Title: Do Wearable Devices Bring Distraction Closer to Drivers? Comparing Smartphones and Google Glass

Article Type: Full Length Article

Keywords: Texting while driving, Driver distraction, Multitasking strategy, Wearable devices, Head-mounted display, Google Glass

Abstract: BACKGROUND: Head-up and wearable displays, such as Google Glass TM, are sometimes marketed as safe in-vehicle alternatives to phone-based displays, as they allow drivers to receive messages without eye-off-the-road glances. However, head-up displays can still compromise driver performance (e.g., He et al., 2015), as the distracting effect of interacting with any device will depend on the user's multitasking strategies. The present experiment examined drivers' interaction with a head-down smartphone display and a wearable head-up display. METHOD: Participants performed a simulated driving task while receiving and responding to text messages via smartphone or the head-mounted display (HMD) on the Google GlassTM. Incoming messages were signaled by an auditory alert, and responses were made vocally. RESULTS: When using Google Glass, participants' responses were quicker than that of smartphone, and the time to engage a task did not vary according to lane-keeping difficulty. Results suggest that a willingness to engage more readily in distracting tasks may offset the potential benefits safety benefits of wearable devices.
August 19, 2017

Dear Editor,

Please find attached a revision of manuscript JERG-D-17-00071, “Does Wearable Device Bring Distraction Closer to Drivers? Comparing Smartphones and Google Glass”. We thank you and the reviewers for the encouraging remarks and very helpful suggestions on the original submission, and are optimistic you’ll find the revision suitable for publication. The study investigates the multitasking strategy and distraction effects of wearable head-mounted display (e.g. Google Glass) on driving performance. Our finding can inform the design of in-vehicle display technologies and reduce distraction to drivers.

The comments from the reviewers were in general very positive. We thank their great advice and supports and have carefully revised the manuscript following their comments and suggestions. Please see a list of revisions and responses to the reviewers’ comments below.

Again, thanks very much for your time and consideration,

Sincerely,

Jibo He, Ph.D.

jibo.he@wichita.edu

Associate Professor

Department of Psychology

Wichita State University
[Reviewer #1]
I think the paper considers an important topic and it is suitable for the journal. The results section reports the findings in a detailed and scientifically robust way. My main concern is with the methods section: The experiment is not replicable with the given information, and some information should be given to the reader earlier on. In addition, the discussion needs some rewriting.

Reply: Thanks for all the suggestions. We added detailed experiment information: driving simulator and task scenarios; secondary texting task; two displays with detailed screen size and resolution.

We also revised the discussion section: Although Google Glass was demonstrated to show a reduction of performance decrement compared to smartphones (He et al., 2015; Sawyer et al., 2014); be less disruptive to driving performance in laboratory settings (Beckers et al., 2014; He et al., 2015; Sawyer et al., 2014; Young, Stephens, Stephan, & Stuart, 2016); voice recognition and head-mounted display that are embedded to reduce distraction (He et al., 2013; He et al., 2015; Liu & Wen, 2004), If drivers intuitively believe or are frequently told that Google Glass is less disruptive to driving performance than smartphones, frequent use and quick access to Google Glass in actual daily driving may put Google Glass users at higher risks than smartphone users.

Big issues:
1) Time-to-engagement and time-on-task, and Tap to reply and Tap to Send. These need to be defined clearly and preferably when they are first mentioned. Showing a timeline might be helpful.

Reply: Thanks for the reminder. We defined the time-to-engagement and time-on-task when they are first mentioned. And adding a timeline to show the relationship among tap to reply, tap to send, time-to-engagement, and time-on-task.

a. In section 1.5, it is mentioned that t-2-e was measured from the start of the auditory alert, until Tap to Reply was clicked. Time-on-task was the time between Tap to Reply to Tap to Send. Does this mean the speech recognition was active during the whole time?

Reply: Yes, during the time on task, the speech recognition was active.

b. In addition, please explain why these two metrics were chosen. I am concerned that these measures would be difficult to use in real conditions. I would imagine that after receiving a message, a user would pause and think for a reply, then click on Reply and speak the message & send. Did you measure or observe if there were long quiet moments between the arrival of message and the taps? How long did it take to reach for the smartphone? If you want to measure how fast the user reacts to the arrival of the message, a good measure would be to use the instant when the user starts to reach for the smartphone.

Reply: These metrics were chosen to distinguish the driver’s willingness/readiness to respond to the an incoming messages from the time spent distracted by or working on the message. The time-to-engagement (TTE) measures how quickly the driver is willing to accept and begin responding to the incoming message. Time-on-task (TOT) measures how long the driver spends engaged in processing the message after accepting it.

It is important to note that in our design, drivers did not actually see or hear the message until they tapped to reply. We fully agree with the reviewer that the driver might require time to think about their response before dictating and
sending it. However, in the present case, this thinking time would have been rolled into TOT, not TTE; TTE included only the time necessary to acknowledge and accept the message, not the time to read or process it. Again, our goal was to separate willingness to engage with the message (TTE) from the demands of actually processing the message and crafting a response (TOT).

We agree that in future experiments, it would be useful to have a measure of how quickly the user began reaching for the phone, and we thank the reviewer for the suggestion. Our best guess, though, is that this measure would produce a pattern of effects very similar to our current measure of TTE. In other words, we suspect that variability in TTE across task conditions is driven largely by variability in time taken to begin reaching, as we have no theoretic reasons to expect that differences in TTE across the three task load conditions (texting only, text + easy drive, text + hard drive) would be driven by movement time AFTER reaching had begun. But again, this is certainly a point worth following up on.

c. In Figure 2 caption, it is said “Tap to Reply” was pressed to _read_ the message - please clarify.

**Reply:** In the procedure of the experiment, a notification alerts the participants when a message arrived and the participants tap the “Tap to Reply” button to display the message on the phone’s screen. After reading the message, participants verbalize their response and tap the “Tap to Send” button.

2) What smartphone and HMD were used? Brand, model, version, screen size? Figures would be preferable.
   a. How was the fit/wearability of the HMD?
   b. A photo of the simulator showing the placement of the smartphone would be helpful.

**Reply:** We have added the following contents into the paper. Pictures for the smartphone, Google Glass and driving simulator are all added in Figure 3 and 1.

   The phone was a 4.0 in. Samsung touch-screen smartphone running Android 4.04 operating system with a 1.2 GHz dual-core processor. The resolution of the Super AMOLEDTM display was 800 * 480 WVGA. Google Glass was a monocular optical HMD, which was similar to a 25 in. high definition screen in visual angle viewed from eight feet away. The display was placed in front of the right eye, and the participants were allowed to adjust the display to the angle they were most comfortable with.
   
   The Google Glass’s frame was made of lightweight titanium while maintaining its durability. Because of the flexibility of the frame, it can adjust to different head circumference.

3) Does the simulator have a manual or automatic gear?

**Reply:** Yes, the simulator has an automatic gear by default.

4) How were the participants instructed? To react as fast as possible or to keep driving as straight as possible?

**Reply:** Participants were instructed to follow a lead car, a red Toyota Celica Sedan with a width of 1.728m, in the middle lane. Participants should try their best to stay in the middle of the lane when following the car.

5) How were they instructed to follow the lead car?

**Reply:** Try to keep away from the lead car and do not crash.

6) Did all participants experience the same wind conditions? Did they try the conditions in the same order?
Reply: They experienced the same wind condition manipulation, but the directions and strengths of the winds were randomly determined. The order of the conditions was counterbalanced using Latin Square design.

7) “Question and answer” task is mentioned in the Discussion. This needs to be stated in the methods, with examples, to ensure replicability.
Reply: Actually “question and answer” in the method was the part that messages were the questions and participants read the messages (questions) and answered it loud. The APP automatically recorded their answers.

8) Did the participants check for typos in their responses?
Reply: Participants read the messages and responded them verbally so they need not check the typos.

9) Discussion: Please discuss why there was more deviation from the center of the lane in the easy condition (Figure 3). Did the cones placed closer actually help the participants? How did the participants comment the tasks?
Reply: Thank you for the consideration. You are right. Cones are good cues to help participants estimate the center of the lane and closer cones make the lane maintain easier, which make the Hard condition easier than the Easy condition.

10) Discussion: The reader is left slightly confused as to what the new knowledge is compared with the earlier results. For example, the 5th paragraph beginning with "Wearable devices, such as..." mostly refers to earlier studies. The same applies to the end of the 2nd paragraph, sentence "The current study further elucidated...".
Reply: The new knowledge presented in this paper is that the extent of distraction depends on not only how distracting the device itself is relatively, but also on the multitasking strategies drivers adopt. The fact that drivers responded quicker to the incoming messages in wearable devices is concerning, as more proneness to distractions in wearable devices may offset the potential benefits provided by wearable devices.

To explain our contribution explicitly, we have added the following paragraph in the DISCUSSION section:

Although Google Glass was demonstrated to show: a reduction of performance decrement compared to smartphones (He et al., 2015; Sawyer et al., 2014); be less disruptive to driving performance in laboratory settings (Beckers et al., 2014; He et al., 2015; Sawyer et al., 2014; Young, Stephens, Stephan, & Stuart, 2016); voice recognition and head-mounted display that are embedded to reduce distraction (He et al., 2013; He et al., 2015; Liu & Wen, 2004). If drivers intuitively believe or are frequently told that Google Glass is less disruptive to driving performance than smartphones, frequent use and quick access to Google Glass in actual daily driving may put Google Glass users at higher risks than smartphone users.

Minor issues
1) What is the difference between a secondary and a distracting task? Please define or use either one consistently.
Reply: There is no difference between a secondary and a distracting task. We changed the distracting task into secondary task to keep consistency.

2) "Conversely, wearable interfaces reply primarily on vocal input..." - Do they? With smart watches, swiping is a common input method.
Reply: We put the word "sometimes" into the sentence to make it reasonable.

Smartwatch developers are still facing the challenges to implement an acceptable input methods for the small display of smartwatches. At least, for the Apple watch with 75% market share still do not have a good input methods. See the work on smartwatch input method by Turner, Chaparro, He, 2016; Turner, Chaparro, He, 2017. We also hope and anticipate there is a more common input methods in addition to vocal inputs.


3) Table 1: I slightly disagree with some of the information. A smartphone can produce a tactile alert if it is vibrating on the dashboard and the driver feels it via the steering wheel. A driver can also see a visual alert with peripheral vision. I would also add a row for Auditory alerts.

Reply: We agree with you. We have added the auditory alert into the table and changed the tactile alert row.

<table>
<thead>
<tr>
<th>Tactile alerts</th>
<th>Most often not, if phone is not vibrating in the pocket or vibrating on the dashboard</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory alerts</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

4) Were the participants left or right-handed?

Reply: Since the Google Glass display is on the right eyes, the right hand will be convenient for participants to touch the pad. So most of the participants are right-handed and just two participants are left-handed.

5) In the country the study was done, is it legal to text while driving? It could affect the participants’ experience with multitasking while driving. Please state.

Reply: under a 2011 law, all Kansas drivers are prohibited from texting. In this study, the secondary task is to respond to the messages verbally not texting. Many participants have the experience of using bluetooth headset to answer the phone or message, which was similar to the task in this study.

6) Figure 1b: It looks like the distance between the cones is about the same as the width of the lane (4m), but in the text it says it should be 3.3m. Please check.

Reply: The distance between the lane and cones is just 0.35m that is small and make the width looks the same in the view angle where the screenshot was taken.

7) Please define the scale min and max for SDDQ (p.11).

Reply: The Susceptibility to Driver Distraction Questionnaire (SDDQ) includes 39-items, and measures three dimensions: 1) engagement in distraction while driving, with seven items rated on a 5-point Likert scale: ‘never’, ‘rarely’, ‘sometimes’, ‘often’, and ‘very often’. 2) potential facilitators of voluntary distraction, with six items rated on a 5-point Likert scale: from ‘strongly agree’ to ‘strongly disagree’ and 3) susceptibility to involuntary distraction, with eight items, scored using a 5-point Likert scale with an additional option of ‘never happens’. Participants majorly chose 3 (often) or 4 (very often) in the SDDQ scale, producing no meaningful or significant results. Thus, data on the SDDQ scale are not further reported.

8) Figure 3, mark units to the Y axis.

Reply: Yes. We marked the units in the old Figure 3 (which is the Figure 6 in the current manuscript).
Other minor comments:
Some units (blood alcohol level?) and terms (billion = one thousand million or one million million?) need to be defined more accurately. The use of kilometres instead of miles would be more consistent with other metric units.
The abstract is very long.
Please check referencing style of multiple authors.
Reply: According to the National Institute of Health, a .08 blood alcohol level is roughly equivalent to 4 drinks for a 180-pound male and a person who is at a .08 would likely need 6 hours to completely sober up. We changed the units for the consistency. We make the abstract short with 181 words now.

Typos:
p.8, For example, Liang and colleague_s_
p.12 texing -> texting
p.22 time-to-engagement -> italic.

Reply: Sorry for the typos. We corrected the typos

[Reviewer #2]:
The study conducted a driving simulator experiment to investigate the effects of different device on primary and secondary task performance. Although this paper has a clear and simple aim, the manuscript requires substantial revisions and clarifications. See detailed comments below.

1. In general, the paper is very long. While the purpose of the study is very clearly formulated, much text is used, especially in Introduction and Methods, to put forward the main message. The text should be considerably reduced.

Reply: We have deleted some repeated contents and re-edited it. For example, we deleted: The recent boom of wearable devices has caught the attention of driving safety researcher.

2. There are countless typographic errors and awkward sentences throughout the manuscript, these needs to be attended to.

Reply: We double-checked and tried to fix all the typos and repeated contents, and rewrote parts of the paper.

3. The References did not list all of the previous works cited in this manuscript, in particular the studies cited in Methods.

Reply: Sorry for the missing reference. We checked it one by one and added them.

4. The abstract needs to be re-written, according to the Guide for Authors, a concise and factual abstract of between 100-150 words is required. The abstract should state briefly the purpose of the research.

Reply: Yes, the abstract is a little long. We deleted some contents and re-edited it into 181 words

Methods
5. In section 1.2, it seems that participants responded the Driver Distraction Questionnaire (SDDQ) when they completed all of the eight conditions. This might be the reason most of participants' responses were 3 or 4 for this questionnaire. The SDDQ can be used as a measurement for RM ANOVA if it was administered at the end of each experiment condition.

Reply: As a scale, the SDDQ should have its validity and reliability, which means its response should be reliable across a period of time. However, it is interesting to know and it may indeed that participants' response to the SDDQ may be different from the current results at the end of each experiment condition. We will consider use it after each driving session in the next study.

6. What is the implication of response 3 or 4 in the SDDQ?

Reply: Participants most likely choose 3 (often) or 4 (very often) in the distracting scale producing no meaningful or significant results. Thus, data on the SDDQ scale are not further reported.
7. Typically experimental design should include the descriptions of independent and dependent variable, I suggest you moving the descriptions of dependent variable from 1.5 Data analysis to 1.3 Experimental design.

Reply: Thanks for the suggestion. We adopted your suggestions by moving the data analysis part to the experiment design.

8. There is some repetition throughout the method (such as the description of participants in 1.4 Procedure).

Reply: We deleted the repeated parts and re-edited it. For example, we deleted the last paragraph in the procedure section.

9. In 1.3 Experimental design, authors use the Driving Difficulty and Task Load as the name of independent variables, but in 1.5 Data analysis, Driving Difficulty and Task Load are used for driving performance analysis and Texting Device and Texting Load are used for texting strategy analysis. Readers will be confused with the inconsistency. I recommend the authors to use the Difficulty of Lane Keeping and Verbal Texting as the name of independent variables. In driving performance analysis, A 3 × 2 repeated-measures ANOVA was performed. The independent variables were Difficulty of Lane Keeping (two levels: Hard and Easy), and Verbal Texting (three levels: with smart, with Google Glass, and Non Texting). The texting strategy analysis used a 3×2 repeated-measures design. The independent variables were Difficulty of Lane Keeping (three levels: Hard, Easy, Non Driving), and Verbal Texting (two levels: with smart and with Google Glass).

Reply: Thank you for the suggestion. Based on the suggestion, we re-edited the experiment design. We changed the independent variables into Driving Difficulty, Task Load, and Text Device. In the driving performance analysis, the independent variables are driving difficult (easy, hard) X Task load (driving only, drive with smart phone, drive with google glass). In the multitasking strategy analysis, the independent variables are text device (smartphone, google glass), task load (texting only, drive with smart phone, drive with google glass).

10. In 1.5 Data analysis, it shows that the mean and standard deviation of the headway distance are recorded as a driving performance, but this measurement does not show in 2. Results.

Reply: Thanks for the reminder. We deleted it as it is not significant.

11. In Table2, the arrows seem adverse or incomprehensible. For example, the results in page 15 show that the SDLP for Drive - Only condition was significantly lower than that for Drive + Glass condition. According to the definition of arrow, it should be obtained a downward arrow that indicates significant decreases for the first condition (Drive - Only) over the second condition (Drive + Glass) in the comparing condition pairs. However, it shows an upward arrow for the Drive - Only vs. Drive + Glass by Standard deviation of lane position cell in Table 2.

Reply: We followed your advice and made it more clear. See it below.

<p>| Table 2. Comparisons of driving performance under different driving conditions. |
|----------------------------------|------------------|------------------|------------------|
|                                  | Drive + Glass vs. Drive - Only | Drive + Phone vs. Drive - Only | Drive + Phone vs. Drive + Glass |
| Mean lane position               | ≦                  | ≦                  | ≦                  |
| Standard deviation of lane position | ↑                  | ↑                  | ≦                  |
| Steering reversal rate           | ↑                  | ↑                  | ↑                  |
| Standard deviation               | ↑                  | ↑                  | ↑                  |</p>
<table>
<thead>
<tr>
<th>of steering wheel position</th>
<th></th>
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<tbody>
<tr>
<td>Mean speed</td>
<td>✅</td>
<td>✅</td>
<td>≅</td>
</tr>
<tr>
<td>Standard deviation of speed</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
</tr>
</tbody>
</table>

*Note:* ✅ indicates significant increases for the first condition over the second condition in the comparing condition pairs; ✅ indicates significant decreases for the first condition over the second condition in the comparison condition pairs; ≅ indicates no changes of driving performance with statistical significance.

12. Although the SDDQ results did not allow for the correlational analysis, please provide an explanation for the participants’ similar responses.

*Reply:* Since the SDDQ measure results are not significant so we delete this part and would not report it. This MIGHT be the homogeneity of our participants, who are most college-age students.
Do Wearable Devices Bring Distraction Closer to Drivers?

Comparing Smartphones and Google Glass

HIGHLIGHTS

- Interacting with either Google Glass or a smartphone impairs driving performance;
- Participants respond more quickly to messages on Google Glass than on a smartphone;
- Quicker response to distraction tasks may offset the potential benefits of wearable devices.
Does Wearable Device Bring Distraction Closer to Drivers?

Comparing Smartphones and Google Glass

Jibo He$^{1,2*}$,

Jason S. McCarley$^3$,

Kirsten Crager$^1$,

Murtuza Jadliwala$^4$,

Lesheng Hua$^1$,

Sheng Huang$^5$

$^1$Department of Psychology, Wichita State University, Wichita, KS, 67260, USA

$^2$School of Education, Laboratory of Cognition and Mental Health, Chongqing University of Arts and Science, Yongchuan, Chongqing, China

$^3$School of Psychological Science, Oregon State University, Corvallis, OR, 97331, USA

$^4$Department of Electrical Engineering and Computer Science, Wichita State University, Wichita, KS, 67260, USA

$^5$USee Eye-Tracking Technology Company, Beijing, 100871, China

*Corresponding author:
Jibo He, Ph.D.
Associate Professor
Wichita State University
1845 Fairmount St.
Wichita, Kansas 67260, USA
E-mail: jibo.he@wichita.edu
Cell phone: +1-217-417-3830
Words counts: 5846
ABSTRACT

BACKGROUND: Head-up and wearable displays, such as Google Glass™, are sometimes marketed as safe in-vehicle alternatives to phone-based displays, as they allow drivers to receive messages without eye-off-the-road glances. However, head-up displays can still compromise driver performance (e.g., He et al., 2015), as the distracting effect of interacting with any device will depend on the user’s multitasking strategies. The present experiment examined drivers’ interaction with a head-down smartphone display and a wearable head-up display. METHOD: Participants performed a simulated driving task while receiving and responding to text messages via smartphone or the head-mounted display (HMD) on the Google Glass™. Incoming messages were signaled by an auditory alert, and responses were made vocally. RESULTS: When using Google Glass, participants’ responses were quicker than that of smartphone, and the time to engage a task did not vary according to lane-keeping difficulty. Results suggest that a willingness to engage more readily in distracting tasks may offset the potential benefits safety benefits of wearable devices.

Keywords: Texting while driving, Driver distraction, Multitasking strategy, Wearable devices, Head-mounted display, Google Glass
1. **Introduction**

Engaging in secondary tasks, such as talking on cell phone or texting, is a popular risky behavior while driving and one of the major factors that impair driving performance (Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009; He et al., 2014; He, Choi, McCarley, Chaparro, & Wang, 2015; He, McCarley, & Kramer, 2013; Sawyer, Finomore, Calvo, & Hancock, 2014) and contribute to traffic crashes (Wilson & Stimpson, 2010). The Cellular Telephone Industries Association (CTIA) estimated that 169.3 billion texting messages were sent in US every month in 2014, and driver distraction was associated with as many as 3,179 casualties and 431,000 injuries in 2014 (CTIA, 2014). The number of accidents involving cell phone use has increased, which represents 26% of the total of motor vehicle accidents in 2014 (National Safety Council, 2014; National Highway & Transportation Administration, 2011). Wilson and Stimpson (2010) estimated that texting while driving caused 16,141 more driving fatalities than would have been otherwise expected from 2002 to 2007.

Driver distraction has been found to be as dangerous in some ways as drunk driving at the 0.08 blood alcohol level (Strayer, Drews, & Crouch, 2006), and impairs various aspects of driving performance (Caird, Johnston, Willness, Asbridge, & Steel, 2014; Caird, Willness, Steel, & Scialfa, 2008). For example, drivers who talk or text over a cellphone while behind the wheel produce longer braking response times (Drews et al., 2009; He et al., 2014) and take longer to recover speed after braking (Strayer et al., 2006). Those who text also show higher lane and speed
variability (Alosco et al., 2012; He et al., 2014; He, Chaparro, Wu, Crandall, & Ellis, 2015; Hosking, Young, & Regan, 2009). Distracted drivers also report higher workload (He et al., 2015; Owens, McLaughlin, & Sudweeks, 2011) and make longer off-road glances (Hosking et al., 2009; Libby, Chaparro, & He, 2013; Owens et al., 2011) than undistracted drivers. Drivers who talk while driving increase their crash risk by about three times (Klauer et al., 2006), and those who text while driving increase their risk by as much as 8 to 23 times (Olson, Hanowski, Hickman, & Bocanegra, 2009). The recent booming of wearable devices, such as Google Glass and smartwatches, may exacerbate these trends, by bringing more distracting devices into the vehicle (Beckers et al., 2014; Giang, Shanti, Chen, Zhou, & Donmez, 2015; He et al., 2015; Sawyer et al., 2014) and raising new questions for transportation safety.

Motivated by the potential safety benefits of speech-based inputs and head-mounted display, wearable devices (such as Google Glass) are intuitively believed to reduce the costs of distraction to driving performance, as compared to conventional hand-held cellphones. Preliminary studies have provided evidences for some benefits of wearable devices (Beckers et al., 2014; Giang, Hoekstra-Atwood, & Donmez, 2014; Giang et al., 2015; He et al., 2015; Sawyer et al., 2014). For example, Sawyer et al. (2014) asked participants to drive following a lead vehicle while texting using either Google Glass or a smartphone. Drivers who texted through Google Glass showed a lower standard deviation of lane position (SDLP) than those texting through a smartphone, implying lower driving risk. Google Glass users also returned to the roadway speed more quickly after texting, and maintained shorter following distances. Studies reported that drivers using Google Glass showed lower costs to driving performance than
those using a smartphone (He et al., 2015; Sawyer et al., 2014). The two studies provided important preliminary evidence of the effects of Google Glass use on driving performance. Nevertheless, neither study directly examined distracted drivers’ multitasking strategies.

Studies have shown, though, that the costs of distraction to driving performance depend on the duration of secondary task (Burns, Harbluk, Foley, & Angell, 2010), the location and format of the secondary task display (head-up vs head-down vs head-mounted, e.g., He et al., 2015; Horrey, Wickens, & Consalus, 2006; Liu & Wen, 2004; Sawyer et al., 2014), and the secondary task input modality (speech-based versus manual entry; He et al., 2014; Maciej & Vollrath, 2009; Weinberg, Harsham, Forlines, & Medenica, 2010). Message entry using hands-free, speech-based inputs is often reported to be less distracting than hand-held, manual message entry, as it requires less motor and visual resources (He et al., 2014). Similarly, drivers generally show less of a performance decrement when viewing information on a head-mounted or head-up display, or on displays at small retinal eccentricity, than when viewing information on a head-down display or at large eccentricity (He et al., 2015; Horrey & Wickens, 2004; Liu & Wen, 2004; Sawyer et al., 2014), as a result of fewer and shorter glances off-road.

More research is needed to uncover the whole picture of the potential effect of wearable devices on driving performance for two major reasons. First, wearable devices may have very different effects than conventional cell phones and other forms of distracting technologies that have already been well studied. The proximity of a wearable display to the human body and eyes may reduce the effort needed to initiate a secondary task, encouraging drivers to multitask more
than they might with a conventional cell phone. Tactile and auditory alerts from a wearable device may be harder to ignore than visual and auditory alerts from a cellphone (Calhoun et al., 2004; Lee & Starner, 2010), and the onset of new visual information with a wearable display may tend to draw drivers’ attention reflexively away from the road (Yantis & Jonides, 1990). Transparent wearable displays may also reduce text contrast, making information difficult to read and engendering longer shifts of visual attention away from the driving task. Conversely, wearable interfaces rely primarily on speech input, which tends to be less distracting than manual inputs that is typically used for smartphones (He et al., 2014; He et al., 2013; He et al., 2015). A comparison of the difference between smartphone and Google Glass in the driving context is shown in the Table 1.

Second, compared to the emphasis on driving performance, secondary task performance and strategy of multitasking have received relatively little attention in the literature. But driving performance can hardly be thoroughly investigated without considering drivers’ multitasking strategy. Multitasking strategy can also moderate the costs of a secondary task driving performance (Horrey & Lesch, 2009; Liang, Horrey, & Hoffman, 2012). More specifically, distracted drivers can potentially moderate the multitasking demands by delaying, interrupting, or abbreviating the secondary task (Becic et al., 2010). Two important variables need to be compared to provide a fair comparison of the effect of HMDs and smartphones on driving performance and describe the multitasking strategy: time-to-engagement and time-on-task.
Table 1. Comparisons of smartphone and Google Glass in the driving context

<table>
<thead>
<tr>
<th></th>
<th>Drive with a smartphone</th>
<th>Drive with HMD (e.g. Google Glass)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Saliency</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Eccentricity</strong></td>
<td>Far</td>
<td>Close</td>
</tr>
<tr>
<td><strong>Effort</strong></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Values</strong></td>
<td>Task-dependent, low for texting while driving</td>
<td>Task-dependent, low for texting while driving</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>Mostly at least 720x1280 pixel resolution with 4.3 to 6 inch physical size</td>
<td>640x360 pixels (equivalent of a 25 in/64 cm screen from 8 ft/2.4 m away)</td>
</tr>
<tr>
<td>** Contrast**</td>
<td>Good</td>
<td>Poor for the transparent display</td>
</tr>
<tr>
<td><strong>Tactile alerts</strong></td>
<td>Most often not, if phone is not vibrating in the pocket or vibrating on the dashboard</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Auditory alerts</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Visual onset</strong></td>
<td>No, if not in the field of view</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Input methods</strong></td>
<td>Manual, vocal</td>
<td>Vocal</td>
</tr>
</tbody>
</table>

Time-to-engagement is defined as the period between when the message is sent to the device and when drivers make their first reaction (visual glance, movement, or button clicks) towards the device (Giang, Hoekstra-Atwood, &Donmez, 2014). In this study, time-to-engagement was operationally defined as the time from the auditory alert signaling that a message had arrived until participants clicked the “Time to Replay” button. Time-on-task was the duration of the secondary task. The two variables were used to describe the reaction and time taken on the secondary distraction task. Because wearable devices, such as HMDs and
smartwatches, are situated on the human body and sometimes directly in front of the eyes, the effort required to initiate a secondary task on a wearable device may be smaller than needed on a smartphone task or a dashboard task. This may make wearable device users more likely to initiate a secondary task, producing shorter time-to-engagement. To the best of our knowledge, only one study has investigated the time-to-engagement for smartwatch, reporting that the time-to-engagement was shorter for a smartwatch task than a smartphone task (Giang et al., 2014). The rejection or the delay of a distraction task can be an adaptive strategy to accommodate the increased workload of multitasking (Iqbal, Horvitz, Ju, & Mathews, 2011; Liang et al., 2012; Schömig, Metz, & Krüger, 2011), but is a behavior that drivers may not always use (Horrey & Lesch, 2009). For example, Liang and colleagues found that drivers sometimes avoided transitioning from low-demand driving tasks to high-demand driving tasks when initiating secondary tasks with in-vehicle devices (Liang et al., 2012). However, they did not intentionally start the secondary task in a low-demand driving scenario, and they did not delay the secondary task when driving demands have been already high. These studies demonstrated that the multitasking strategy of when to initiate a distraction task might be specific to the driving context and the adaptive anticipatory delaying of a secondary task may not be perfect, especially in the high driving load condition. However, till now, no efforts have been made to investigate the time-to-engagement for drivers who use a wearable HMD.

*Time-on-task* may also modulate the distracting effects of in-vehicle technology use. Burns et al. (2010) emphasized that “*Any metric that ignores task duration and duration-related metrics in the assessment of visual-manual tasks will have an incomplete and possibly...*
misleading, estimation of distraction risk” (Burns et al., 2010, p. 17). If drivers intuitively believe wearable devices are less distracting to driving performance, they may spend longer times interacting with wearable devices than with smartphones, offsetting any potential benefits of wearable devices.

The current study aims to answer four important questions concerning the influence of wearable devices on driving performance. First, which display medium is less compromising to driver performance, HMD or smartphone? Second, does an HMD display’s proximity to human body and eyes encourage shorter time-to-engagement or higher chance to engage in a distraction task than a smartphone? Third, will drivers spend longer time interacting with an HMD than with a traditional smartphone? Fourth, will drivers interacting with either an HMD or a smartphone adapt their secondary task behaviors in response to changing levels of driving demand (Liang et al., 2012)?

2. Methods

2.1. Participants

Participants were twenty-nine students recruited from a midwestern university (eighteen females and eleven males; mean age = 23.5, SD = 6.2, range = 18 to 43 years) who received course credit as remuneration for their participation. Only students who possessed a valid driver’s license and had been driving for at least two years were invited to participate. Their average driving experience was 5.71 years, and they drove 148.28 miles weekly. Each participant was required to pass a standardized vision test to ensure that they had at least 20/20 vision ability
with or without corrective contact lenses. Participants wearing corrective glasses were not able to participate in the experiment due to the potential structural interference with Google Glass. All participants reported that they owned a smartphone. Twenty-six participants reported experience using a smartphone while driving and the other three participants did not.

2.2. Apparatus and tasks

**Driving simulator.** The simulated driving task and scenarios were created using HyperDrive Authoring Suite™ Version 1.6.1 and Drive Safety’s Vection Simulation Software™ Version 1.6.1 (see Figure 1.). The driving simulator consisted of three 26-inch ASUS monitors (1920 × 1080) and a Logitech Driving Force GT steering wheel and pedals. Drivers sat approximately two meters away from the front monitor. The monitors simulated the driving environment through front and side windows. Vehicle dynamics were sampled at 60 Hz.

![Figure 1. Setup of the driving simulator with a participant wearing Google Glass](image)
The driving conditions featured a straight three-lane highway. Participants were instructed to follow a lead car, a red Toyota Celica sedan with a width of 1.728m, in the middle lane. The lane-keeping difficulty was manipulated by pairs of cones that were intermittently placed on either side of the center lane (see Figure 2.). The lateral distance between cones in each pair was 3.3m for the difficult lane-keeping condition and 5.3m for the easy lane-keeping condition. The width of the lane was 4m, identical for the easy and difficult lane-keeping conditions. This manipulation was inspired by the work of Liang et al. (2012) who used cones to manipulate driving difficulty in their closed track study. Lateral wind gusts also intermittently caused vehicles to sway simulating natural conditions. The manipulation of the lateral wind was inspired by previous work studying lateral lane keeping performance (Andersen & Ni, 2005; He et al., 2013). The direction of the wind was randomly determined. The strength of the wind followed a delayed exponential distribution, with a range of 2000 to 3000 Newtons. The interval between adjacent lateral wind events was 2.5 to 75 seconds. The same lateral wind existed in both the easy and difficult lane-keeping conditions.

Secondary verbal texting task. Under distracted driving conditions, participants performed a secondary verbal texting app to receive, read, and respond to messages, using either a Samsung touch-screen smartphone (Android) with a 800×480 resolution Super AMOLED™ display or an HMD (Google Glass) with a 640×360 resolution (see Figure 3.). The Google Glass display was placed in front of the right eye, which was adjusted into a comfortable view angle.
(a). Easy Lane Keeping  
(b). Difficult Lane Keeping

Figure 2. Lane-keeping difficulty manipulated by cone distance.

Figure 3. Examples of Smartphone (left) and Google Glass (right)

In the smartphone condition, the phone remained at a marked location on a table between messages. An auditory notification alerted the participant when a message arrived, after which the participant was required to pick up the phone and tap the “Tap to Reply” button (See Figure 4, left panel) to display the message on the phone’s screen. The participant was required to dictate a response to the message verbally, and then tap the “Tap to Send” button (See Figure 4, right
panel). After responding, the participant returned the smartphone to the marked location. This procedure was intended to simulate the process of placing and retrieving a cellphone from the dashboard or console in a vehicle.

In the HMD condition, a notification again alerted the driver when a message arrived. The driver was then required to tap the side of the Google Glass spectacle frame near the right temple to display the message. After the message appeared on the Google Glass screen, participants verbalized their responses before tapping again to send.

Incoming messages were selected at random without replacement from a set of 112 questions. The time interval between messages was sampled from a uniform distribution with a range of 40 to 60 seconds. Participants received about 11 messages during any given task involving the smartphone or HMD. The app, which displayed the texting messages, also recorded participants’ time-to-engagement and time-on-task.

Figure 4. The verbal texting app for Google Glass and Android phone. (Left: participants press “Tap to Reply” button to read the message; Right: participants read the message and press “Tap to Send” button when finish)
The Susceptibility to Driver Distraction Questionnaire (SDDQ) was administered at the end of the experiment (Feng, et al., 2014). The SDDQ is a 39-item tool that compiles self-reported information about distraction engagement, attitudes and beliefs about voluntary distraction, and susceptibility to involuntary distraction. The scale was used with an intent to correlate the susceptibility to distraction in the scale with actual multitasking strategy, more specifically, the time-to-engagement and time-on-task. However, the survey results showed that participants’ responses were mostly either 3 or 4 for the five-option questionnaire, without a wider distribution of responses, which did not allow correlational analysis. Thus, the results of SDDQ scale are not reported or discussed further in the RESULTS section.

2.3 Experimental design

This study employed a within-subject repeated measures design, with Driving Difficulty, Task Load, and text device as factors. Two aspects of data were collected: lane keeping performance and multitasking strategy. To measure lane keeping performance, the dependent variables included: mean and standard deviation of lane position (SDLP), steering reversal rate, and the standard deviation of steering wheel position. The independent variables were Drive Difficulty (Easy versus Hard lane keeping difficulty) and Task Load (Drive-only, Drive + Phone, Drive + Glass). A 3×2 repeated-measures ANOVA with Drive Difficulty and Task Load as factors was performed on each dependent variable.

The mean lane position represents the average position (in meters) that the participants maintained relative to the midline of the center lane. Positive values indicate offset to the right,
and negative values indicate offset to the left. Larger values of the SDLP indicate poorer lane-keeping performance and higher risks of lane departure. Following Ranney et al. (2005) and Tijerina, Kiger, Rockwell, and Tornow (1995), a steering reversal was defined as a change of steering wheel position larger than 2° within the time that steering wheel velocity left and then reentered zero-velocity band. The steering reversal rate was defined as the number of steering reversals per second. Higher steering reversal rates indicate more corrections to steering wheel position, which suggest more effort in maintaining lane position (MacDonald & Hoffman, 1980). Increased standard deviation of steering wheel position implies decreased vehicular control and increased workload (Dingus, 1995; McLaughlin et al., 2009).

Multitasking strategy for texting while driving was assessed using time-to-engagement and average time-on-task per message (Giang et al., 2014; Giang et al., 2015; Liang et al., 2012). Time-to-engagement was measured from the start of the auditory alert that signaled an incoming message until participants clicked the “Tap to Reply” button on the devices (see Figure 4.). Total task engagement time per message was defined as the time period from participants clicked the “Tap to Reply” button until they clicked “Tap to Send” button on the devices (see Figure 5.). Using a 3 × 2 repeated-measures design, the independent variables included Texting Device (smartphone, Google Glass) and Task load (Texting - Only, Drive + Phone, Drive + Glass). IBM SPSS v18.0 was used in the statistical analysis. Bonferroni adjustments were included to correct for multiple comparisons. Mean differences were considered significant at the .05 alpha level.
2.4. Procedure

After granting informed consent and showing proof of a valid driver’s license, participants finished a vision ability test. Only people with at least two years driving experience and a normal vision or corrected vision ability of at least 20/20 were allowed to participate. Afterwards, they completed a demographic survey, asking their age, gender, and driving experience. Each participant practiced driving with the simulator, texting with the smartphone, and texting with Google Glass prior to beginning the experiment for five minutes each. A previous study indicated that after five minutes of practice on Google Glass, texting performance was almost equal to that using an Android (MacArthur, Greenstein, Sawyer, & Hancock, 2014). The practice drive followed a commonly accepted protocol, which train drivers to follow a lead vehicle with a two second headway time (Kubose et al., 2006).

After practicing using the smartphone, Google Glass and the driving simulator, participants completed the experimental conditions. Each task condition lasted for approximately
ten minutes, and the experiment (including time allotted for practice and administering surveys) lasted approximately two hours in total. Each participant completed all eight task conditions, with the order of the conditions counter-balanced using a Latin square design. Upon completion of the experiment, participants were asked to complete the SDDQ scale, then they were debriefed about the purposes of experiment, and rewarded with course credits for their participation.

3. Results

3.1. Driving performance

Initial analyses compared driver performance across conditions to gauge the distracting effects of texting with the smartphone and HMD interfaces.

The mean lane position (as shown in Figure 6) showed a significant main effect of Driving Difficulty, $F(1, 28)= 4.35, p = .05, \eta^2_p = 0.13$, with the Easy conditions ($M = -0.04$ m, $SD = 0.14$ m) producing mean lane position farther left than that of the Hard conditions ($M = 0.01$ m, $SD = 0.11$ m). The main effect of Task Load was not significant, $F(2, 56)= 0.91, p = .41, \eta^2_p = 0.03$, nor was the interaction, $F(2, 56) = 0.05, p = .96, \eta^2_p = 0.002$.

SDLP (Figure 7) showed a significant main effect of Task Load, $F(2, 56) = 12.09, p < .001, \eta^2_p = 0.30$, indicating less lane-keeping variability in the Drive-Only condition ($M = 0.28$ m, $SD = 0.05$ m) than in either the Drive + Phone ($M = 0.33$ m, $SD = 0.08$ m) or the Drive + Glass ($M = 0.33$ m, $SD = 0.06$ m) condition, $t(28) = 3.98, p < .001$ and $t(28) = 4.49, p < .001$. SDLP did not differ significantly between the Drive + Phone and Drive + Glass conditions, $t(28) = 0.60,
$p = .55$. Neither the main effect of Driving Difficulty, $F(1, 28) = 0.57, p = .46, \eta^2_p = 0.02$, nor the interaction, $F(2, 56) = 0.02, p = .99, \eta^2_p = 0.001$, reached statistical significance.

Figure 6. Mean lane position (m). Error bars in all figures indicate within-subject 95% confidence intervals based on the main effect of task conditions (Loftus & Masson, 1994).
Figure 7. The standard deviation of lane position.

Steering reversal rate (Figure 8) showed a significant main effect of Task Load, $F(2, 56)= 24.45$, $p<.001$, $\eta^2_p = 0.47$. Pairwise comparisons showed that the steering reversal rate was lower in the Drive-Only ($M = 0.36 \text{ Hz}, SD = 0.10 \text{ Hz}$) than in the steering reversal rate in the Drive + Glass conditions ($M = 0.39 \text{ Hz}, SD = 0.11 \text{ Hz}$) or the Drive + Phone condition ($M = 0.45 \text{ Hz}, SD = 0.14 \text{ Hz}$), $t(28) = 2.17, p = .04$ and $t(28) = 6.18, p < .001$ respectively. The steering reversal rate in the Drive + Glass conditions was also lower than that in the Drive + Phone conditions, $t(28)$
Data also showed a significant main effect of Driving Difficulty, $F(1, 28) = 24.02, p < .001$, with Easy conditions ($M = 0.38$ Hz, $SD = 0.11$ Hz) producing lower values than Hard conditions ($M = 0.41$ Hz, $SD = 0.11$ Hz). There was no significant interaction effect between Task Load and Driving Difficulty, $F(2, 56) = 1.52, p = .23$, $\eta^2_p = 0.05$.

Figure 8. The steering reversal rate.

The standard deviation of steering wheel position (Figure 9) produced a significant main effect of Task Load, $F(2, 56) = 24.02, p < .001$, $\eta^2_p = 0.46$. Pairwise comparisons showed that the
standard deviation of steering wheel position in the Drive-Only conditions (\(M = 2.17\, ', SD = 0.57\) \('\)) was smaller than that in either the Drive + Phone conditions (\(M = 3.25\, ', SD = 1.40\)) or the Drive + Glass conditions (\(M = 2.80\, ', SD = 0.88\)), \(t(28) = 6.10, p < .001\) and \(t(28) = 5.82, p < .001\) respectively. Additionally, the standard deviation of steering wheel position in Drive + Phone conditions was larger than that in the Drive + Glass conditions, \(t(28) = 2.56, p = .02\). The main effect of Driving Difficulty was also significant, \(F(1,28) = 25.11, p < .001, \eta^2_p = 0.47\), with Easy conditions (\(M = 2.54\, ', SD = 0.92\)) produced significantly smaller standard deviation of steering wheel position than Hard conditions (\(M = 2.94\, ', SD = 0.90\)). The interaction was not significant, \(F(2,56) = 0.87, p = .42, \eta^2_p = 0.03\).
Figure 9: The standard deviation of steering wheel position.

Mean speed (Figure 10) produced a significant main effect of Task Load, $F(2, 56) = 9.01, p < .001$, $\eta^2_p = 0.24$. Pairwise comparisons showed that the mean speed in the Drive-Only conditions ($M = 44.89$ mph, $SD = 1.87$ mph) significantly faster than Drive + Glass ($M = 42.29$ mph, $SD = 3.21$ mph) and the Drive + Phone conditions ($M = 43.37$ mph, $SD = 2.60$ mph). $t(28) = 4.21, p<.001$ and $t(28) = 2.73, p=.01$ respectively. Mean speed in the Drive + Glass conditions did not differ significantly from that in the Drive + Phone conditions, $t(28) = 1.62, p = .12$. No
significant main effect of Driving Difficulty was found, \( F(1, 28) = 1.63, p = .21, \eta^2_p = 0.06 \), nor was a significant interaction, \( F(2, 56) = 0.62, p = .54, \eta^2_p = 0.02 \).

![Figure 10. The mean speed.](image)

The standard deviation of speed (as shown in Figure 11) produced a significant main effect of Task Load, \( F(2, 56) = 37.36, p < .001, \eta^2_p = 0.57 \). Pairwise comparisons showed that the standard deviation of speed was significantly lower in the Drive-Only conditions (\( M = 7.03 \) mph, \( SD = 0.94 \) mph) than in either the Drive + Phone (\( M = 8.90 \) mph, \( SD = 1.21 \) mph) or the Drive +
Glass conditions ($M = 10.21$ mph, $SD = 2.43$ mph), $t (28) = 7.37, p < .001$ and $t (28) = 7.51, p < .001$ respectively. The standard deviation of speed was also smaller in the Drive + Phone conditions than the Drive + Glass conditions, $t (28) = 3.21, p = .003$. Neither main effect of driving difficulty, $F (1, 28) = 0.25, p = .62, \eta^2_p = 0.01$, nor the interaction of driving difficulty by task load, $F (2, 56) = 0.59, p = .56, \eta^2_p = 0.02$, was significant.

![Figure 11](image.png)

Figure 11. The standard deviation of speed.

Table 2 summarizes the driving performance. Texting using an HMD and a smartphone
both impaired lane-keeping performance by increasing the standard deviation of lane position, the steering reversal rate, and the standard deviation of the steering wheel position.

Table 2. Comparisons of driving performance under different driving conditions.

<table>
<thead>
<tr>
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<th>Drive + Glass vs. Drive – Only</th>
<th>Drive + Phone vs. Drive – Only</th>
<th>Drive + Phone vs. Drive + Glass</th>
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<tr>
<td>Mean lane position</td>
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<tr>
<td>Standard deviation of lane position</td>
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<tr>
<td>Steering reversal rate</td>
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<tr>
<td>Standard deviation of steering wheel position</td>
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<tr>
<td>Mean speed</td>
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<tr>
<td>Standard deviation of speed</td>
<td>↑</td>
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Note: ↑ indicates significant increases for the first condition over the second condition in the comparing condition pairs; ↓ indicates significant decreases for the first condition over the second condition in the comparison condition pairs; ≅ indicates no statistically significant change.

3.2. Texting strategy
The mean time-to-engagement (as shown in Figure 12.) did not produce a significant main effect of Task Load, $F(2,56) = 2.24$, $p = .12$, $\eta^2_p = 0.07$, but did show a significant main effect of Texting Device, $F(1,28)= 84.89$, $p<.001, \eta^2_p = 0.75$, qualified by a significant interaction, $F(2,56) = 5.43$, $p = .007$, $\eta^2_p = 0.16$. Simple effects tests explored these effects. When texting with Google Glass, the simple main effect of Task Load was not significant, $F(2,56) = 0.28$, $p = .76$, $\eta^2_p = 0.01$. In contrast, when texting with a smartphone, the simple effect of Task Load was significant, $F(2,56) = 6.55$, $p = .003$, $\eta^2_p = 0.19$, indicating that the time-to-engagement in a smartphone-based texting task increased when they were texting while driving using a smartphone (comparing Texting - Only with a smartphone versus Texting + Easy Drive and Texting + Hard Drive). The time-to-engagement did not vary between the Texting + Easy Drive and Texting + Hard Drive conditions when using a smartphone, which indicates that increasing driving difficulty did not affect time-to-engagement.
Figure 12. Mean time-to-engagement. Error bars in all figures indicate within-subject 95% confidence intervals based on the main effect of texting task load.

The mean time-on-task (Figure 13) showed no significant main effect of either Task Load, $F(2,56) = 1.36, p=.27, \eta^2_p = 0.05$, or Texting Device, $F(1,28) = 1.69, p=.20, \eta^2_p = 0.06$, and no significant interaction, $F(2,56) = 0.52, p=.60, \eta^2_p = 0.02$. 
4. Discussions

As a follow-up of the earlier work on HMD use while driving (He, Choi, et al., 2015; Sawyer et al., 2014), this study compared the impacts of HMD versus smartphone on driving performance, with an emphasis on the multitasking strategy to initiate and engage in a secondary texting task while driving. Both HMD and smartphone impaired driving performance by increasing the standard deviation of lane position (SDLP), the standard deviation of steering
wheel position and the steering reversal rate. These findings raise safety concerns due to the higher risks of lane departure. The standard deviation of speed, an indication of stability of keeping headway distance, was also higher during distracted driving for both Google Glass and smartphone. As a comparison between the two devices, Google Glass might have had less negative impact than smartphone, reflected by smaller standard deviation of steering wheel position and steering reversal rate. These results resonated with previous findings comparing HMD and smartphones (Beckers et al., 2014; He, et al., 2015; Sawyer et al., 2014). This study also reveals one indicator, the standard deviation of speed, was larger in the Drive + Glass conditions than the Drive + Phone conditions, which suggests that HMDs may be more disruptive to driving performance than HDDs in a smartphone. This measurement was not significant between the Drive + Glass and Drive + Phone conditions in a previous study (He et al, 2015), or not measured in several other studies (Beckers et al., 2014; Sawyer et al., 2014; Wu, He, Ellis, Choi, & Wang, 2016). It is important to use diversified matrix and driving scenarios to measure performance so we can have all-sided perspectives on how technologies impact driving performance.

Another important goal for the current study was to investigate drivers’ multitasking strategy by comparing time-to-engagement and time-on-task for different forms of texting interface. HMD users initiated the secondary task more quickly than smartphone users. Additionally, initiation times for HMD users were statistically similar across task conditions, whereas initiation times for smartphone users increased when participants were driving. Shorter time-to-engagement has also been also reported in other wearable devices, like smartwatches.
(Giang et al., 2014). The data confirmed our hypothesis that wearable devices indeed encouraged quicker response to initiate a distraction task for Google Glass than smartphones. The time to initiate a secondary task while driving for smartphone users increased as total task load increased, which showed an anticipatory strategy to accommodate secondary texting task and driving tasks, and this finding is consistent with some of previous studies (such as Schömig et al., 2011). In contrast, the time to engage a secondary task while driving for Google Glass users did not change according to the task load, which showed no cues of anticipatory behaviors for increasing driving difficulty (Horrey & Lesch, 2009). Previous studies have reported mixed finding on whether drivers have anticipatory behaviors to initiate a secondary task or not (Horrey & Lesch, 2009; Schömig et al., 2011). The inconsistency on the existence of anticipatory behavior might be that such behavior depends on the driving difficulty(Liang et al., 2012), the secondary task demand, and the overall multitasking load. Liang and Horrey (2012) reported that drivers could delay initiation of a secondary task when transitioning from low demand to high demand contexts, but not when their driving demand was already high. The current study further elucidated that drivers could exhibit such anticipatory behavior to delay a secondary task when they believed a smartphone was too distracting for driving, but not such behavior if they thought intuitively that Google Glass was just a little bit distracting, or not distracting enough to deserve delaying an important text message(He et al., 2015).

For the time-on-task in a secondary texting task, we did not find difference between HMD and smartphone. If drivers believe HMD is less distracting than a smartphone and there is a need to engage in longer texting or conversation, it is possible that they might spend longer
time on Google Glass. Drivers in current study did not showed a difference in the task duration when using Google Glass or smartphone, perhaps because our secondary verbal texting task did not require longer replies. Future studies can further test the hypothesis that whether a relatively easy texting method can encourage users to texting indulgently and spend longer time. Researchers can consider using a conversation task, a story-retelling task, or destination entry task, which may allow drivers to spend different amount of time on the texting task depending on the driving demand (Becic et al., 2010; Beckers, et al., 2014; Gaspar et al., 2014).

Although Google Glass has been demonstrated to be less disruptive to driving performance (Beckers et al., 2014; He et al., 2015; Sawyer et al., 2014; Young, Stephens, Stephan, & Stuart, 2016); voice recognition and head-mounted display that are embedded to reduce distraction (He et al., 2013; He et al., 2015; Liu & Wen, 2004), if drivers intuitively believe or are frequently told that Google Glass is less disruptive to driving performance than smartphones, frequent use and quick access to Google Glass in actual daily driving may potentially put Google Glass users at higher risks than smartphone users.

And misuse or technology complacency may encourage users to engage more often in a distraction task, or initiate the distraction task quicker, which may eventually reduce or even overshadow the benefits that are brought by the advancement of technology. Thus, it is important to emphasize that although wearable devices, voice recognition and head-mounted display, are designed in a hope to reduce visual and manual distraction and these technologies do work to some extents, however, these technologies are not distraction-free or risk-free (He et al., 2015;
Drivers are discouraged to engage in distraction tasks not just in a smartphone, but also Google Glass and smartwatch, as all these devices impair driving performance.

Future studies shall consider studying the possibility of inattentional blindness for Google Glass usage while driving. Although Google Glass’ head-mounted display can facilitates viewing of the road and the display, however, drivers’ ability to attend to both the road and the transparent display of Google Glass may be limited, causing inattentional blindness or looked-but-failed-to-see error (Clabaux et al., 2012; Hyman, Boss, Wise, McKenzie, & Caggiano, 2010; Krupenia & Sanderson, 2006). For example, two studies have reported that Google Glass users missed more targets (such as lane change signs) than smartphone users (Beckers et al., 2014; Young et al., 2016). Future studies may also consider investigating the impacts of Google Glass on real-world or closed-track driving performance, as existing studies on Google Glass are all based on driving simulation.

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