DRIVING WHILE READING USING GOOGLE GLASS VERSUS USING A SMARTPHONE:

WHICH IS MORE DISTRACTING TO DRIVING PERFORMANCE?

Jibo He[1], Jake Ellis[1], William Choi[1], Pingfeng Wang[2]
[1]Department of Psychology, Wichita State University, Wichita, KS, United States
[2]Department of Industrial and Manufacturing Engineering, Wichita State University, Wichita, KS, United States
E-mail: jibo.he@wichita.edu

Summary: Using a phone while driving leads to distraction and impaired driving performance. When reading text on a phone, the act of looking away from the road could cause driving impairment. Wearable displays like Google Glass might reduce the visual impairment caused by looking away, even if they do not overcome other factors contributing to impaired driving. However, such devices could also increase impairment by giving drivers the mistaken impression that they can pay attention to both the display and the road simultaneously or impair visual processing by superimposing visual information in the driving scenes. We compared driving performance in a simulated naturalistic driving task while drivers read text on Google Glass or on a smartphone. As expected, reading on Google Glass and the smartphone both impaired driving performance by increasing lane variations, but drivers using Google Glass showed less lane variation compared to smartphone users. To the extent that these metrics reflect better driving performance, Google Glass might somewhat reduce the costs of reading text while driving.

Keywords: Driver distraction; Tactical vehicle control; Google Glass; Cellphone

INTRODUCTION

In-vehicle information systems and mobile devices, such as MP3 players, mobile media players, and smartphones, are booming (Chisholm, Caird, & Lockhart, 2008), but using these devices can pose a risk to drivers (He, Chaparro, Nguyen, Burge, Crandall, Chaparro, Rui, & Cao, 2014; Lee, Roberts, Hoffman, & Angell, 2012). As many as 16,141 additional distracted driving fatalities were caused by increases in texting between 2002 and 2007 (Wilson & Stimpson, 2010).

The advent of wearable technologies such as Google Glass brings another class of gadgets into vehicles. Google Glass is a monocular optical head-mounted display in the shape of a pair of glasses. It acts a bit like a head-up display in that it presents information on a partially transparent surface in front of the observer. Unlike a traditional head-up display, though, the transparent surface of the Google Glass display maintains its position with respect to the observer's head. Head-mounted and head-up displays both allow users to look at or through the displayed image and view the world beyond (Wickens, Ververs, & Fadden, 2004). Both devices differ from a head-down display which requires observers to look away from the world to view it. Little research has examined the relative impact of such devices on driving safety. Only a few studies have compared the costs of head-up displays (HUD) and head-down displays (HDD) on driving performance (Liu, 2003; Liu & Wen, 2004), finding relatively reduced costs with a

HUD. However, HMD differs from HUD in several aspects, such as stability of the display information and binocular rivalry. Will HMD incur the same costs as HDD, or will they be more comparable to HMD? Safety researchers have only recently begun exploring how Google Glass influences driving performance (Beckers, Schreiner, Bertrand, Reimer, Mehler, Munger, & Dobres, 2014; He, Choi, McCarley, Chaparro, & Wang, under review; Sawyer, Finomore, Calvo, & Hancock, 2014). These studies all used a car-following task and did not assess other aspects of driving performance, such as tactical lane changes. Additionally, these studies also majorly focused on the speech-recognition feature of Google Glass (Beckers, et al., 2014; Sawyer, et al., 2014)—and they did not examine the costs of using the HMD of Google Glass. We investigated how reading using the see-through HMD of Google Glass influences driving performance, specifically tactical lane change behaviors.

We expect Google Glass will impair driving performance, much as other visual and cognitive distractions do. Our question is whether the impairments are as large for an HMD like Google Glass as they are for reading on a smartphone? The combination of speech-recognition and HMD may help Google Glass reduce the amount of visual distraction compared to a smartphone (He, et al., 2014; Kaptein, 1994), but it might introduce new risks to driving performance as well. HMD may incur binocular rivalry (Laramee & Ware, 2002), eyestrain, fixation tunneling (Kaptein, 1994), and inattentional blindness (Patterson, Winterbottom, & Pierce, 2006). For example, pilots wearing a HUD or a HMD are more likely to miss a runway incursion than when using a HDD, even when the runway incursion is clearly visible in their field of view (Crawford & Neal, 2006). Moreover, HMD such as Google Glass brings potential distractors closer to the eyes, which may increase drivers' exposure to distractions. Users of Google Glass can initiate a distracting task, such as sending text messages, simply by nodding their head. The easy accessibility of Google Glass may increase the frequency of risky behaviors by users. Thus, Google Glass might prove to be more distracting than a smartphone in typical use.

This study investigates whether the distractions imposed by Google Glass will be less or greater than those induced by a smartphone when performing tactical lane change behaviors. We used a secondary reading task to simulate the demands of reading emails, websites, or text messages while drivers performed a tactical lane change in a simulator (Horrey & Simons, 2007). Participants drove on a three-lane road with intermittent traffic and passed other cars when necessary in order to maintain a safe distance (Horrey & Simons, 2007). Although the reading task does not capture all of the ways in which devices might distract users while driving, it provides a test case in which using a head-mounted display might be maximally advantageous relative to a cell phone: Reading requires sustained attention, and with Google Glass, participants did not need to look at their phone.

METHOD

Participants

Thirty-five college-age drivers from a midwestern university community (18 males, 17 females, mean age = 21.26 years, *SD* = 4.59 years) received course credit for participating. All had held a driver's license for at least three years prior to the experiment (*M* = 6.10 years, *SD* = 4.01 years), and they reported driving an average of 10864 miles annually (*SD* = 7823 miles). All participants had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli

Driving simulator: The driving scenarios were created using HyperDrive Authoring Suite™ Version 1.6.1 and controlled by Drive Safety's Vection Simulation Software™ Version 1.6.1 (DriveSafety, 2004). The driving simulator consisted of three 26" ASUS monitors (1920 x 1080). Drivers sat approximately one meter away from the front monitor, at a visual angle of 75.55°. Road information was visible through the windows and rear-view and side mirrors, and vehicle dynamics were sampled at 60 Hz.

Mobile devices: A smartphone and a Google Glass were used to display the secondary reading task. The smartphone was a 4.0" Samsung touch-screen smartphone running Android 4.04. It had a 1.2 GHz dual core processor and a Super AMOLED™ display with a resolution of 800 x 480. Google Glass has a monocular optical head-mounted display equivalent to a 25-inch high definition screen viewed from a distance of 8 ft. Google Glass is worn like a regular pair of glasses, has a 1.2GHz dual core processor and display resolution of 640 x 360.

Tasks

Tactical vehicle control task: The tactical vehicle control task simulated highway driving with moderate traffic flow, and focused on tactical vehicle control with both car following and lane changes (modeled after Horrey & Simons, 2007). The driving task consisted of an unconstrained drive on a straight, six-lane divided freeway, with three lanes in each direction. The vehicle started on a freeway entry ramp, and drivers then merged onto the freeway. The posted speed limit was 55 mph. Drivers were told to obey all traffic rules, but were free to change lanes and pass vehicles when appropriate. Other vehicles (all four-door sedans) drove in the same direction as the driver's vehicle. The initial gaps between vehicles were randomly selected from a uniform distribution ranging from 140 m to 180 m, and each vehicle's speed was randomly selected from a uniform distribution between 40 and 75 mph. Faster vehicles spontaneously passed slower ones by changing lanes while maintaining safe headway distances. The variability of vehicle speed and spontaneous passing led to naturalistic patterns of traffic congestion, with some dense traffic regions and other regions with little traffic.

Reading task: In the distracted driving conditions, drivers performed a secondary reading task, which simulated one aspect of visual distraction caused by in-vehicle systems (e.g., reading web pages, email, or text messages). Both Google Glass and the smartphone presented an average of 110.9 characters per screen (*SD* = 3.9), similar to the length of typical text messages and the length of the text passages used in other driving safety research (Peng, Boyle, & Lee, 2014). The reading materials were excerpted from chapters 1-6 of Alice's Adventures in Wonderland (Carroll, 1865), with the excerpts counter-balanced across the different reading conditions. Drivers read aloud as they drove. Subjects wore Google Glass or held the smartphone in their hand when reading. Subjects were instructed to place the smartphone on the simulator desk when they were not reading.

The same custom-built application controlled the display of reading materials and timing of responses for both the smartphone and Google Glass. Drivers pressed a ‘start’ button to begin reading. When using the phone, drivers tapped anywhere on the touch-screen to display the next page of text. When using Google Glass, drivers tapped anywhere on the touch pad to display the next page. We recorded the time stamp each time participants advanced to the next page. The text content, number of words, font size, and text-alignment (left-aligned) were the same across the two devices. For Google Glass, text appeared on a transparent display positioned at the upper side of the right eye’s field of view when the subject looked straight ahead. The text appeared to be overlaid on the simulated world.

Procedure

Participants signed an informed consent form, completed a demographic and driving experience survey, and completed the Snellen visual acuity test before participating in the study. Only drivers who had normal visual acuity and at least three years of driving experience were allowed to participate. After receiving a brief description of the driving and reading tasks, participants completed a practice drive to familiarize themselves with the simulator and the driving environment. The practice drive included all three task conditions in the following order: drive-only, drive + smartphone, drive + glass, each lasting about three minutes. The experimental blocks began after participants fully understood the instructions and were comfortable driving in the simulator. All participants completed three drives, one in each task condition, with the order of conditions counterbalanced across participants.

The reading materials were shown in a fixed order from chapter one through chapter six. An experimenter pressed buttons to log when drivers started reading and when they paused for more than one second. These time-stamped key presses were logged into the vehicle dynamics data files so that we could determine when drivers were performing the reading task. Each drive lasted exactly 15 minutes, and subjects were given a chance to rest between drives. At the end of each drive, participants reported their mental workload using the NASA-TLX workload scale (Hart & Staveland, 1988).

Data Analysis

The measures of lane-keeping performance included the standard deviation of lane position and the number of lane changes. The zero reference point of lane position was the center of the right lane. A larger standard deviation of lane position indicated poorer lane-keeping performance, with higher risks of lane departures and collisions with vehicles in the neighboring lanes. Secondary reading task performance was operationally defined as the reading rate in words per minute for each drive.

RESULTS

The mean standard deviation of lane position was significantly different across conditions, F (2, 68) = 7.97, p = .001. The standard deviation of lane position was comparable for the drive + glass condition (M = 0.500 m, SD= 0.084 m) and the drive–only baseline condition (M =0.491m, SD = 0.076m), t (34) = 0.67, p = .51. In contrast, performance was more variable in the drive + smartphone condition (M = 0.530 m, SD = 0.085m) than in the drive - only baseline condition (t

(34) = 4.01, $p < .001$) and the drive + glass condition (t (34) = 3.32, $p = .002$). The standard deviation of lane position may vary during tactical vehicle control and steady state. Thus, we also calculated standard deviation of lane position in the steady state. We defined a steady-state period as the time period when the change rate of headway distance fell below 1.5 m/s for at least five seconds (Horrey & Simons, 2007). The standard deviation of lane position during the steady states produced similar results as that calculated across the entire trial. The number of lane changes was also significantly different across conditions, F (2, 68) = 11.56, $p < .001$. Drivers changed lanes more frequently in the drive - only condition (M = 26.97, SD = 11.10) than in either the drive + glass condition (M = 23.37, SD = 8.69, t (34) = 2.39, $p = .022$) or the drive + smartphone condition (M = 20.04, SD = 7.66, t (34) = 4.38, $p < .001$). Drivers were less likely to change lanes when using a smartphone than when using Google Glass (t (34) = 2.75, $p = .010$).

Driving speed also varied across conditions, F (2, 68) = 9.61, $p < .001$. Drivers maintained a slower average speed when using either device than when they just drove. Drivers were fastest in the drive-only baseline condition (M = 62.68 mph, SD = 3.21 mph) than in the Glass condition (M =60.62mph, SD = 4.15 mph, t (34) = 3.74, $p = .001$) or the Smartphone condition (M = 57.56 mph, SD =7.96 mph, t (34) = 3.63, $p = .001$). Drivers were also slower when using a smartphone than when using Google Glass, t (34) = 2.25, $p = .031$. The variability in driving speed did not vary significantly across conditions, F (2, 68) = .25, $p = .78$.

Drivers showed less variability in lane position when reading from Glass than a smartphone. This difference in variability could result from a difference inherent to Glass, or it could reflect a strategy change or a secondary effect of the medium. For example, drivers might just read faster or slower in the Glass condition. Participants read significantly faster when using Google Glass (M = 93.61 words per minute, SD = 34.38) than when using the smartphone (M = 84.40 words per minute, SD = 36.99), t (32) = 2.08, $p = .046$. The data thus suggested that the performance advantage of Google Glass was not because subjects deprioritized the reading task when using Google Glass. We also measured drivers' workload at the end of each trial using the NASA-TLX scale (Hart & Staveland, 1988). Three subjects did not finish the NATA-TLX scale and were excluded from the analysis, leaving 32 valid participants. Participants' overall total workload was significantly different across driving conditions, F (2, 62) = 82.20, $p < .001$. Drivers in the drive – only condition (M = 25.08, SD = 16.56) reported significantly lower workload than the drive + glass condition (M = 55.64, SD = 18.99) and drive + smartphone condition (M = 62.92, SD = 18.08), t (31) = 10.94, $p < .001$ and t (31) = 12.17, $p < .001$. The self-reported workload in the drive + glass condition was also significantly lower than the drive + smartphone condition, t (31) = 2.10, $p = .044$.

DISCUSSION

This study compared driving performance when drivers read materials displayed on a smartphone or on Google Glass. As expected (Peng, Boyle, & Lee, 2014), driving performance was impaired when reading medium to long text messages, both with Google Glass and with a smartphone. Interestingly, we also found that the impairment was greater when using a smartphone to read than when using Google Glass, which suggested that the display medium could modulate the distracting effect of a text-reading task. Thus, alternative display systems, such as head-mounted display (Sawyer, et al., 2014) and head-up display (Liu, 2003; Liu & Wen, 2004), can reduce the visual distraction caused by in-vehicle systems, such as GPS navigation system.

The difference in driving performance with Google Glass and a smartphone might result from the reduced need to look away from the road when using Google Glass. Head-mounted displays and head-up displays allow users to shift their focus between their primary task and the display more efficiently, perhaps letting them remain focused on the external world (Lino & Otsuka, 1988). For example, compared to a standard monitor, anesthesiologists wearing a head-mounted display spent more time looking at their patients and less time looking at the anesthesia machine (Sanderson, Watson, Russell, Jenkins, Liu, Green, Llewelyn, Cole, Shek, & Krupenia, 2012).

Note that drivers using Google Glass were still impaired relative to the drive – only baseline. They incurred larger standard deviation of lane position than when driving without any device. Using Google Glass rather than a smartphone did not eliminate the risks of distracted driving. Moreover, the ease with which people can look to Google Glass without having to look away from the road might lead drivers to the mistaken belief that Google Glass is not distracting. If so, people might be tempted to use Google Glass more than they would be tempted to look down at their smartphone, thereby increasing how long or how often they are distracted while driving. Although this study showed a reduction of distraction effect for Google Glass compared to a smartphone in a tactical vehicle control task, it does not show that it is acceptable to drive with either Google Glass or a smartphone. The relative distraction effect during on-road driving will depend on many factors that are not explored in this study, such as the visual clutter of the application running in Google Glass and smartphone and drivers' exposure to the distracting task. It is important for the IT companies and National Highway Traffic Safety Administration to provide some design guidelines for in-vehicle systems and application development suggestions for mobile device developers.

Future studies should consider using eye-tracking technologies to examine whether interaction with Google Glass meets the NHTSA guidelines for in-vehicle systems (National Highway Traffic Safety Administration, 2012).

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