Proceedings of the 10th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '18), September 23–25, 2018, Toronto, Canada

Establishing the Role of a Virtual Lead Vehicle as a Novel Augmented Reality Navigational Aid

Bethan Hannah Topliss
University of Nottingham
Nottingham, UK
bethan.topliss@nottingham.ac.uk

Sanna M Pampel
University of Nottingham
Nottingham, UK
sanna.pampel@nottingham.ac.uk

Gary Burnett
University of Nottingham
Nottingham, UK
gary.burnett@nottingham.ac.uk

Lee Skrypchuk
Jaguar Land Rover Research
Coventry, UK
lskrypch@jaguarlandrover.com

Chrisminder Hare
Jaguar Land Rover Research
Coventry, UK
chare2@jaguarlandrover.com

ABSTRACT

This paper reports on two studies investigating how following a lead vehicle could act as a metaphor for an Augmented Reality (AR) system to support navigation tasks. For the first formative study, 34 participants completed a video-based evaluation of the role of a real lead vehicle when navigating a coherent journey. Verbal protocols indicated that a lead vehicle may be a valuable navigation aid at a range of different junction types, but not where drivers may desire a preview of upcoming steps or their overall orientation. A subsequent driving simulator study with 22 participants examined whether an AR lead vehicle may support drivers when navigating at complex junctions, specifically large multi-exit roundabouts. The virtual car led to good navigation and driving performance, which was comparable to a more traditional screen-fixed interface. Overall, this work demonstrates that a virtual lead vehicle may be beneficial within AR navigation devices.

Author Keywords

Augmented reality; Head-up display; Navigation; Virtual car

CCS Concepts

Human-centered computing~Displays and imagers.

INTRODUCTION

Head-Up Displays (HUDs) are increasingly practical for use within the automotive industry and have a range of benefits and opportunities when presenting navigation-related information [cf. 10]. As a result, numerous novel navigation interfaces have been proposed or introduced, including screen-fixed distance-to-turn information, arrows virtually placed onto the road and landmarks augmented by boxes or arrows [2]. In general, the ability of HUDs to directly superimpose information onto a driver's view of the road environment, has been shown to improve navigation and driving performance, as well as reduced reaction times to hazards [2, 13, 16]. Furthermore, studies indicate a stronger personal preference, lower mental workload levels and easier familiarisation when using a HUD compared to traditional in-vehicle navigation displays that require drivers to clearly glance off the road [13, 16]. Despite the numerous potential benefits, each novel concept requires rigorous research to ensure ideal performance and safety.

AutomotiveUI '18, September 23–25, 2018, Toronto, ON, Canada

ACM ISBN 978-1-4503-5946-7/18/09…$15.00
https://doi.org/10.1145/3239060.3239069

Stages of Navigation

To develop any novel user-interface, a detailed understanding of the users' tasks is required. In this respect, the navigational task, according to Burnett [5], is a continuous process with several stages: Planning, Preview, Identify, Confirm, Confidence and Orientation (see Figure 1). At each of these stages a driver will have different goals feeding into the overall navigation task. The first stage, Planning, typically occurs prior to the task's initiation where a driver will consider and arrange a route. Relevant to the actual driving manoeuvres are the Preview, Identify and Confirm stages. First a driver will gather knowledge to anticipate the manoeuvre required (the Preview stage). Next, they will distinguish the precise location, speed and positioning required (the Identify stage). Finally, the driver searches for indications that the manoeuvre they identified was correct or false (the Confirm stage). The final two stages occur throughout the navigational task. Confidence, refers to obtaining reassurance that the correct route is being followed. Orientation, is the aim of verifying overall direction and location within one's surroundings, and in

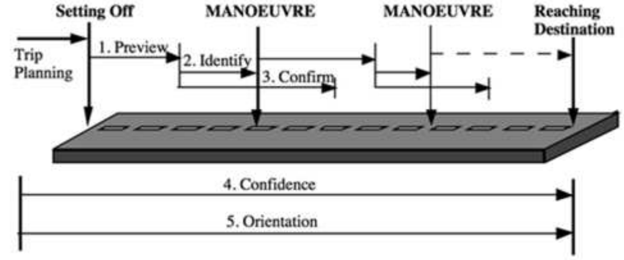

Figure 1. Burnett's Navigation Stages [5]

relation to the destination. Burnett’s definition of the navigational task is well supported [12, 17] and contends that different navigational information is required to meet the user’s goals for each stage [5].

The Current Studies

Following another vehicle is a well-known navigation method, yet it has received minimal attention in the Human Factors and HCI literature (e.g. [15]). Therefore, there was a requirement to establish exactly how a leading vehicle can support the navigational task and, subsequently how it could be deployed as a metaphor within a user-interface for a vehicle navigation system.

This work first investigated the role of a real lead vehicle during navigation by conducting a between-subject video-based study. This approach enabled in-depth qualitative data to be collected, according to identical journey experiences without order effects confounding responses. In order to understand the beneficial role of a lead vehicle, a verbal protocol method was utilised. Verbal protocols [7] can aptly capture the rich and complex navigational information within the working memory on a moment by moment basis. Although this method is not without issue [8, 9], it appears to have minimal detrimental effects on driving performance [18, 19] and has even been a valuable method in time-restricted emergency scenarios [1], thereby suggesting it would not be disruptive for the present study. The findings from this study established the appropriate role of a virtual lead vehicle within a navigational device. This informed a second study which tested a virtual lead vehicle performing this role within a driving simulator, which allowed for a safe, consistent environment. Comparisons to another navigational aid were conducted to evaluate the virtual lead vehicle’s relative performance.

In summary, this work first aimed to establish how navigation is conducted whilst following another real-world vehicle. Secondly, it used this knowledge to inspect a potential implementation of a virtual lead vehicle as a metaphor for an interface supporting the driver’s navigation task. An established definition of navigational stages [5] was used as a framework for assessment throughout.

STUDY 1

Design

The first study was developed as a video-based procedure with a between-subjects design.

The independent variable was the level of the visual or auditory navigational information available from a navigation system. This independent variable was selected for manipulation because the information provided by a satellite navigation system might reasonably be expected to be part of a novel navigation system, and therefore the consequence of their presence was important to understand. Participants were opportunistically allocated to one of the four conditions which are outlined in Table 1. Concurrent verbal protocols were collected during the procedure as a primary measure.

Condition Name	Video Summary	Number of participants
L (Lead)	only the lead vehicle present within the video footage	10
LV (Lead and Visual)	the lead vehicle and a visual-only satellite navigation system is present	8
LA (Lead and Audio)	the lead vehicle and an audio-only satellite navigation system is present	8
F (Full)	the lead car and a full satellite navigation system with audio and visual prompts was present	8

Table 1. A description of the conditions used within study 1.

Participants

Thirty-four participants of mixed gender (26 male, 8 female) were opportunistically selected through group email at the University of Nottingham. Each participant held a driving licence, though they could originate from any country to be accepted for participation. As compensation for their time, participants were offered a £5 Amazon voucher. The vast majority of participants (29 of 34) stated that they were unfamiliar with the area used in the study. Participants were collected in 5 age categories ranging from 18 to 65 years, but primarily participants were in the 26-35 years range (44.1%).

Apparatus

Dashboard camera footage was filmed using a Blackvue DR550GW-2CH. The dashboard camera faced forward out the front of the vehicle, recording a lead car taking the same route, in addition to the surrounding environment (see Figure 2). All camera footage included environmental sounds and was then further edited for each of the conditions (Table 1). Two videos were recorded for use in the study. Video footage for a practice verbal protocol demonstrated a 4 minute journey from a residential area to a supermarket, all within Beeston, Nottinghamshire, United Kingdom.

Figure 2. An example screen capture of video footage with visual navigation system present.

Code Name	Code Description	Time Frame	Examples from Verbal Protocols
Preview	Attempting to discover preparatory knowledge for the next manoeuvre including: road position, time or distance until the next manoeuvre, and develop a mental picture	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	Participant 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	Participant 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	Participants aiming to establish whether they are following the right path	Can occur at any point	"Maybe the GPS is not really updated", "still following the blue car"
Orientation	Participant attempting to locate themselves within the environment, or in relation to the destination	Can occur at any point	"Going towards engineering", "we seem to be in Clifton town centre now", "we're on Glencoe Road", "I think I'm near my destination "

Table 2. The Information Use Coding System from the Verbal Protocols

All footage contained a leading vehicle, driven by a researcher of the University of Nottingham. To create the video for the main experimental task, the same dashboard camera was used to film a 15 minute journey from Nottingham University Park Campus to a public house called The Fairham in Clifton, Nottinghamshire, United Kingdom. Whereas previous research has required repeating routes with loops or U-turns (e.g. [14]) this study aimed to provide a coherent route to a logical location. The route was constructed to include as many different road and junction environments as possible, in order to explore many different navigational scenarios (e.g. large/small roundabouts, traffic lights crossroads, dual-carriageways, right and left turnings within residential areas). The footage of the visual satellite navigation system (Garmin Nüvi 52LM) was filmed simultaneously and edited into the dashboard camera where required (Table 1). At junctions the system showed a white arrow over the route and distance to intersection information (Figure 3).

Figure 3. The visual navigation system approaching a junction

Procedure

Ethical approval was provided by the Faculty of Engineering Ethics Committee. At the session, participants were initially asked to read through the information sheet, complete the consent form and demographic questions. Next, the formal instructions for the practice task were read to them. The practice task was included to train participants in providing a concurrent verbal protocol, as is suggested [7], in order to ensure effective data collection. Within these instructions participants were asked to imagine they were driving the vehicle, and to think aloud (i.e. verbalise their current thoughts regarding the task) about any potential hazards which they see; (this topic was used so that participants were not primed for the main task). A hazard was defined as anything that could pose a risk to themselves or any other person.

During the practice task, they were asked to watch the video and mimic the movements of the car on-screen with the desktop steering wheel as though they were driving. This technique was used to ensure maintained engagement and has been successfully used by others [14]. This experiment took the approach of concurrent verbal protocol from [3], meaning that the experimenter could acknowledge, ask for clarification, and encourage contributions from the participant.

Once the participant completed the practice task, and the experimenter was confident they were comfortable with verbal protocol production, the experimenter read the instructions for the main task. The main task required participants to act in the same manner as the practice, but instead talk about their navigation information requirements rather than hazards. Participants were told that this could include factors that helped them to understand where and when to turn, which way to turn, confirming their route and knowing where they are. During the video the experimenter prompted the participant if necessary.

Participants were given the opportunity to ask questions throughout and were presented with a debrief sheet at the end of the session. The total procedure lasted approximately 35 minutes.

Analysis

The verbal protocols were first transcribed and then imported to NVivo 10 for content analysis. The content analysis inspected how navigational information was used in each of the conditions. This analysis was based on the stages of navigation identified by Burnett [5]. The stages and coding system are detailed in Table 2. This framework, unlike others [21] allowed information usage to be linked to a time scale and therefore to specific manoeuvres during the route. As a result, subjective comments could be made regarding specific driving situations, and in what way they may change how information is used. Throughout the coding process other reoccurring themes were also noted by the researcher for further discussion.

Results

Preview

Based on the verbal protocols, participants felt the lead car in isolation (condition L), poorly provided information required for the Preview stage of navigation. This is evident where participants were speculating about the upcoming route; if the information was readily available it is unlikely they would display this behaviour:

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

Indications of this occurred in 6 of the 10 participants in condition L.

Identify and Confirm

The verbal protocols demonstrated that the exact use of the lead vehicle within the navigation task stages is somewhat dependent on timing. If the navigation system (present within LV, LA or F) first indicated a manoeuvre, then the lead car largely appears to be used for the Confirm stage:

"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, condition LV)

"Yep this is guy signalling off" (Participant 29, condition F)

However, when the car is first to indicate an upcoming manoeuvre, the car is used for the Identify stage:

"We are going to the left according to the blue car's light, to the left" (Participant 20, condition LA)

"Indicating left and there's a filter lane so we're moving over into the filter lane." (Participant 12, condition LV)

Furthermore, the navigation system and car often resulted in more mixed or unclear stages of Identification and Confirmation, since both often indicated a manoeuvre simultaneously. As a result, distinct Identify and Confirm stages were not always identifiable, so here the two stages are reported on together.

Overall, the car was commonly mentioned in the verbal protocols during the Identify and Confirmation stages. Importantly, participants sometimes expressed an inclination to default to using the lead vehicle as a primary source of navigational information, even while the visual and/or auditory navigation system was present (conditions LV, LA and F):

"Here I feel like… they're a better reference of where to go." (Participant 26, condition F)

In total 14 (out of 24) participants in conditions LV, LA, and F in some way mentioned using the car for navigation over the navigation system. Typically, the participants commented on the area, or difficulty of the driving task as the cause for this behaviour:

"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, condition F)

"Ok this part is a bit complicated, so I'm just following the blue car." (Participant 27, condition F)

Although, one blamed the complexity or length of the audio instructions:

[In response to an audio instruction] "Think it's a bit too long, a- mean to understand, I think I'll just follow the blue car now." (Participant 22, condition LA)

There is also evidence of the lead vehicle being preferred over the navigation system for the specific purpose of aiding identification of the exact manoeuvre they are required to complete:

"OK, when it says miles I just don't know how long that is, will be, so I think I'll just, follow the car, in front of me to look at where they're actually turning and indicating." (Participant 22, condition LA)

"So I'm going right but depending on the front car, yeah to give the correct lane." (Participant 28, condition F)

"The car in front's indicating, and I can follow him so I don't need to worry about lane changes or anything, just, just follow him." (Participant 33, condition LA)

During the identification of manoeuvres at roundabouts, directions were more commonly discussed (119 instances) than exits numbers (48 instances), across conditions. This occurred despite exit numbers being provided in LV, LA and F conditions.

Confidence

There were instances of frustration and concern in some participants:

"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)

"But if I were present in the car I would use the visual information to, tell where I'm supposed to go by looking at the geometry of the uh the roundabout instead." (Participant 21, condition LA)

Although the route was designed to feel logical, 6 participants commented that the route took arbitrary diversions, and/or thought that the lead vehicle 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

The leading vehicle appeared largely ineffective at providing Orientation information, since in the L condition, 9 out of 10 of the participants referred to the district they were in order to contemplate their overall location in relation to their 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)

Discussion

Completion of this study has demonstrated how navigational information is used when following a leading vehicle; an element that was previously unexplored.

Overall, different information sources appear to address different stages within the navigation task. Interpretation of the verbal protocols demonstrated that the L and LA conditions were poor at providing larger perspective information for Preview and Orientation purposes during the journey. This was evident in how participants tried to use other information, or simply started to speculate. It was also evident when participants expressed frustration or concern due to their uncertainty, and expressed a desire for a better visual understanding of the road layout. Thus, a lead vehicle, either in isolation or with supplementary auditory information, may not satisfactorily allow goals to be met during the Preview and Orientation stages of navigation.

Analysis of the Confidence stage indicated that there was frustration and concern (primarily in L and LA) from some participants, which was largely due to the Preview and Orientation stages as discussed above. The verbal protocols did indicate that some participants felt lost during the journey. Typically, people use the hierarchy of street classes, such as motorways, main roads and side roads, as a method of determining ideal routes [6]. As a result, there is an expectation that smaller roads will not be used until necessary at the end of the journey, yet the route within this study used them approximately halfway into the journey. Thus, these instances were likely due to the route within this study rather than the lead vehicle itself; it may have led to some trust issues, but this would not occur in a more typical journey. Additionally, these instances of confusion confirm that drivers used the road environment, and their knowledge of typical journeys, as a source of navigational information across conditions.

In contrast, it was also clear that the lead vehicle excelled as a navigational aid during the Identify and Confirm stages. Participants commonly reverted to the leading vehicle, over any of the navigation systems, as a source of information during points of the journey when the Identify and Confirm stages occur. Namely, when they needed clarification of exact manoeuvres, and during complex intersection environments. Participants also reverted to the lead vehicle when the navigation system (in LV, LA or F) was unclear to them. Thus, whilst a lead vehicle may not facilitate some stages (Preview and Orientation) it was clearly relied upon for others (Identify and Confirm). In total the findings indicate that, the lead vehicle's role in navigation was to support navigation during the Identify and Confirm stages.

STUDY 2

Study 2 tested whether the beneficial role of the real lead vehicle (during the Identify and Confirm stages) was also present when it was incorporated as a virtual element in an AR navigation system at a complex junction (large, multi-exit roundabout). Furthermore, the study contrasted the virtual lead vehicle with a fixed-screen arrow, navigation system (which provided and exit number) in order to clarify whether a virtual lead vehicle holds any benefit over other navigational aids.

Participants

Twenty-two experienced drivers (owned a UK licence for >3 years; currently drive and use navigation systems regularly) were recruited for the study. Participants were mostly self-selecting volunteers who responded to email advertisements sent around the University of Nottingham campus. As compensation for their time, they were given a £15 Amazon voucher. The participant base consisted of 14 males (mean age 31 years) and 8 females (mean age 30 years), with ages ranging from 22 to 57 years.

Apparatus

The experiment took place in a medium-fidelity, fixed-based driving simulator located at the University of Nottingham. The simulator comprises a right-hand drive Audi TT car positioned within a curved screen 270 degrees setup, rear mirror projection and side mirror screens. A bespoke driving

Figure 4. University of Nottingham fixed-base driving simulator with roundabout scenario

scenario was created using STISIM Version 3 software, to replicate a mixed suburban and rural road scene presenting a challenging navigation environment (i.e. large roundabout with many potential exits, some of which are not visible from the entrance, as can be seen in Figure 4).

For the AR condition, the HUD imagery needed to correspond with the required turnings and remain consistent between participants. Therefore, the software that was running the graphic displays for the HUD, was synchronised with STISIM. In this scenario, drivers progressed along the route with a posted speed limit of 50 mph throughout. Navigation cues were created independently of the road scene and displayed using a Pioneer Carrozzeria Laser ND-HUD1 head-up display unit (an aftermarket device). The HUD was affixed in place of the driver's sun visor in order to present the AR imagery over the appropriate section of the road scene for the driver (see Figure 5). Digital camcorders were unobtrusively located in order to record the driver's responses.Throughout all drives, participants wore a Tactile Detection Task (TDT) device, to provide an objective measure of workload and thus the mental 'burden' of the navigation task. The TDT is an ISO standardised method [11], in which drivers wear a small vibro-tactile motor attached to the lower part of the neck. Periodically, (but seemingly randomly) the motor vibrated with a brief low intensity pulse. The task of the participants was to press a button on their index finger against the steering wheel when they noticed the pulse, in order to switch it off.

Figure 5. Position of the HUD unit and a photo of the virtual car during a drive from a participant's perspective

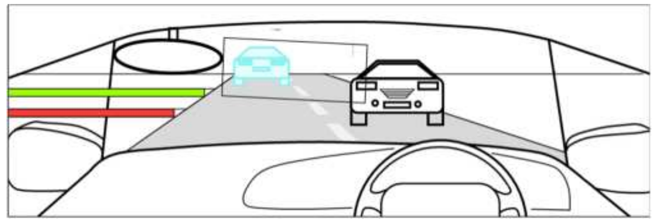

Figure 6. The VC representation on the HUD, showing a car projected onto the road ahead

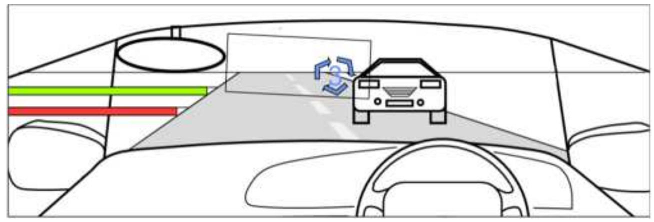

Figure 7. The SA representation on the HUD, showing a circle of arrows with the roundabout exit number inside

Design

Using a within-subjects design with a counterbalanced order of presentation, the experimental conditions were the novel 'Virtual Car (VC)' and the 'Screen-fixed Arrow (SA)', a system currently available on the market. Within the VC condition, the HUD displayed a dynamic leading vehicle (see Figure 6), which communicated the correct roundabout exit by appearing at a distance of 150 feet before the roundabout entry and drove in front of the host car. It indicated left to inform the driver that they should exit the roundabout moving to the correct exit and then left the roundabout visibly for the participant. In the SA condition, the HUD displayed the roundabout exit number within a set of screen-fixed arrows (see Figure 7).

Procedure

Participants were asked to complete a consent form and a demographic questionnaire prior to the study. They were then seated in a driving simulator and undertook a practice drive to familiarise themselves with the primary vehicle controls.

Two short (approx. 5 minutes long) driving routes were driven during the session to provide the basis of the navigation task. These were the same for each participant and showed alternative HMI configurations communicating a turn off a large roundabout. Drivers completed the driving scenarios using each of the two presentations of navigational instructions. In each scenario, drivers progressed along the route with a posted speed limit of 50 mph, encountering five large roundabouts in total. Participants were asked to use the information presented on the HUD to select the 'correct' turning, and drive into the exit.

Each of these roundabouts contained five possible coloured exits to the left. Participants were asked to indicate their choice of turning by activating the left indicator to exit the roundabout and speaking aloud the colour of the road that they would follow based on the information provided to them. The driver made the turning – but needed to return to the road if the correct turning was missed or repeat the drive (if it was not possible to navigate back to the correct route). Participants were asked to signal and announce their turning selection as soon as they were confident that they were 'correct'. They were also asked to state the rating of their confidence with their choice from 1 (not at all confident) to 5 (very confident). No voice information was provided as navigational cues, to provide a focus on the visual representations.

At the end of each drive, participants completed a NASA-TLX questionnaire for subjective workload and were briefly interviewed regarding their experiences with the two different HUD navigation systems. The entire study lasted approximately 90 minutes and was approved by the Faculty of Engineering Ethics Committee.

Results

Navigation Performance, Confidence and Mental Workload

Both navigation system HMIs generally resulted in correct exit decisions, with errors occurring for less than 5% of the roundabouts experienced with the VC and 2% with the SA. In terms of the stated confidence levels, there was no significant difference between the VC and SA conditions ($p = .135$).

An analysis of the TDT performance also did not result in significant differences for the measures of reaction time ($p = .632$) and hit rate ($p = .758$). Similarly, an overall score of the subjective responses to the NASA-TLX (Figure 8) were not significantly affected ($p = .858$). The results for navigation performance and mental workload are provided in Table 3.

	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
VC	104	5	4.01	1.19	631	166	57	26	49.2	24.3
SA	107	2	4.24	1.08	583	121	61	19	48.5	21.7

Table 3. Results for navigation performance and mental workload (shading denotes significance)

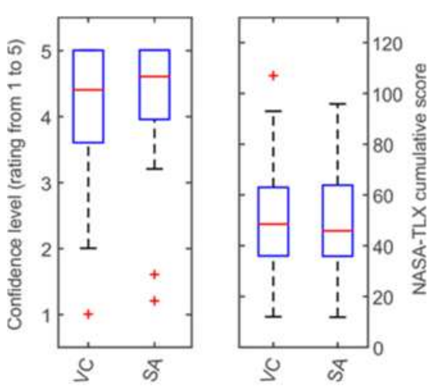

Figure 8. Confidence ratings and NASA-TLX scores

	Mean speed (mph)		SD speed (mph)		SD lateral position (ft)		Time to indicate (ms)		Steering reversal rate (no/min)	
	M	SD	M	SD	M	SD	M	SD	M	SD
VC	30.4	5.90	9.59	3.69	6.29	1.45	880	484	11.0	3.3
SA	31.3	6.68	9.05	3.78	6.53	1.28	472	150	7.35	2.3

Table 4. Results for driving behaviour (shading denotes significance)

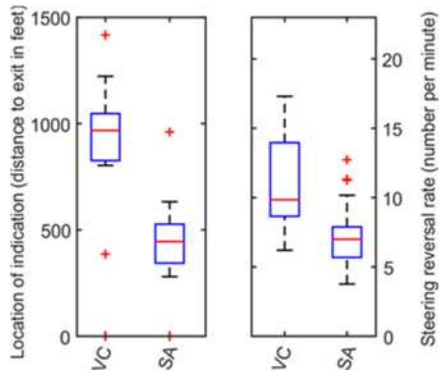

Figure 9. Location of indication and steering reversal rate for the VC and SA conditions

Driving Behaviours

No significant effects were found for the measures of mean speed ($p = .209$), speed variation ($p = .294$) as well as the variation of the lateral lane position ($p = .494$).

However, the virtual car led drivers to indicate sooner [$t(21) = 3.250$, $p = .001$, $r = .578$] and led to a higher number of steering reversals [$t(21) = -8.581$, $p < .001$, $r = .882$], see Figure 9. The driving behaviour measures are listed in Table 4.

Discussion

Although the VC and SA concepts are fundamentally different, they both resulted in a high navigation performance with few wrong exits being taken, despite the evident complexity of the roundabout manoeuvre. There were no significant differences in confidence levels, mental workload (objective and subjective) as well as general driving performance in terms of speed, speed variability and lateral position. These findings support that drivers were performing comparably well with both systems, according to the measures used in the study. This occurred even though the VC does not fully support the Preview stage but has advantages in the Identify and Confirm stages, according to the first study.

Interestingly, differences were apparent in the speed of indication and steering corrections. Participants indicated earlier with the VC, although the SA provided them with the exit information earlier. Hence, it can be assumed that they imitated the VC's 'actions' and simply used their indicators whenever the lead vehicle did so. The increased number of steering corrections can also point to participants attempting to closely imitate the VC.

GENERAL DISCUSSION

Overall, this work has revealed the potential role of a lead vehicle within navigation, and how it may be successfully integrated within an AR navigation system.

The results of the first study indicated how a lead vehicle is used and valued during the stages of navigation [5]. A real-world lead vehicle was proficient in providing detailed information regarding manoeuvres, which meant participants defaulted to it as a source of information at complex intersections. Thus, it helped to fulfil the goals of the Identify and Confirm stages of navigation.

The second study investigated how a virtual lead vehicle may be implemented at a complex roundabout, and also how it compared to providing navigational information in another manner: using screen-fixed roundabout exit numbers. Both systems resulted in good navigational performances - perhaps because they both address the need for information in the Identify stage, which would be the most essential stage for navigating successfully at a junction, such as a roundabout. The exit numbers (SA condition) should have given an earlier indication of which exit to take, over the virtual car. However, the opposite appeared to be true as indications to exit were made earlier in the VC condition. A possible explanation is that participants were simply mimicking the actions of the virtual lead vehicle: when the VC indicated, the driver indicated, whether they knew which road to take or not. Instead of a front vehicle, the participants may also have thought of it as a virtual representation of their own vehicle projected ahead of them, with similar effects on their behaviour.

The possibility that participants were mimicking the lead vehicle, could mean that it provides straightforward information, as postulated by the navigational stages from [5]. It may act as a role model, which can be copied or followed. Drivers commonly follow other vehicles when within streams of dense traffic; a phenomenon known as car-following [4]. However, only one previous study has examined this behaviour in relation to aiding navigation [15]. That study found that following another vehicle for navigational guidance has been shown to lead to more erratic driving and poorer overall performance [15]. However, social pressures, time pressures and fear of getting lost were named as the main causes for such issues, and these factors should not be present in a virtual car navigation system, assuming it is well appraised before use. Equally, such erratic behaviour could not be found in the present study, except for a higher steering reversal rate with the VC. However, the steering corrections can also point at closer following behaviours, similar to situations in which drivers exert more effort to stay in the lane, e.g. at faster speeds [20, 22]. The indication behaviours, which were closer to the VC's 'behaviour', support this explanation. However, blindly copying a VC's indication behaviour could lead to problems, for example in case a driver indicates two turnings before the actual turn. This may mislead other road users. Hence, a VC system needs to be aware of the road network.

The second study found no indication of frustration or concern when using a lead vehicle as a navigation aid, whereas the first study did in some participants. This was likely due to the second study only investigating complex junctions, where the virtual car should provide valuable information for the Identify and Confirm stages (based on the findings of the first study). In contrast, the first study included a full coherent journey with long stretches where a lead vehicle could not indicate to the following vehicle that no action was required for some time. Thus, the frustration in the first study was caused by the lead car not providing any Preview or Orientation information during these periods. The second study did not cause this as there was no need for this information, and the VC appeared at a set distance before a manoeuvre.

CONCLUSIONS

Overall, the findings of this work indicate that a virtual car may be a valued element of an AR navigation system when used for complex junctions where multiple decisions are possible, since it helps indicate the exact manoeuvres required. In contrast, it may not sufficiently aid the Preview and Orientation stages, thus it would be best suited for use at intersections. Pragmatically, only implementing the feature at intersections would also help reduce instances where the VC may conflict with real-world traffic. However, for full implementation as a navigational aid other solutions to this conflict may be required.

Future work could expand on other stages of the navigational task to establish whether a virtual car would be able to provide (additional) information for the earlier stages of the navigation task. For example, how a lead vehicle could be used within areas of a journey with no need to indicate manoeuvres such as long stretches of motorway to prevent frustration or concern, as seen in the first study. Furthermore, it would be valuable to investigate whether the virtual vehicle is valued in the same manner during different manoeuvres. Additionally, exploring different styles of VC system could also be informative. It could also be further investigated why both systems resulted in good performance, and whether certain elements of one system are able to compensate for the other; eye-tracking comparisons could further illuminate how different systems are used.

ACKNOWLEDGMENTS

We thank Jaguar Land Rover Research for the generous funding, and all the volunteers in our studies.

REFERENCES

1. Victoria A. Banks, Neville A. Stanton, and Catherine Harvey. 2014. What the drivers do and do not tell you: using verbal protocol analysis to investigate driver behaviour in emergency situations. *Ergonomics* 57, 3: 332-342.
2. Adam Bolton, Gary Burnett, and David R. Large. 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 (ACM), 56-63. https://doi.org/10.1145/2799250.2799253

3. Ted M. Boren and Judith Ramey. 2000. Thinking Aloud: Reconciling Theory and Practice. *IEEE Transactions on Professional Communication* 43, 3: 261-278.

4. Mark Brackstone and Mike McDonald. 1999. Car-following: a historical review. *Transportation Research Part F: Traffic Psychology and Behaviour*, 2, 4: 181-196.

5. Gary. E. Burnett. 1998. Turn Right at the King's Head': Drivers' Requirements for Route Guidance Information. Unpublished PhD Dissertation.

6. Adrijana Car and Andrew U. Frank 1994. Modelling a hierarchy of space applied to large road networks. In *IGIS'94: Geographic Information Systems*, 15-24. http://dx.doi.org/10.1007%2F3-540-58795-0_30

7. Karl A. Ericsson and Herbert A. Simon. 1993. *Protocol analysis*. Massachusetts Institute of Technology, Cambridge, MA.

8. Mark C. Fox, Anders K. Ericsson and Ryan Best. 2011. Do procedures for verbal reporting of thinking have to be reactive? A meta-analysis and recommendations for best reporting methods. *Psychological bulletin,* 137**,** 316.

9. Paul Ford, Nicola J. Hodges, N. J. & A. Mark Williams, A. M. 2005. Online Attentional-Focus Manipulations in a Soccer-Dribbling Task: Implications for the Proceduralization of Motor Skills. *Journal of Motor Behavior,* 37**:** 386-394.

10. Joseph L. Gabbard, Gregory M. Fitch, and Hyungil Kim. 2014. Behind the Glass: Driver Challenges and Opportunities for AR Automotive Applications. In *Proceedings of the IEEE*. 102, 2: 124-136. http://dx.doi.org/10.1109%2FJPROC.2013.2294642

11. ISO 17488. 2016. *Road vehicles -- Transport information and control systems -- Detection-response task (DRT) for assessing attentional effects of cognitive load in driving*. Standard. International Organization for Standardization.

12. Joonhwan Lee, Jodi Forlizzi, and Scott E. Hudson. 2008. Iterative design of MOVE: A situationally appropriate vehicle navigation system. *International Journal of Human-Computer Studies,* 66, 3: 198-215.

13. Yung-Ching Liu, and Ming-Hui Wen.Liu. 2004. Comparison of head-up display (HUD) vs. head-down display (HDD): driving performance of commercial vehicle operators in Taiwan. *International Journal of Human-Computer Studies* 61, 5: 679-697. https://doi.org/10.1016/j.ijhcs.2004.06.002

14. Marieke H. Martens and Micah Fox. 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.

15. Jaimie McNabb, Michael Kuzel, and Rob Gray. 2017. I'll Show You the Way: Risky Driver Behavior When "Following a Friend". *Frontiers in Psychology* 8: 1-6.

16. Zeljko Medenica, Andrew L. Kun, Tim Paek, and Oskar Palinko. 2011. Augmented reality vs. street views: a driving simulator study comparing two emerging navigation aids. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services* (ACM), 265-274. http://doi.org/10.1145/2037373.2037414

17. Tracy Ross and Gary Burnett. 2001. Evaluating the human–machine interface to vehicle navigation systems as an example of ubiquitous computing. *International Journal of Human-Computer Studies,* 55, 4: 661-674.

18. Paul M. Salmon, Natassia Goode, Antje Spiertz, Miles Thomas, Eryn Grant, and Amanda Clacy. 2017. Is it really good to talk? Testing the impact of providing concurrent verbal protocols on driving performance. *Ergonomics* 60, 6: 770-779.

19. Miles Thomas, Natassia Goode, Eryn Grant, Natalie Z. Taylor, and Paul M. Salmon. 2015. Can we talk about speed? The effect of verbal protocols on driver speed and perceived workload. *Procedia Manufacturing* 3: 2629-2634. https://doi.org/10.1016/j.promfg.2015.07.608

20. John R. McLean and Errol R. Hoffmann. McLean, J.R. and E.R. Hoffmann. 1975. Steering Reversals as a Measure of Driver Performance and Steering Task Difficulty. *Human Factors* 17, 3: 248-256.

21. John A. Michon. 1985. A critical view of driver behaviour models. In *Human Behaviour and Traffic Safety,* L. Evans and R. S. Schwing (eds.) Plenum Press, New York, USA, 485-524.

22. Dario D. Salvucci and Rob Gray. 2004. A Two-Point Visual Control Model of Steering. *Perception*. 33, 10: 1233-1248.