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In the eye of the beholder: A simulator study of the impact of Google Glass on driving performance

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ABSTRACT

This study examined whether, and to what extent, driving is affected by reading text on Google Glass. Reading text requires a high level of visual resources and can interfere with safe driving. However, it is currently unclear if the impact of reading text on a head-mounted display, such as Google Glass (Glass), will differ from that found with more traditional head-down electronic devices, such as a dash-mounted smartphone. A total of 20 drivers (22–48 years) completed the Lane Change Test while driving undistracted and while reading text on Glass and on a smartphone. Measures of lateral vehicle control and event detection were examined along with subjective workload and secondary task performance. Results revealed that drivers' lane keeping ability was significantly impaired by reading text on both Glass and the smartphone. When using Glass, drivers also failed to detect a greater number of lane change signs compared to when using the phone or driving undistracted. In terms of subjective workload, drivers rated reading on Glass as subjectively easier than on the smartphone, which may possibly encourage greater use of this device while driving. Overall, the results suggest that, despite Glass allowing drivers to better maintain their visual attention on the forward scene, drivers are still not able to effectively divide their cognitive attention across the Glass display and the road environment, resulting in impaired driving performance.

1. Introduction

Wearable head-mounted displays (HMD) have been in use for decades in military and aviation domains to deliver primary flight or mission information (Rash, 1999). 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 (Stuart et al., 2001). This configuration theoretically allows users to view information on the display while simultaneously being able to scan the environment. With the introduction of Google Glass (hereafter referred to as Glass), HMDs are now being marketed to the general population. Google Glass includes a small, monocular (single) transparent display mounted on a frame worn like a standard pair of glasses. While Glass has the ability to deliver many of the features of a smartphone in a hands-free, wearable unit, its use in various contexts, such as driving, has raised concerns about the potential for distraction (He, 2013; Klopott and Selway, 2014).

A wealth of research exists on the usability of HMDs and how they impact users' visual behaviour and cognitive load. The information provided on a HMD is projected in the users' field of view, allowing them to quickly shift between monitoring the outside world and viewing the displayed information (Prinzel and Risser, 2004). An advantage of HMDs over traditional displays is that they make information easily accessible, reducing the amount of time users spend looking down to scan information or instruments (Prinzel and Risser, 2004) and reducing operators' workload (Fadden et al., 2000).

Having an image projected in the line of sight can, however, mean 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 (Rash et al., 2009). For instance, overlaying information onto the user's view of the world can obscure objects in the environment, leading to a failure to detect hazards entirely, or in time to react to them effectively (Stuart et al., 2001; He, 2013). The information provided on HMDs may also disrupt users' visual scanning behaviour, with research showing that the size and range of users' eye and head movements can be restricted by the use of head-up symbology (Patterson et al., 2006; Stuart et al., 2001). HMDs can also cause problems with visual accommodation, or the focusing of the eyes. HMDs still required small shifts in eye movements (Stuart et al., 2001) and, in particular, repeated shifts in depth of gaze to focus and

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re-focus on near (display) and far (road environment) objects, can fatigue the muscles involved in accommodation (Sullivan, 2008). Edgar et al. (1994) also found that some users can focus inappropriately on HMDs, leading to misperceptions in the size and distance of objects in the real world and reduced target detection rates due to a loss of contrast sensitivity.

A potential drawback of HMDs from an attentional point of view is that the information displayed can capture user attention and they may consequently miss elements of the outside scene; a phenomenon termed *attention capture* (Rash et al., 2009; Ververs and Wickens, 1998). Even if users are capable of 'seeing' both the information on the display and the outside world, humans are not always capable of attending to both sets of information at the same time. Thus, if the user's attention is focussed on the HMD imagery, they may miss an event occurring in the outside world, possibly even if their gaze is fixated on it. This failure to detect an unexpected object or event is termed *inattentional blindness* (Mack and Rock, 1998). Research has found instances where the use of HMDs can cause inattentional blindness, such as delays in aircraft operators detecting and reacting to unexpected events (e.g., Fadden et al., 1998).

Of particular importance, is 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) and the users are highly trained and highly experienced (e.g., Wickens and Long, 1995). It is unclear if, and to what extent, the presentation of non-relevant information, which is what can occur with Glass, could exacerbate the visual and cognitive issues observed with HMDs.

Reading text will be a key component of using Glass. Reading text on electronic devices is a task that 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 behaviours, including longitudinal and lateral control, visual scanning and reaction time to hazards (Drews et al., 2009; Hosking et al., 2009; Owens et al., 2011; Young et al., 2014). It is currently unclear if the impact of reading text on a head-mounted display such as Glass will differ from that found with more traditional head-down displays such as a dash-mounted smartphone given that the information displayed is closer to the driver's line of sight. Compared to a phone, wearable technology such as Glass may increase visual attention to the forward roadway and facilitate the detection of hazards and signs. However, having the display in the driver's field of view may not be enough to facilitate attention switching and negate the impact of attention capture.

A small number of research studies have examined the impact of Glass on driving performance (Beckers et al., 2014; He et al., 2015; Sawyer et al., 2014; Tippey et al., 2014). Sawyer et al. 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 to a text and a faster return to normal speed), for many driving measures, texting on either device impaired performance compared to when driving and not texting. He et al. (2015) also found that reading text on Glass and a smartphone both increased lane position variation from baseline; however, drivers showed less lane variation when using the Glass, suggesting that the head-up display design may modulate the distracting effects of text reading to some extent. When then examining voice-activated destination entry on Glass and a smartphone, Beckers et al. (2014) found similar performance for the Glass and the smartphone; although, when using Glass, drivers completed destination entry faster, but missed a higher number of detection targets.

A notable aspect of previously published Glass driving research is that users have almost exclusively interacted with the device using voice activation (e.g., Beckers et al., 2014; Sawyer et al., 2014; Tippey et al., 2014). However, manual interaction with the device via the touchpad is also possible and, based on our initial pilot testing, may even be preferred over voice-activation by a large proportion of users. It is therefore important to examine how manual interaction with Glass impacts driving performance.

This study was designed to examine the performance and safety implications of driving while using Google Glass and, in particular, whether the head-up design of this device offers any advantages over a more traditional head-down display. Drivers were required to read text aloud on Glass and also, during a separate drive, on a dash-mounted smartphone while driving the Lane Change Test (LCT; Mattes and Hallén, 2009). This work extends the work of Sawyer et al. (2014) by using manual touch gestures to control Glass and using longer, more ecologically valid, text messages, as opposed to artificial tasks such as mathematical tasks. 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 min (MacArthur et al., 2014). Approximately half of our sample had 1.5 h experience with Glass prior to completing the current study.

In relation to lateral control, we predicted that, compared to driving undistracted, driving while accessing and reading text on both Glass and the smartphone would be associated with more variable lateral control. This is based on evidence that activities requiring high levels of visual-manual input, such as accessing and reading text, have a particularly detrimental impact on lateral control (e.g., Engstrom et al., 2005; Young et al., 2011). It was also expected that drivers would correctly respond to fewer lane change signs when multitasking, but that they would make a greater number of correct lane changes when using Glass compared to when using the phone. This hypothesis is based on evidence that the use of head-up displays is associated with increased speed of detecting expected events, such as the lane change signs (Fadden et al., 1998). Finally, based on previous Glass findings (e.g., Sawyer et al., 2014), we anticipated that, in comparison to the smartphone, drivers would rate reading text on Glass as less demanding in terms of workload.

2. Method

2.1. Participants

Twenty licensed drivers (16 male; 4 female) aged 22–47 years ($M = 32.2$, $SD = 6.3$) participated in the study. Table 1 provides demographic details of the sample. All participants were required to have a valid Australian (or equivalent) driver licence and have normal or corrected-to-normal visual acuity. All participants reported regularly text messaging and a large proportion reported reading text messages while driving despite this being illegal in Australia.

To examine if familiarity with Glass moderates the impact of the device on driving performance, a portion of the sample had prior Glass experience. Eight of the twenty simulator participants had taken part in a Glass usability study a week prior and, thus,

Table 1
Simulator study participant demographics.

Mean age (years)	32.2 (6.3)
Mean driving experience (years)	12.3 (6.4)
Mean hours driving per week	7.3 (5.8)
Mean hours using mobile phone each week	3.2 (3.6)
% who *read* texts while driving	75.0%
% who *send* texts while driving	40.0%

Standard deviation in parentheses.