An Investigation of Augmented Reality Presentations of Landmark-Based Navigation using a Head-Up Display

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ABSTRACT
Using landmark-based navigation can greatly improve drivers' route-finding performance. Previous research in this area has tended to focus on the inclusion of text or icon-based landmark information utilising dashboard-mounted displays. In contrast, we present landmark-based navigation information using a Head-Up Display (HUD). A major issue with using landmarks for navigation is their inherent variability in quality, with many 'poor' candidates that are not easily identifiable or communicable. A proposed solution to improve the usefulness and utility of such landmarks is to highlight/enhance them using augmented reality (AR). Twenty participants undertook four drives in a driving simulator utilising an AR navigation system presented on a HUD. Participants were provided navigational instructions presented as either conventional distance-to-turn information, on-road arrows or augmented landmark information (arrow highlighting or box enclosing landmark adjacent to the required turning). Participants demonstrated significant performance improvements while using the AR landmark 'box' presentations compared to conventional distance-to-turn information, with response times and success rates enhanced by 43.1% and 26.2%, respectively. Moreover, drivers reported a significant reduction in workload when using the AR landmark 'boxes'. We conclude that there are significant benefits to providing navigational information utilising AR presentations of landmark information on a HUD.

Author Keywords
Heads-Up Display; Augmented Reality; Landmarks; Navigation Systems.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

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INTRODUCTION
Originally deployed with aerospace, Head-Up Displays (HUD) have attracted significant interest within the automotive research community. By presenting information on a HUD, drivers are able to maintain their view of the road ahead whilst acquiring the displayed information, leading to improvements in driving performance and safety [9]. Traditionally, HUD in vehicles have been used to provide limited task-related information, such as current speed, revs, warnings, etc. More recently, researchers have investigated the potential of displaying other driving-related information on HUD, such as navigational advice/ instructions (with the aim of reducing navigational decision time and uncertainty) [3]. These studies have tended to simply re-present traditional distance-to-turn styles of information, previously intended for Head-Down Displays (HDD). Nevertheless, performance enhancements have still been realised.

For example, in a comparative study involving a secondary observation task, participants achieved 100% success rate while following navigation information presented on a HUD, compared to 80% associated with the equivalent 'head-down' display. The HUD navigation system was also deemed to be less physically and mentally demanding [12]. A similar study demonstrated that the gaze retention period (amount of time focused on the navigational cues) was significantly lower when using the HUD, suggesting that less time is 'spent' acquiring information from the HUD [2]. Both [9] and [11] reported similar preferences, in addition to improvements in driving performance, when using a HUD, with the latter study revealing that 72.2% of participants felt their driving was better when using the HUD and two thirds of participants expressed a preference towards using the HUD. However, opposite effects have been reported within other fields, such as aviation – pilots made more errors and collided with unexpected runway obstacles when using a HUD in a Boeing 727 simulator under conditions of low visibility and turbulence [7]. This was attributed to pilots directing attention towards the HUD imagery, rather than the real world situation, suggesting that pilots were not fully engaged with the outside world. This highlights the importance of ensuring that HUD information is presented in a manner that minimises distraction effects. [14] advise that priority should always be given to visual information corresponding to the primary task, and thus HUD information and iconography should not be placed such that it obscures real world information.

A related concern is that of visual clutter, whereby too much information presented on the HUD can distract drivers and cause objects in the outside world to be missed. [16] highlighted the deleterious effects of visual clutter when observing military personnel equipped with helmet-mounted displays (HMD) to detect targets hidden in terrain in the far domain. Reductions in detection times when there was no assistance from the HMD were attributed the highly detailed display causing clutter. [1] thus recommend that a maximum of three items can be displayed before deterioration in performance occurs due to 'clutter.'

The effect of workload on task performance may also influence a driver's ability to acquire visual information presented on a HUD. Complex driving situations (dense traffic, complicated road situations, high road speed etc.) naturally elevates drivers' cognitive and visual workload, compared with driving along a straight road absent of traffic. Furthermore, increases in secondary task demand will elevate overall workload, and may encourage drivers to prioritise the secondary task at the expense of driving, thereby diverting their attention in-vehicle and leading to decrements in driving performance (e.g. [15]).

Landmarks

There has been much interest regarding the use of landmarks to support route-finding. Using landmarks during the provision of directions is consistent with basic human wayfinding strategies [5] and has been shown to improve navigation and driving performance, increase driver confidence, improve engagement with the environment, promote enhanced spatial learning and reduce reliance on the navigation system, compared with conventional distance-to-turn systems [4].

The provision of additional landmark information has been shown to significantly reduce navigational decision time, but failed to deliver any additional accuracy benefits [13], although this may have been due to the use of an over-simplified driving scenario, where the ability to make errors was significantly compromised. Indeed, [10] found that using landmarks to navigate resulted in significantly fewer errors than using a conventional distance-to-turn device. Moreover, both [10] and [6] also witnessed an increase in both driver performance and confidence when using landmarks, and both studies demonstrated significantly lower frequency of glances to the in-vehicle display, thereby reducing eyes-off-road time.

A key consideration when selecting a landmark for use in a navigation system is its 'quality' and effectiveness as a navigational aid. Several formative studies have taken place in order to determine the qualities that a 'good' navigational landmark should possess (e.g. [5]). A common consensus is that 'good' navigational landmarks should be permanent (in form and labelling), easily visible, unique, have a useful location and be easily identifiable. [10] found that the quality of navigational landmarks is extremely important as 'good' landmarks resulted in a significant reduction in navigation errors when compared to landmarks deemed to be 'poor' navigational aids. Furthermore, drivers reported a higher confidence in route-finding when using 'good' landmarks. Examples of landmarks that are deemed to be 'good' navigational cues, include: traffic lights, petrol stations, public houses, churches, schools and railway stations [5]. However, there may be certain situations in which the quality of 'good' landmarks is diminished (perhaps temporarily), e.g. a church obscured by summer vegetation, several sets of traffic lights in close proximity to each other etc. [4]. A possible solution, in these situations, is to enhance or augment the required landmark.

The aforementioned 'landmark' studies, though revealing, were all conducted using 'head-down' in-vehicle displays, and to the authors' knowledge, no research has been reported comparing landmark-based navigation presented on a HUD with conventional distance-to-turn system instructions presented in the same manner. It is hypothesized that, by augmenting navigational instructions with landmark information and presenting these on a HUD, synergetic benefits (HUD versus HDD and landmark versus conventional instructions) may be realised.

A study was conducted to compare conventional distance-to-turn information with augmented reality presentations of landmark-based navigation. The study aimed to investigate if landmark-based navigation reduced navigational decision time and enhanced navigational success compared to a conventional distance-to-turn approach. Furthermore, the study considered whether using AR to enhance potentially 'poor' landmarks would increase their usability and utility as 'good' navigational landmark candidates.

METHOD

Participants

Twenty participants were recruited to take part in the study (14 males, 6 females). Ages ranged from 21 to 54 years (mean, 27.7 years). All participants held a valid UK driving license, but were not necessarily regular drivers. Mean annual mileage for the 12 months prior to the study was 4115 miles (max. 15,000 miles), with 9 participants driving daily and 11 driving occasionally. One participant used a navigation device on a weekly basis, 16 occasionally and 3 never. Eight participants had previously used a driving simulator and 6 had some experience using a HUD.

Apparatus, Design and Procedure

The experiment took place in a medium-fidelity, fixed-based driving simulator located at the University of Nottingham. The simulator comprises the front half of a 2001 right-hand drive Honda Civic car positioned within a curved screen setup. A bespoke driving scenario was created using STISIM Version 3 software, to replicate a

Figure 1. In-vehicle setup showing HUD, road scene and participant wearing ETG

suburban road scene presenting a challenging navigation environment (i.e. many turnings close to one another). The road scene was projected onto the curved screen in front of participants using an overhead projector. To ensure that the display of HUD imagery corresponded with the required turnings and remained consistent between participants, a video recording of the road scene was used. Participants were required to maintain a normal driving position within the simulator for the duration of each drive, but were not actually in control of the vehicle. Navigation cues were created using Synfig Studio animation software independently of the road scene and displayed using a Pioneer Carrozzeria Laser ND-HUD1 head-up display unit (customised to allow VGA input) affixed in place of the driver's sun visor (see Figure 1). Thus, the information presented on the HUD appeared to be superimposed on the driving scene. Playback of the driving scenario and HUD cues was synchronised by the experimenter. SensoMotoric Instruments (SMI) Eye Tracking Glasses (ETG) were used to collect binocular gaze data at 30 fps. A digital camcorder was unobtrusively located in order to record the driver's behaviour and their route selection.

Drivers completed the driving scenario using each of four presentations of navigational instructions – conventional (CV), AR arrows (AR), landmark arrows (LA) and landmark boxes (LB) (see Figure 2). The conventional (CV) presentation displayed the distance-to-turn (in metres) and turn direction (utilising a fixed arrow) on the right or left of the HUD display (depending on which direction was being indicated). During the AR condition, an augmented arrow was displayed in the centre of the road that pointed to the required turning and changed dynamically (shortened and increased in size) as the car approached the junction. Landmarks were highlighted either by using an arrow pointing at the landmark (LA) or by using boxes that enclosed the landmark (LB). Distance-to-turn information was present in all conditions. The HUD elements initially appeared 15 seconds before each junction and were synchronised with the road scene, thus updating/moving as the participant approached the designated junction (e.g. the distance-to-turn indicator counted down at increments of 10 metres, the landmark 'box' changed with perspective etc.).

Figure 2. Experimental conditions showing HUD images superimposed on road scene (top to bottom: CV, AR, LA, LB)

The landmarks selected for the LA and LB conditions were representative of 'poor' landmarks (as defined within the aforementioned literature) and as such were neither unique nor easily identifiable. These primarily comprised generic, nondescript buildings. Both landmark conditions utilised the same landmarks, ensuring consistency between conditions, but they were encountered in a different order and similar landmarks were presented at multiple junctions to prevent the participant learning which landmark would be highlighted. Throughout the simulated environment, all traffic lights remained 'green' to avoid influencing driving behaviour.

Drivers progressed along the route at a constant speed of 30 mph, encountering eight route-decision points. Each of these contained eight possible road selections presented in close proximity (4 to the right and 4 to the left). Participants were asked to use the information presented on the HUD to select the 'correct' turning. During the LA and LB conditions, participants were advised that the correct turning would always be immediately in front of the highlighted landmark. Each roadway was coloured differently (using primary colours) to aid identification.

Participants indicated their choice by initiating the appropriate signalling action (activating right or left indicator) and speaking aloud the colour of the road that they would follow based on the information provided to them. Participants were asked to signal and announce their selection as soon as they were confident that they were 'correct.' No voice information was provided as navigational cues, to ensure participants were wholly reliant on the visual representations.

Following each drive, participants completed a NASA-TLX questionnaire [8] to record the workload they associated with each presentation. After completing all four conditions, participants were asked to rank each presentation (from 1 to 4, with 1 being most preferred and 4 being least). Drivers only experienced one style of navigational cue during each drive and the order of presentation was counterbalanced between subjects. Each drive took approximately 5 minutes to complete and participants wore ETG throughout. The entire study lasted approximately 45 minutes. Participants received £10 (GBP) as compensation for their time.

Measures

The following measures were captured:

1. *Response Time*. Defined as the time between the cue being displayed on the HUD and the participant indicating their choice by activating the appropriate indicator.

2. *Success Rate*. Defined as the number of correct road selections for the entire route, expressed as a percentage.

3. *Subjective Workload*. Captured using the NASA TLX questionnaire and reported as a raw cumulative mean value determined across all subscales (mental, physical and temporal demand, performance, effort and frustration).

4. *Driver Preference*. Captured using a bespoke questionnaire completed after all conditions had been experienced and presented as a mean ranking.

5. *Eye Glance Behaviour*. Captured using SMI ETG. Coded by Area of Interest (AOI) and presented as fixation intensity (%), heat map visualisations and gaze sequence charts.

6. *General Comments*. Captured using a bespoke questionnaire at the end of the study and presented, where appropriate, within the discussion section.

RESULTS

Response Time

A repeated measures ANOVA, with Greenhouse-Geisser correction, revealed a significant difference for the mean response times between the four conditions ($F(2,44)= 35.75$, $p<.0001$). Post hoc comparisons, applying Bonferroni correction, indicated that participants' navigational decision time was significantly shorter during the LB condition (mean 5.01 seconds, at a distance of

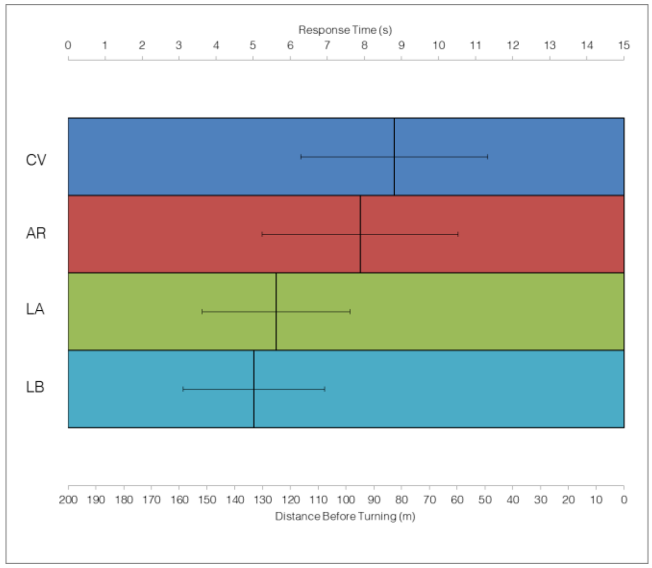

Figure 3. Mean response time and distance before turning

133.0m before the turning) compared with LA (5.62s, 122.4m; $p<.05$), AR (7.88s, 94.9m; $p<.0001$) and CV presentations (8.81s, 80.5m; $p<.0001$) (see Figure 3). The LA presentation was also significantly faster than AR ($p<.0001$). In addition, participants performed significantly slower during CV than in both AR ($p<.05$) and LA ($p<.0001$).

Success Rate

A second ANOVA, with Greenhouse-Geisser correction, revealed a significant difference between the success rates for each of the four conditions ($F(2,34)= 7.07$, $p < .005$). The Bonferroni-corrected post hoc tests showed that participants achieved a significantly higher success rate (mean 7.67 out of 8, 95.8%) while using the LB presentation compared to both CV (6.08, 76.0%; $p<.001$) and AR (7.17, 89.6%; $p<.001$). However, participants were no more successful using LB than LA (7.42, 92.7%; $p=.086$). Similarly, there were no significant differences in success rates between the two non-landmark conditions, CV and AR ($p=.114$) (see Figure 4).

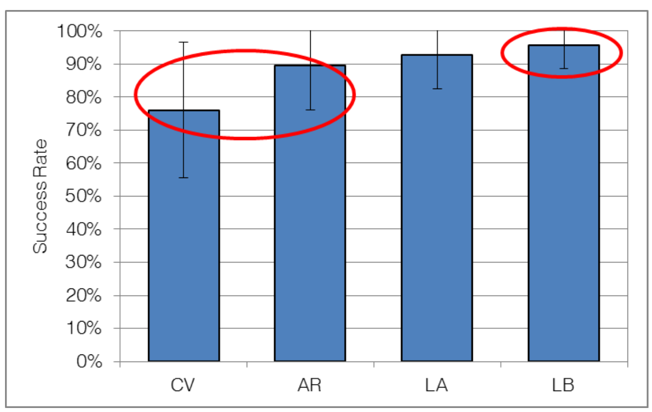

Figure 4. Success rate with standard error bars

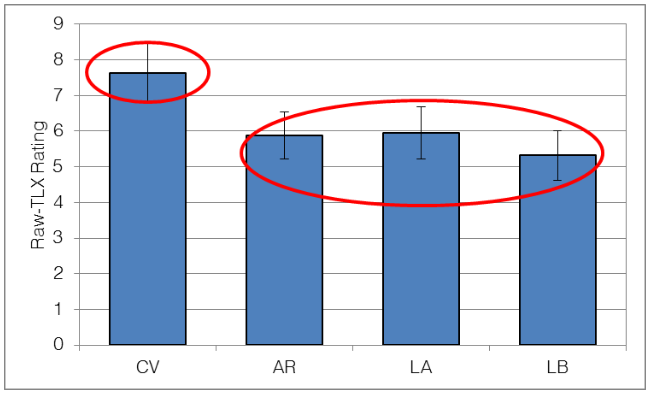

Figure 5. Mean workload ratings (raw-TLX) with standard error bars

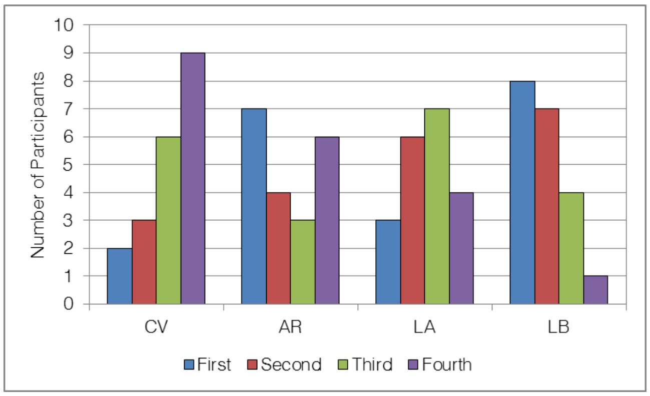

Figure 6. Drivers' preference ratings

Subjective Workload

A repeated measures ANOVA test revealed significant differences between workload ratings (raw-TLX score) ($F(3,57)=4.671$, $p=.005$), with participants rating the CV presentation as most demanding (mean score: 7.64). Ratings for AR, LA and LB were not significantly different from each other (5.88, 5.96 and 5.32, respectively) (see Figure 5). It is also noteworthy that, on average, participants felt that they performed better (revealed by the NASA-TLX 'performance' subscale ratings) during the AR presentation compared to LA, despite objective results showing the opposite effect for both response time and success rate.

	Area Of Interest (AOI)			
	Distance-to-turn	**Road**	**Arrow**	**Land-mark**
CV	14.0	26.6	NA	NA
AR	8.8	12.7	17.5	NA
LA	2.1	7.1	5.0	11.2
LB	1.2	13.8	NA	10.2

Table 1. Gaze fixation times (% of total time cues presented).

Driver Preference

A Friedman test revealed statistically significant differences between participants' preference rankings ($\chi^2(3)=8.88$, $p=.031$). The LB presentation was most preferred (mean ranking, 1.9) with CV being least preferred (ranking: 3.1). Additionally, AR tended to be more preferred than LA, with mean rankings of 2.4 and 2.6 respectively. Post hoc Wilcoxon Signed Ranks tests indicated significant differences between LB and CV ($p<.01$) and LA ($p<.05$) only. Mean preference rankings for AR were less perspicuous as this configuration divided opinion – 7 participants ranked this as their most preferred ('1'), while 6 indicated that this was their least preferred presentation ('4') – and this had opposing effects on the mean value (see Figure 6).

Eye Glance Behaviour

Eye-tracking data were analysed from the time at which the navigation cue was displayed to when the participant indicated their response. Data recorded after each response were not included during the analysis as there was no direct driving involved in the task, meaning that participants were not required to maintain attention. Eye glance fixations were coded based on different areas of interest (AOI) for each presentation. These were: distance-to-turn countdown and the side-road turning itself (for all presentations). Additionally, the following AOIs were coded (where applicable): AR arrow (for AR), landmark (for LA and LB) and landmark arrow (for LA).

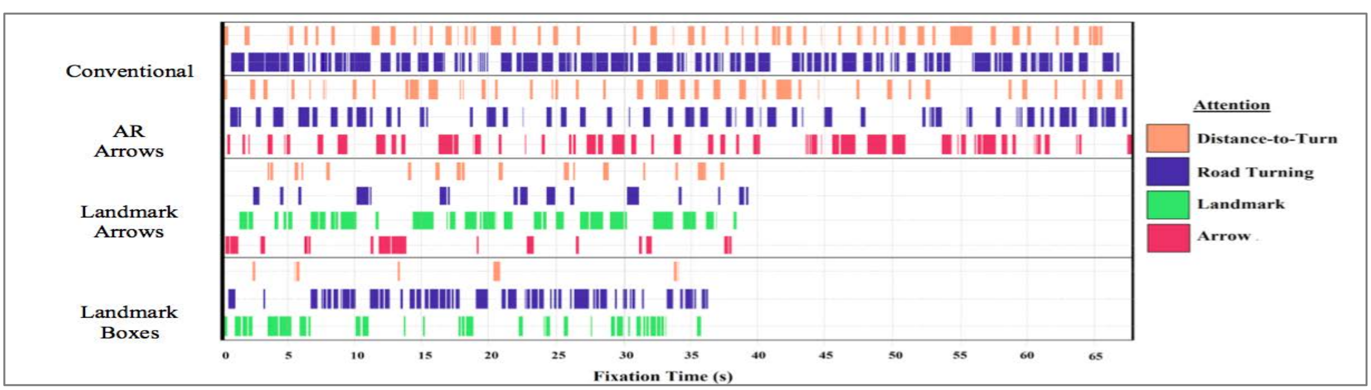

Figure 7. Sequence chart visualisation of eye glance data (participant 20).

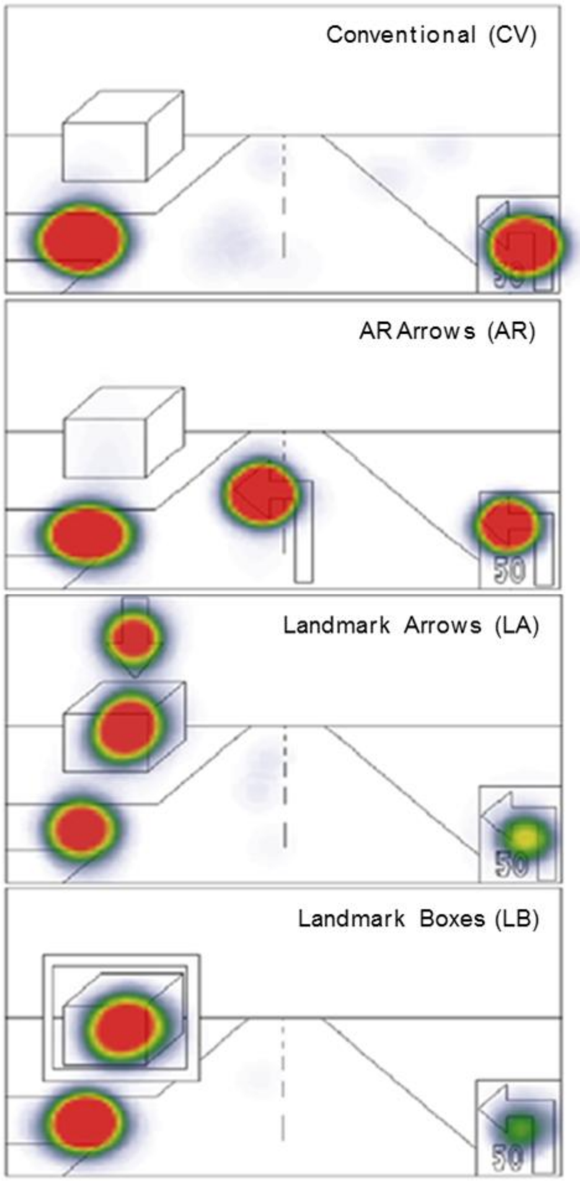

Figure 8. 'Heat map' visualisations of eye glance behaviour

Gaze fixation time, defined as the total time that participants' visual attention was directed towards elements presented on the HUD (expressed as a percentage of the total time (120 seconds) that each cue was presented), was calculated for each condition (see Table 1). The 'distance-to-turn' cue received the highest proportion of participants' visual attention during CV and AR (14.0% and 8.8% respectively), compared to 2.1% for LA and 1.2% for LB, indicating less reliance on the conventional cue during the 'landmark' presentations. These data also highlight that the total time looking at the navigational cues is significantly lower during the two landmark conditions (LA, 30.2s; LB, 30.5s) compared with the CV (48.7s) and AR (46.8s).

The sequence chart (Figure 7) shows typical visual strategies employed during each of the presentations. Heat maps were also generated to visualise the frequency that participants attended to each AOI (see Figure 8). The size and colours represent the intensity of fixations, with larger, redder areas indicating high fixation intensity and smaller, greener dots indicating fewer fixations. It is evident from the sequence charts that participant 20 viewed the distance-to-turn information frequently when using the CV and AR presentations. However, this information was attended to less during the landmark presentations. For example, during the LB condition, distance-to-turn information was sampled at the start of each navigational decision point but not used again until the next decision point. It is also noteworthy that the road itself was attended to least during the LA presentation.

DISCUSSION

The main aim of the study was to compare different formats of navigation advice presented on a HUD, with particular focus on AR enhancement of landmarks. In line with similar comparative studies conducted using HDD (e.g. [10]), landmark-based navigation resulted in significant improvements in performance, revealed by reduced decision times and enhanced success rates, compared with conventional distance-to-turn approaches. Furthermore, both landmark presentations resulted in significantly lower response times compared with the distance-to-turn and more common AR presentations, such as arrows overlaid on the road scene. The reduction in response time indicates that participants were able to distinguish which landmark was being highlighted and determine the 'correct' turning more quickly than when provided with distance-to-turn or roadway arrows (approximately 50 metres sooner).

In addition to quicker mean response times, the success rate for the landmark-based conditions was also significantly higher, on average, than the more conventional methods. It is suggested that this is due to there being less ambiguity when using landmarks, i.e. once the landmark has been identified, it is 'known' and drivers simply select the corresponding roadway. Furthermore, drivers are more likely to remain confident that their choice of turning is correct, as the landmark remains unchanged. In contrast, drivers appeared to be less able to identify which turning was highlighted by the CV and AR presentations, and therefore either delayed these decisions or selected the incorrect turning.

A major concern when using landmark-based navigation is the quality and availability of landmarks during normal driving [5]. By conducting the experiment using traditionally 'poor', nondescript landmarks, the study also demonstrated the feasibility of elevating the status of unremarkable landmarks, and promoting their utility as effective navigational cues. Furthermore, it was evident that there was no requirement to name or identify the purpose/function of the landmark in order to promote its status – physically highlighting the landmark by using an arrow or box appears to be sufficient to enhance its utility. In contrast, other landmark-based navigation paradigms require clear descriptors to allow users to identify landmarks correctly (e.g. the name of a public house). Results from the current study suggest that any building, object or feature could be utilised for navigational purposes, provided it can be highlighted on the HUD and persists in the driver's field of view, suggesting that there are significant benefits to this navigational approach. However, it is unclear from the current data whether participants were actually attending to the landmark, or were solely fixated on the box enclosing it (or a combination both). This has clear implications for the design/acceptance of such a system.

It is also noteworthy from the eye-tracking data that drivers relied less on the conventional distance-to-turn cues when following the AR landmark-based navigation approaches, compared to AR arrows. This suggests that once participants had identified the 'correct' landmark, they remained confident with their selection, and displayed no tendency to interrogate the distance-to-turn cue to confirm/re-affirm their choice. Such a strategy is highlighted in the sequence map (Figure 7). When using either the CV or AR presentations, participant 20 alternated their fixations between the physical turning and the distance-to-turn cue, suggesting constant checking/re-affirming. However, while using the LB, the participant made a brief glance to the distance-to-turn at the start of each manoeuvre but thereafter very few, if any, confirmation checks were made, suggesting much higher confidence in route selection.

It is also evident from the NASA TLX ratings that using the LB approach to highlight the required turning significantly reduced drivers' perceived workload compared to the more conventional AR approaches. This is likely to have been influenced by a number of factors. For example, drivers were not required to estimate distances when using landmark presentations, thus reducing their cognitive/visual effort. Consequently, the NASA-TLX scores for the landmark conditions were relatively low, suggesting that this style of presentation is likely to impose reduced workload, allowing drivers to maintain their attention on the primary driving task.

Participants' preference ratings revealed that the least preferred presentation was the conventional distance-to-turn information. This is likely to be due to the fact that many participants found it difficult to judge distances accurately (highlighted by higher workload ratings and comments recorded on the feedback form) and thus found it difficult to identify the correct turning, particularly given that there were several possible roads in close proximity; this is supported by the objective data.

There were mixed responses to the AR presentation with many participants scoring this either as most or least preferred. Participant 6, who ranked AR as 'least preferred', commented that, "it was difficult to concentrate on two changing arrows simultaneously". Others, who ranked this presentation more highly, stated that the (road) arrow was "quick" and "easy to read." Nevertheless, none of the participants who ranked AR as 'most preferred' performed best using this presentation, suggesting that, although the information was 'quick' and 'easy' to understand, this did not necessarily translate to enhanced performance. This may be because there was no performance feedback – participants did not know if they had selected the correct turning and may therefore believe that they had selected correctly, even if they had not. Another possible explanation is that this presentation was most comparable in design to existing navigation systems and thus participants were responding to 'familiarity' or expectations. This may also have contributed to some of the positive responses to the CV presentation.

When considering the two landmark conditions, it was evident that there was a strong preference towards using a box to identify the landmark rather than an arrow to highlight it. Participants' comments suggested that this was because it was more difficult to identify to which landmark the arrow pointed (there was also a high concentration of buildings/other landmarks in the scenario). The arrow provided limited depth perception cues making it difficult to judge distance. Distance/depth perception is notoriously difficult to determine within a simulated environment, due to the monoscopic two-dimensional projection of the three-dimensional world. In the current study, using a box to identify the landmark is effective even with poor depth perception – the box assumed and maintained the same approximate proportions as the landmark being represented and thus there was little ambiguity or confusion identifying the landmark and hence the correct turning. Indeed, there were notably very few errors and responses times were quickest using this presentation (identification was, "clear, even in the distance"). In a commercialised product with a wider field of view, one might conceive that the 'box' would assume an exact outline of the chosen landmark, thus making identification even easier.

Some participants also highlighted the desire/necessity of maintaining the conventional distance-to-turn information ("the distance was extremely useful in all conditions, especially for confirming selection") even with the more 'novel' presentations. Indeed, there was evidence from the sequence maps that, even during the landmark presentations, some participants made their selection using the landmark cue and then confirmed that this was correct by interrogating the distance-to-turn information repeatedly until the road had been reached.

There was little evidence to suggest that drivers were distracted by any of the HUD imagery during the study or that they allocated their attention inappropriately. Furthermore, there was no evidence of poorer performance due to inattention on the primary task when using the HUD, as observed by [7], although it is recognised that no baseline comparisons were made using a traditional 'heads-down' display during the study. Two participants commented that they felt distracted when using the landmark ‘box’ presentation (“focus was directed to the box instead of the turning”). However, although participants were seated in a car and were required to adopt a driving position throughout the study, they were not actually in control of the vehicle. Further work should investigate the specific implications of these displays on the driving task.

CONCLUSIONS

The study investigated different augmented reality presentations of navigational information using a HUD. Results revealed strong preferences and navigational performance benefits (in terms of speed of response and accuracy) when using AR landmark presentations, compared to other, more traditional presentations. Particular benefits were associated with using a ‘box’ to highlight a landmark located at the required intersection (with improvements of 43.1% and 26.2% for response time and success rate, respectively); this was also the most preferred presentation and attracted the lowest ratings of workload. The study also revealed that the usability and utility of landmarks, that were previously assumed to be ‘poor’ navigational candidates, could be enhanced by highlighting them using AR. Furthermore, there was no requirement to use descriptors to identify these landmarks, suggesting that any building, object or feature that persists in the driver’s (HUD) field of view could be used to support route-finding, The inclusion of additional distance-to-turn information would allow drivers to confirm their decisions, if required.

We conclude that there are significant benefits to this navigational approach. In future work, care should be taken to minimise the distraction effects of presenting additional information to drivers and to avoid information ‘clutter’. Further work should also consider the effects on driving and consider the impact of improved depth perception in a real world, rather than simulated environment.

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