International Journal of Mobile Human Computer Interaction
Volume 11 • Issue 2 • April-June 2019

Follow the Leader:

Examining Real and Augmented Reality Lead Vehicles as Driving Navigational Aids

Bethan Hannah Topliss, The University of Nottingham, Nottingham, UK
Sanna M. Pampel, University of Nottingham, Nottingham, UK
Gary Burnett, University of Nottingham, Nottingham, UK
Lee Skrypchuk, Jaguar Land Rover Research, Coventry, UK
https://orcid.org/0000-0002-9619-6161

Chrisminder Hare, Jaguar Land Rover Research, Coventry, UK

ABSTRACT

Two studies investigated the concept of following a lead vehicle as a navigational aid. The first video-based study (n=34) considered how drivers might use a real-world lead vehicle as a navigational aid, whist the second simulator-based study (n=22) explored how an Augmented Reality (AR) virtual car, presented on a head-up display (HUD), may aid navigation around a complex junction. Study 1 indicated that a lead vehicle is most valued as a navigation aid just before/during a required maneuver. During the second study the dynamic virtual car (which behaved like a real vehicle) resulted in greater confidence and lower workload than a static virtual car that "waits" at the correct junction exit, but resulted in more gaze concentration. It is concluded that a virtual car may be a valuable element of a navigation system, in combination with other forms of information, to completely fulfil all a driver's navigational task requirements.

KEYWORDS

Augmented Reality, Heads-Up Display, Navigation, Virtual Car

INTRODUCTION

The rapid development of head-up displays (HUDs) is reducing the limitations on how navigational aids may function within vehicles. At present, information can be layered over the driver's view of the road environment (Gabbard et al., 2014), potentially reducing the need to look away from the road scene for gathering display information (cf. Victor, 2005). Hence, augmentation of the road environment poses a tempting opportunity to better provide the driver with information, as many have started to investigate (e.g. Tonnis, Sandor, Klinker, Lange, & Bubb, 2005). Currently, novel augmented reality (AR) HUD concepts are highlighting hazards in real time to encourage the driver's attention to safety critical information (Park, Park, Won, Kim, & Jung, 2013). Others are aiding navigation by highlighting relevant road signs (Chu, Brewer, & Joseph, 2008) or superimposing paper airplanes on to the road environment, which act as arrows to indicate a direction (Bark, Tran, Fujimura, & Ng-Thow-Hing, 2014). A study investigating AR navigation systems highlighting relevant landmarks

DOI: 10.4018/IJMHCI.2019040102

found that these landmark cues required less visual attention than conventional cues (Bolton et al., 2015). The present work investigates a novel approach to aiding navigation using an AR HUD.

Using a 'front' vehicle as a navigational aid may be considered a broadly familiar experience: A driver who is aware of a route may lead another, unaware driver in a separate vehicle who follows behind. Although work has examined car-following behaviours extensively from the perspective of general traffic behaviours, with consideration of driver behaviours (Ranney, 1999), minimal research has actually investigated car following for navigational purposes (McNabb, Kuzel, & Gray, 2017).

This work aims to clarify how drivers use a lead vehicle as a navigational aid in this manner, how this lead vehicle affects visual behaviour (eye-movement) since driving is a predominantly visual task (Foley, 2009), and then examine how an AR version of this concept may perform within a specific navigational example.

The Navigational Task

In order to appreciate how navigational information is used whilst driving and during car following scenarios, it is first vital to understand the typical structure of the navigational task (see Figure 1). Burnett (1998) developed a framework based on interviews and a direction-giving study that considers the navigational task a continuous process; making it ideal for the current application. According to Burnett (1998), before setting off, drivers will usually go through some form of "Trip planning" stage, where they establish a route, and then there are 5 subsequent stages of the navigational task that occur whilst driving.

The stages of navigation are distinguished by the different aims or goals a driver is trying to achieve. Each of these different goals requires or benefits from different types of navigational information. The first three stages are described in relation to a manoeuvre the driver is required to make to stay on the correct route. The driver first goes through the "Preview" stage, where they aim to gather information in order to anticipate the upcoming manoeuvre. The "Identify" stage then occurs, where the driver will attempt to apprehend the precise speed, direction and road positioning required for the upcoming manoeuvre. Next, the "Confirm" stage occurs just before and after the manoeuvre; during this stage the driver searches for indications that the correct manoeuvre is being performed or occurred.

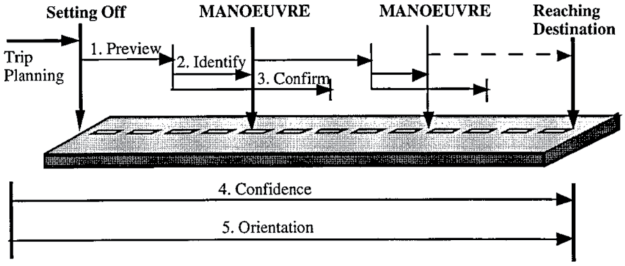
Two further stages are described by (Burnett, 1998) which can take place at any point during the navigational task. The "Confidence" stage occurs when a driver is aiming to gain reassurance that they are on the correct route or gain reassurance that the method they are using to navigate is functioning as it should. Finally, the "Orientation" stage describes a point in the navigation task where a driver aims to identify their overall direction in relation to their destination and the surrounding environment.

This definition of the navigation task in the driving context has been used by others (e.g. Lee, Forlizzi, & Hudson, 2008) – since the thorough and continuous depiction of the task makes evaluating information from a navigational system simpler to analyse. Therefore, it forms an ideal framework to evaluate lead vehicles (whether real or as an AR implementation) as navigational aids.

Our Studies

Two studies were conducted. The first study aimed to establish how drivers use different types of visual and auditory information to navigate during a short journey with several different junctions and manoeuvres. Specifically, the work focused on how drivers, who are following another vehicle for navigational purposes, use the lead vehicle as an aid for navigation. The second study, conducted within a simulator environment, used the information gathered during the initial investigation to explore how an AR lead vehicle, presented on a HUD, could be used as an element within a vehicle navigation system.

Figure 1. Stages of the driver's navigation task (Burnett, 1998)



STUDY 1

Methodology

Design

In order to evaluate how drivers would typically use a real-world lead vehicle as a navigational aid, a study was first conducted using a video-based procedure with a between-subject design.

Participants were distributed into 4 conditions, each involving a lead car; the independent variable was the modality of information available from a satellite navigation device (Garmin Nüvi 52LM). This variable was selected as it was assumed that a lead-vehicle would not be used in isolation as a navigational aid but would instead be included to supplement. Thus, evaluating how a driver may use a lead vehicle simultaneously with other information available would be important to understand for the development of AR systems. The four levels of information available were: lead car only with no additional information (L), the lead car with the visual elements of a satellite navigation system (LV), the lead car with the audio instructions from a satellite navigation system (LA) and finally, the lead vehicle with a full satellite navigation system with all elements functioning (F). These conditions are summarised in Table 1.

Two primary measures were recorded during the procedure. First, a verbal protocol was collected: Participants were asked to continuously speak aloud whilst watching a video of a car journey. The verbal responses were recorded and analysed in order to gain insight into their thought processes. Secondly, SMI eye-tracking glasses monitored participant eye-movements, which were analysed according to number of glances and glance duration to areas of interest.

Participants

A total of 34 participants were opportunistically selected via the email system at the University of Nottingham and were opportunistically allocated to one of the four conditions. All participants held a driving licence, though the driving licence could originate from any country to be eligible for participation. Most participants (29) answered that they were unfamiliar with the area where the journey took place. Participants belonged to 5 different age categories, with the largest portion being

Table 1. A summary of the four conditions

Condition	Information Present in Video
L	Lead car only
LV	Lead car and visual navigation system
LA	Lead car and audio navigation system
F	Lead car with full navigation system (visual and audio)

Figure 2. A screen capture from the main video, condition LV

in the 26-35 years range (44.1%), then the 18-25 years range (35.3%), then the 35-45 range (11.8%), then the 46-55 range (5.9%) and finally the 56-65 range (2.9%). Participants were provided with a £5 amazon voucher upon completion of the study as compensation for their time.

Materials

The study was video-based and conducted using an LCD screen standing on a desk for participants to sit at (see Figure 2). A desk-mounted steering wheel was placed in front of the participant to provide some context, although there was no actual driving task involved.

The videos, which were displayed on the monitor, were all recorded using a Blackvue DR550GW-2CH dashboard camera and included the natural environmental sounds from driving. Two videos were shown: the "practice" video presented a short journey to familiarise participants with the procedure, whilst the second "main" drive was used during the full experimental procedure. The satellite navigational elements were edited in the video later. The experimental video always contained a lead vehicle showing the way through a journey and the satellite navigation, if present, was added to the bottom left corner of the video image (see Figure 2 & 3). Both the lead vehicle, and the following vehicle, which contained the dashboard camera, were driven by researchers from the University of Nottingham. The journey for the "practice" video involved a 4-minute drive around Beeston, Nottinghamshire, UK. The journey for the "main" video started at the University of Nottingham and finished at a public house in Clifton, Nottinghamshire, UK, and lasted approximately 15 minutes.

Procedure

Prior to the study's initiation, ethical approval was granted by the Faculty of Engineering ethics committee.

When arriving at their scheduled time, participants were asked to read the information sheet and sign a consent form. Next, they completed a demographic questionnaire and were provided with standardised instructions by the researcher.

In order to ensure they were familiar and comfortable with providing a verbal protocol, participants first completed the procedure with the practice video. During the short car journey, the participants were asked to verbalise their internal thoughts on any hazards (anything that could be a risk to themselves or others) they were encountering. This focus was different to the focus of the main task

Figure 3. An example of the visual satellite navigation system approaching a roundabout junction (movements through junctions were indicated by white arrows on this system)

so that no priming occurred. Participants were instructed to imagine that they were the one driving the vehicle. They were asked to turn the desk-mounted wheel in order to mimic the on-screen movements. Asking participants to complete the additional task of mimicking steering wheel movements ensured they were engaged in the video, and is a method successfully used by others (Martens & Fox, 2007). The verbal protocol technique used was developed from Boren & Ramey (2000), and meant that the researcher could prompt and ask for clarification when required.

Once the practice video finished, the instructions for the main video were read to the participants: "Because you are unsure how to get there, you are following the blue car in front." Rather than verbally reporting instances of hazards, participants were instead asked to recount anything that was helping them understand the upcoming route, where to turn and where they were. They were informed they were traveling from The University of Nottingham to a public house in Clifton and that the journey should take around 15 minutes. Participants were asked to put on the SMI eye-tracking glasses, which were then calibrated. During the "main" video, participants were again asked to interact with the mounted steering wheel to mimic the filmed car's movements. The whole procedure lasted roughly 35 minutes. At any point, participants were permitted to ask questions.

Analysis

The eye-tracking data were analysed using areas of interest. These included but were not limited to: the lead car, road signs, road markings, pedestrians, other traffic (stationary and moving), traffic lights, the junction environment and building/ landmark/ the general environment. Whenever a glance was recorded over one of these elements the fixation was assigned to that location for further scrutiny. These areas of interest are represented in the heat map results in Figure 4. The analysis involved comparisons of length of glance duration and glance count between areas of interest.

The verbal protocols were transcribed and analysed by one coder in NVivo based on Burnett's (1998) framework of the navigational task. Coding within this framework is described, with examples, in Table 2.

RESULTS

Verbal Protocol

Preview

During condition L, participants indicated that the lead car in isolation did not provide sufficient information to reach their aims during the Preview stage:

I'd like to know kind of how far we need to go 'cause I'm just waiting for that moment when it's indicating- the front car. (Participant 1, minute 6, condition 1)

These issues are largely evident in participants speculating about potential routes:

I wonder whether we are going onto the A45-6 or 453, I wonder whether we take that. I don't know. (Participant 1, minute 5, condition 1)

If the lead vehicle readily informed the participants with previews of the upcoming route, it is unlikely these comments would be made.

Identify and Confirm

The reporting of the Identify and Confirm stages have been combined, as distinguishing when the participants were within these stages was complicated due to them often being mixed.

Table 2. The coding system from the verbal protocols

Code Name	Code Description	Time Frame	Examples From Verbal Protocols
Preview	The participant attempts to discover preparatory knowledge for the next manoeuvre including: road position, time or distance until the next manoeuvre, and develop a mental picture of the next manoeuvre	Occurs from the completion of a manoeuvre up until the approach of the next	"The road bends", "road clear", "front person not indicating", "he's in the right-hand lane"
Identify	The participant is in the process of determining the exact speed, location, positioning and direction, details of the next manoeuvre	Occurs during the final approach to a manoeuvre	"Taking the third exit", "just going straight on", "bearing right"
Confirm	The participant is establishing whether the manoeuvre was identified correctly	Occurs immediately before and after a manoeuvre	"Not exiting here, they stopped indicating", "we are indicating so through there, I see now, yep"
Confidence	The participant is aiming to establish whether they are following the right path	Can occur at any point during the journey	"Maybe the GPS is not really updated", "still following the blue car"
Orientation	The participant is attempting to locate themselves within the environment, or in relation to the destination	Can occur at any point during the journey	"Going towards engineering", "we seem to be in Clifton town centre now", "we're on Glencoe Road", "I think I'm near my destination "

Whether participants relied upon the lead vehicle or the navigational system (if provided), during these stages largely depended on the timing of when information became available. If the navigation system was first to indicate an upcoming manoeuvre (present in conditions LV, LA and F) then it was used to identify the required manoeuvre, whilst the lead vehicle was used for the Confirm stage to affirm the route:

OK, and he's gone into the 3rd lane now. That confirms that we're going right but he's, oh yes we are indicating so through there. (Participant 12, minute 3, condition 2)
Yep this is guy signalling off. (Participant 29, minute 3, condition 4)

The reverse was also evident. If the lead car was first to indicate an upcoming manoeuvre it fulfilled the Identity stage whilst the navigation system was used to confirm:

We are going to the left according to the blue car's light, to the left. (Participant 20, minute 6, condition 3)

This indicates that a lead vehicle is able to support both the Identify and Confirm stages of the navigation task.

Furthermore, 14 out of 24 participants did express a desire to use the lead vehicle as a primary aid during these stages, even with at least some element of a satellite navigation system present:

…here I feel like… they're a better reference of where to go. (Participant 26, minute 8, condition 4)

Typically, participants referred to the complexity of the route, or hazards in the area as a reason for this preference:

It's a bit of a, it's a bit hard to keep looking at the sat nav at the moment because the roads quite um, quite narrow, speed bumps, parked cars so, and as there's a guy in front who's leading the way it seems to make sense to follow him rather than pay so much attention to the sat nav. (Participant 12, minute 8, condition 2)
Ok this part is a bit complicated, so I'm just following the blue car. (Participant 27, minute 12, condition 4)
looking at what the car in front of me is assigning cause it's too fast that I can't look at the navigation system. (Participant 15, minute 8, condition 2)

It is apparent in these quotes that participants also preferred the location of the lead vehicle, since it enabled them to maintain focal attention towards the road environment.

Confidence

During this stage participants did not always gain overall reassurance from the lead vehicle or feel confident that they were taking the correct route. This was evident in the frustration some participants expressed:

Still following the blue car, they're not making any indication to do anything. (Participant 2, condition L)
Ah, because I don't have a visual of the map. Ah! (Participant 24, condition LA)

These responses also demonstrate that some participants prefer a map view of the upcoming route in order to feel reassured that the route is planned and the navigational aid is functioning.

The route displayed to participants was designed to contain many different junction types. As a results, six participants commented that it felt as though the lead vehicle was taking an indirect route or arbitrary diversions or thought it had become lost:

Feels like we have, like, done a circle, made a circle around the square. (Participant 8, condition L)
I actually think that we're a little lost as well. (Participant 8, condition L)
I feel like I'm going in a circle. (Participant 24, condition LA)
So I'm now wondering if they are lost as well. (Participant 5, condition L)

Orientation

Broadly, the lead vehicle appeared inefficient in communicating information for the Orientation stage of the navigation task. Within condition L, with only the lead vehicle present, 9 of 10 participants relied upon environmental cues, regarding the district they were in, to understand their orientation and proximity to the destination:

Looks like a more likely area for a pub to be compared to the dual carriage way but I still don't know. (Participant 5, condition L)
Ok the pub, yeah, it sounds like it would be in a more residential area. It seems like we're getting close. (Participant 7, condition L)

Eye-Tracking

A summary of results are found in Table 3.

The average glance duration of each participant was compared, no significant difference was found between the conditions [F(3,29) = 1.20, p = 0.33]. There was also: no difference in the glance durations towards the lead vehicle [F(3,29) = 1.22, p = 0.32]; the junction environment [F(3,29) =

0.80, p = 0.50]; the buildings/ landmarks/ environment [F(3,29) = 0.67, p = 0.58]; or towards hazards (such as traffic and pedestrians) between conditions [F(3,29) = 0.19, p = 0.90].

Looking at the overall number of glances between conditions found no significant differences [F(3,29) = 0.94, p = 0.43], meaning the number of glances participants performed was roughly equal across conditions. Inspecting the number of glances to the lead vehicle, a significant difference was found [F(3,29) = 3.29, p < 0.04], with participants in condition LA performing significantly more glances than the L condition. The number of glances towards the buildings/ landmarks/ environment between conditions was not significant [F(3,29) = 2.27, p = 0.10].There was a significant difference in the glances towards the junction environment [F(3,29) = 3.57, p < 0.03]. The post-hoc revealed a significant difference between conditions LV and LA (p<0.03); with condition LA demonstrating a higher mean number of glances (331.25). Next, inspecting the number of glances towards potential hazards: an ANOVA found no significant differences in the glances towards pedestrians [F(3,29) = 2.32, p > 0.09] between conditions, or other traffic [F(3,29) = 1.97, p = 1.41]. Finally, t-tests found that participants in condition LV [t(7) = 2.47, p = 0.04] and condition F [t(7) = 4.70, p < 0.00]exhibited a significantly higher glance count to the lead vehicle over visual satellite navigation system. A summary of these results is presented in Table 3. Heat maps were produced to evaluate the distribution of glances, these showed that the glance distribution was largely similar between conditions. See Figure 4.

Discussion

The results here demonstrate how drivers use a lead vehicle as a navigational aid. The verbal protocol responses revealed that the information requirements during the Preview and Orientation stages were perhaps least fulfilled by the lead vehicle. To reach the aims for both these stages, global information about the whole journey was used instead. For example, participants were reliant on the general environment they were in (whether they were on a major road, or in a residential area) to determine their orientation to the destination, and preview upcoming manoeuvres. Thus, the lead car was insufficient for these particular stages.

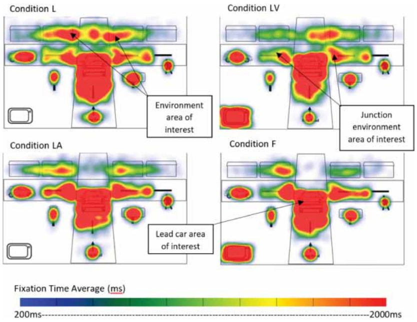
Some difficulties were also evident during the Confidence stage of the navigation task. Some participants became frustrated or concerned. The reason for this is most likely similar to the Preview and Orientation stages, as discussed above – specifically, the lead car was not able to provide global information about the route, and thus participants were unable to gain reassurance that they were on the correct route or that the lead car knew where it was going. This effect was likely amplified by the route the lead car took since, in order to incorporate many road and junction environments, the car took regular turnings. Generally, drivers would anticipate a hierarchy of roads during a journey: with motorways leading to main roads and then smaller roads if taking an ideal route (Car & Frank,

Table 3. A summary of significant eye-tracking results. Shaded/bolded areas denote significance.

	Number of Glances to Lead Vehicle		Number of Glances to Buildings/ Landmarks/ Environment		Average Number of Glances to the Junction Environment		Number of Glances to Pedestrians		Number of Glances to Other Traffic	
	M	SD	M	SD	M	SD	M	SD	M	SD
L	**736.67**	311.67	329.78	191.354	264.89	49.592	30.78	15.802	105.67	27.987
LV	859.63	353.86	214.50	185.260	**241.63**	74.780	26.00	10.690	75.25	27.932
LA	**1160.13**	216.78	233.00	80.278	**331.25**	55.224	32.88	7.376	106.38	31.744
F	896.25	223.43	149.25	67.646	298.75	54.316	19.00	9.695	96.88	30.442

M: Mean
SD: Standard Deviation

Figure 4. Heat maps of participant glance behaviours across conditions



1994). Residential streets would commonly be used at the beginning/end of the journey, yet they were present from half way into the journey for this study. The confusion and trust issues expressed are expected to be due to these two factors.

In contrast, the verbal protocol responses indicated that the lead car excelled at aiding the participant to complete the Identify and Confirm stage of the navigational task. First, participants used the lead vehicle to aid both stages, depending on the timing of when information was provided (by either the lead car or any other navigation system, if present). Secondly, participants showed a clear indication to use the lead car over other navigational systems which were present. According to participants' comments, this preference was commonly due to the complexity of the junction or hazards in the environment. Based on these results, the lead car offered the clearest clarification of where to go in a complex immediate environment whilst also enabling participants to maintain their attention, at least, towards the road scene, where their peripheral vision can be used to detect immediate hazards. Recent work (e.g. Wolfe, Dobres, Rosenholtz, & Reimer, 2017) has reaffirmed the importance of peripheral vision while driving, and these issues are likely to be impactful with the increasing implementation of HUDs. Our results clearly indicate that the participants relied upon a lead vehicle primarily during the Identify and Confirm stages, and therefore, may benefit from a "lead-vehicle navigational aid" during these stages. Thus, as demonstrated by Figure 1, this would be best implemented just before, during and immediately after a manoeuvre in the route. The verbal protocol reliability was limited by the use of one coder, these conclusions would be further supported if another coder was used and inter-rater reliability was assessed.

The eye-movement analysis showed that glance duration did not vary between conditions or stimuli within the videos. The number of glances to the lead vehicle was greatest in the LA condition where the audio navigation system was present. Potentially, the regular audio inputs may have encouraged glances to the lead vehicle, whilst the added information participants received from the audio system made them feel that they did not need to look elsewhere for other navigation information. In contrast, participants in the L condition (lead car only), performed the fewest glances to the lead vehicle. In combination with the verbal protocol results, it is likely that they were surveying their environment for further information and greater guidance, which the lead vehicle could not provide. A significant difference was also found in the number of glances to the junction environment; with most glances being performed by participants in the LA condition. Again, it is possible that the audio system was encouraging more glances. The LV condition performed the fewest number of glances to the junction environment, this was likely due to the presence of the visual system. A final examination of participant eye-movement revealed that participants glanced significantly more often to the lead vehicle than the visual navigation system (when it was present in the video). Research on eye-movement whilst driving has shown that when drivers follow other vehicles, the lead vehicle becomes their primary focal point with 38.7-44.3% of eye-glances being directed toward the lead vehicle (Mourant, Rockwell, & Rackoff, 1969). Thus, the participants here may be mimicking this typical driving behaviour whilst watching the video, and as a result, focusing primarily on the lead vehicle rather than the visual navigation system. Equally, the lead car's movement (or its position within the centre of the image) could further encourage glances towards it. Furthermore, in order to "follow" the lead car as instructed, participants would have been required to regularly monitor its movements. A combination of these factors likely led to a high number of the fixations on the lead car compared to the visual navigation system. It is important to note that fixations on hazards (such as other traffic or pedestrians) and the general road environment was not significantly different between tasks. Thus, although the participants were not driving, the eye-tracking results suggest that they still attended to hazards throughout the conditions. In relation to the development of AR navigation aids, the eye-tracking results indicate that although and AR lead vehicle may encourage regular glances, drivers will still appropriately attend to hazards and the road environment.

In summary, different sources of navigation information (in this respect the lead vehicle and the satellite navigational system) appear to aid the accomplishment of different navigational task stages. In particular, the lead vehicle was most proficient at the Identify and Confirm stages, which occur immediately before and after a manoeuvre. Thus, these results would suggest that an AR lead vehicle would be best be integrated as an aid at these points during a journey. This concept of an AR lead vehicle was tested in the subsequent study.

STUDY 2

Design

A within-subjects design was used to evaluate two different designs of AR lead vehicle as well as a more traditional AR arrow navigation system presented on a HUD. The independent variable was the exact nature of the HUD interface:

- The dynamic virtual car condition (DC), where a virtual car moved through the junction ahead of the participant's vehicle, just as a real-world vehicle would;
- The static virtual car condition (SC), a virtual car appears but only "waits" for the driver at the correct exit; it does not move through the junction as in the DVC condition;
- The screen-fixed arrow condition (SA), where a ring of arrows was shown to indicate the upcoming junction is a roundabout. Within the arrows a number is displayed to inform the driver which exit number they should take.

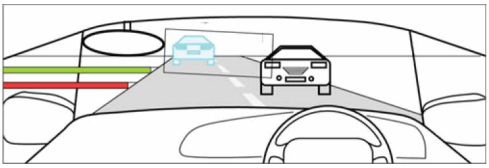
Depictions of these conditions are shown below (Figure 5 & 6). These conditions were selected so that a realistic virtual car could be tested (DC) and a more typical form of information could be examined (SA). The static virtual car (SC) was also included since a virtual car is not limited in the same way as a real one, so it was important to examine whether variations in a lead cars behaviour would make a difference. It was considered that the static car "waiting" at the correct exit could act as a landmark to drivers; landmarks are considered important elements in navigational aids for effective navigation whilst driving (Burnett, 2000) and augmented landmarks have been successfully implemented in HUD navigation systems before (Bolton et al., 2015).

Measures

Dependent variables were defined and aimed to understand:

- Driving performance:
    - *Speed*: Mean and standard deviation;
    - *Lateral control*: Standard deviation of lateral position;
    - *Speed of decision*: Indication location;

Figure 5. A stylised depiction of what the participant could see in the virtual car conditions (DC and SC)



  - *Steering reversal rate*: Number of specified changes in the steering angle per minute (related to task difficulty, e.g. higher speeds, de Groot et al., 2011, Theeuwes et al., 2002);
- Navigation performance:
  - *Accuracy of decision*: Correct turns;
  - *Subjective confidence level*;
- *Objective workload*: Tactile Detection Task (TDT) performance:
  - *Reaction time*: Mean and standard deviation indicating general workload level and variability of workload during different phases of roundabout navigation and presence of the Human Machine Interface (HMI), indicating interference by visual stimuli and the participants' movements over time (Juravle et al., 2010);
  - *Hit rate*: % correct responses;
- Subjective workload (NASA-TLX cumulative scores, Hart and Staveland, 1988);
- Visual behaviour:
  - *Mean fixation duration*: Mean duration of all fixations in a drive - represents task difficulty and degree of information processing;
  - *Glances towards the HMI*, in number and duration;
  - *Spread of search*: Standard deviation of horizontal coordinates of the fixations in a drive [in pixels (px)];
  - *Percent road centre*: Share of fixations in the road centre (200 px horizontally and 150 px vertically around the mean fixation point) - measure of task difficulty and cognitive load (Victor et al., 2005).

Participants

Twenty-two participants were recruited opportunistically via The University of Nottingham email system. They were selected if they were experienced drivers (UK driving licence held for >3 years) and were familiar with navigational systems. The 22 participants were aged 22 to 57 years and consisted of 14 males (mean age 31.3 years, SD = 10.9 years) and 8 females (mean age 30.3 years, SD = 10.4 years). As compensation for their time, participants were given a £15 Amazon voucher.

Figure 6. A stylised depiction of what the participants could see in the SA condition

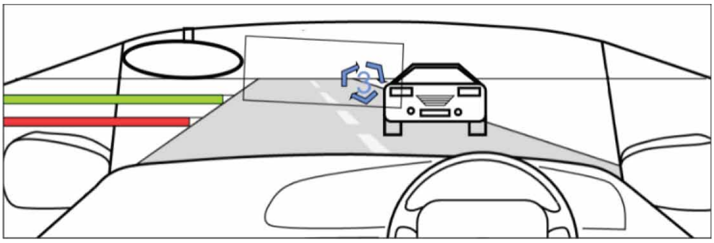


Figure 7. Driving Simulator at The University of Nottingham showing the car entering the roundabout with one exit visible

Materials

The second study was conducted at the University of Nottingham in a medium-fidelity stationary driving simulator (Figure 7). The simulator consists of a complete right-hand drive Audi TT and a 270-degrees curved screen. LCD side panels and a rear-view mirror reflecting the view onto a rear screen provide side and rear-views for the driver. Within the driving simulator, a Pioneer Carrozzeria Laser NDHUD1 display was placed in the position of the sun visor. The glass combiner screen is visible from the driver's perspective in Figure 8.

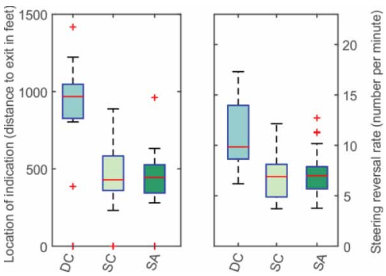
The driving scenario was developed using STISIM version 3. The posted speed limit was 50mph throughout. During the scenario, the participants travelled through rural and suburban roads followed by a large roundabout environment, with most exits invisible from the entry point (see Figure 7). The roundabout was selected as it represented a difficult navigation challenge (multiple navigational options, high workload driving task, etc.). Based on study 1, the roundabout was also expected to be a scenario where a lead vehicle could be valuable.

The navigation aid imagery was presented on the HUD. In order to co-ordinate with the participants' position within the road environment, the graphic display for the HUD was synchronised with the STISIM software. AR imagery (differing according to the condition) was therefore overlaid onto the road environment from the perspective of the driver (see Figure 8). Video cameras were unobtrusively placed within the simulator to record participant responses to the conditions. SMI eye-tracking glasses were used to monitor the participants' eye movements.

In order to measure objective workload, the Tactile Detection Task (TDT) was used. This is an ISO standardised method (ISO 17488) involving the attachment of a small motor to the base of the participant's neck. When the motor then vibrates seemingly randomly with a brief low intensity pulse, the participant is asked to dismiss the buzzing by pressing a button attached to their finger (this could be pressed against the steering wheel so as not to interrupt control over the car).

Figure 8. Internal view of the HUD and virtual car imagery demonstrated

Figure 9. Location of indication and steering reversal rate



Procedure

Before the study was initiated, approval was gained from the Faculty of Engineering Ethics Committee. Once participants arrived for the scheduled time, they were provided with an information sheet to read and a consent form to sign. Next, they completed a practice drive within the simulator to ensure they were familiar with the controls. Prior to the main experimental conditions, the participants were asked to put on the SMI eye-tracking glasses, which were then calibrated.

One short journey (5 minutes) was completed for each HUD configuration. Part way through each journey, the participant would encounter a large roundabout junction and at this point (150ft/46m before the junction), the HUD started to communicate to the driver which exit of the roundabout should be taken. Participants had to use this information to navigate out of the junction through the correct exit.

To test navigational performance and confidence, roundabout exits were labelled using coloured overlays on the roads. When a participant had decided which exit they were going to take, they were asked to first activate the car's indicators, and then speak aloud the colour of their choice and rate their confidence on a scale of 1 (not at all confident) to 5 (very confident) (e.g. "green, 4").

If the driver made a mistake and travelled along the wrong exit participants were instructed to turn the vehicle around as the simulated environment did not continue along incorrect routes. If this was not possible, the drive was repeated, but the repeated road sections were excluded from the analysis.

At the end of each journey, subjective workload was measured using the NASA-TLX questionnaire. Participants were also briefly questioned about their experiences. In total, the experiment lasted approximately 90 minutes.

Results

Driving Behaviours

A summary of the driving behaviour results are presented in the table below (see Table 4) and the significant differences in Figure 9. A main effect for the reaction time [$\chi^2(21) = 23.52$, $p < 0.01$, $\varphi = 1.06$] shows that the DC led drivers to indicate earlier (further away from the exit) than the SC ($p < 0.01$) and the SA ($p < 0.01$). The analysis of the number of steering reversals also produced a main effect [$F(1.49,31.29 = 45.92$, $p < 0.01$, $\eta^2 = 0.69$], with more steering corrections in the case of the DC than the SC ($p < 0.01$) or SA ($p < 0.01$).

No significant effects were found for the measures of mean speed ($p = 0.07$), speed variation ($p = 0.64$) as well as the variation of the lateral lane position ($p = 0.46$).

Navigation Performance, Confidence and Mental Workload

All of the navigation system interfaces tested generally resulted in correct exit decisions, with errors occurring for less than 5% of the roundabouts experienced with the VC and SC, and 2% with the SA. In terms of the stated confidence levels, there was a significant main effect [$\chi^2(21) = 11.7$, $p < 0.01$,

Table 4. A summary of driving behaviour results. Significant results are shaded/bolded.

	Mean Speed (mph)		SD Speed (mph)		SD Lateral Position (ft)		Location of Indication (ft)		Steering Reversal Rate (no/min)	
	M	SD	M	SD	M	SD	M	SD	M	SD
DC	30.4	5.90	9.59	3.69	6.29	1.45	**880**	484	**11.0**	3.3
SC	29.5	6.45	9.37	3.73	6.73	1.36	**465**	261	**6.95**	2.1
SA	31.3	6.68	9.05	3.78	6.53	1.28	**472**	150	**7.35**	2.3

$\varphi = 0.75$]. Post-hoc comparisons assign this effect to lower confidence levels with the SC compared to the SA condition ($p = 0.04$).

An analysis of the TDT performance also did not result in significant differences for the measures of reaction time ($p = 0.58$) and hit rate ($p = 0.05$). However, the overall score of the subjective responses to the NASA-TLX was significantly affected [$F(2,42) = 7.07$, $p < 0.01$, $\eta^2 = 0.25$]. Post-hoc tests show that subjective workload was higher with the SC compared to the DC ($p < 0.02$) and SA ($p < 0.01$). The results for navigation performance and mental workload are provided in Table 5 and the significant differences are illustrated in Figure 10.

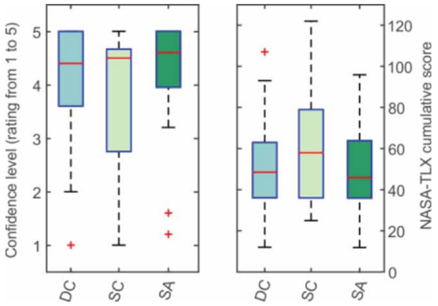
Visual Behaviours

A summary of visual behaviours is provided in Table 6. There was a main effect for mean fixation duration [$F(2,34) = 6.41$, $p < 0.01$, $\eta^2 = 0.27$]. The dynamic virtual car resulted in 14% longer fixation durations compared to the screen-fixed arrow ($p < 0.01$). Also, the duration of glances onto the HMI produced a main effect [$F(1.35,22.94) = 11.12$, $p < 0.01$, $\eta^2 = 0.4$]. Compared to the screen-fixed arrow, single HMI glances were longer with the DC ($p < 0.01$) and the SC ($p < 0.01$). The total glance duration towards the HMI showed a significant effect as well [$F(2,34) = 60.65$, $p < 0.01$, η^2

Table 5. A summary of navigation performance, confidence and mental workload results. Significant results are shaded/bolded.

	Correct Exits (c) vs. Errors (err)		Confidence Level (1-5 Scale)		TDT Reaction Time (ms)		TDT Hit Rate (%)		NASA-TLX Score	
	c	err	M	SD	M	SD	M	SD	M	SD
DC	104	5	**4.01**	1.19	631	166	57	26	**49.2**	24.3
SC	102	5	**3.76**	1.27	605	139	48	25	**60.1**	26.1
SA	107	2	**4.24**	1.08	582	121	61	19	**48.5**	21.7

Figure 10. Confidence ratings and NASA-TLX scores



= 0.78], with the highest glance duration for the DC compared to the SC ($p<0.01$) and the SA ($p < 0.01$). The SC also attracted a longer total glance duration than the SA ($p = 0.01$). A main effect also occurred for the number of glances towards the HMI [$F(2,34) = 73.938$, $p < 0.01$, $\eta^2 = 0.81$]. They were higher with the DC than for the SC ($p < 0.01$) and the SA ($p < 0.01$), but still higher for the SC compared to the screen-fixed arrow ($p < 0.01$).

The analysis of the percentage of fixations towards the road centre resulted in a main effect [$F(2,34) = 26.3$, $p < 0.01$, $\eta^2 = 0.61$]. The concentration on the road centre was higher for the DC than for the SC ($p<0.01$) and SA ($p < 0.01$). In the case of the SC, however, it was lower than for the SA ($p = .012$). The dispersion of glances may be an indication of a drivers situational awareness (Salmon, Stanton, Walker, & Green, 2006). The horizontal spread of search also indicated a main effect [$F(2,34) = 20.49$, $p < 0.01$, $\eta^2 = 0.55$]. The SC resulted in a wider visual search than the DC ($p<0.01$) and the SA ($p < 0.01$). This analysis is reflected in the heat maps (Figure 11), which demonstrate the location and duration of fixations.

Discussion

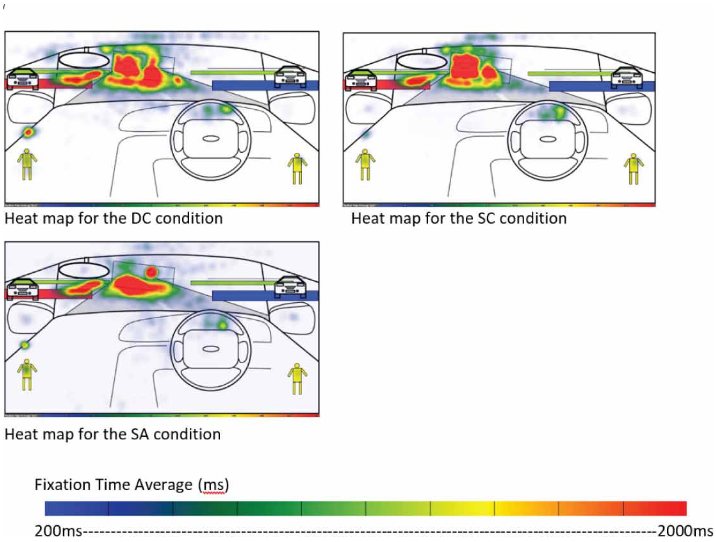
The concept of an AR lead car was tested at a large complex junction (roundabout), where it was expected to be the most useful to drivers, as study 1 suggested. The comparison of the dynamic virtual AR car with its static equivalent and a screen-fixed arrow provided interesting results. Navigation performance was good in all conditions. However, stated confidence levels were lowest with the SC, and this system also produced the highest subjective workload. Objective mental workload, measured with the TDT, was not affected by the navigation systems. These results could indicate a certain subjective discomfort with the static virtual car, which did not behave as naturally as a lead car or the DC system. Additionally, the increased workload may be due to the participants having to work harder to interpret what the static car's intentions were.

Regarding eye-movement behaviors, the dynamic vehicle (DC) resulted in longer glance durations. Single glances made towards the dynamic virtual car were longer and the highest number of glances towards the HUD occurred in this condition. It is likely that the dynamic nature of the car in the DC condition attracted attention towards the HUD more than the other conditions, in an effect similar to video roadside advertising (Chattington, Reed, Basacik, Flint, & Parkes, 2009). Furthermore, the information provided in the SA condition was relatively simplistic, and could be received in a quick glance if required. In contrast, the DC would require constant monitoring to understand which exit was correct. Thus, increased eye-glances would be encouraged by this condition. As mentioned in relation to the previous study, drivers following other vehicles spend a primary portion of glances looking towards the lead vehicle (Mourant et al., 1969). In typical driving, drivers performing these glances are maintaining a safe distance to the lead vehicle (cf. Goodrich et al., 1998). However, this is not necessary with the virtual car used in the second study since it is not a real object, but the effects on the perceived need to observe the safety margin may still occur. The SC condition also attracted increased visual attention, which may be reflective of the increased workload. Further work

Table 6. A summary of visual behaviours. Significant results are shaded/bolded.

	Mean Fixation Duration (ms)		Mean Glance Duration Towards HMI (ms)		Total Glance Duration Towards HMI (s)		Total Number of Glances Towards HMI		Percentage Road Centre		Horizontal Spread of Search (px)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
DC	**240**	**63.0**	**267**	**76.6**	**78.4**	**31.8**	**291**	**99.2**	**54.5**	**11.5**	**180**	**33.1**
SC	**228**	**64.8**	**288**	**102**	**36.7**	**25.7**	**127**	**72.2**	**25.5**	**11.2**	**233**	**33.6**
SA	**212**	**58.7**	**211**	**66.4**	**17.2**	**14.5**	**72.2**	**51.5**	**36.0**	**10.5**	**200**	**33.2**

Figure 11. Heat maps across conditions from study 2



is required to establish whether this eye-glance behaviour could interrupt the detection of hazards in the road environment, and to what extent typical scanning behaviours are influenced.

No conditions affected driving performance (speed, speed variation and lateral stability) significantly, but the dynamic AR front car led to activations of the indicator furthest away from the exit (sooner indication) and the largest number of steering corrections. These behavioural changes could mean that participants were closely “following” the dynamic lead car and copying its actions, which led to earlier indicating. An increase of steering reversals with no deteriorations in lane keeping has also been shown in a recent driving simulator study employing a secondary visual task placed in the front of the driver (Kountouriotis et al., 2016). It is not clear, whether our behavioural change can be explained by heightened mental workload or the visual task characteristics. The placement of the DC in the present research, however, could have caused very similar effects. A comparison between the AR system and a more typical LCD display would help clarify this phenomenon.

Overall, all three conditions successfully guided participants through the complex roundabouts encountered in their journeys. Focusing on the virtual vehicles, the dynamic car performed better than the static with respect to workload and confidence rating, while both virtual cars attracted more visual attention than the traditional HUD arrow interface.

GENERAL DISCUSSION

In total, this work has explored the concept of a lead vehicle, real or virtual, as a navigational aid while driving.

The first study has clearly demonstrated the role of a ‘real’ lead vehicle in the navigation task. Based upon these results, a lead car should aid drivers aiming to identify upcoming manoeuvres and confirm the correct manoeuvre has been performed, within Burnett’s (1998) framework.

The second study has further shown that an AR lead vehicle, presented on a HUD, has potential as a navigational aid within the roles indicated by the first study. Since, previous novel navigation HUD designs have also been beneficial, (Bark, Tran, Fujimura, & Ng-Thow-Hing, 2014) it is evident that HUD navigation designs can vary greatly yet be valued navigational aids. All HUD conditions tested led to good navigational performances, indicating that they all fulfil the needs of the Identify and Confirm stages of navigation. In addition to testing a dynamic lead vehicle (acting as a real vehicle would), a static version was examined that “waited” for the participant at the correct exit of the roundabout. Although the dynamic car attracted more visual attention from the driver, the static car resulted in higher workload. Thus, it can be assumed the static car was not functioning as intended, as a landmark for participants. Drivers indicated earliest in the DC condition despite the SA condition providing the participant with the correct exit number sooner. A possible explanation for this is that participants in the DC condition were imitating the behaviour of the dynamic virtual car; when it indicated they would also indicate.

This observation of participants mimicking the virtual lead vehicle is of particular interest. Positively, it suggests the virtual car was clearly providing them with information and could even act a role model for considerate driving. However, thoughtlessly imitating the dynamic virtual car’s behaviours could be problematic. For example, if a driver indicates two turnings before their intended turning, other road users could be misled. McNabb et al. (2017) have demonstrated that following a friend in another vehicle has the potential to encourage risky behaviours, due to time and social pressures. However, in this instance, these issues are not entirely applicable. The driver should not experience any time or social pressures from the navigational aid examined here. Furthermore, the virtual car navigation aid should be aware of the road network to prevent it encouraging indication which would mislead other road users. Finally, the studies here show no signs of dangerous or erratic driving behaviours, except a greater steering reversal rate in the DC condition. Steering reversal rates can reflect how much effort a driver is putting in to maintain lane positioning and can be linked to improved lateral performance (Kountouriotis et al., 2016), for example, at higher speeds (McLean & Hoffman, 1975; Salvucci & Gray, 2004). The higher steering reversal rate could also be indicative of following behaviours, where drivers are putting in extra effort to stay in a particular position behind the lead vehicle, rather than an indication of distracted or dangerous driving.

Comparing study one and study two, eye-tracking showed some behavioural similarities. Both demonstrated a high concentration of glances towards the lead vehicle, be it a virtual or real-world vehicle, which may be a concern. This is perhaps due to the dynamic nature of the lead vehicle, as discussed previously (Chattington et al., 2009), or simply representative of typical driver focal positioning (Mourant et al., 1969; Land & Horwood, 1995). Furthermore, the lead vehicle may have required more regular monitoring in order to interpret its ongoing intentions throughout the junction environment, compared to the navigation system in study one and the SA condition in study two. Either way, it could be argued that car following for navigational purposes does encourage drivers to keep their attention towards the forward road environment, so that hazards may be detected with peripheral vision (see Ward & Parkes, 1994).

Participants in study one experienced some frustration and concern when using solely the lead vehicle to navigate. This was largely the result of the lead vehicle being unable to provide and preview or global information about the upcoming route, leaving some participants feeling anxious. There was no evidence of this within the second study since it focused on the stages around the junction (Identify and Confirm) where the lead car was observed to perform well in study 1. Based on these findings, a virtual car should only be used in combination with other elements that are able to provide information which can fulfil the Preview and Orientation stages of the navigational task (Burnett, 1998).

It is important to discuss how an AR HUD virtual car system may behave within a naturalistic environment with many other real-world vehicles. First, it should only be present at junctions. This would prevent it conflicting with other vehicles for the majoring of a journey. Furthermore, study one indicates it may only be useful to drivers at this point anyway, where Identification and Confirmation are most important. The second study then shows that a virtual lead car is useful at complex roundabouts during these same stages. Personalisation options would also help prevent the system from being intrusive. However, interactions with other road users, and possible strategies to accommodate them together with an AR overlay, still need to be investigated in future research. Further work would also need to investigate where the higher visual attention towards the dynamic car could be problematic.

CONCLUSION

Our results demonstrate that a lead car for navigation purposes is best valued during the Identify (approaching a turning) and Confirm (approaching and immediately after a turning) stages of the navigational task. Moreover, we have established that AR virtual cars presented on a HUD can successfully support drivers through complex roundabout junctions, with the most representative dynamic version, which acts similar to a real front vehicle, having advantages in terms of confidence levels and subjective workload. These AR systems could provide a valued element to future vehicle navigation systems, especially when complemented by more global information sources (e.g. an in-vehicle map display, additional voice instructions).

ACKNOWLEDGMENT

Many thanks to our study participants, and Jaguar Land Rover Research for the generous funding.

REFERENCES

Bark, K., Tran, C., Fujimura, K., & Ng-Thow-Hing, V. (2014). Personal Navi: Benefits of an Augmented Reality Navigational Aid Using a See-Thru 3D Volumetric HUD. In *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 1-8). New York, NY: ACM. doi:10.1145/2667317.2667329

Bolton, A., Burnett, G., & Large, D. R. (2015). An investigation of augmented reality presentations of landmark-based navigation using a head-up display. In *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, Nottingham, UK. ACM. doi:10.1145/2799250.2799253

Boren, T., & Ramey, J. (2000). Thinking Aloud: Reconciling Theory and Practice. *IEEE Transactions on Professional Communication*, *43*(3), 261–278. doi:10.1109/47.867942

Burnett, G. (1998). *Turn right at the King's Head': drivers' requirements for route guidance information*. Unpublished doctoral dissertation, Loughborough University Institutional Repository, Loughborough, UK.

Burnett, G. (2000). 'Turn right at the Traffic Lights': The Requirement for Landmarks in Vehicle Navigation Systems. *Journal of Navigation*, *53*(3), 499–510. doi:10.1017/S0373463300001028

Car, A., & Frank, A. U. (1994). Modelling a Hierarchy of Space Applied to Large Road Networks. In *International Workshop on Advanced Research in Geographic Information Systems* (pp. 15-24). Springer. doi:10.1007/3-540-58795-0_30

Chattington, M., Reed, N., Basacik, D., Flint, A., & Parkes, A. (2009). Investigating driver distraction: the effects of video and static advertising. *Transport Research Laboratory.* Retrieved from http://www.trl.co.uk/reports-publications/report/?reportid=6575

Chu, K., Brewer, R., & Joseph, S. (2008). *Traffic and Navigation Support through an Automobile Heads Up Display (A-HUD)*. Retrieved from http://hdl.handle.net/10125/33376

Crundall, D. E., & Underwood, G. (1998). Effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics*, *41*(4), 448–458. doi:10.1080/001401398186937

De Groot, S., De Winter, J. C. F., García, J. M. L., Mulder, M., & Wieringa, P. A. (2011). The Effect of Concurrent Bandwidth Feedback on Learning the Lane-Keeping Task in a Driving Simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *53*(1), 50–62. doi:10.1177/0018720810393241 PMID:21469533

Foley, J. P. (2009). Now You See It, Now You Don't: Visual Occlusion as a Surrogate Distraction Measurement Technique. In M. A. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: theory, effects, and mitigation*. New York: CRC Press.

Gabbard, J. L., Fitch, G. M., & Kim, H. (2014). Behind the Glass: Driver Challenges and Opportunities for AR Automotive Applications. *Proceedings of the IEEE*, *102*(2), 124–136. doi:10.1109/JPROC.2013.2294642

Goodrich, M. A., Boer, E. R., & Inoue, H. (1998). *Brake initiation and braking dynamics: A human-centered study of desired ACC characteristics*. Basic Research, Nissan Research and Development, Inc. Citeseer.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In P. A. Hancock & N. Meshkati (Eds.), *Advances in Psychology* (pp. 139–183). North-Holland: Elsevier Science Publishers.

Juravle, G., Deubel, H., Tan, H. Z., & Spence, C. (2010). Changes in tactile sensitivity over the time-course of a goal-directed movement. *Behavioural Brain Research*, *208*(2), 391–401. doi:10.1016/j.bbr.2009.12.009 PMID:20018212

Kountouriotis, G. K., Spyridakos, P., Carsten, O. M. J., & Merat, N. (2016). Identifying cognitive distraction using steering wheel reversal rates. *Accident; Analysis and Prevention*, *96*, 39–45. doi:10.1016/j.aap.2016.07.032 PMID:27497055

Land, M., & Horwood, J. (1995). Which parts of the road guide steering? *Nature*, *377*(6547), 339–340. doi:10.1038/377339a0 PMID:7566087

Lee, J., Forlizzi, J., & Hudson, S. E. (2008). Iterative Design of MOVE: A Situationally Appropriate Vehicle Navigation System. *International Journal of Human-Computer Studies*, *66*(3), 198–215. doi:10.1016/j.ijhcs.2007.01.004

Martens, M. H., & Fox, M. (2007). Does road familiarity change eye fixations? A comparison between watching a video and real driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*(1), 33–47. doi:10.1016/j.trf.2006.03.002

McLean, J. R., & Hoffman, E. (1975). Steering Reversals as a Measure of Driver Performance and Steering Task Difficulty. *Human Factors*, *17*(3), 248–256. doi:10.1177/001872087501700304

McNabb, J., Kuzel, M., & Gray, R. (2017). I'll show you the way: Risky driver behavior when "following a friend.". *Frontiers in Psychology*, *8*, 1–6. doi:10.3389/fpsyg.2017.00705 PMID:28536545

Mourant, R. R., Rockwell, T. H., & Rackoff, N. J. (1969). Drivers' Eye Movements and Visual Workload. *Highway Research Record*, *299*, 1–10. Retrieved from http://pubsindex.trb.org/view.aspx?id=116321

Park, H. S., Park, M. W., Won, K. H., Kim, K. H., & Jung, S. K. (2013). In-Vehicle AR-HUD system to provide driving-Safety information. *ETRI Journal*, *35*(6), 1038–1047. doi:10.4218/etrij.13.2013.0041

Ranney, T. A. (1999). Psychological factors that influence car-following and car-following model development. *Transportation Research Part F: Traffic Psychology and Behaviour*, *2*(4), 213–219. doi:10.1016/S1369-8478(00)00010-3

Salmon, P., Stanton, P. N., Walker, G., & Green, D. (2006). Situation Awareness Measurement- A review of applicability.pdf. *Applied Ergonomics*, *37*(2), 225–238. doi:10.1016/j.apergo.2005.02.001 PMID:16023612

Salvucci, D. D., & Gray, R. (2004). A two-point visual control model of steering. *Perception*, *33*(10), 1233–1248. doi:10.1068/p5343 PMID:15693668

Theeuwes, J., Alferdinck, J. W. A. M., & Perel, M. (2002). Relation Between Glare and Driving Performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *44*(1), 95–107. doi:10.1518/0018720024494775 PMID:12118876

Tonnis, M., Sandor, C., Klinker, G., Lange, C., & Bubb, H. (2005). Experimental Evaluation of an Augmented Reality Visualization for Directing a Car Driver's Attention. *Symposium*, 56–59. doi:10.1109/ISMAR.2005.31

Victor, T. (2005). *Keeping Eye and Mind on the Road* [PhD Doctoral thesis]. Uppsala University, Uppsala, Sweden.

Victor, T. W., Harbluk, J. L., & Engström, J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*(2), 167–190. doi:10.1016/j.trf.2005.04.014

Ward, N. J., & Parkes, A. (1994). Head-up displays and their automotive application: an overview of human factors issues affecting safety. *Accident, Analysis and Prevention,* *26*(6), 703–717. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7857487

Wolfe, B., Dobres, J., Rosenholtz, R., & Reimer, B. (2017). More than the Useful Field: Considering peripheral vision in driving. *Applied Ergonomics*, *65*, 316–325. doi:10.1016/j.apergo.2017.07.009 PMID:28802451