Evaluating Head-Up Displays across Windshield Locations

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ABSTRACT

Full windshield displays (WSDs) have the potential to present imagery across the windshield. Current knowledge on display location has not investigated translucent displays at high eccentricities from the driver's forward view. A simulator study (n=26) was conducted aiming to, (a) investigate the effects of Head-Up Display (HUD) location across the entire windshield on driving performance, and (b) better understand how the visual demand for a complex HUD imagery differs from that for a Head-Down Display (HDD). Lane-keeping was poorer when HUD imagery was furthest from the driver (and for the HDD compared to the HUD). Equally, counts of "unacceptable" driving behaviour were greater for displays furthest from the driver's forward view. Furthermore, drivers preferred HUD imagery that was closer to them. The results indicate that HUD evaluations should account for image location, because of how driver gaze location can impact lateral driving performance.

Author Keywords

head-up display, evaluation, distraction

CSC Concepts

Human-centered computing~Displays and imagers

INTRODUCTION

Driving is a predominantly visual-manual task, such that the appropriate allocation of visual attention is fundamental to effective driving performance [5]. Thus, it is vital to assess how in-vehicle visual displays may impact the primary driving task, to ensure the display is not too visually distracting to the driver. Head-Up Displays (HUDs) present the driver with visual information on a translucent screen over the driver's forward view of the road environment. Despite known issues, they offer the opportunity to improve driver interaction with visual information over Head-Down Displays (HDDS) such as those placed on the centre console [6].

Comparisons of HUDs and HDDs have largely demonstrated HUDs to be beneficial. There is commonly a preference for HUDs over HDDs [13] and faster response times to the tasks they present [24]. Importantly, HUDs regularly result in drivers responding faster to hazardous or urgent events [11] [12]. Similarly, Liu and Wen [20] found that commercial lorry drivers rated their mental stress as lower and responded faster to urgent events when using a HUD rather than HDD. Thus, HUDs are likely to continue increasing in popularity, since they have the potential to greatly reduce the limitations of HDD displays while maintain the flexibility of visual displays [9]. The benefits of HUDs are largely attributed to the eye-movement behaviours they encourage [9]. First, as Ablaßmeier et al. [1] demonstrated, HUDs result in a lower gaze retention period across all age groups. Furthermore, being presented over the forward road environment means that HUDs have the potential to reduce the transition time between the driver taking-in information from the display and then looking back to the road. Finally, the positioning of the driver's focal attention (usually towards the forward road environment) enables drivers to better detect hazards compared to HDDs [12].

However, the potential for a full Windshield Displays (WSDs) is increasingly being investigated (e.g. [8] [3]). These displays enable HUD imagery to be presented anywhere across the full windshield of the vehicle. As a result, secondary task interfaces (which do not aid the primary task of driving) may be placed at increasing eccentricities away from the driver's forward road view.

Previous work on opaque displays, displaying secondary tasks, has clearly demonstrated screen location and eccentricity can have a marked impact on driving performance and situational awareness (e.g. [31] [27] [19]) with displays at greater eccentricities largely resulting in poorer performance. However, HUD imagery in future WSDs is likely to be positioned at different and more extreme eccentricities compared to these displays (e.g. high on the windscreen, to the left/right of the driver's natural gaze) making this previous work often not applicable to

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future display designs. Furthermore, HUD imagery varies greatly from the opaque displays used in these studies: it can be translucent and vary in luminance/contrast, which has the potential to delay reaction time [30] and thereby recognition. As a result, the findings of these studies are not readily applicable to future WSDs. This study aims to fulfil the need for this knowledge.

Recent work has begun to address some of these points. Smith [23] investigated three potential positions of a HUD in a vertical arrangement in front of the driver. The author found higher locations resulted in better longitudinal vehicle control whilst the lowest HUD position resulted in less lane position deviation. However, the locations inspected only encompassed one axis (and a total of three positions) which were not at large eccentricities from the driver's forward view. Equally, the tasks used were visual search tasks which allowed participants to glance between the task and the forward road view. Therefore, more work is needed to inspect how highly complex HUD tasks (which require long glances) impact drivers in order to appreciate a "worst-case scenario". Thus, the tasks used in this work required long continuous glances to complete successfully and the locations used span the whole windshield to large eccentricities.

Consequently, this work primarily aimed to address:

(a) How the location of HUD imagery across the windshield impacts on visual demand.

Furthermore, the research aimed to extend previous work comparing HUDs and HDDs by:

(b) Examining how the visual demand between the recommended HUD position and HDD differs when using a time-consuming, complex task.

To investigate these aims, a simulator study compared normal driving to instances where participants were required to look at HUD imagery across nine different locations of a windshield (and a HDD). The display presented a secondary task, rather than one supporting the primary task of driving. So far previous studies concerning HUD location (e.g. [29]) have aimed to identify the ideal location for short, non-visually demanding messages in relatively close proximity to the driver's forward road view. In contrast, the current work examines an extreme scenario where a complex task requires uninterrupted focal attention for a comparatively long time period (~15 seconds), in order to further explore how the visual demand of HUDs vary with location and compare to a HDDs. Equally, the study progresses the area by examining extreme, windscreen fixed locations using two laser-based HUDs. This work is required to further explore differing visual demand due to HUD imagery location, in order to better inform how HUDs should be evaluated.

METHODS

Design

The study was conducted in a medium fidelity driving simulator (Figure 1) at The University of Nottingham and a within-subject design was employed. The study involved a secondary non-augmented reality task, which was highly visually demanding. The independent variable was the location of the display imagery (see Figure 2). Each participant experienced ten experimental drives (a different display location was active during each drive). The order of display location was counterbalanced across participants. Dependent measures included driving performance (lateral and longitudinal) collected from driving simulation software (Carnet Soft) and subjective data from questionnaires on demographics and display preferences.

Figure 1. An external view of the driving simulator used for study.

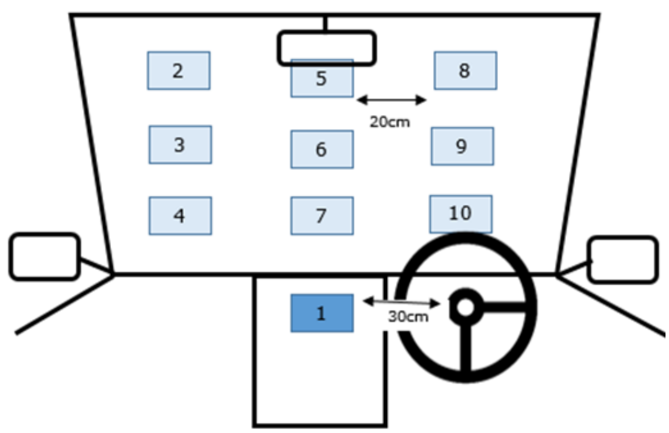

Figure 2. A representation of all the display locations.

Participants

Twenty-six drivers were recruited for the study (mean age=36.5, standard deviation=13.04 years) via a University mailing list. In total, there were 16 male participants, 9 female and 1 other. The participants had held a driving license for an average of 15.9 years and self-reported that they drove regularly. On average the participant eye-line was 14.6cm down from the car's ceiling.

Materials

The car simulator was composed of the front half of a 2001 Honda Civic (right-hand drive) and Carnet Soft simulation software was used to portray the road environment. Three projectors displayed the driving simulation software on to screens placed around the car. No rear-view, side mirrors or speedometer were incorporated for this study.

During the drives in the simulator, participants completed a secondary task using a display in one of ten positions. The task was designed to ensure continuous visual attention over an extended time period and involved 60 rapidly alternating letters in the centre of the screen. The letters appeared for a total of 0.2 seconds each. Three times per task a letter would be delayed and remain on screen for a longer time period (0.5 seconds). Drivers were prompted to the task through 3 auditory beeps. Altogether, a task lasted for a total of 15 seconds. Participants were required to speak aloud the name of any letter that remained on screen for a longer time. The letters, and the position of the delayed letters within the sequence of letters, were randomly selected.

The ten display positions were implemented using three displays (see Figures 2 & 3). Two Pioneer HUDs were attached in the position of the driver's and passenger's sun visor. A novel attachment system meant each HUD could be manoeuvred to present imagery in different locations across the windscreen. This is a novel method of simulating a WSD (see [8] for a summary of common WSD prototyping methods). The nine windscreen locations were marked with a whiteboard marker to indicate where the HUD imagery should appear to the participants.

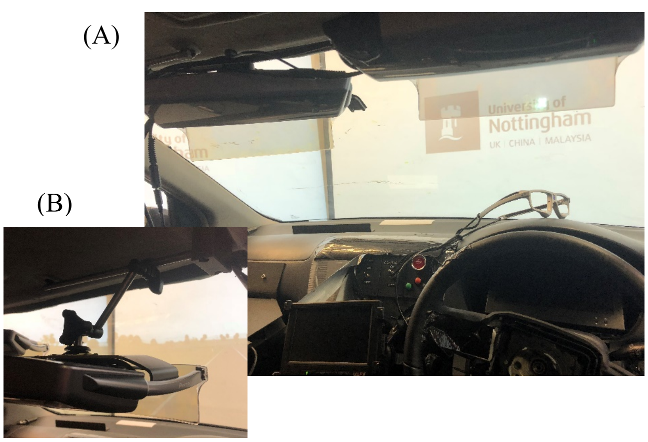

Figure 3. (A) The Two Pioneer HUDs and HDD in position within the driving simulator (B) The novel attachment system which enabled the HUDs to move freely.

Participants were instructed to move the HUD themselves until the imagery overlaid the marks. This ensured the HUD imagery was located in the same position (although slightly different eccentricities due to participant differences) for each HUD location. The other display position was in the centre console; a small LCD was temporarily attached to the vehicle interior.

Within the road environment the participant was asked to join a 2-lane dual carriage way and follow a yellow car in the inside (left lane). During the drive the yellow car would occasionally reduce speed and the participant had to slow down (or turn) in order to avoid it. The inclusion of the braking lead vehicle was based on previous work [25] which argued that, since glance behaviours are problematic for the assessment of HUD distraction, indications of situational awareness should be incorporated within HUD analysis. Therefore, during the task in the present study, participants needed to maintain situational awareness in order to detect that the lead car was braking (both during normal driving and when the display was active).

Procedure

Participants were initially asked to read through an information sheet and a consent form, complete a demographic questionnaire, and were informed they could ask questions at any point during the procedure. Once they understood and signed the consent form, the display task was demonstrated to participants and they drove a practice drive, so they were familiar with the task, the road, the car controls and the lead vehicle's behaviour.

During the study participants drove along a slip road and joined a motorway. They were asked to follow the yellow lead car throughout all drives. During each drive participants experienced: a section where nothing happened; a section where the lead car braked; a section where the task was active on a display; and finally, a section where the task was active, and the lead car braked. Thus, participants experienced the task twice during each drive. The different sections were included to compare "task" driving (when the task was active) to "normal" driving, with hazards present and not present. The order of these sections was systematically varied between drives.

During each drive, the task appeared in one of the display locations (Figure 2). The HDD remained in a fixed position for all participants, whilst the HUD was manipulated by participants themselves to the designated location from their perspective. Participants were asked to primarily pay attention to the secondary task when it was present. In between drives participants were monitored for simulation sickness using a standard questionnaire [14].

After the drives, participants ranked which display location they preferred. Finally, participants were provided with a debrief sheet. In total the full experimental procedure took approximately 1 hour.

Analysis

Analyses looked at five dependent measures – based on definitions outline in [7]: the standard deviation of lane position (SDLP), the standard deviation of the participants' velocity (SDV), the standard deviation of distance to the lead vehicle (SD lead gap), the minimum time to collision (MinTTC) and steering reversal rate (SRR). For this latter measure, a steering reversal was defined as a change from clockwise to anticlockwise rotation (or the opposite) as long as the rotational speed was greater than 3 degrees/seconds within the last 2 seconds [4] [28]. The results are presented in reversals per minute.

For the analysis "task" driving was considered to be whenever the secondary task was active while "normal" driving predefined sections when the task was not active.

The Pioneer HUD is designed be suspended from the drivers' sun visor attachment (as can be seen in Figure 3). Thus, position 8 examined in this study is the typical and recommended position for the Pioneer HUD. Therefore, the HDD (position 1) and the typical HUD position (position 8) were compared to clarify the difference between HDDs and HUDs (aim b).

RESULTS

Comparing Normal and Task Driving

We compared "normal" driving, when no task was active, to "task" driving, when participants were completing the secondary task presented on the display. Paired t-tests compared the variables listed above, between the two conditions and three comparisons showed a significant difference: SD lead gap [$t(25)=4.78$, $p<0.001$]; SDV [$t(25)=7.59$, $p<0.001$]; SRR [$t(25)=13.54$, $p<0.001$]. SDV was higher during task driving, demonstrating that participants' driving was more variable during tasks. SRR was also highest when the task was active, indicating that more lateral position corrections were made by participants during a task. SD lead gap was significantly smaller during "task" driving, indicating that participants maintained a more consistent distance to the lead vehicle when the task was active than during "normal" driving.

Dependent Measure	"Normal" Driving		"Task" Driving	
	Mean	SD	Mean	SD
MinTTC (seconds)	5.88	2.52	5.10	1.48
SD lead gap (metres)	11.98[a]	5.03	7.45[a]	2.48
SDV (metres /second)	1.62[a]	0.41	2.53[a]	0.53
SDLP (metres)	0.33	0.12	0.31	0.08
SRR (per minute)	25.79[a]	7.39	29.97[a]	8.26

[a] Significant difference between normal and task driving was found

Table 1. Comparing "Normal" and "Task" driving

Comparing HDD and Recommended HUD Positioning

The Pioneer HUD is designed be suspended from the drivers' sun visor attachment (as can be seen in Figure 3). Thus, position 8 examined here is the typical and recommended position for the Pioneer HUD. Therefore, the HDD (position 1) and typical HUD position (position 8) were compared to clarify the difference between HDDs and HUDs (aim b). This analysis found significant differences in SDLP [$t(23)=5.71$, $p<0.001$] and Min TTC [$t(20)=2.89$, $p<0.01$]. SDLP was higher for the HDD (mean =0.57m) than the HUD (mean=0.20m), whilst Min TTC was lower for the HDD (mean = 3.81s) compared to the HUD (mean=6.73s). In total, this indicates that both lateral and longitudinal driving performance was improved with the use of a HUD.

Comparing Display Positions

A further ANOVA analysis compared all 10 display positions. Only SDLP [$F(3.37, 74.21)=10.589$, $p<0.001$] and SRR [$F(5.75, 126.45)=2.4$, $p<0.04$] were significant. For both analyses' sphericity was violated so a Greenhouse-Geisser correction was used. A Bonferroni correction was used for post-hoc analysis to further inspect the results. For SRR the difference between positions 7 and 1 was approaching significance ($p=0.055$), and no other significant differences were found. For SDLP the post-hoc analysis revealed a significant difference between the following display positions 1:6, 1:7, 1:8, 1:9, 1:10, 2:6, 2:7,

Display Location	SRR (per minute)		SDLP (meters)		MinTTC (seconds)		SD lead gap (m)		SDV (m/s)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	28.30[b]	8.63	0.58[a]	0.36	3.57	2.87	6.66	3.02	2.50	1.00
2	29.73	8.66	0.36[a]	0.11	4.56	2.55	8.13	5.56	2.31	1.13
3	30.65	8.47	0.36[a]	0.22	3.34	1.45	8.41	4.84	2.89	1.43
4	29.72	9.95	0.31[a]	0.12	3.85	2.02	7.82	7.31	2.45	0.76
5	31.00	10.98	0.35	0.26	4.45	3.58	7.58	3.07	3.01	1.46
6	31.20	10.46	0.26[a]	0.09	5.74	3.72	5.56	4.09	2.45	0.78
7	33.64[b]	10.29	0.25[a]	0.09	4.49	2.46	5.87	3.08	2.43	0.70
8	30.45	8.96	0.20[a]	0.07	6.75	3.41	5.23	3.00	2.43	0.62
9	29.41	10.23	0.21[a]	0.07	5.25	2.75	6.36	5.20	2.47	0.75
10	27.49	8.58	0.26[a]	0.11	5.56	3.41	6.35	3.03	2.58	0.89

[a] Significant differences between display positions
[b] Approaching significance ($p=0.055$)

Table 2. Comparing all display positions.

2:8, 2:9, 2:10, 3:8, 4:8 and 8:10. The full results of this analysis are in Table 2. In order to more clearly visualise the findings they were graphed, as in Figure 4. The position of the graphics in the figure a representative of the display locations (see Figure 2).

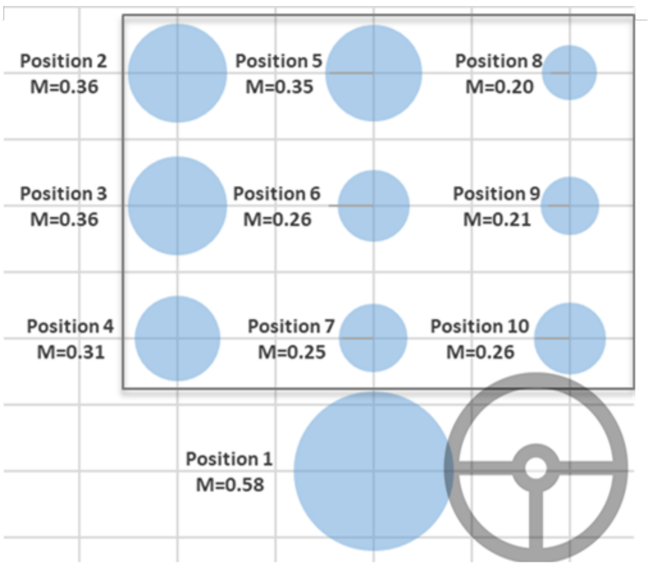

Figure 4. The mean SDLP across all display conditions. The width of the circle represents the mean SDLP.

Count Analysis

A further analysis was conducted for each display location, inspecting whether a participant's driving became "unacceptable". For this analysis "unacceptable driving" was considered to have occurred if any of the following safety-critical conditions were met, such that if the participant:

- crashed
- left their lane. This was registered when the centre of the front bumper exceeded the lane (the lane was 3.5m wide)
- moved within 2 meters of the lead vehicle (at which point the lead vehicle would accelerate to attempt to prevent a collision)
- time to collision was lower than 2.5 seconds. This timing was selected as it is accepted by drivers within collision warning systems [2] so should be considered perceptively dangerous.

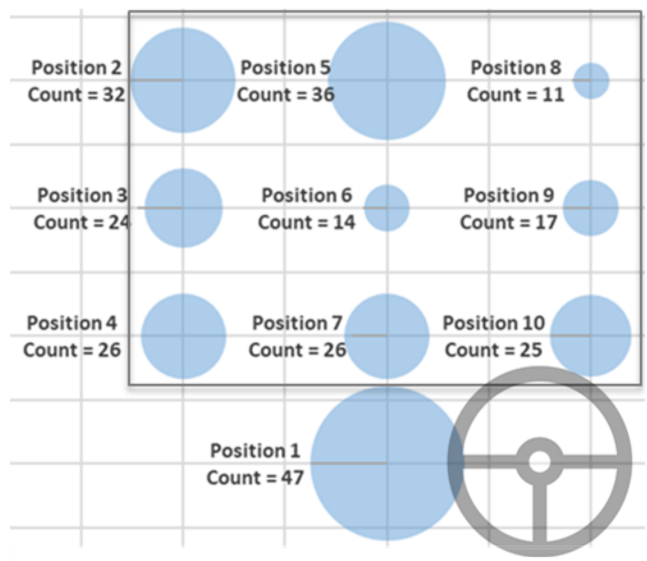

Figure 5. The number of tasks where "unacceptable" driving occurred for each display position. The width of the circle represents the count of tasks where "unacceptable" driving occurred.

Each individual task was inspected and it was noted whether or not the "unacceptable" criteria was met at any point. The number and percentage of tasks where unacceptable driving occurred are detailed in Table 3 and Figure 5.

The data where unacceptable driving occurred was also further evaluated to find the percentage of the task window when "unacceptable" driving was occurring. Crash data was excluded as it was considered to be binary. This review is presented in Table 4.

	"Unacceptable" Driving Criteria Count								
Display Location	Crash	%	Out of Lane	%	Distance to Lead Vehicle	%	Time to Collison	%	TOTAL COUNT
1	2	3.85	17	32.69	11	21.15	17	32.69	47
2	1	1.92	6	11.54	9	17.31	16	30.77	32
3	2	3.85	3	5.77	3	5.77	16	30.77	24
4	1	1.92	3	5.77	7	13.46	15	28.85	26
5	3	5.77	3	5.77	13	25	17	32.69	36
6	0	0	0	0	3	5.77	11	21.15	14
7	0	0	0	0	8	15.38	18	34.62	26
8	0	0	0	0	3	5.77	8	15.38	11
9	1	1.92	0	0	6	11.54	10	19.23	17
10		0	0	0	8	15.38	17	32.69	25
TOTAL COUNT	10		32		71		145		258

Table 3. The number and percentage of tasks where "unacceptable" driving occurred.

A Friedman test inspected the differences in percentage between the different measures of "unacceptable" driving, which was significant [χ^2 (2) =24.58, p<0.001]. A Bonferronni correction was used and Wilcoxon tests were conducted as a post hoc to compare the different measures. There was no significant difference found between TTC and Out of Lane. However, there was a significant difference between Out of Lane and Lead Gap (Z=4.31, p<0.001) and Lead Gap and TTC (Z=4.34, p<0.001). Therefore, out of lane occurrences took up a significantly larger proportion of the task than lead gap occurrences, when they occurred. Equally, TTC occurrences took up a significantly larger proportion of the task than Lead Gap occurrences, when they occurred. See Table 4.

Display Location	Average % Out of Lane	Average % Lead Gap	Average % of Time to Collison	Average % for each Display Position
1	20.69	6.08	12.39	14.00
2	14.90	3.38	12.40	10.33
3	25.83	3.75	11.13	12.13
4	16.11	3.88	8.45	8.25
5	19.65	8.30	12.76	11.78
6	0	8.83	10.96	10.50
7	0	4.14	10.14	8.29
8	0	7.95	12.50	11.26
9	0	6.40	11.79	9.77
10	0	14.65	11.67	12.62
Overall Average	19.44[a]	6.74[ab]	11.42[b]	

[a/b] Significant differences were found between measures

Table 4. The average percentage of each task window when "unacceptable" driving was occurring.

A further Friedman test was conducted on this data (the percentage of the task where unacceptable driving was occurring) to compare display positions, which found no significant differences between the displays [χ^2 (9) =6.43, p>0.6]). Thus, when "unacceptable" driving occurred, the length (percentage of the task) was not different between display positions.

Preference Analysis

Finally, an analysis was conducted on participant preferences for the 10 display conditions. The participants were asked to rank all 10 of the displays; low scores indicated the highest preference. As the data was non-parametric (ordinal), a Friedman test was conducted to analyse the results. A significant difference was found [$\chi2$ (9) =138.41, p<0.001]. See Table 5. A Bonferroni correction was used for a post-hoc analysis (using Wilcoxon tests). Positions 1, 8 and 4 were compared in order to evaluate the HDD, the recommended HUD location (position 8) and the HUD location furthest from the recommended HUD location (position 4). No difference was found between position 1 and 4. However, there was a significant difference between position 8 and 1 (Z=4.36, p<0.001), meaning participants significantly preferred the HUD over the HDD. Equally, a significant difference was found between positions 4 and 8 (Z=4.40, p<0.001) meaning participants significantly preferred the HUD display closer to their forward view compared to the one in the far corner of the windshield.

[a] Multiple modes exist. The smallest value is shown

Display Position	Mean	Median	Mode	Minimum	Maximum
1	8.38	10[c]	10	3	10
2	7.62	8	7[a]	3	10
3	7.04	7	7[a]	2	9
4	8.50	9[b]	9	7	10
5	3.69	3.5	2[a]	1	6
6	3.27	3.5	4	1	7
7	5.44	6	6	2	9
8	2.60	2[bc]	1	1	6
9	2.50	2	1	1	6
10	5.60	5	5	2	10

[b/c] Significant differences were found

Table 5. Participant preference for each display location. (1=most preferred; 10=least preferred)

A visual representation of these results (Figure 6) demonstrates that in general, participants tended to prefer display positions which were close to their natural viewing of the road centre (lower ranking indicates greater preference).

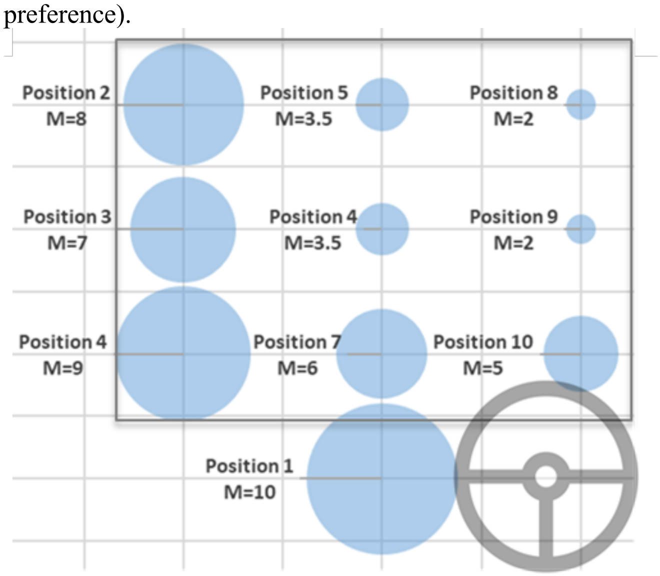

Figure 6. The median of participant preference for each display location. The width represents the median preference (1=most preferred; 10=least preferred).

DISCUSSION

Normal and Task Driving Compared

As anticipated, driving while a secondary task was active generally resulted in poorer driving performance than when participants were not interrupted. The standard deviation of participant velocity (SDV) was significantly greater when tasks were active, meaning that participants varied their speed more when completing a task. Steering Reversal Rate (SRR) was also significantly greater during tasks. Thus, participants performed more steering corrections during the task. This indicates that the tasks caused an increased cognitive workload, as SRR is suggestive of real-time cognitive workload [26].

Standard deviation of distance to the lead vehicle (SD lead gap) was significantly greater during normal driving, indicating that participants' distance to lead vehicle varied more when they were driving without interruption from a task. Variance in longitudinal performance, as found here, could be due to increased workload [10]. However, it is more likely the result of participant following behaviour. During a task, participants were commonly observed braking heavily. As a result, during "normal" driving segments some participants were required to accelerate to the lead vehicle to try and keep a consistent distance to it. The variance in SD lead gap is likely the result of this behaviour.

HUD and HDD Compared

Position 8 and position 1 were compared since position 1 was in a typical HDD position on the centre console, and the Pioneer HUD is designed to be suspended from the drivers' sun visor attachment in position 8. Thus, a typical HUD and HDD were compared. The results found significant differences in lane-keeping (SDLP), with the HUD being lower, and Minimum Time to Collision (Min TTC), with the HDD being lower. Thus, both longitudinal and lateral driving performance was better when the task was displayed on the HUD. This is similar to previous result comparing HDDs and HUDs [24] and demonstrates that extremely visually demanding tasks, such as those used here, do not alter the typical finding that HUDs generally result in better driving performance when compared to HDDs.

Comparing all Display Positions

Analysis of the display positions also showed significant differences in SDLP between several display positions. It is apparent (Figure 4) that the displays furthest away from the driver's forward road view resulted in greater SDLP, which indicates that participants could not maintain a consistent lateral position whilst also completing a secondary task located visually at a high eccentricity. As indicated by prior research, this may be the result of the "eyes-on-road" benefit of HUDs [15], if the driver's visual focus is located closer to the forward road environment, driving performance can be maintained. Kountouriotis et al. [18] found support for this perspective when investigating how visual tasks could lead to greater SDLP. The authors argued that, rather than increased processing resources, the results were due to gaze direction. Thus, in the present study: participants looking at a proximate HUD position were easily able to monitor their lane position and make accurate steering corrections, due to the display's proximity to the driver's view of the road. In contrast participants looking at a HUD on the opposite end of the windshield (or the HDD) were unable to easily view the road, making lane position corrections more difficult.

Previous work using opaque LCDs [31] has found similar results, whereby lateral driving performance degrades with displays at large eccentricities, indicating that for extreme positions the unusual attributes of HUD graphics (e.g. transparency, lower luminance etc.) may be irrelevant. Further research would be needed to clarify whether this is the case.

The count analysis monitored how many tasks resulted in "unacceptable" driving. Similar to the SDLP results, the findings (Figure 5) neatly demonstrate that displays located at extreme eccentricities to the driver's forward view were more likely to result in "unacceptable" driving. This was particularly true for the HUDs at the top of the windscreen (far from the driver) and the HDD. Correspondingly, it is also worth considering the lack of "unacceptable" driving occurring when the displays were located close to the driver's view of the road. The task was designed to require uninterrupted visual attention with over six times the recommended eye-off-road time proposed by NHTSA [21] [22], yet "unacceptable" driving was rare when the task was positioned close to the drivers' typical view. For example, there were only two tasks where "unacceptable" driving occurred with the HUD image located in position 8. Thus, the position of the task greatly impacts how long a driver can attend to it before driving performance becomes "unacceptable". Overall, these results also demonstrated that HUD imagery eccentricity has a more marked impact on lateral, rather than longitudinal driving performance. This may be the result of the lead car looming [16], enabling drivers to detect and predict their longitudinal performance regardless of being forced to look at extreme display positions.

Finally, participant preferences for display location largely reflect the objective driving performance results: Displays which were close to the forward view of the road environment were rated more highly than those at extreme eccentricities. These preferences imply that participants will be more willing to use and accept this technology when positioned in close proximity to their forward view of the road – at least for tasks that are clearly secondary to driving-related activities.

In total, the results indicate that the same secondary task (in cognitive load and duration) can lead to significant differences in lateral driving performance when presented through varying displays (HDD vs HUD) or in alternative locations across a windshield (HUD graphic location). Poor lateral driving performance is highly meaningful, as there is a risk of collision with other vehicles or roadside obstacles. These findings have implications for methodology when evaluating vehicle displays for distraction potential – particularly when deciding whether a task accessible through certain displays/controls is acceptable/unacceptable (acceptability criteria). For example, it may be argued that the task which was used in the present study was often acceptable when located close to the driver's view of the road (e.g. location 8) since it did not result in any crashes or out-of-lane occurrences, yet would be unacceptable when positioned further from the driver, where the same task resulted in several crashes and out-of-lane occurrences. Thus, the danger associated with "eyes-off-road" time may be too simplified. It is important to know when evaluating distraction, not only that a driver's eyes are off the road, but rather where they are attending to. A driver may be able to look to a HUD for an extended time period without poor driving performance occurring, since their gaze is directed towards the road environment.

Limitations and Future Work

While the work here has revealed the varying demand of different HUD graphic locations, it is limited. The work only addresses HUDs displaying secondary tasks, rather than HUDs that are able to augment or aid the primary task of driving. Methods are being developed in order to evaluate such displays [17], although it should be noted that work will be required to examine graphics at large eccentricities, similarly to the work conducted here. Furthermore, this research aimed to examine the "worst case scenario". Consequently, the task which was examined was extremely visually demanding, requiring almost constant visual attention to complete successfully. Equally, the lead car the participant followed, regularly and unpredictably braked in order to investigate the participants' situational awareness regarding hazards. Naturally, both of these events are unusual during typical driving, thereby threatening the ecological validity of these results. Further work will need to be conducted to examine more common place driving, and examine how more monotonous driving may impact the results. The study was also conducted in a simulator with a right-hand steering wheel. Therefore, it is unclear whether the results would be replicated in a left-hand vehicle, however, there is nothing to suggest that the results wouldn't be the same but mirrored. Finally, a broader range of participants would be beneficial for result generalisation.

CONCLUSIONS

In conclusion, this study has demonstrated that the location of HUD imagery across a windshield can have a significant impact on lateral driving performance. Equally, our results emphasise that HUDs should not be solely evaluated according to whether a driver's eyes are off the road, but also incorporate where the driver is looking (graphics location), as they may be able to maintain driving performance whilst also attending to a task, if their gaze is still directed enough towards the road environment. In summary, specific guidelines for evaluating HUDs and WSDs are required and location should be incorporated into new evaluation criteria.

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