Post and During Event Effect of Cell Phone Talking and Texting on Driving Performance—A Driving Simulator Study

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Objective: A number of studies have been done in the field of driver distraction, specifically on the use of cell phone for either conversation or texting while driving. Researchers have focused on the driving performance of drivers when they were actually engaged in the task; that is, during the texting or phone conversation event. However, it is still unknown whether the impact of cell phone usages ceases immediately after the end of task. The primary objective of this article is to analyze the post-event effect of cell phone usage (texting and conversation) in order to verify whether the distracting effect lingers after the actual event has ceased.

Methods: This study utilizes a driving simulator study of 36 participants to test whether a significant decrease in driver performance occurs during cell phone usage and after usage. Surrogate measures used to represent lateral and longitudinal control of the vehicle were standard deviation (SD) of lane position and mean velocity, respectively.

Results: Results suggest that there was no significant decrease in driver performance (both lateral and longitudinal control) during and after the cell phone conversation. For the texting event, there were significant decreases in driver performance in both the longitudinal and lateral control of the vehicle during the actual texting task. The diminished longitudinal control ceased immediately after the texting event but the diminished lateral control lingered for an average of 3.38 s. The number of text messages exchanged did not affect the magnitude or duration of the diminished lateral control.

Conclusion: The result indicates that the distraction and subsequent elevated crash risk of texting while driving linger even after the texting event has ceased. This finding has safety and policy implications in reducing distracted driving.

Keywords: distracted driving, driving simulator, cell phone effect, driver performance, lateral control, longitudinal control

Introduction

Driver distraction continues to be the focus of scientific inquiry as various bodies, including government agencies, traffic safety advocacy groups, and law enforcement agencies, continue to increase public awareness of its traffic safety risks. Currently, 41 U.S. states have banned texting while driving but only 12 U.S. states prohibit all handheld cell phone use while driving. According to the U.S. Department of Transportation, in 2011, 3,331 people were killed and 387,000 people were injured in motor vehicle crashes involving a distracted driver, compared to 3,267 people killed and 416,000 injured in 2010 (www.distraction.gov). The use of cell phones and other electronic devices has been acknowledged to be one of the causes of distracted driving, with an estimated 660,000 drivers involved in such activity while driving at any given moment in the United States (Pickrell and Ye 2013). Though the percentage of drivers using handheld cell phones remained constant at 6% from 2009 to 2011, the percentage of drivers texting during driving or visibly manipulating handheld devices increased from 0.6 to 1.3% during the same time period (Pickrell and Ye 2013).

In considering cell phone conversation, several studies using a driving simulator and naturalistic studies have reported its increased crash potential when combined with the primary task of driving due to its negative impact on driving performance (Rakauskas et al. 2004; Rosenbloom 2006; Strayer et al. 2004). Notwithstanding these findings, several others have found hands-free cell phone conversation to have no significant effect on driver performance during driving (Briem and Hedman 1995; Parkes and Hooijmeijer 2001; Törnros and Bolling 2005). Yet a recent study by Fitch et al. (2013) concluded that neither handheld nor hands-free conversation increased the risk of a crash. This may be one of the reasons why there is no consistency among different U.S. states in legislation governing cell phone use during driving.
On the contrary, texting while driving is considered to have the highest level of distraction potential for all cell phone uses (Ranney et al. 2011) and has been found to negatively affect driver performance (Drews et al. 2009; Hallett et al. 2012; Owens et al. 2011; Rudin-Brown et al. 2013; Young et al. 2006).

All of the studies found in the literature focused on the distracting effect (cognitive, manual, or visual) of activities such as texting during the time of activity itself. Though drivers are known to be distracted during the execution of such activities, it is believed that some activities may have a prolonged effect on distracted driving; that is, drivers continue to experience signs of distraction even after such activities are ceased. This is because some drivers may not be able to regain their normal cognitive skills immediately after they terminate such activities. It is believed that drivers may need a recovery period, however short it may be, to return to normal driving tasks. However, no research has been identified that attempted to address this safety issue. This study therefore attempts to investigate the extent of prolonged distraction on driving performance in order to capture the overall effect of such activities. This clearly magnifies the adverse impact of engaging in such activities during driving in terms of safety. Specifically, this study seeks answers for the following research questions:

- Is there evidence of a post-event distracting effect of cell phone usage on driving performance?
- If there is post-event distracting effect, then how long after the main event does this last?
- Is the level of distraction during the main event the same as that experienced post-event?
- Does the intensity of the main event influence the level of the distracting effect?
- Does the intensity of the main event influence the duration of the post-event distracting effect?

The following section contains a description of the methods used in the study, followed by the results and then a discussion of the findings.

**Methods**

**Driving Simulator**

Participants were tested in the Louisiana State University (LSU) driving simulator, a full-sized passenger car (Ford Fusion but with no wheels) combined with a series of cameras, projectors, and screens to provide a high-fidelity virtual environment. Figure 1 shows pictures of one side of the LSU driving simulator and some of its series of computer screens.

**Participants**

A total of 36 participants from the LSU community of students and staff members including 6 females and 30 males with an average age of 28.44 years (SD = 9.26 years) participated in the experiment. Overall, 42 were recruited but 6 were unable to fully participate because of simulator sickness, leading to an uneven distribution of participants among the 3 groups. All were in good general health with normal or corrected visual acuity, were active drivers with a valid driver’s license, and had prior experience using a cell phone for texting and having a conversation while driving. They were recruited using flyers on university bulletin boards and in accordance with the university’s Institutional Review Board’s standards.

**Experimental Design**

The experiment was designed as a 3 × 8 repeated measures design with duration of the event as a between-subjects factor (3 levels) and event as within-subjects factor (8 levels including phone conversation event and corresponding no-distraction drives; texting event and corresponding no-distraction drives; post–phone conversation event and corresponding no-distraction drives; and post-texting event and corresponding no-distraction drives). The average time for a participant to complete the entire experimental procedure was 60 min. Each of the 36 participants performed all 8 events under identical traffic conditions. Three groups were created randomly to account for the between-subjects factor. Group A had 11 participants, exchanged a single text message, and spent 90 s on a phone conversation. Group B had 13 participants, exchanged 4 text messages, and spent 150 s on a phone conversation. Group C had 12 participants, exchanged 7 text messages, and spent 210 s on a phone conversation.

**Procedure**

The first part of the experiment, “the pre-event” stage, consisted of participants being briefed on the experiment, signing the consent sheet, randomly selecting the order of events (no distraction, phone conversation, and texting), and practicing with the simulator until such time that they became familiar with its operation.

The second part of the experiment, “the main event” stage, consisted of the actual test. Participants were asked to drive as they would normally on their way to work or college but to always stay in the right lane, avoid changing lanes or overtaking, and maintain a consistent following distance that they considered as safe. The test route consisted of a divided 4-lane straight road as per NHTSA guidelines. It had a solid double yellow line down the center, solid white lines on the outside edges, dashed white lines separating the 2 standard 3.7-m-wide lanes that go in each direction, and was on a flat grade. The other vehicles in the simulated environment drove
at about 65 mph, which was the posted speed limit. Participants used their own cell phones (all had touch-pad surfaces) for all tasks. Data collection began when a participant picked up the phone and ended when the phone was returned to its original location. Phone conversation dwelled on questions on participant’s personal details, job or school commitments, and observations on the experiment set up. A transcript of the text messages sent to participants is included as Appendix 1 (see online supplement).

The third part of the experiment, “the post-event” stage, refers to the time period immediately after the end of the main event. For both the texting and phone conversation events, data collection for the post-event began after participants had returned the phone to the original position and ended after a full minute. For the no-distraction event, data were collected for a duration based on a judgment on the typical duration for the other events.

Data Collection

Data were collected on each participant’s lane position and speed for all of the drives at 60 Hz. The standard deviation of lane position and the mean speed were calculated for each participant along specific segments of the route so that each participant had a single observation for each variable and for each event to allow for direct comparison. Previous studies have used similar methods for lane position (Caird et al. 2008; Drews et al. 2009; Holland and Rathod 2013; Törnros and Bolling 2005) and mean speed (Rakauskas et al. 2004; Schattlet et al. 2006; Törnros and Bolling 2005). Because the objective of this study is to measure the variability of the driving performance in the lateral direction and the change in the overall speed in the longitudinal direction, it was deemed appropriate to use mean of velocity and standard deviation of lane position as the performance measures. The resulting variables for each of the drives were as follows:

- \( \sigma_{LO,PC} \): standard deviation of lane position during the phone conversation event
- \( \sigma_{LO,TXT} \): standard deviation of lane position during the texting event
- \( \sigma_{LO,ND,PC} \): standard deviation of lane position during the no-distraction phone conversation event
- \( \sigma_{LO,ND,TXT} \): standard deviation of lane position during the no-distraction texting event
- \( \bar{X}_{V,PC} \): mean velocity during the phone conversation event
- \( \bar{X}_{V,TXT} \): mean velocity during the texting event
- \( \bar{X}_{V,ND,PC} \): mean velocity during the no-distraction phone conversation event
- \( \bar{X}_{V,ND,TXT} \): mean velocity during the no-distraction texting event

Statistical Analysis

The PROC MIXED procedure (linear mixed model) in SAS was the analysis tool employed to account for the correlation in observations resulting from the same participants experimenting in all of the drives or 8 events. Participants were used as the subject for the random option. All data were first tested at a 1% significance level to ensure that the normality assumptions of the tests were not violated. For nonnormal data, negatively skewed data were cube or square root transformed, and positively skewed data were log or squared transformed. To analyze the post-event effect, F-tests for the equality of variance were performed. All tests were performed using SAS 9.3 at a 5% level of significance. For the main event, the hypothesis was that if the treatment condition under study had no effect, then the mean variability (specifically, the standard deviation of lane position and mean velocity) under that specific treatment condition (phone conversation or texting) would be the same as that under the no-distraction event and, hence, the difference between these means would be zero. For the post-event, the 1-min data collected after the main event were first segmented into 1-s intervals so that \( \sigma_{LO,TXT}(i,t) \) and \( \bar{X}_{V,.TXT}(i,t) \) respectively represent the SD of lane position and mean velocity variables for participant \( i \) during a specific 1-s time interval \( (t) \) after the texting event; \( \sigma_{LO,PC}(i,t) \) and \( \bar{X}_{V,PC}(i,t) \) are the corresponding data for the phone conversation task; \( \sigma_{LO,ND,TXT}(i,t) \) and \( \bar{X}_{V,ND,TXT}(i,t) \) are the corresponding data for the no-distraction drive during the no-distraction texting event; and \( \sigma_{LO,ND,PC}(i,t) \) and \( \bar{X}_{V,ND,PC}(i,t) \) are the corresponding data for the no-distraction drive during the no-distraction phone conversation event. An F-test for equality of variances can be performed for each of the 36 participants to check for statistical evidence of a post-event effect to determine how long such effect lasts. The F-test was performed for each subsequent 1-s interval following the texting and phone conversation events for 60 s because this time interval was considered a reasonable maximum post-event time that any distraction could still be linked to the main event without possible intrusion of other distraction sources. The 1-s interval was chosen because the driving simulator is able to provide 60 data points during a second interval, and this sample size was considered sufficient to allow a time-step analysis to check for evidence of lingering distraction. Results of the F-tests are presented in the Post-Event Analysis section.

Analysis of Results

Attributes of Surrogate Measures

In addition to the derived variables, 4 variables were calculated for each participant as follows:

\[
\begin{align*}
\Delta \sigma_{LO,PC} &= \sigma_{LO,PC} - \sigma_{LO,ND,PC} \\
\Delta \bar{X}_{V,PC} &= \bar{X}_{V,PC} - \bar{X}_{V,ND,PC} \\
\Delta \sigma_{LO,TXT} &= \sigma_{LO,TXT} - \sigma_{LO,ND,TXT} \\
\Delta \bar{X}_{V,TXT} &= \bar{X}_{V,TXT} - \bar{X}_{V,ND,TXT}
\end{align*}
\]

The variables \( \Delta \sigma_{LO,PC} \) and \( \Delta \sigma_{V,PC} \) represent the difference between the single values obtained for the phone conversation variables and no-distraction variables, and \( \Delta \sigma_{LO,TXT} \) and \( \Delta \bar{X}_{V,TXT} \) represent the difference between the texting variables and no-distraction variables. Figure 2 shows an
aggregate plot of these surrogate measures of distraction for all participants.

It can be observed that, overall, there were more instances of negative values obtained for $\Delta \bar{X}_{\text{VEL}}$ and $\Delta \bar{X}_{\text{TXT}}$, indicating that the mean velocity of participants was higher during the no-distraction event. This trend seems to agree with what is generally accepted; that is, that distracted driving usually results in reduced mean speeds. It can also be observed that there were more instances of positive values than negative values for $\Delta \bar{X}_{\text{LO}}$ and $\Delta \bar{X}_{\text{TXT}}$, indicating that the no-distraction event had lower values of average SD of lane position. Again, this trend seems to agree with the general observation that distracted drivers produce larger lane position variability as they tend to waver more in their lanes.

**Post-Event Analysis**

This analysis was undertaken to provide answers to the first 2 research questions; that is, whether there is evidence of a post-event distracting effect and how long it lasts.

**Post-Phone Conversation Event**

The hypotheses tested for the mean velocity variable were $H_0: \sigma_{\text{VEL,PC}}^2(i, t) = \sigma_{\text{VEL,ND,PC}}^2(i, t)$ vs. $H_A: \sigma_{\text{VEL,PC}}^2(i, t) > \sigma_{\text{VEL,ND,PC}}^2(i, t)$; the hypotheses tested for the mean duration were $H_0: \sigma_{\text{VEL,PC}}^2(i, t) = \sigma_{\text{ND,PC}}^2(i, t)$ vs. $H_A: \sigma_{\text{VEL,PC}}^2(i, t) > \sigma_{\text{ND,PC}}^2(i, t)$. Similar to the phone conversation event, Figure 4 shows the aggregated distribution of the time periods that participants showed significant differences in the post-event analyses of the texting event. For the SD of lane position variable, for the first second after the main event elapsed, all participants continued to show a significant distracting effect. The majority (56%) showed a significant effect duration of 1.5 s and a mean duration of 3.38 s. It can therefore be concluded that there is evidence of a post-event distracting effect of cell phone conversation on driving performance. Research questions 2 to 5 are therefore no longer applicable to the phone conversation task.

**Post-Texting Event**

The hypotheses tested for the mean velocity variable were $H_0: \sigma_{\text{VEL,PC}}^2(i, t) = \sigma_{\text{VEL,ND,PC}}^2(i, t)$ vs. $H_A: \sigma_{\text{VEL,PC}}^2(i, t) > \sigma_{\text{VEL,ND,PC}}^2(i, t)$; the hypotheses tested for the mean velocity variable were $H_0: \sigma_{\text{VEL,TXT}}^2(i, t) = \sigma_{\text{VEL,ND,TXT}}^2(i, t)$ vs. $H_A: \sigma_{\text{VEL,TXT}}^2(i, t) < \sigma_{\text{VEL,ND,TXT}}^2(i, t)$. Similarly, for the mean velocity variable, for which the mean duration was found to be 0.86 s, a majority (55%) of the participants showed no post-event effect. Because there were no significant effects during the main event, and the majority of participants also showed no effects for the post-event task, it may be prudent to conclude that the results indicate that there is no evidence of an overall post-event distracting effect of cell phone conversation on driving performance.
definitive evidence of an overall post-event distracting effect of cell phone texting on the longitudinal control of the simulator. Research questions 2 to 5 are therefore no longer applicable to the mean velocity variable of the texting task.

**Statistical Model Description**

The model designed in SAS was based on 6 conditions (phone conversation event and corresponding no-distraction event, texting and corresponding no-distraction event, and post-texting event and corresponding no-distraction event); 3 groups (A, B, and C); 1 driving performance measure (standard deviation of lane position); and duration (a continuous variable showing the duration of the post-texting effect of each participant).

Linear mixed modeling was used to model the effects of the explanatory variables (condition, group, and duration) on the response variable SD of lane position. The factors condition and group were included in the model as classification variables. Together with duration, these variables were included in the model as fixed effects. A random effect for participant was included in the model to account for potential correlation among the responses for a given participant. Each participant belonged to a particular group, and each of the 6 responses (SD of lane position) for a participant corresponded to the 6 conditions. A model-building approach was used to assess the significance of model effects and reduce model complexity by removing in stepwise fashion nonsignificant effects. The initial full model included main effects for condition, group, duration, as well as their 2- and 3-way interactions for each of the response variables. The nonsignificant interaction effects that were removed were Condition * Group * Duration ($P = .5287$), Condition * Group ($P = .7287$), Duration * Group ($P = .4002$), and Condition * Duration ($P = .0935$). In addition, the main effect of the measured explanatory variable duration was found to be nonsignificant ($P = .3010$) and was removed also. The group main effect, though nonsignificant ($P = .3586$), was retained in the final model because it was considered a design factor. The final model included the main effects for condition and group and showed a significant variability among participants ($P = .0025$), confirming that it was necessary to assign participant as a random effect in the model. The main effect for condition was significant ($P < .0001$), but the main effect for group was not significant ($P = .3305$). This final model was used to answer the remaining research questions and are presented below.

**Main Effect of Phone Conversation and Texting**

The hypotheses tested on the SD of lane position variable were $H_0 : \Delta \sigma_{LO} = 0$ vs. $H_A : \Delta \sigma_{LO} > 0$.

**Phone Conversation**

The results, $t(174) = 0.02, P = .9876$, showed no significant effect of cell phone conversation on the driving performance of the participants during the main event.

**Texting**

The results, $t(174) = 6.41, P < .0001$, showed significant effect of texting on the driving performance of participants during the main event.

**Comparison of During and Post-Event Level of Distraction**

This analysis was undertaken on the SD of lane position variable for the texting event to provide answers to the third research question; that is, whether the level of distraction during the main event is the same as that experienced during the post-event. The hypotheses tested were $H_0 : \Delta \sigma_{LO, TXT} = \Delta \sigma_{LO, TXT}(t)$ vs. $H_A : \Delta \sigma_{LO, TXT} > \Delta \sigma_{LO, TXT}(t)$, where $\Delta \sigma_{LO, TXT}$ represents the magnitude of the main event level of distraction and $\Delta \sigma_{LO, TXT}(t)$ represents that for the post-event such that

$$\Delta \sigma_{LO, TXT}(t) = \Delta \sigma_{LO, TXT} - \Delta \sigma_{LO, ND, TXT}(t), \quad (5)$$

where $t$ refers to the interval between the completion of the texting event and 3 s after, chosen because the distracting effect ceases to be significant after an average of 3.38 s. The results, $t(174) = 2.54, P = .0120$, suggest that the level of distraction experienced by participants during texting was significantly higher than the few seconds after texting had ceased. However, the previous analysis shows that even at this reduced post-event effect, participants showed increased lateral deviations compared to a no-distraction drive.

**Effect of Intensity of Event on Level of Distraction**

This analysis was undertaken to provide answers to the fourth research question; that is, to determine whether the intensity of texting (characterized by the number of text messages exchanged) influenced the level of distraction during the actual texting event and, secondly, during the 3 s after the texting event. The overall interaction effect of condition by group was nonsignificant, $F(10,159) = 0.69, P = .7287$. Therefore, it was not found that the intensity of texting influenced either
the actual texting event or the critical few seconds after the texting event had ceased.

Effect of Intensity of Event on Post-Event Duration of Distraction

This analysis was undertaken to provide the answer to the last research question; that is, to determine whether the intensity of the main event influenced the duration of the post-event distracting effect. The duration of the post-event distracting effect for each participant, as shown in the SD of lane position variable of Figure 4, was partitioned into the 3 groups A, B, and C. Group comparisons were then performed to check whether the group means were identical or not. The result was nonsignificant, \( F(2, 159) = 0.92, P = 0.4002 \), so it was not found that higher intensities of the texting influenced the duration of the post-event distracting effect.

Post hoc Analysis of Sample Size

Following on the analysis, G-power 3.1 software (Faul et al. 2007) was used to verify whether the sample size utilized for the study was adequate to give enough power. Due to the nonsignificant effect of the mean velocity variable, it was used to calculate the effect size because its effect size was smaller than the significant effect of the SD of lane position variable. The effect size is calculated based on an equality of variance test for the texting and no-distraction drives. Figure 5 shows the different sample sizes that will correspond to an expected test for the texting and no-distraction drives. It can be seen that a sample size of 36, as used for the study, generates a power of almost 95%. Therefore, the sample size utilized for the study is deemed suitable.

Discussion

In summary, being engaged in a handheld cell phone conversation while driving did not negatively affect driving performance. However, this could be as a result of the nature of the conversation itself and its impact on the driver’s mood. Intuitively, conversations that involve significant cognitive effort such as retrieval of information from memory and other emotional and distressing types will have higher impact on a driver’s concentration levels than a normal conversation would. In this study, however, participants were engaged in normal conversation that did not cause any distress and, consequently, no significant impact was detected. On the contrary, the results of this study suggest that texting while driving resulted in significant lateral deviation from what would be observed when not distracted. This seems to agree with previous studies.

Additionally, the results of the study suggest that only the significant lateral deviations from texting lingers for an average duration of 3.38 s after the texting activity had ceased. This equates to a post-event effect lingering for a distance of nearly 100 m (322 ft) for a vehicle traveling at 29 mps (65 mph). The observation could be attributed to the fact that texting involves more visual demand than a cell phone conversation. The residual effect of readjusting the eyes onto the road from the phone could be what is observed as the lingering effect. Interestingly, the results also suggest that the intensity of the main event, in this case represented by the number of text messages exchanged, does not affect the distraction levels experienced by drivers during and after the texting event. Likewise, the intensity of the main event does not affect the duration of the post-event distracting effect. These results suggest that drivers who are distracted momentarily, as in responding to a single text message, could be potentially as dangerous as being engaged in prolonged distraction such as continual text messaging. Findings from this study lend credence to the many bodies that support the ban on texting while driving.

It is recommended that future research analyze the effect on other additional variables. It will be interesting to see the results from a multivariate analysis that incorporates several dependent variables rather than the univariate analysis used in this study. Another study that can be undertaken is to determine whether the posted speed limit has any effect on the post-event distracting effect. Future research can also utilize a much larger sample size to investigate the effect of age on the duration of the post-event effect, because it is well known that older drivers tend to struggle more with visual and cognitive tasks. Further, the current research was based on a simulation study; that is, using a driving simulator. It will be interesting to investigate whether a naturalistic driving experiment will produce similar findings. Again, the current study was limited to cell phone usage, particularly texting and talking. However, there are numerous distracting sources that are assumed to have a major impact on driving performance. The post-event effects of those distracting sources are appropriate areas to conduct future research.

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Supplemental Materials

Supplemental data for this article can be accessed on publisher’s website.
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