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An examination of the effect of Google Glass on simulated lane keeping performance

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Abstract

Head or helmet mounted displays, such as Google Glass, have the ability to deliver many features of a smartphone in a hands-free, wearable unit. Their use in various contexts including driving has, however, raised concerns about the possibility of distraction. This study aimed to examine whether, and to what extent, simulated lane keeping performance is affected by reading messages on Google Glass. Reading text messages requires a high level of visual resources and can interfere with driving. However, it is currently unclear if the impact of reading text messages on a head-mounted display such as Glass will differ to that found with mobile phones given that drivers do not have to shift their gaze as far or make head movements away from the roadway to read messages on the Glass. A total of 20 drivers (22-48 yrs) completed the Lane Change Test while not performing any secondary task and while reading text messages on Glass or a smartphone. Measures of lateral vehicle control were examined along with subjective workload. Results revealed that drivers’ lane keeping ability was significantly impaired by reading text messages on both the Glass and the mobile phone. In terms of subjective workload, drivers rated reading on the Glass as subjectively easier than on the mobile phone, primarily because they did not have to shift their gaze as far to read on the Glass. Overall, the study results suggest that, despite the Glass allowing drivers to maintain their visual focus on the forward scene, drivers are unable to effectively divide their attention across the Glass display and the road environment, resulting in impaired lane keeping performance.

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1. Introduction

Head or helmet mounted displays (HMD) have been in use for decades in military and aviation domains. With the introduction of Google Glass, HMDs are now being marketed to the general population. A HMD is a display that is incorporated into a helmet or other wearable head unit and used to project images onto the visual field of the user [1]. This configuration allows users to see information on the display while also being able to view the environment. The Google Glass works on a similar premise; it delivers a small, monocular (single) display mounted on a frame that can be worn like a standard pair of glasses. While Glass has the ability to deliver many of the features of a smartphone in a small, hands-free, wearable unit, its use in various contexts, such as driving, cycling and walking, has raised safety concerns about possible user distraction.

In the military and aviation domains, a wealth of research exists on the usability of HMD and how they impact users’ visual behavior and cognitive load. Information provided on a HMD is always projected in, or in close proximity to, the users’ line of sight, meaning that the ability of the user to look away from or ignore the information presented on the display is limited. This can lead to a range of undesirable visual/perceptual and cognitive effects.

With respect to perceptual issues, overlaying information onto the user’s view of the world can obscure objects in the environment, leading users to miss hazards or events or detect them too late to react to them effectively [1,2]. The information provided on HMDs may also disrupt users’ visual scanning behavior, with research showing that the size and range of users’ eye and head movements are restricted by the use of head-up symbology [1].

An advantage of HMDs is that users reduce the amount of time spent looking down to scan information displays or instrument panels. This can potentially reduce a phenomenon termed ‘change blindness’, whereby humans miss changes that occur in the outside world while their visual and/or cognitive attention is focused away from the visual scene. By having information overlaid on the forward scene, the use of HMDs is designed to allow users to quickly shift between monitoring the outside world and viewing the displayed information [3]. Indeed, the use of head-up displays has been associated with increased speed of detecting expected, but not unexpected, events in the outside world compared to head-down displays [4].

A potential drawback of HMDs from an attention point of view is that the information displayed may capture users’ attention and they may consequently miss elements of the outside scene. This phenomenon is termed ‘attentional capture’ [1,2]. Even if users are capable of ‘seeing’ both the information on the display and the outside world, humans are not capable of attending to both sets of information at the same time. Thus, if the user is paying attention to the HMD, they are unlikely to perceive an event occurring in the outside world, possibly even if their gaze is fixated on it (inattentional blindness). This is one reason why HMDs may cause delays in operators reacting to unexpected events [4].

It is important to note that the perceptual and attention issues observed with the use of HMDs have been found even when the information presented is task-relevant (e.g. flight coordinates for pilots). It is unclear if the presentation of non-relevant information, as occurs with devices such as Google Glass, may exacerbate the visual and cognitive issues observed with HMDs.

Reading text will be a key component of using Glass. Text messaging on electronic devices requires a high level of resources, many of which are shared with driving (i.e., visual and manual). Indeed, research has found that text messaging on a mobile phone negatively impacts a range of driving behaviors, particularly lane keeping [5-8]. However, it is unclear if the impact of reading text messages on a head-mounted display such as Glass will differ to that found with mobile phones given that the information displayed is closer to the driver’s line of sight.

A small number of research studies have examined the impact of Glass on driving performance [9-11]. Sawyer et al., for example, compared voice-activated text messaging on Glass and a smartphone-based messaging interface. They found that, while the Glass moderated some aspects of driving detriment (e.g., better lane keeping when replying and a faster return to normal speed compared to when using a smartphone), for many driving measures texting on either device impaired performance compared to normal baseline driving.

All of the previously published Glass driving research has almost exclusively used voice activation [e.g., 9-11]. However, manual interaction with Glass via the touchpad is also possible and it is important to examine how manual interaction with Glass impacts driving performance.
1.1. The current study

This study examined the performance and safety implications of driving while using Google Glass. Drivers were required to read a text message aloud on the Glass and also, during a separate drive, on a smartphone, while driving the Lane Change Test (LCT) [12]. Manual touch gestures were used to control the Glass. The current study also examined if familiarity with Glass moderates the impact of the device on driving performance. Previous research has found that users quickly become familiar with Glass, with performance plateauing after only 5 minutes [13]. Approximately half of the participants in the current study had 1.5 hours prior experience with the Glass.

We predicted that, compared to driving without a secondary task, driving while accessing and reading text messages on the Glass and smartphone would be associated with degraded lane keeping performance. In addition, based on previous Glass research, we anticipated that drivers would rate text messaging on the Glass as less demanding in terms of workload than the smartphone.

2. Method

2.1. Participants

Twenty licensed drivers (16 male; 4 female) aged 22-47 years (M = 32.3, SD = 6.3) participated in the study. Table 1 provides demographic details of the sample. All participants were required to have a valid Australian (or equivalent) driver license and have normal or corrected-to-normal visual acuity. All participants reported regularly text messaging and a large proportion read and write text messages while driving, despite being illegal in Australia. Participants were recruited through advertisements at Monash University. Approval for the study was granted by the Monash University Human Research Ethics Committee. Participants received $30 for their time and expenses.

Table 1. Simulator study participant demographics. Standard deviation in parentheses.

<table>
<thead>
<tr>
<th>Mean age (years)</th>
<th>32.2 (6.3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean driving experience (years)</td>
<td>12.3 (6.4)</td>
</tr>
<tr>
<td>Mean hours driving per week</td>
<td>7.3 (5.8)</td>
</tr>
<tr>
<td>Mean hours using phone each week</td>
<td>3.2 (3.6)</td>
</tr>
<tr>
<td>% who read texts while driving</td>
<td>75.0%</td>
</tr>
<tr>
<td>% who send texts while driving</td>
<td>40.0%</td>
</tr>
</tbody>
</table>

2.2. Apparatus

2.2.1. Lane Change Test

Driving performance was measured using the Lane Change Test (LCT; ISO 26022:2010). The LCT is a simple driving simulation designed to measure the level of driving performance degradation induced by performing a concurrent secondary task [12]. It comprises a 3000 meter straight, three-lane road with no other traffic present. Drivers are instructed which lane to drive in by signs that appear on each side of the road every 150 meters, on average (range: 140 to 188 meters). There are 18 pairs of signs presented in total. The six possible lane change configurations that can be made by drivers (e.g. from the middle to left lane) are counterbalanced across trials to limit learning effects. Speed is limited to 60 km/h, which participants are asked to maintain throughout the drive. The LCT driving scene is displayed in Figure 1a.

The LCT was run on a driving simulator that comprises three 46” LED LCD screens (see Figure 1b). The visual scene was presented on the center screen only. Control of the simulation was achieved through a Logitech G27 force feedback steering wheel with accelerator and brake foot pedals. The simulator was programmed so that drivers were able to maintain the required speed of 60km/h by pressing the accelerator pedal to maximum.
2.2.2. Text message task

Participants used Google Glass (software version XE 22) and a Motorola Moto G to read pre-loaded text messages. Four text messages were loaded on each device. Participants read one text message on each device while not driving (static) and one message on each device while completing a run of the LCT. The order of messages and text conditions was counterbalanced across participants to reduce order effects. Each message was exactly 300 words and was taken from the Victorian ‘Road to Solo Driving Part 4 rules and Responsibilities’ handbook to ensure that length, content and style of writing were comparable across messages. Participants were instructed to read the text messages aloud and at their own pace. During the drives, participants read as much of the text message as they could during the 3 minute drive. In the few cases that the text message was completed before the end of the drive, participants were instructed to scroll back and re-read the message. This ensured that participants were interacting with the devices continuously for the entire drive. For each message, the number of words read and errors made were recorded and compared across devices and the static and driving conditions.

The Glass was worn high on the bridge of participants’ nose and the display arm adjusted for each participant so that the imagery was clearly positioned just above their normal line of sight. Participants were instructed to access the pre-loaded messages using manual gestures on the touchpad located on the right arm of the Glass. The involved ‘tap’ gestures to unlock the device and open the relevant message card in the timeline. Each text message was split across 8 screens (on average), requiring a forward or backward horizontal stroke on the touchpad to scroll back and forth through the message. On task completion, participants exited the message using a series of downward strokes on the touchpad.

The phone was located to the left of the steering wheel at approximately the same height as the top of a car dashboard. Messages were accessed by tapping and swiping the screen to unlock the phone, tapping the ‘Hangouts’ icon and using finger swipes to scroll through messages. Tapping the ‘back’ button was used to exit messages.

2.2.3. Subjective workload

The NASA – Raw Task Load Index (NASA-RTLX) [14] was used to measure subjective workload. This multi-dimensional rating scale provides an indication of the workload associated with performing the LCT under single-task (driving only) and dual-task (driving plus texting) conditions. Participants were asked to rate the tasks using a numerical score (from 0 to 20) on six workload dimensions (mental, physical, and time demand, performance, effort, and frustration level) as well as an overall workload score.

2.3. Procedure

After a brief explanation of the study, participants signed the consent form and then completed a demographic questionnaire. Participants were then shown the Glass and mobile phone, instructed how to access the text messages on each and then had a short (2 min) practice with each device. Next, participants read one text message on each
device without driving. The LCT was verbally explained to participants who then completed 1-2 practice drives until they could change lanes according to the ISO instructions. Once participants were comfortable with the LCT, they completed four trial runs: baseline (driving only), Glass (no texting), texting with Glass and texting with smartphone. The order of the four trial runs was counter-balanced across participants to accommodate practice effects. For the texting runs, participants opened the text message at the start of the drive and read each aloud at their own pace. Participants read the message in its entirety or until they reached the end of the drive. A Dictaphone was used to record participants reading the texts and the transcripts were later used to determine the errors made on the texting tasks across the static (texting only) and dual-task (texting and driving) conditions. On completion of each LCT drive, participants completed the NASA-RTLX workload questionnaire. In the dual task conditions, participants were instructed to give priority to the driving task but to not ignore the text message task.

2.4. Data analysis

Prior to all analyses, the data were checked for violations of statistical assumptions, missing data points and outliers, which were excluded from the analysis. In all cases, a two-tailed α-level of .05 was used to determine statistical significance. The LCT measures included mean deviation and lane excursions:

**Mean deviation:** Mean lateral deviation scores were compared to the LCT normative model that is automatically calculated by the LCT analysis software. The normative model represents an ideal lane change path. Deviation scores were calculated for each run over the entire length of the drive.

**Lane excursions:** The number of lane excursions made during each run was calculated by examining the lateral position trace schematics produced by the LCT. A lane excursion was defined as any instance where the participants’ LCT deviation trace moved outside of the correct lane of travel.

The mean deviation and subjective workload measures were analysed using repeated-measures ANOVA with four conditions: baseline, Glass (no texting), Glass with texting and phone with texting. A Generalized Estimating Equations (GEE) model was fitted to examine the number of lane excursions. The GEE model was specified with a Poisson error function and a log link function which is appropriate for count data, which are non-negative integers that were not normally distributed. The inter-correlation between the repeated measures was specified as unstructured. All analyses were carried out using IBM SPSS Statistics 22. The LCT data for one participant was excluded from analysis due to failure to perform the driving task to a required standard during a number of the test trials. Thus, all analyses involved 19 participants.

3. Results

3.1. Impact of Glass familiarity

To examine if familiarity with the Glass moderates the impact of the device on driving performance, a portion of the current sample were given prior Glass experience. Eight of the twenty simulator participants took part in a usability testing study a week prior where they had approximately 1.5 hours experience with the Glass. The remaining participants had no previous experience using Glass. Participants who had previous experience with Glass were compared, using independent sample t-tests, to those who had no prior experience on the LCT measures to examine if practice has an impact on task sharing efficiency and driving performance. Participant age, driving experience, kms travelled each week and mobile phone use did not vary significantly across participants who had prior Glass experience and those who did not (all p > .05).

No significant differences were found across the two groups on any of the LCT metrics (all p > .05), suggesting that a limited amount of prior experience with the Glass device (~1.5 hours) does not impact the ability to task share the Glass tasks with driving. Given the lack of significant differences, all further analyses were conducted with the data for the two familiarity groups combined.
3.2. Mean deviation

The mean deviation scores for the entire drive and the straight line segments are presented in Figure 2. The mean deviation across the entire drive differed significantly across the task conditions ($F (3,54) = 14.92$, $p < .001$). Pairwise comparisons revealed that mean deviation was lower in the baseline and Glass (no text) conditions than in the two text messaging conditions (all $p < .05$). Mean deviation did not differ significantly across the two baseline conditions, or across the Glass and phone text messaging conditions (all $p > .05$).

Significant differences in straight line mean deviation (between signs) were also found across conditions ($F (3,54) = 12.88$, $p < .001$). Again, straight line mean deviation was lower in the baseline and Glass (no text) conditions than in the Glass and phone text conditions (all $p < .01$). Straight line mean deviation did not differ significantly across the two baseline conditions, or the Glass and phone text messaging conditions (all $p > .05$).

3.3. Lane excursions

The mean number of lane excursions in each condition is displayed in Figure 3. Due to issues with Hessian matrix singularity, the baseline condition (where no lane excursions were made) was dropped from the GEE model and the condition where participants wore Glass, but did not text, served as a baseline. Significant differences in the number of lane excursions were found across conditions ($Wald \chi^2 (2) = 20.07$, $p < .001$). The rate of lane excursions when reading text messages on Glass was 19 times the rate for the Glass (no text) condition (Incidence rate ratio (IRR)=19.00, $p<.001$), while the lane excursion incidence rate when reading on the phone was 12 times that for the baseline (IRR=12.00, $p<.005$). The number of lane excursions did not differ significantly across the two devices.
3.4. Subjective workload

As displayed in Figure 5, significant differences in overall subjective workload scores (NASA-RTLX) were found across conditions (F (4,29) = 34.63, p < 0.001). Post-hoc comparisons revealed that overall workload was significantly higher in the Glass and phone text message conditions than in the baseline and Glass (no text) conditions (all p < .001). Subjective workload was also significantly higher in the phone text condition compared to the Glass text condition (p > 0.035).

4. Discussion

This study examined whether, and to what extent, driving is affected by reading text on Google Glass and compared this to reading text on a smartphone. Overall, results indicate that Glass negatively impacts lane keeping performance and offers few benefits over the head-down display of a smartphone. Further, a small amount of prior experience with Glass (1.5 hours) did not negate the observed effects of the device on driving.

As expected, drivers’ lane keeping performance was significantly impaired by reading messages on the Glass and mobile phone. This was evidence by an increase in overall and straight line mean deviation scores and the number of lane excursions made. These results are in line with previous research, which has shown that increased visual-manual load increases lane keeping variation [15-17]. While the manual load of scrolling through the text may have partly contributed to the degraded lane keeping performance (structural interference), it is believed that this effect is largely the result of cognitive interference. Although the Glass facilitates viewing of the road while looking at the display, drivers’ ability to attend to both sources of information at once may have been limited. As such, drivers were not able to prevent the build-up of heading errors and maintain their baseline lane keeping performance. Further support for the cognitive interference hypothesis comes from the findings of Sawyer et al. [10], who also found that lane keeping performance was impaired by use of the Glass even though participants in their study used voice-activation, not manual gestures, to interact with the Glass.

In line with expectations, drivers perceived that reading texts on the Glass was subjectively easier than on the phone. This finding is consistent with the work of Sawyer et al. [10] who found that using a smartphone to text message induced a significantly higher level of physical demand on drivers than the Glass. A number of reasons may explain why participants found the phone more demanding to use than the Glass. First, the greater demand may derive from the fact that participants were required to take their eyes off the forward roadway to view the phone display, whereas drivers could shift their gaze more easily and quickly between the road and the Glass display. Second, the layout of the text on the phone, whereby large amounts of text is presented on each screen, may have also played a role.

The fact that participants viewed the Glass as less demanding to use than a phone while driving is of interest because the driving data revealed few benefits of the Glass over the phone in terms of safety benefits and the Glass
had an even more detrimental impact than the phone on failures to detect the lane change signs. This indicates that drivers may not be well calibrated as to how the use of a device affects their driving behavior. The greater perceived ease of use of the Glass may also encourage drivers to use such a device more often when driving than they would a phone, which is of concern.

Overall, the results of the project concur with previous human factors head mounted display research that, despite the Glass allowing users to maintain their visual focus on the forward scene, humans are fundamentally limited in their ability to divide their cognitive attention across two sources of information (the Glass display and the outside environment). This was evidenced by the observed lane keeping decrements observed in the study. In sum, the head-up design of Glass does not appear to render text messaging while driving safe and, given that drivers perceive this type of device less demanding than traditional head-down displays, may even encourage technology use while driving.

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References