and sat nav.

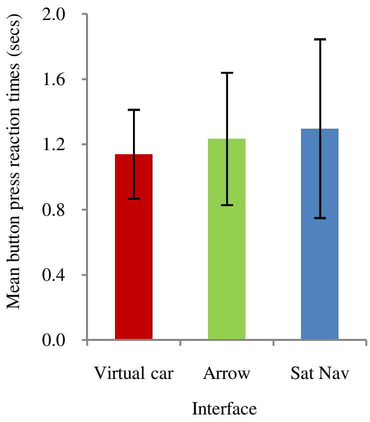


Fig. 8. Mean button press reaction times

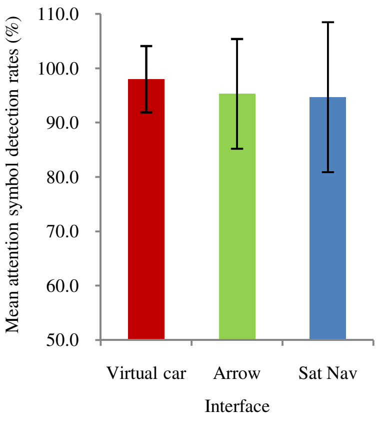


Fig. 9. Mean attention symbol detection rates

From the questionnaire feedback, the virtual car head-up display was associated with the least physical and mental demand and level of distraction followed by the arrow head-up display and sat nav. The virtual car head-up display was associated with the best performance followed by the arrow head-up display and sat nav. The virtual car head-up display was rated as the easiest to use and most preferred interface followed by the arrow head-up display and sat nav. The findings led to the conclusion that the virtual car head-up display supported better driving and navigation behavior when compared with the arrow head-up display and sat nav because it was able to reduce the workload and distraction for the participants.

4 Discussion

The virtual car head-up display concept was explored as a potential means of reducing driver workload whilst improving behavior and performance in relation to existing user interfaces. The fundamental benefits predicted with the virtual car head-up display are its ability to reduce the shift of attention away from the road and the need to constantly engage with the display while driving. The virtual car head-up display reduces the shift in the locus of work from the road by ensuring that the driver's attention is fixed on events in their field of view while driving. The benefit is that drivers are less exposed to stress and fatigue which can lead to inattention. This is because any increase in the driver's workload e.g. visual scanning for information that is not in the driver's field of view or the need to process complex information that takes time to complete is avoided. The reduced need to constantly engage with the interface ensures that the drivers are able to focus their attention instead on the critical activities that are needed to safely control the vehicle on the road. Furthermore, there is the potential for better hazard awareness where the driver is able to see the road scenery in a short period of time. This can allow for quicker reaction times to avoid any unwanted occurrences on the road.

The novelty of the virtual car head-up display concept implies that the navigation instructions are presented to drivers using new techniques. For example, the virtual car used in the head-up display presents navigation instructions using regular practices which are employed in real-world driving. The competent knowledge of drivers is exploited through a set of practices displayed which are based on their familiarity with how vehicles behave on the road. Also, the inactive state of the virtual car head-up display is a novel way of reducing the need for drivers to be continuously engaged with the navigation interface. When the virtual car image remains in the forward, idle position, drivers can perceive that the virtual car image is not presenting any instructions that are needed to turn and know that they are required to keep driving straight based on their familiarity with what happens when following real-world vehicles.

Another useful aspect of the virtual car head-up display is that it replaces any abstractions that are used by current navigation interfaces to provide instructions (e.g. arrow, speech, written information etc) with visual driving actions (indicating and turning) that are potentially easy to understand and require little or no time to process. This eliminates the need for drivers to map the abstractions to specific executable actions. The drivers basically carry out the instructions that are presented by the virtual car image and in essence, mimic its behavior. Thus, the virtual car head-up display helps reduce the mental workload of the navigation task when compared to that which might be experienced with sat nav. For example, the driver may receive the following instruction from a sat nav; "after 200 yards turn left". This instruction is a vague abstraction which the driver has to mentally process and map to the real world to follow the route. The driver has to estimate 200 yards from his/her current location, project that distance down the road and identify the exact location of the turn. Carrying out these tasks can increase the driver's visual and cognitive workload which can impact on how they allocate their attention.

Furthermore, mapping the instructions to specific actions and being able to correctly carry out the sequence of activities that are needed to take the turn at the same time may pose risk of work increase for the drivers. The virtual car prompts the driver to prepare to turn by indicating (with the indicating light and sound) at a certain distance away from the turn and uses the vehicle turn movement to signal the arrival at the turning point. The indicating sound used by the virtual car head-up display does not require as much time to process as spoken words thus reduces the processing time for the instruction. This ensures that drivers are able to allocate more time to the driving task than when spoken audio commands are issued.

Despite the benefits of the head-up displays over traditional in-vehicle sat nav, their impact on headway allocation due to the presence of information on the windshield is an area of interest. This was particularly evident when participants drove using the arrow head-up display where they were presumably reading the information on the windshield and visual acuity was required. The result was that they left bigger gaps between their vehicle and the vehicle in front which was considered to be a potential distraction behavior associated with possible tunneling effect of the interface. With the virtual car head-up display, an area of interest was that because the virtual car image was a virtual object that appeared on the road in the same way that the simulated vehicles did and the virtual car was responsible for providing instructions to the participants, it may have been possible that the participants perceived the virtual car image to be another vehicle on the road rather than an image on their windshield. It is proposed that road trials should be done as part of future work to investigate any possible effects which the virtual car head-up display can have on the allocation of headway to vehicles where there is a clear distinction between the real and virtual car on the road.

5 Conclusion

The virtual car head-up display has been identified to have the potential to reduce the driver's workload when compared with an arrow head-up display and sat nav. Automobile designers can benefit from the potentials which the virtual car head-up display offers and use them to inform future designs of In-Vehicle Navigation Systems. The safety implications of the virtual car head-up display are consistent with the philosophy of key documents in this area including the AAM (Alliance of Automobile Manufacturers), European State of Principles and JAMA (Japan Automobile Manufacturers Association). The virtual car head-up display is in its development stage and additional work is needed before the interface can be considered for integration into real-world vehicles. Road trials should be carried out to provide more validity to the findings from the driving simulator.

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