

Effects of Cell Phone Conversations and Device Manipulation on Objective Measures of Driving Performance

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Abstract

The main purpose of this study is two-fold: first to evaluate how different levels of cell phone use, or engagement, impact driving performance, and second to estimate whether drivers self-regulate the use of cell phones while driving. Naturalistic driving data from the Integrated Vehicle-Based Safety Systems Field Operational Test with 108 drivers were used for identifying cell phone use while driving and corresponding driving performance. Five second clips were selected from the data set when both cell phones were in use (visual-manual task or cell phone conversation) and were not in use (baseline). Three measures of driving performance were used in this analysis, Mean following distance and standard deviation of following distance, Standard deviation of lateral position within the lane. Mixed linear regression models were used. Results suggest that visual-manual tasks, as compared to cell phone conversations and baseline conditions, result in significant degradation in driving performance. Whereas simply engaging in a cell phone conversation had no effect on lane keeping performance, and only effected following behavior for older drivers.

Introduction

In recent years, distracted driving has become a major topic of consideration and research in traffic safety. Although distractions have always been present, the increase in telematics and infotainment devices in recent years has offered new competition for drivers' attention. According to the latest U.S. government data (NHTSA 2012), in 2010, 3,092 people were killed in crashes involving all types of driver distractions (9% of total fatalities) and an estimated 416,000 were injured in police reported distraction-affected crashes involving distractions of all types. In spite of the increase in portable electronic devices and in-vehicle telematics, the percentage of injured people in distraction-affected crashes involving all sources of distraction has remained relatively constant (about 19%) between 2006 and 2010 (the latest 5 years of government records analyzed) and NHTSA (2012: p. 4) reports that "...the number of people injured in distraction-affected crashes has fallen from 503,000 to 416,000, a 17 percent decline (compared to a 13% decline in the number of people injured overall during this time period)." . Additionally, in 2010, fatalities in the United States fell to their lowest levels in recorded history (NHTSA 2011). While much remains to be done, highway safety is improving even as telematics systems and portable device technologies advance and proliferate.

The literature on distracted driving often focuses on cell phones because their use is thought to be relatively easy to identify, and their use is often associated with nearly the entire driver population. In addition, use of a cell phone while driving can be regulated, as has been done in certain states and local jurisdictions. Unfortunately, the actual

association between cell-phone use by drivers and instances of crashes, or near crashes, has become a contentious issue where it is often difficult to find a rational assessment of scientific results. A wide variety of approaches, ranging from laboratory studies to analyses of real-world crash data, have regularly provided inconsistent, even conflicting results. While many, but not all, studies of cell phone use while driving suggest an increase in crash risk, real world crash rates are decreasing all the while that cell phone use is increasing, or at least remaining constant (NHTSA 2013). This conundrum has led to theory that self-regulation of cell-phone use by drivers might be ameliorating any impact of cell-phone use on crashes (IIHS 2010), among others factors. Prior research on self-regulation in driving has focused primarily on older drivers. Older drivers have been shown to self-regulate, enabling them to remain active as drivers but reducing their exposure to driving conditions that they find difficult (Baldock, Mathias, Mclean, Berndt 2006; Stalvey and Owsley 2000).

Where Funkhouser and Sayer (2012) reported cell phone use patterns under naturalistic driving conditions, the present study examines driving performance when using cell phones—attempting to further understand any link between cell phone use and crash risk. Two common indicators of driving performance were examined from a data set of naturalistic driving behavior in order to compare driving performance between when a cell phone was, and was not, in use. The main purpose of this study is of two-fold: first to evaluate how different levels of cell phone use, or engagement, impact driving performance, and second to estimate whether drivers self-regulate the use of cell phones while driving.

Method

Video data from the Integrated Vehicle-Based Safety Systems Field Operational Test (IVBSS FOT) (Sayer, Bogard, Buonarosa, LeBlanc, Funkhouser, Bao, Blankespoor, and Winkler 2011) was coded manually for instances of cell phone use while driving, including cell phone conversations and visual/manual interactions with a cell phone. Five second clips were pulled from the data set when both cell phones were in use and were not in use (baseline). Driving performance measures from events when a cell phone was in use were compared to driving performance from baseline events.

This study examines driver performance both while using a cell phone and not using a cell phone. Two measures of driving performance were used in this analysis:

- Car following behavior: Mean following distance and standard deviation of following distance
- Lane keeping behavior: Standard deviation of lateral position within the lane.

Naturalistic Data

As part of the Integrated Vehicle-Based Safety Systems Field Operational Test (IVBSS FOT), 108 participants drove instrumented vehicles (2006/2007 passenger cars) for 6 weeks each. While not purely naturalistic in nature, specifically these were not participants' personal vehicles and behaviour was knowingly being monitored, the type and frequency of overall behavior on the part of participants strongly suggests that they are not actively considering the presence of the monitoring equipment. For the first two weeks of the FOT the vehicles behaved like standard sedans, however, in weeks 3

through 6 the participants drove with an integrated suite of collision warning systems enabled. Only data from the first week of participation was used in this analysis, and therefore the activation, or potential activation, of the integrated warning systems would not have altered the participants driving behavior. Data was recorded continuously, at 10Hz, during all six weeks, with over 600 channels of numerical data and 5 on-board cameras recording video data both inside and outside of the car. There were no audio recordings of conversations with passengers or on cellular phones. Participants were fully informed of the data recording and the camera locations, in addition to being trained in the operation of the integrated warning system.

Participants

Participants were a stratified, random sample of licensed drivers from eight counties in southeastern Michigan. This region includes the urban areas of Detroit, the suburbs of Detroit, and the surrounding rural areas. Participants were selected based on demographics and qualified based on their estimated annual miles driven being within at least 25 percent of the mean annual miles driven for their age and gender cohorts nationally. Participants were evenly divided by gender and into 3 age groups, “Younger” (20-30 years old), “Middle-aged” (40-50 years old), and “Older” (60-70 years old). Each gender/age group pair contained 18 individuals.

Cell Phone Event Video Review

After the FOT was completed, trained reviewers watched every moment of video from the first week of driving for all 108 participants. The video data was scored specifically for cell phone usage, including phone calls (referred to here as “conversations”) as well as any manipulation, or reading, of the cell phone while driving. Interactions with the phone that were not conversations are henceforth referred to as Visual/Manual, or VM, tasks. VM tasks included manipulating the keys or the touch screen on the phone (to dial, text, email, etc.), or looking away from the road at the phone screen when the phone was in hand. Simply reaching for the phone, having the phone on the lap, or held in the hand (with no manipulation or glances) was not considered a VM task. Also, the simple act of answering a call or hanging up a call, provided it was done quickly (as it was in general) was not scored as a VM task. However, a participant studying the caller ID before answering or immediately looking at the screen at the completion of a call would be considered a VM task. Anything less taxing (i.e. one button press to answer or to hang up, often without looking at the device) was not coded as a VM task. Conversations or VM tasks observed at the start or end of an ignition cycle were specifically scored as such, however no distinction is made in this analysis.

A conversation was logged when the participant was holding the phone to their ear, or clearly speaking into/listening to a handheld device on speakerphone. Additionally, some participants frequently were observed in conversation employing a hands-free earpiece. These conversations were more difficult to score. However, based on the video reviewers’ familiarity with each participant’s behavior, it was fairly clear when a participant was engaged in a hands-free call versus simply wearing the earpiece. In these hands-free cases clues about the scenario (whether there were passengers) and clues from the participants’ expressions and mannerisms were used to determine if they were actually engaged in a phone conversation as opposed to a conversation with a passenger. Often participants manually answered or hung up after these conversations,

and these actions provided further clues on the nature of the participants' hands-free behavior.

After being coded for the use of a cell phone, the associated time series data representing driving performance was analyzed. Initially, attempts were made to separately analyze dealing the phone versus other types of manipulations, but it was determined to be both difficult, and potentially inaccurate, given the camera positioning and range of lighting conditions. Therefore, all visual/manual interactions are grouped together and referred to as "VM tasks."

Clip Selection Criteria

Five-second duration samples of time series data representing driving performance were pulled for both cell phone-associated and baseline periods of driving. The baseline periods may include other, non-cell-phone related, secondary tasks occurring within them (i.e., engaging in a conversation with a passenger, eating, grooming, etc.). While the baseline sample cannot be described as not purely "undistracted" driving, it is assumed to be representative of what people normally do while driving. Therefore, the comparisons discussed here are between driving with "cell phone use" (differentiating between conversations and VM interactions) and driving without "no cell phone in use" (all other driving including a variety of common secondary behaviors).

Baseline clips were selected from any data which was not associated with cell phone use. Additionally, for data to be included in the baseline set, the vehicle must be on public roads, and over the five second clip must have a minimum velocity of not less than 6m/s (13 mph). Baseline five second clips were also required to have come from a trip in which the vehicle exceeded 25 mph at least once. This constraint was included to eliminate very short, largely unrepresentative trips from the data set.

Baseline data were only pulled from drivers who had some cell phone conversation events when being compared to cell phone conversation data, and only from drivers who had some VM tasks observed when being compared to VM task data. As fewer drivers engaged in VM tasks than in cell phone conversations (e.g., picking up and engaging an incoming call would not have much if any VM activity), the baseline set for comparison with VM tasks is smaller than the baseline set used for comparisons with the conversation events.

For any analysis of the driving performance to be valid, the driver and the vehicle must be in a relatively steady-state for the duration of the 5 second clip. For each performance measure the constraints used to select the baseline data set were slightly different in order to ensure that the driving performance measure of interest was not influenced by transient events, and that the driver was truly in a "steady state." Finally, all clips from the baseline set were required to be at least 1 minute apart in order to increase the independence of the samples. The constraints on the baseline clip selection for each performance measure are presented below.

Following Behavior

- Must be same lead vehicle present for +/- 5 sec on each side of clip
- No brake use
- Mean headway as an independent variable
- Range rate < +/-2m/s

Lane-Keeping Behavior

- No lane change (for +/- 5 sec on each side of clip)
- Not in a curve (for +/- 5 sec on each side of clip)
- 100% confidence in lane tracking
- Known boundaries in lane tracking
- Brake use as a independent variable

Cell Phone-associated Clip Selection

Cell phone-associated clips were selected from sections of data during which the driver was either engaged in a cell phone conversation or manipulating the cell phone. In order to attempt to achieve steady state cell phone use, only cell phone events (of either type) lasting longer than 30 seconds were considered when selecting five second clips for analysis. All selected cell phone event clips must have corresponding baseline clips that match on driver, roadway type, traffic density, time of a day, wiper state and traffic rush hour.

Specific analysis was done to determine whether selecting five second clips from the beginning, middle, or end of cell phone events affected the driving performance measures of interest, and no difference was found between clips from the three different temporal locations. To reduce the time depending effect, a 15 second-long time interval was required between two consequent five-second clips pulled during each cell phone event.

Data Analysis and Results

Results from both inferential and descriptive data analysis are presented. For the inferential statistical analysis, mixed linear regression models were used with many independent factors represented in the analysis to attempt to impart structure on what is an otherwise uncontrolled, naturalistic data set. The seven fixed effect factors that were included in the analysis were:

- Road type (surface street, highway)
- Day/Night (before or after civil twilight)
- Windshield Wipers On / Wipers Off
- Traffic Density (1,2,3 = most dense)
- Traffic Rush Hour (6am to 9am or 4pm to 7pm) / Non-Rush Hour (9am to 4pm or 7pm to 6am)
- Age Group (younger(20 – 30 years), middle-aged (40 – 50 years), or older (60 – 70 years))
- Gender (male or female)

Driver effects, and interactions between driver and any fixed effects, were treated as random effects. This accounts for within-subject variance from repeated observations from the same driver, and effectively compares a driver to him/her self. Considering driving speed may also have effects on the dependent variables, driving speed it was included in the model as a covariate.

Following Behavior

Mean and standard deviation of headway were evaluated for all 5-second event and baseline clips, and used as dependant variable in the analysis. A total of 6,922 clips were used for this analysis, and distribution is shown in Table 1.

The analysis of mean following distance showed statistically significant main effects for cell phone use ($F(2, 106)=16.8, p<0.05$), age group ($F(2, 98)=15.22, p<0.05$), gender ($F(1, 89)=3.95, p<0.05$), road type ($F(1, 74)=16.01, p<0.05$), day or night ($F(1, 52)=8.11, p<0.05$), and traffic density ($F(2, 105)=23.61, p<0.05$). Pair-wise comparisons of car following data showed that drivers had a higher mean following distance value during VM tasks when compared to both cell phone conversations and baseline conditions ($t(181)=3.89, p<0.05$; $t(163)=5.68, p<0.05$). The mean car following distances were 47.84 meters, 40.81 meters, and 37.98 meters when engaging in VM tasks, cell phone conversations, and baseline conditions, respectively. It was also observed that mean car following distances increased with driver age. Younger drivers had significantly shorter following distances (mean=34.98 m) than both middle-aged ($t(82)=4.00, p<0.05$; mean=43.78 m) and older drivers ($t(109)=5.01, p<0.05$; mean=47.94 m). No significant differences were observed between middle-aged and older drivers. Male drivers had significantly shorter following distances than female drivers (mean=40.27 m and mean=44.15 m, respectively). Significant longer mean following distances were observed for night time driving compared to daytime driving (mean=43.95 m and mean=40.48 m, respectively), and mean following distances were found to decrease with increasing traffic density (mean=46.37 m under sparse traffic; mean=41.36 m under moderate traffic; mean=38.92 m under dense traffic conditions).

Table 1 **Number of clips in each category**

Event Category	Number of clips	Range of clips /person
Cell Phone Conversation	2760	Between 5 and 250
Visual Manual Task	555	Between 5 and 100
Baseline	3607	Between 5 and 250

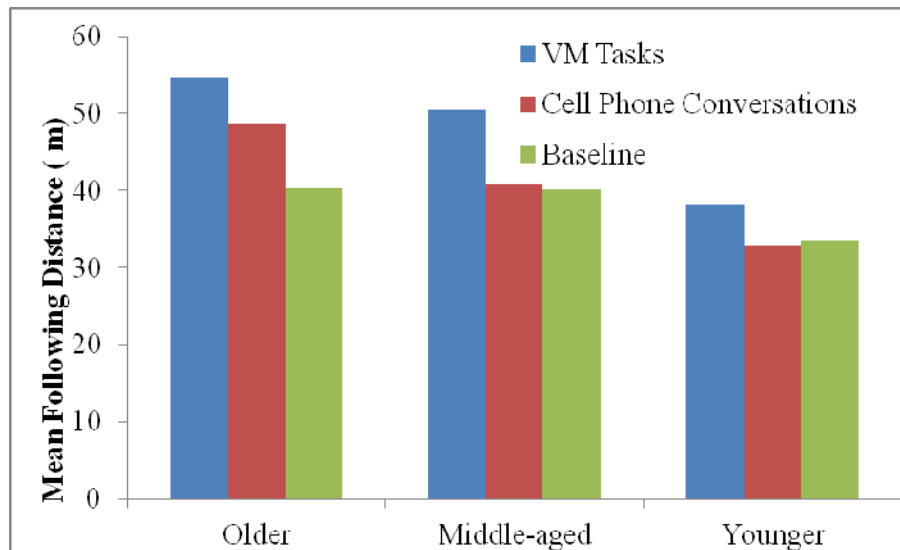


Figure 1 Mean following distances under three cell phone use conditions, by age group

The interaction between cell phone use and age group was found to be significant ($F(4,90)=3.68, p<0.05$). Older drivers showed a more conservative driving behavior when using cell phones, by maintaining the longest mean following distance during VM tasks, followed by cell phone conversations, and finally baseline conditions (Figure 1). Both middle-aged and younger drivers also tended to maintain longer following distances during VM tasks relative to when engaged in the cell phone conversation or during baseline periods. However, different from older drivers, similar following distances during cell phone conversation and baseline conditions were observed for both middle-aged and younger drivers.

Results of the pair-wise comparison analysis of the standard deviation of following distance showed that the VM tasks led to a significantly higher value mean=1.19 m for VM task condition) than cell phone conversations (mean=1.09 m for cell phone conversation condition, $t(117)=2.12, p<0.05$). No significant differences were observed between cell phone conversation and baseline or between VM task and baseline. Traffic density was found to have a significant impact on the standard deviation of following distance ($F(2, 92)=3.84, p<0.05$). Pairwise comparison tests found the standard deviation of following distance value decreases slightly with increasing traffic density (mean=1.16 m under sparse traffic condition; mean=1.12 m under moderate traffic condition; mean=1.10m under dense traffic condition). A main effect of driver age group was also found to be significant ($F(2, 66)=3.04, p<0.05$). Older drivers had a significantly higher standard deviation value of following distance compared to middle-aged drivers ($t(75)=2.43, p<0.05$, mean=1.18 m for older drivers; mean=1.09 m for middle-aged drivers).

Lane keeping behavior

Standard deviation of lateral position within the lane was calculated for all 5-second cell phone use and baseline clips. A total of 9,090 clips were used for this analysis, and the distribution is shown in Table 2.

Results of the analysis of standard deviation of lane position showed statistically significant differences related to cell phone use in general ($F(2, 70)=32.44, p<0.05$) but no difference between cell phone conversations and baseline driving (mean=0.12 m for VM tasks; mean=0.10 m for cell phone conversations; mean=0.10 m for non-cell phone use). Further pair-wise comparisons showed that the VM tasks led to significantly higher standard deviation of lane position than cell phone conversations ($t(101)=7.54, p<0.05$) and baseline samples ($t(112)= 7.73, p<0.05$). Main effects of age group ($F(2,116)=5.3, p<0.05$) and time of day were also found to be significant ($F(1,98)=9.6, p<0.05$). Younger drivers had smaller standard deviation of lane position than older drivers ($t(134)=3.22, p<0.05$; mean= 0.09 m for younger drivers; mean=0.11 m for older drivers), while the standard deviation of lane position of middle-aged drivers (mean=0.10 m) was not statistically different from the other age groups. Daytime driving led to smaller standard deviation of lane position (mean=0.09 m) than nighttime driving (mean=0.11m).

Table 2 **Number of clips in each category**

Event Category	Number of clips	Range of clips /person
Cell Phone Conversation	3405	Between 5 and 250
Visual Manual Task	809	Between 5 and 100
Baseline	4876	Between 5 and 250

The interaction effect between cell phone use and age group was found to be significant ($F(4,59)=5.84, p<0.05$). As shown in Figure 2, all three age groups had significantly higher standard deviation of lateral position during VM tasks, while younger drivers showed the smallest value change. Of particular note, cell phone conversations did not lead to higher variances in lateral deviation when compared to baseline conditions. Also, middle-aged drivers showed smaller standard deviation of lateral position during cell phone conversations than during baseline conditions, while similar (higher) values were observed for the other two age groups.

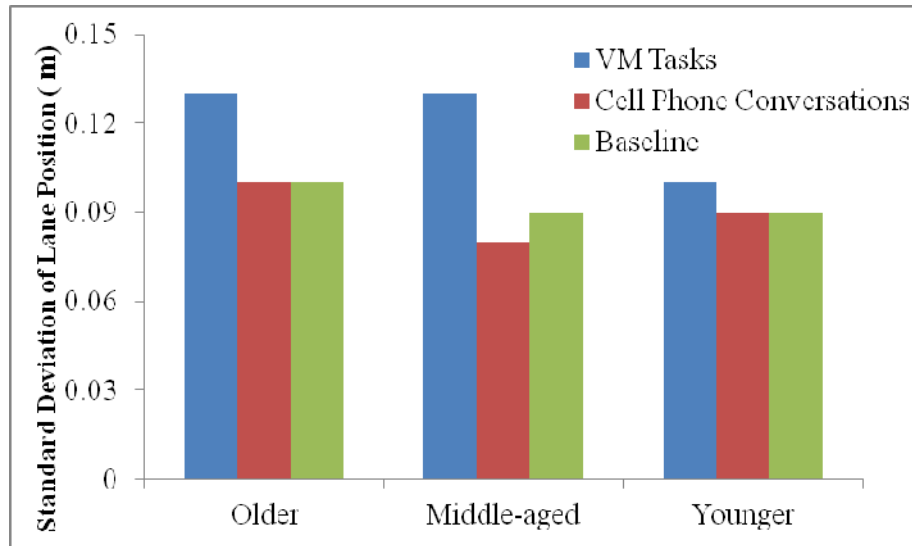


Figure 2 Average standard deviation of lateral position under three cell phone use conditions for three age groups

Conclusions

All the analyses and results were based on the naturalistic driving data 50 drivers who made at least one phone call during the first week of participating in the IVBSS FOT. Fourteen drivers that participated in the FOT were not observed using a cell phone during the first week.

Results from analyses of both standard deviation and mean of following distances suggest that drivers do tend to maintain longer mean following distances when engaging in VM tasks, along with consequently higher variations in following distance, when compared to both periods of cell phone conversation and baseline driving. This result seems to suggest possible self-regulatory behavior on the part of drivers, with drivers tending to select circumstances with longer than average following distances under which to perform complex tasks such as texting or entering phone numbers. Consistent with previous studies (Baldock, Mathias, McLean, Berndt 2006; Stalvey and Owsley 2000), this self-regulation behavior is more obvious in older drivers than the other two age groups.

Young and middle-aged drivers maintained similar following distances when engaging in a cell phone conversation as compared to driving without a cell phone in use. Longer following distances during cell phone conversations were observed for older drivers as compared to their baseline driving. Younger drivers tended to have shorter following distances than both older and middle-aged drivers. Significant effects have also been observed on the factors of time of day, gender, and traffic density. Drivers tend to maintain longer following distances during night-time driving as compared to the daytime, possibly suggesting another form of self-regulatory driving behavior. Male drivers averaged shorter following distances than female drivers, and following distances decrease with increasing traffic density.

Drivers exhibited similar standard deviations of lane position when engaging in a cell phone conversations as compared to baseline periods, but have larger standard deviations of lane position when engaging in a VM task. In general, when drivers are

engaging in texting or dialling of a cell phone while driving, their lane keeping was less stable than when they were either talking on the phone or during baseline periods. One previous study reported that cell phone conversations have a primary impact on the reaction time of drivers, with smaller decrements in lane-keeping performance (Horrey & Wickens 2006). The present study found similar effects of cell phone conversations on lane keeping, but further found that VM tasks, such as texting, had a significant effect on lateral control relative to a cell phone conversation.

In conclusion, the present study demonstrates that different levels of cell phone engagement are associated with different effects on driving performance. VM tasks, as compared to cell phone conversations and baseline conditions, result in significant degradation in driving performance. Consistent with the findings of Funkhouser and Sayer (2012), a certain level of self-regulatory behavior is observed in all drivers, but especially for older drivers, in terms of maintaining larger following distances from lead vehicles when engaging in more complex cell phone tasks, such as texting.

Limitations to this Research

As previously noted, the study was, strictly speaking, not naturalistic. Specifically participants were not driving their personal vehicles. While it was a field operational test, only data from the baseline period were used in the present analyses in order to eliminate the potential confounding effects of the on-board crash warning system. While this naturalistic, or largely naturalistic, approach offers significant face validity, it is limited to the measurement of driver performance measures alone. Additional analyses that could have, and may yet be conducted, include the measurement of driver eye glance behavior. Future studies can focus on other measures which could be used to assess and confirm self-regulation behaviour during cell phone use while driving, such as drivers' self-report data—which was not collected in this field operational test.

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