Report #17-UT-048

NSTSCE

National Surface Transportation Safety Center for Excellence

Investigating Drivers' Compensatory Behavior when Using a Mobile Device

Gregory Fitch • Laura Toole • Kevin Grove • Susan Soccolich • Richard J. Hanowski

Submitted: January 12, 2017

Technology
Impairment
Mobility
Infrastructure

Housed at the Virginia Tech Transportation Institute
3500 Transportation Research Plaza • Blacksburg, Virginia 24061

ACKNOWLEDGMENTS

The authors of this report would like to acknowledge the support of the stakeholders of the National Surface Transportation Safety Center for Excellence (NSTSCE): Tom Dingus from the Virginia Tech Transportation Institute, John Capp from General Motors Corporation, Chris Hayes from Travelers Insurance, Martin Walker from the Federal Motor Carrier Safety Administration, and Cathy McGhee from the Virginia Department of Transportation and the Virginia Transportation Research Council.

The NSTSCE stakeholders have jointly funded this research for the purpose of developing and disseminating advanced transportation safety techniques and innovations.

EXECUTIVE SUMMARY

Naturalistic driving studies (NDSs) have found no significant increase in safety-critical events (SCEs) with cell phone conversations (Fitch et al., 2013; Hickman, Hanowski, & Bocanegra, 2010; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Klauer, Guo, Sudweeks, & Dingus, 2010; Olson, Hanowski, Hickman, & Bocanegra, 2009). Two commercial motor vehicle (CMV) NDSs even found that CMV drivers were at a decreased risk when conversing on a hands-free cell phone (Hickman et al., 2010; Olson et al., 2009). At the same time, non-NDS research has found that driving performance degrades when conversing on a cell phone (Atchley & Dressel, 2004; Drews, Pasupathi, & Strayer, 2004; Horrey, Lesch, & Garabet, 2008; Strayer, Drews, & Johnston, 2003). In light of these differences, a better understanding of the effects of cell phone conversation while driving was sought.

The purpose of this study was to investigate driver performance and risk associated with mobile device use (MDU) from previously collected naturalistic driving data. There were two primary objectives. Each objective and the resultant findings are summarized below.

Objective 1: Investigating CMV Driver Adaptation when Conversing on a Cell Phone

The first goal was to investigate whether CMV and light vehicle (LV) drivers alter the way they drive when conversing on a cell phone. It was hypothesized that drivers may increase their safety margin when conversing on a mobile device by slowing down and increasing their headway to a lead vehicle, thus compensating for the increased workload.

Analysis addressing the first goal provided no indication that CMV or LV drivers increased their longitudinal safety margins when conversing on a cell phone. CMV drivers' headway to a lead vehicle did not differ despite the fact that they significantly increased their speed by 4 km/h when conversing on a cell phone. However, CMV drivers changed lanes significantly less when conversing on a handheld cell phone. These changes suggest that CMV drivers slightly reduced the driving demands when conversing on a cell phone. Overall, the changes in driving performance observed were not substantial for CMV or LV drivers. Because drivers look forward more often when conversing on a cell phone, it is foreseeable that the increased visual attention to the forward roadway may be the ultimate reason why conversing on a cell phone has not been found to increase SCE risk.

Objective 2: Investigating the Relationship between Drowsiness and the SCE Risk Associated with Mobile Device Use

The second goal was to investigate the relationship between drowsiness and the SCE risk associated with MDU in CMV drivers. Research has shown that drivers become more alert when conversing on a mobile device (Jellentrup, Metz, & Rothe, 2011). It was thus hypothesized that CMV drivers were at a decreased risk of an SCE when conversing on a hands-free cell phone because the conversation served to stave off drowsiness.

The CMV NDS data set used in Olson et al. (2009) was analyzed to address the second goal. Drivers' driving time and time on duty were used to assess their fatigue level, while the time of day and the amount of sleep they obtained in the previous 24 hours (measured via actigraphy) were used to indirectly assess their drowsiness level. Odds ratios computed the SCE risk for

MDU subtasks across binned levels of fatigue and drowsiness. Generalized linear mixed models and chi-squared tests were used to assess changes in MDU frequency across bins. It was found that there was an increase in SCE risk for visual-manual subtasks for all bins in which analyses were possible. CMV drivers had a higher proportion of MDU from 2:00 a.m. to 3:59 a.m. (circadian low period) than for the other times of day that were analyzed.

Conclusion

Overall, the research shows that LV and CMV drivers did not increase their longitudinal safety margins when talking on a cell phone. However, it was found that both groups of drivers looked forward more frequently when conversing on a cell phone. This study also found that CMV drivers used their cell phones more frequently at times when they would be drowsy. The increased visual attention to the road as well as the increased use during the early hours of the morning may be reasons why conversing on a cell phone has not been found to be associated with an increased SCE risk.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

CB	Citizens Band (radio)
CDL	Commercial Driver's License
CMV	commercial motor vehicle
CVO	Driver Distraction in Commercial Vehicle Operations (CVO study)
DAS	data acquisition system
EEG	electroencephalogram
FMCSA	Federal Motor Carrier Safety Administration
GCWR	gross combination weight rating
GLMM	generalized linear mixed model
GVWR	gross vehicle weight rating
HOS	hours of service
HV	heavy vehicle
MDU	mobile device use
LV	light vehicle
NDS	naturalistic driving study
NHTSA	National Highway Traffic Safety Administration
NSF	National Sleep Foundation
NTDS	Naturalistic Truck Driving Study
NTSB	National Transportation Safety Board
SAS	Statistical Analysis Software
SCE	safety-critical event
SV	subject vehicle
TTC	time-to-collision
U.S. DOT	United States Department of Transportation
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

In 2013, 32,719 individuals were killed on the nation's roadways (National Highway Traffic Safety Administration, 2015c), and 3,964 (12%) lost their lives in crashes involving a large truck (National Highway Traffic Safety Administration, 2015d). The Federal Motor Carrier Safety Administration (FMCSA) and other organizations are actively working to decrease the number of crashes and fatalities involving commercial motor vehicles (CMVs). This effort has focused on mitigating commercial driver distraction, particularly with regard to mobile device use (MDU), and curbing driver fatigue.

The FMCSA's rules were created based on findings from driving research. Early epidemiological studies found that using a cell phone quadruples the risk of injury and property damage crashes (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997). A series of naturalistic driving studies (NDSs) investigating the risk of drivers performing specific cell phone subtasks, however, found that safety-critical event (SCE) risk was associated with complex subtasks such as text messaging and dialing, but conversing on a cell phone was not associated with an increased SCE risk (Fitch et al., 2013; Hickman & Hanowski, 2012; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; Olson, Hanowski, Hickman, & Bocanegra, 2009). These results were observed for both CMV and light-vehicle drivers, as well as across broad classifications of low, moderate, and high driving task demands (Fitch & Hanowski, 2011). Furthermore, CMV drivers were found to be at a decreased risk when conversing on a hands-free cell phone (Hickman & Hanowski, 2012; Olson et al., 2009). The FMCSA has enacted distraction-related rules banning CMV drivers from reaching for, dialing, or holding a cell phone to make a call while driving (Federal Motor Carrier Safety Administration, 2010a). Text messaging while participating in interstate commerce has also been banned, and CMV carriers are prohibited from requiring drivers to text while driving (Federal Motor Carrier Safety Administration, 2010b).

Currently, the research examining the relationship between fatigue, drowsiness, and distraction is limited (Williamson, 2009). Keeping a vehicle on the road can become monotonous due to a decrease in attention caused by technologies such as cruise control, or predictable and uneventful environments such as straight, rural roadways (Larue, Rakotonirainy, & Pettitt, 2011). Talking on a mobile device has the potential to break the monotony and decrease distraction. A study by Jellentrup, Metz, and Rothe (2011) examining the relationship between cell phone calls and driver alertness found that participants were more alert during the 20 minutes after a call compared to the 20 minutes before a call. The FMCSA's current hours-of-service (HOS) regulations prohibit a CMV driver from driving too long without a break or off-duty period and limit work hours (Federal Motor Carrier Safety Administration, 2011a). An additional provision, that drivers need to be off duty for two periods between 1:00 a.m. and 5:00 a.m. in their 34-hour restart period, is currently suspended and undergoing further study.

Nationwide discussion of what, if any, electronic devices should be restricted in vehicles is ongoing. For instance, the National Transportation Safety Board (NTSB) has recommended that all portable electronic devices should be banned nationwide for light-vehicle drivers, except for certain situations (i.e., emergencies or those that support driving) (2011). As this discussion continues, it is clear that a better understanding of the risks and benefits associated with performing specific tasks on handheld and hands-free mobile devices will be valuable in reducing CMV crashes and fatalities.

Given the complex picture emerging in the research regarding the role of MDU in driver distraction and driver fatigue, further investigation is necessary to understand the risks and benefits of mobile device interactions. The first part of this report investigates the relationship between different MDU subtasks and SCEs, and discusses evidence suggesting that drivers who are talking on a mobile device tend to focus forward, leading to fewer road departures, fewer lane changes, and an increased state of attention and vigilance. The second part of this report addresses factors that contribute to driver fatigue and drowsiness, and the relationship of those factors to different MDU subtasks.

PURPOSE

The general scope of this study was to investigate driver performance and risk when conversing on a cell phone using previously collected naturalistic driving data. The study included data from two driver populations: commercial motor vehicle (CMV) drivers and light vehicle (LV) drivers.

The CMV data were originally collected during the Naturalistic Truck Driving Study and analyzed further in the Distracted Driving in Commercial Vehicle Operations (CVO) study (Blanco et al., 2008; Olson et al., 2009). The LV data were collected in a naturalistic driving study, which occurred between February 2011 and November 2011, and included drivers who reported talking on a cell phone at least once per day while driving. There were two primary objectives.

Objective 1: To investigate whether drivers alter the way they drive when conversing on a cell phone. It was hypothesized that drivers may increase their safety margin when conversing on a cell phone by slowing down and increasing their headway to a lead vehicle, thus compensating for the increased workload. The CMV NDS data set from Olson et al. (2009) was used to assess CMV driver behaviors while conversing on a cell phone. Cell phone conversations were identified in the data set. To choose baseline data, reductionists then stepped backwards through the video data to identify the start of the cell phone conversation and a 6-second sample that began 30 seconds prior to the beginning of the cell phone interaction was selected. The LV data included cell phone interactions (one hand-held, portable hands-free, and integrated hands-free devices) and baselines occurring 30 seconds prior to the start of the first cell phone subtask of the interaction.

Objective 2: To investigate the relationship between drowsiness and the SCE risk of mobile device use (MDU). The term MDU is used to encompass Citizens Band (CB) radio conversation in addition to cell phone use. The impetus for this experiment was that research has shown that drivers become more alert when conversing on a cell phone (Jellentrup et al., 2011). It was hypothesized that CMV drivers may be at a decreased risk of an SCE when conversing on a mobile device, as the conversation acts as a countermeasure to drowsiness. The CMV NDS data set used in Olson et al. (2009) was analyzed to address this objective. Drivers' driving time and time on duty were used to assess their fatigue level, while the time of day and the amount of sleep they obtained in the previous 24 hours (measured via actigraphy) were used to indirectly assess their drowsiness level.

Objectives 1 and 2 are discussed in Chapters 2 and 3, respectively, of this report.

CHAPTER 2. DRIVER ADAPTATION WHEN CONVERSING ON A CELL PHONE

INTRODUCTION

With the increasing popularity of mobile devices such as smartphones, distracted driving resulting from the use of cell phones has become a serious concern in transportation safety. In 2013, 3,154 people were killed in distraction-related crashes. Fourteen percent of those (411) involved at least one driver who was using a cell phone at the time (National Highway Traffic Safety Administration, 2015b).

Research has called particular attention to the hazards created by the visual-manual subtasks associated with operating a cell phone. Activities such as reaching for a cell phone, dialing, text messaging, browsing, and putting the phone away require drivers to take their eyes off the road and to remove at least one hand from the steering wheel. A number of studies, using a variety of methodologies including driving simulators, test tracks, and instrumented vehicles on public roads, have documented performance decrements from visual-manual distraction in terms of longitudinal vehicle control, lateral vehicle control, and response time to surprise events (Klauer et al., 2006; Angell et al., 2006; Ranney, Baldwin, Parmer, Martin, & Mazzae, 2011; Owens, McLaughlin, & Sudweeks, 2010; National Highway Traffic Safety Administration, 2012; Neurauter, Hankey, Schalk, & Wallace, 2012). In addition, visual-manual distraction has been associated with greater risk of an SCE by multiple naturalistic driving studies (Klauer, Guo, Sudweeks, & Dingus, 2010; Fitch et al., 2013; Hickman & Hanowski, 2012; Klauer et al., 2006; Olson et al., 2009).

Despite the general agreement that the visual-manual subtasks involved in cell phone use increase driving risk, studies are still divided about the effects of talking on a cell phone when conversation is considered as a distinct subtask. The essence of the debate is whether the cognitive load of talking alone affects safety. Maples, DeRosier, Hoenes, Bendure, and Moore (2008) and Atchley and Dressel (2004) observed that talking on a cell phone restricts the visual field of view. Meta-analyses by Caird, Willness, Steel, and Scialfa (2008) and Horrey and Wickens (2006) identified an increase in reaction times with cell phone use. Strayer, Drews, and Johnston (2003) examined inattention blindness during cell phone conversations, finding that drivers failed to remember seeing billboards. Strayer et al. (2013), in a study for the AAA Foundation for Traffic Safety, created a scale for cognitive distraction using eight secondary activities performed concurrently with driving and concluded that cell phone conversations moderately increase cognitive distraction.

On the other hand, naturalistic driving studies have not found an increase in safety-critical risk when drivers converse on cell phones. These results have been seen in studies involving both light vehicle (LV) and heavy vehicle (HV) drivers (Klauer et al., 2006; Fitch et al., 2013; Hickman & Hanowski, 2012; Klauer et al., 2010; Olson et al., 2009; Fitch & Hanowski, 2011). CMV drivers were even found to be at a decreased risk when conversing on a hands-free phone (Hickman & Hanowski, 2012; Olson et al., 2009).

The reasons are not clear why the results of the empirical research have not been observed in the real-world-driving context of naturalistic studies. One possible explanation is that drivers compensate for the increased workload of conversing on a cell phone by increasing their safety margins (Flannagan & Sayer, 2010; Tijerina, 2009; Young, Regan, & Hammer, 2003; Lerner, Singer, & Huey, 2008). Some driving simulator studies support this hypothesis. Young et al. (2003) and Cooper, Vladisavljevic, Strayer, and Martin (2008) found that drivers who were engaged in a cell phone conversation, when not directed to maintain a set speed and headway, decreased travel speed, increased following distance, and were less likely to change lanes when conversing on a cell phone.

Evidence of such compensatory behavior has also been found in naturalistic research. A study of cell phone use conducted by the Virginia Tech Transportation Institute (VTTI) for the National Highway Traffic Safety Administration (NHTSA) observed that drivers drove slower while browsing on a mobile device than during the baseline condition and that drivers employed significantly greater headways while texting than during baseline. However, these results are based on a small subsample that limits generalization to the broader driving population. A reanalysis of the data sets used in two studies of driver distraction, one on CMV drivers (Olson et al., 2009) and one on LV drivers (Klauer et al., 2006), suggests that CMV drivers may self-regulate their cell phone activities. The study divided drivers' cell phone use into low, moderate, and high task demand categories based on external factors such as weather, traffic density, and roadway profile. In contrast to the drivers of LVs, CMV drivers reduced their usage of cell phones in high task demand situations.

Given the current uncertainty in the scientific understanding of driver cell phone use, compensation, and self-regulation, more research is needed to inform safety policy and the development of mobile devices. The objective of this study was to analyze naturalistic data specifically for evidence that drivers alter their cell phone use in response to the workload they experience. We compared driving performance during cell phone conversations to driving performance during an epoch 30 seconds before the call. The proximity of the samples allowed greater experimental control in terms of similarity in driver state and environmental conditions. The study also attained high external validity by recording natural driving behavior.

METHOD

CMV Driver Data

Driver performance when conversing on a cell phone was investigated as follows. Baseline epochs identified in the Olson et al. (2009) study where the driver was observed to be conversing on a cell phone were selected. This process generated 1,738 samples, which will be referred to as "talking samples" in this report. Data reductionists recorded various parameters pertaining to the driver, vehicle, and environment at the beginning of these talking samples. Table 1 presents the parameters that were recorded. Reductionists then stepped backwards through the video data to identify the start of the cell phone conversation. A 6-second sample that began 30 seconds prior to the beginning of the cell phone interaction was selected. The parameters shown in Table 1 were then recorded for these matched samples, which will be referred to as "baseline samples." Matched baseline samples could not be produced for some talking samples for the following reasons: (1) the talking sample began at the start of the file; (2) the driver used the cell phone at some point during the baseline sample, and (3) the vehicle was not moving during the entirety of the baseline sample. It was important to select baseline samples that were close in time to the sampled cell phone interaction so that the environmental contexts remained similar. A higher degree of experimental control was gained as a result.

Table 1. Driver performance measures.

Measure	Operational definition	Talking sample interval	Baseline sample interval
Speed	Vehicle speed at the start of the sample interval.	Recorded at the first frame of the talking sample	Recorded at first frame of the baseline sample
Headway	Subject vehicle's (SV's) headway to a lead vehicle at the start of the sample interval. Reductionists visually verified the lead vehicle's radar target ID prior to computing the headway.	Recorded at the first frame of the talking sample	Recorded at first frame of the baseline sample
Time-to-collision (TTC)	SV's TTC to a lead vehicle at the start of the sample interval. TTC was computed as the range to the lead vehicle divided by the range rate to the lead vehicle. Reductionists visually verified the lead vehicle's radar target ID prior to computing the TTC.	Recorded at the first frame of the talking sample	Recorded at first frame of the baseline sample
Lane change	Reductionists indicated whether the driver started, or was in the process of, changing lanes within a 10-s interval spanning 5 s before the start of the sample up to 5 s after the start of the sample. The lane change could be in any direction.	10 s (± 5 s centered on the start of the talking sample)	10 s (± 5 s centered on start of baseline sample)
If the SV changes lanes, does driver use the turn signal?	If the driver started, or was in the process of, changing lanes within a 10-s interval spanning 5 s before the start of the sample up to 5 s after the start of the sample, then a measure of whether the turn signal was activated in this interval was taken from the vehicle network.	10 s (± 5 s centered on the start of the talking sample)	10 s (± 5 s centered on start of baseline sample)
SV lane position	Reductionists indicated the lane position of the SV at the start of the sample interval. A score of "1" was assigned to the leftmost lane. Reductionists also indicated the number of lanes available for travel so that the rightmost lane could be identified.	Recorded at the first frame of the talking sample	Recorded at first frame of the baseline sample
SV unintentional lane departure	Reductionists indicated whether the driver unintentionally departed the travel lane.	Duration of the talking sample	Duration of the baseline sample

The driver's emotional states during the talking sample and the baseline sample were recorded using a protocol developed in previous research (Fitch et al., 2013). Reductionists recorded the following emotions if they were exhibited:

- neutral/no emotion shown
- happy
- angry/frustrated/impatient

- sad
- surprised
- other (could be concerned/opinionated/apologetic/guilt/contempt)
- unable to determine

Reductionists also assessed the emotional intensity of the emotion exhibited:

- neutral/no emotion shown
- slight (emotion somewhat shown)
- marked or pronounced (emotion very much shown)
- severe (emotion extremely shown)
- unable to determine

Light Vehicle Driver Data

This study also used data collected from LV drivers. The LV data set was originally collected in an NDS that occurred between February 2011 and November 2011. The study included 204 light vehicle drivers, each participating for an average of approximately 31 days, who drove their own vehicles. Drivers were recruited from the Northern Virginia suburbs of Washington, D.C., the Blacksburg/Roanoke region of Virginia, and the Raleigh/Durham region of North Carolina. Drivers were eligible for the study if they reported talking on a cell phone at least once per day while driving. Their vehicles were instrumented post-recruitment with a data acquisition system (DAS) that included video cameras, kinematic data recorders, and sensors.

The data set also included cell phone records provided by 191 of the 204 drivers (94% cell phone record participation rate). Although the data provided by individual cell phone carriers may have differed slightly, the cell phone records included timestamps of calls and texts and indications of direction of call or text (incoming or outgoing). A sample of 10% of all calls while driving, with a minimum of four calls per driver, was randomly sampled, for a total of 1,564 calls while driving. Reductionists used video data for each sampled phone call to determine the type of phone in use (handheld, portable hands-free, or integrated hands-free), plus which cell phone subtasks occurred (including conversational subtasks, like talking or listening, and visual-manual subtasks, like reaching, browsing, dialing, etc.). A portable hands-free cell phone interface was defined as a device that allowed drivers to accept incoming calls and talk or listen without holding a cell phone in their hand, such as headsets, earpieces, or phones using speakerphone technology. An integrated hands-free interface was defined as a system that integrated the cell phone with the vehicle through microphones, speakers, push buttons, and software installed in the vehicle by the manufacturer.

Interactions with only one observed cell phone type were included for analysis. If a cell phone interaction involved more than one cell phone type, it was removed from analysis. Baselines sampled from the data were 20-second epochs occurring 30 seconds prior to the start of the first cell phone subtask of a cell phone sample. More details on the baseline sampling guidelines can be found in Fitch et al. (2013). The baselines were sampled around cell phone samples in order to better control for extraneous variables, such as driving conditions, driving environment, or driver-related variables. Driver performance measures were calculated for the baseline and cell phone samples.

RESULTS

Speed

The mean speed of the vehicle when conversing on a cell phone was investigated. First, each talking event was classified by use as handheld or hands-free. Then, for each talking sample and matched baseline sample that had a valid speed measure, a one-way within-subject analysis of variance (ANOVA) was performed to investigate whether the mean speed when conversing differed from the mean speed at the start of the baseline. Table 2 presents the results for the LV and CMV drivers. CMV drivers significantly increased their speed by approximately 4 km/h when talking on a handheld cell phone, $F(1, 106) = 10.11$, $p = .0019$. CMV drivers also significantly increased their speed by approximately 5 km/h when talking on a hands-free cell phone, $F(1, 63) = 8.65$, $p < .0046$.

Table 2. Drivers' mean speed when conversing on a cell phone (km/h).

Drivers	Cell phone type	Baseline mean (SE)	Subtask mean (SE)	*n*	df_1	df_2	*F* statistic	*p* value
LV drivers	Handheld	68.8 (2.1)	67.4 (2.1)	207	1	91	0.83	.3645
	Portable hands-free	74.8 (4.0)	68.1 (4.7)	49	1	22	2.88	.1038
	Integrated hands-free	74.9 (2.9)	75.0 (2.7)	109	1	49	1.85	.1798
CMV drivers	Handheld	90.6 (.87)	94.3 (.61)	549	1	106	10.11	.0019
	Hands-free	88.2 (.93)	93.5 (.93)	437	1	63	8.65	.0046

Headway

The mean headway of the vehicle was investigated for when drivers initiated various cell phone subtasks while the vehicle was moving, which was defined as a speed above 8 km/h. For each subtask and matched baseline sample that had a valid headway measure, a one-way within-subject ANOVA was performed to investigate whether the mean headway when initiating the subtask differed from the mean headway at the start of the baseline. Table 3 presents the results for the LV and CMV drivers. No significant differences were found. CMV drivers kept longer headways than LV drivers.

Table 3. Drivers' mean headway when conversing on a cell phone (s).

Drivers	Cell phone type	Baseline mean (SE)	Subtask mean (SE)	*n*	df_1	df_2	*F* statistic	*p* value
LV drivers	Handheld	0.6 (0.0)	0.6 (0.0)	65	1	40	2.26	.1406
	Portable hands-free	0.4 (0.1)	0.5 (0.1)	18	1	12	1.44	.2527
	Integrated hands-Free	0.7 (0.1)	0.6 (0.1)	42	1	28	2.50	.1253
CMV drivers	Handheld	2.9 (0.2)	2.6 (0.1)	115	1	54	1.46	.2321
	Hands-free	2.8 (0.2)	2.5 (0.2)	86	1	30	0.11	.7387

SV Lane Change Behavior

The percentage of subtasks performed above 8 km/h where the SV was observed to change lanes (in any direction) in the 10-second interval spanning from 5 seconds prior to the start of the subtask up to 5 seconds after the start of the subtask was investigated. For each subtask and matched baseline sample, McNemar's change test was performed to investigate whether the proportion of subtasks in which the SV changed lanes differed from the proportion of baseline periods in which the SV changed lanes. A lane change could be made in either direction for this analysis. Table 4 presents the results for LV and CMV drivers. CMV drivers significantly decreased their likelihood of changing lanes by 2.7% when conversing on a handheld cell phone, $\chi^2(1) = 4.0909$, $p = .0431$. No significant differences were found for LV drivers.

Table 4. Percentage of samples that drivers changed lanes.

Drivers	Cell phone type	Baseline percentage	Subtask percentage	*n*	$\chi^2_{McNemar}$	*p* value
LV drivers	Handheld	4.5	8.9	112	1.9231	.2668
	Portable hands-free	8.6	2.9	35	1.0000	0.6250
	Integrated hands-free	11.6	8.7	69	0.4000	0.7539
CMV drivers	Handheld	6.5	3.8	557	4.0909	.0431
	Hands-free	3.4	5.9	358	2.4545	.1172

SV Lane Position

The percentage of subtasks performed above 8 km/h where the SV was traveling in the rightmost lane when initiating the subtask was investigated. For each subtask and matched baseline sample, McNemar's change test was performed to investigate whether the proportion of subtasks in which the SV traveled in the rightmost lane differed from the proportion of baseline periods in which the SV traveled in the rightmost lane. Table 5 presents the results for LV and CMV drivers. No significant differences were found.

Table 5. Percentage of samples that drivers traveled in the slowest lane.

Drivers	Cell phone type	Baseline percentage	Subtask percentage	*n*	$\chi^2_{McNemar}$	*p* value
LV drivers	Handheld	38.4	41.1	112	0.24324	.7428
	Portable hands-free	37.1	34.3	35	0.14286	1.0000
	Integrated hands-free	37.7	37.7	69	0.00000	1.0000
CMV drivers	Handheld	75.0	76.3	557	0.3577	.5498
	Hands-free	72.1	71.0	358	0.1739	.6767

Unintentional Lane Departures

Lateral vehicle control was assessed with respect to whether drivers unintentionally departed lanes while driving above 8 km/h. In the LV data reduction, reductionists counted the number of unintentional lane departures and the point in time in which they occurred. As such, an unintentional lane departure rate was computed by dividing the number of unintentional lane departures in the sample by the duration of the sample. A one-way within-subjects ANOVA was performed to investigate whether the mean unintentional lane departure rate when conversing on a cell phone differed from the mean unintentional lane departure rate during the baseline epoch. Table 6 presents the results for LV drivers. The mean unintentional lane departure rate was significantly lower when talking on a handheld cell phone (M = 0.001, SE = 0.000, n = 207) compared to baseline (M = 0.003, SE = 0.001, n = 207), $F(1, 91) = 5.90$, $p = .0171$.

Table 6. Light vehicle drivers' unintentional lane departure rate.

Drivers	Cell phone type	Baseline mean (s)	SE (s)	Subtask mean (s)	SE (s)	*n*	df_1	df_2	*F* statistic	*p* value
LV drivers	Handheld	.003	.001	0.001	0.000	207	1	91	5.90	.0171
	Portable hands-free	.003	.002	0.000	0.000	47	1	21	2.14	.1581
	Integrated hands-free	.002	.001	0.000	0.000	109	1	49	3.19	.0801

During the CMV data reduction, reductionists scored whether one or more unintentional lane departures occurred in the sample. McNemar's change test was performed to investigate whether the proportion of talking samples during which the driver unintentionally departed the lane differed from the proportion of baseline epochs during which the driver unintentionally departed the lane. No significant effects were found (Table 7).

Table 7. Percentage of samples CMV drivers had an unintentional lane departure.

Drivers	Cell Phone Type	Baseline percentage	Subtask percentage	*N*	$\chi^2_{McNemar}$	*p* value
CMV drivers	Handheld	3.4	4.95	646	2.0833	.1489
	Hands-free	3.2	1.6	436	2.3333	.1266

DISCUSSION

Whether drivers compensated for the increased mental workload inherent in conversing on a cell phone was investigated using a controlled comparison of data obtained from naturalistic driving data sets. Safety margins were assessed in terms of vehicle travel speed, headway, inclination to travel in the slowest lane, inclination to change lanes, and lateral vehicle control. Overall, both CMV and LV drivers did not increase their longitudinal safety margins when conversing on a cell phone. LV drivers traveled at the same speed and headway. CMV drivers significantly increased their speed by 4 km/h, but also traveled at the same headway. In a separate investigation, Fitch & Hanowski (2012) found that this increase in speed varied by the driving task demands; CMV drivers increased their speed by 4 km/h in low driving task demands (i.e., where few vehicles were on the road), and by 2 km/h in moderate driving task demands (i.e., where traffic density increased). A significant difference in speed was not found for high driving task demands (i.e., in high traffic density, when near an intersection, or when near a merge ramp). Given that the 4 km/h speed increase took place in low traffic density and on straight roads, it is not believed to practically implicate driving performance.

With respect to lateral vehicle control, CMV drivers were less likely to change lanes when conversing on a handheld cell phone. When considering that changing lanes with a commercial vehicle demands substantial attention to the large blind spots around the vehicle, it is foreseeable that drivers stayed in their travel lane more often when conversing on a cell phone to reduce the driving task demands. Although this was not observed for LV drivers, they were found to improve their lane keeping performance when conversing on a handheld cell phone. This was likely a result of the increased visual attention to the forward roadway that has been found in previous studies (Fitch et al., 2013; Klauer et al., 2006; Klauer et al., 2010; Olson et al., 2009; Sayer, Devonshire, & Flannagan, 2007).

Overall, the differences in driving performance found in this study were not substantial. Considering the clear evidence that drivers look forward more often when conversing on a cell phone, perhaps the increased visual attention to the forward roadway is the ultimate reason why conversing on a cell phone has not been found to increase SCE risk for LV drivers, and why conversing on a hands-free cell phone was found to be associated with a decreased SCE risk for CMV drivers. This is suspected because the LV studies did not include unintentional lane departures in their operational definition of an SCE, whereas the CMV studies did. Since an unintentional lane departure primarily occurs when drivers are not looking forward, it is reasonable that conversing on a hands-free cell phone decreased SCE risk because CMV drivers looked forward more often. At the same time, it is worth considering that unintentional lane departures also occur when drivers are drowsy. Given that research has shown that drivers' vigilance improves after conversing on a cell phone (Jellentrup et al., 2011), this may be another reason why the SCE risk was observed to decrease (Hanowski, 2011). Perhaps conversing on a cell phone would be associated with a decreased SCE risk for LV drivers if unintentional lane departures were included in the risk analysis, which is a potential direction for future research.

This study shows that a modest change in driving performance (i.e., a 4 km/h increase in travel speed) does not necessarily translate into increased SCE risk; statistical significance does not mean practical significance (Hanowski, 2011). Caution should be taken when concluding that crash risk will increase when conversing on a cell phone based on driving performance degradations observed in a limited context. Drivers may self-regulate their behavior in other ways besides driving. For instance, Fitch & Hanowski (2012) found that CMV drivers reduced how much time they conversed on a cell phone when the driving tasks demands increased. These drivers may have used other ways to adapt to the increased workload given that they need to reach a destination on time. Empirical research has demonstrated the existence of cognitive distraction. However, statements that the cognitive distraction inherent in conversing on a cell phone increases crash risk are not substantiated by the results of this research.

Limitations

The following may limit the results of this study. First, baseline epochs were selected that took place 30 seconds prior to the sampled cell phone conversations. It is possible that performance differences were not observed because drivers had already prepared to use their cell phone when the baseline was sampled. Sampling baselines at different points in time may have produced different results. Second, although the sampling strategy ensured that cell phone conversation was the only cell phone subtask performed, the study did not exclude samples where the driver engaged in other non-cell-phone secondary tasks. The study thus compared driving performance when conversing on a cell phone to general driving performance.

Conclusion

Overall, both LV and CMV drivers were not found to change their longitudinal safety margins when conversing on a cell phone. CMV drivers slightly increased their speed during cell phone use and were slightly less likely to change lanes during handheld cell phone usage, but is unclear how this impacts their risk. LV and CMV drivers were not more likely to occupy the rightmost lane during cell phone usage. Finally, LV drivers using a handheld cell phone showed a lower rate of unintentional lane departures, but this was not observed with hands-free cell phone usage or CMV drivers. This could be due to changes in visual behaviors during cell phone usage.

CHAPTER 3. RELATIONSHIP BETWEEN DRIVER DISTRACTION, FATIGUE, AND DROWSINESS

INTRODUCTION

Research has established that fatigue, drowsiness, and distraction are factors that, individually, contribute highly to crashes and crash-related fatalities in both LVs and CMVs. Knipling and Wang (1994), for instance, reported on drowsiness and fatigue-related crashes from 1989 to 1993 and found that over this time period, the number of drowsiness and fatigue-related crashes decreased by approximately 30,000 but the number of drowsiness and fatigue-related fatal crashes and resulting fatalities (1,544 and 1,357, respectively) remained virtually unchanged. In addition, over half of rear-end collisions, one of the most frequent types of crashes, can be attributed to driver distraction (Knipling et al., 1993). In 2014, distracted driving was a factor in 10% of crash-related fatalities and drowsy driving was a factor in about 3% of fatalities (National Highway Traffic Safety Administration, 2015a).

The objective for this phase of the research was to investigate the relationship between drowsiness and the SCE risk associated with MDU for CMV drivers, through a secondary data analysis of naturalistic driving research. Driver distraction was measured by MDU in SCEs and baselines. Since fatigue and drowsiness cannot be measured directly and are thus elusive (Williamson, 2009), surrogate measures were used: driving time and time on duty for fatigue, and time of day and amount of sleep for drowsiness. The analysis examined the overall risk associated with driver distraction, as well as how the risk of driver distraction and propensity to use mobile devices changed across the four fatigue and drowsiness surrogate factors.

METHOD

Secondary Data Analysis

The current research involved a secondary data analysis of data collected during the Naturalistic Truck Driving Study (NTDS) and subsequently analyzed further in the Distracted Driving in Commercial Vehicle Operations (CVO) study (Blanco et al., 2008; Olson et al., 2009). The NTDS collected data from 100 participants who held a Class-A Commercial Driver's License (CDL) while they drove their normal routes for four weeks. Researchers collected data from vehicle sensors, video cameras, and a lane tracker using a DAS; in addition, actigraphy monitors, driver self-report activity registers, and pre- and post-test questionnaires were also collected. In total, 6.20 terabytes of video and performance data were amassed, including 14,500 hours of driving data, 26,000 on-duty hours, and 65,000 hours of actigraphy data. Also, 2,889 SCEs were identified by the DAS and validated by researchers and trained reductionists using the Data Analysis and Reduction Tool, and 456 baselines were randomly selected (Blanco et al., 2008).

The CVO study used the data that were collected in the NTDS to examine how driver distraction related to CMV crashes. As noted, the researchers identified the tasks that the drivers were performing immediately before or during an SCE or baseline of interest. The SCEs included in the CVO study were the same as the NTDS, but the baselines were sampled using different rates. Therefore, approximately 4,000 baselines were included; however, they did not have information regarding amount of sleep (Olson et al., 2009).

Each SCE and baseline used in the data analysis had been previously reduced for evidence of driver distraction. In this study, the relationship between MDU subtasks and the surrogate fatigue and drowsiness measures was explored. MDU subtasks included the following behaviors: dial cell phone, text message on cell phone, talk/listen to handheld cell phone, talk/listen to hands-free cell phone, talk/listen to CB radio, and interact with/look at dispatching device. The occurrence of each individual MDU subtask was noted in SCEs and baselines. If an SCE or baseline had any MDU subtasks observed, it was marked as "MDU." Certain MDU subtasks were visual-manual in nature, including dial cell phone, text message on cell phone, and interact with/look at dispatching device. The occurrence of any of these visual-manual MDU subtasks were also noted during data reduction (with the event being marked as having visual-manual subtasks).

Definition and Calculation of Factors

Four factors were identified as surrogate measures for fatigue and drowsiness: driving time, time on duty, time of day, and amount of sleep. The first two factors, driving time and time on duty, are associated with fatigue. The latter two factors, time of day and amount of sleep, are associated with drowsiness. The definitions of these factors, which are based on previous research, can be found in Table 8.

Table 8. Definition of each factor.

Factor	Definition
Driving time	Time of only driving since the beginning of a shift until an SCE or baseline of interest. Legal amount is 11 hours. (Blanco et al., 2008)
Time on duty	Time of driving, non-driving work, and breaks since the beginning of a shift until an SCE or baseline of interest. Legal amount is 14 hours. (Barr, Yang, Hanowski, & Olson, 2011; Blanco et al., 2008; Federal Motor Carrier Safety Administration, 2011b)
Time of day	Time of an SCE or baseline of interest according to the 24-hour clock (Hanowski, Wierwille, Garness, & Dingus, 2000; Federal Motor Carrier Safety Administration, 2011b).
Circadian rhythm	An internal biological clock that triggers self-sustained fluctuations in body characteristics (e.g., arousal; Aschoff, 1965).
Amount of sleep	All periods of sleep in the 24 hours before an SCE or baseline of interest (Blanco et al., 2008).

For the current research, driving time and time on duty for all SCEs and baselines of interest had to be calculated, as well as the amount of sleep for the baselines of the CVO study. Time of day of the SCE or baseline was identified using updated activity registers and video data. Driving time and time on duty at SCE or baseline occurrence were calculated using the time of day the SCE or baseline of interest occurred and the driver activity registers. These data were primarily classified based on circadian rhythm, as described in the Bins section later in this report.

The amount of sleep was calculated using a method and algorithm similar to that used in the NTDS; a more detailed description can be found in Appendix V of the NTDS final report (Blanco et al., 2008). The algorithm that was used in the current research was tested on 1,836 SCEs from the NTDS with previously calculated sleep data. The current sleep results were compared to the original results for these SCEs to ensure the accuracy of the calculations. Of the 1,836 SCEs, the current calculation of the amount of sleep differed from the original calculation for 46 SCEs (2.5%); the majority of the differences were a minute or less.

Criteria were established to obtain a consistent data set for amount of sleep. For an SCE or baseline to be included in the analysis:

- The driver had to have actigraphy data.
- At least 23 hours of actigraphy data had to be available before an SCE or baseline.
- The SCE or baseline could not have occurred when the actigraphy data indicated sleep was occurring.
- The SCE or baseline could not have a count of 0 hours of sleep because bad data prevented the data from being counted (i.e., could not be verified as sleep because the driver could have taken the device off).

A total of 749 SCEs and baselines (9.8%) did not meet at least one of these criteria and were removed. Since these criteria had to be used for the sleep data, and certain SCEs and baselines were removed as a result, two subsets of data were used in the analyses: one for driving time, time on duty, and time of day, and one for amount of sleep.

For both subsets of data, only SCEs and baselines within the legal shift limits (i.e., driving time less than 11 hours and time on duty less than 14 hours) were included in the analysis. This provided consistency across the data because all drivers have the opportunity to experience an SCE or baseline within those limits, but only drivers who choose to drive or work past the regulated time have the opportunity for an SCE or baseline in subsequent hours. These individuals could be considered riskier drivers and inclusion of their SCEs and baselines could skew results. In addition, baselines occurring outside the legal limits could not be included in MDU analyses because they would cloud the picture of general device use since they are not typical. Previous studies have used similar criteria and have only included events occurring during the established legal boundaries for driving and working (Blanco et al., 2011).

Of the 7,661 SCEs and baselines for driving time, time on duty, and time of day, 1,551 illegal SCEs and baselines (20.3%) were removed, leaving 2,152 SCEs and 3,958 baselines. The amount of sleep subset included 6,912 SCEs and baselines after the filters were applied; of those, 1,490 SCEs and baselines (21.6%) outside legal driving and time-on-duty limits were removed, leaving 1,839 SCEs and 3,583 baselines.

Bins

For each factor, the data were divided into low, moderate, and high bins based on the method used in Fitch and Hanowski (2011). The number of hours included in each bin was based on previous research that examined how fatigue and drowsiness affect the factors and vice versa. The end times for driving time and time on duty were set to 11 hours and 14 hours, respectively, given the shift limits specified by HOS regulations. Table 9 presents the hours included in each bin for each factor, and a rationale for these bins can be found in Appendix A. For the factor "time of day," the bins are referred to in the text as low morning (2:00 a.m. – 3:59 a.m.), high morning (9:00 a.m. – 10:59 a.m.), low afternoon (1:00 p.m. – 2:59 p.m.), and high evening (7:00 p.m. – 8:59 p.m.).

Table 9. Division of hours in each bin for each factor.

Factor	Low	Moderate	High
Driving time	1 – 4.99 hr	5 – 7.99 hr	8 – 11 hr
Time on duty	1 – 4.99 hr	5 – 7.99 hr	8 – 14 hr
Time of day	2:00 a.m. – 3:59 a.m. 1:00 p.m. – 2:59 p.m.		9:00 a.m. – 10:59 a.m. 7:00 p.m. – 8:59 p.m.
Amount of sleep	0 – 4.99 hr	5 – 8.99 hr	9 – 20 hr

Analysis

All analyses were conducted using SAS software, versions 9.2 and 9.3.

SCE Risk

An odds ratio was used to calculate SCE risk by determining the odds of an SCE occurring when all or certain MDU subtasks were present. When comparing SCEs and baselines, it is important to have a ratio with sufficient power; Maclure and Mittleman (2000) indicated that a ratio of 4:1 has adequate power. A higher ratio was also important as the SCE risk results from the current research were compared to the CVO study (Olson et al., 2009) and Hickman, Hanowski, and Bocanegra (2010), which had a ratio of approximately 5:1. The more similar the ratios are, the fairer the comparison of results will be.

Since the number of baselines could not be changed, in order to increase the ratio from 1.83:1 (i.e., when all SCE classifications were included) to 4:1, the number of SCEs needed to be adjusted. Since the SCEs of interest reflect driver error, it is permissible to combine various classifications. First, the most severe SCE classifications (i.e., crashes, near-crashes, and crash-relevant conflicts) were included in analyses, which resulted in a ratio of 3.21:1. The number of SCEs included in analyses for driving time, time on duty, and time of day decreased from 2,152, when all classifications were included, to 1,232 (57.2%) with the most severe SCEs. For the amount-of-sleep analysis, the number of SCEs decreased from 1,839 to 1,044 (56.8%) with crashes, near-crashes, and crash-relevant conflicts. When these data were divided into bins, the amount of data for each MDU subtask was not large enough to make any conclusions. Consequently, the odds ratio analyses were conducted for the subtasks before the data were divided into bins. In addition, analyses of visual-manual subtasks combined and MDU (including all subtasks) were conducted before the data were divided and for each bin for driving time, time on duty, time of day, and amount of sleep.

MDU and Drowsiness and Fatigue Factors

It was determined that MDU occurred more with SCEs than baselines. Therefore, analyzing the two event data sets as one would lead to bias and would not give a fair picture of general device use. Before making the decision to include only baselines, it was necessary to ensure they were not oversampled in each bin. To do this, a comparison of the number of baselines to the number of driving opportunities in each bin of driving time was conducted. A driving opportunity is any instance in which a participant was driving, per hour, regardless of whether or not there was an SCE or baseline. For example, if a participant completed 2 hours of driving for all of his or her 10 shifts, there would be 10 driving opportunities in driving hour one and two. It can be seen from Table 10 that the percentage of baselines and driving opportunities was similar. This indicated that a comparison of baselines across bins was permissible, so only baselines were included in the MDU analyses for all factors.

Table 10. Frequency and percentage of baselines and driving opportunities for driving time.

Bin	Baseline frequency	Baseline percentage	Driving opportunity frequency	Driving opportunity percentage
Low	1,968.00	49.0%	6,692.91	50.0%
Moderate	1,178.00	30.0%	4,032.04	31.0%
High	812.00	20.0%	2,419.39	18.0%
	Total = 3,958		Total = 13,144.35	

A generalized linear mixed model (GLMM) and chi-squared test were used to analyze MDU. The GLMM modeled the probability of a baseline of interest having MDU based on the factors; it controlled for differences between participants, and the intercept accounted for random error and driver behavior. The chi-squared test determined if the percentage of MDU changed across bins for all factors. If the overall result was significant, additional tests were conducted to determine which bins were different from each other.

RESULTS

The subsets of data differed between driving time, time on duty, and time of day and amount of sleep. This is because filters were applied to the amount of sleep data, which led to the removal of 749 SCEs and baselines. Table 11 displays the frequency of baselines, SCEs, and each SCE classification for each category or subtask used in the current analyses of driving time, time on duty, and time of day. Table 12 contains the same information for the amount of sleep data.

Table 11. Frequency of baselines, SCEs, and SCE classifications for driving time, time on duty, and time of day data.

Category/Subtask	Baselines	SCEs	Crashes	Near-crashes	Crash-relevant conflicts	Unintentional lane deviations
No MDU	3,543	1,787	4	42	1,005	736
MDU	413	365	0	4	177	184
Dial cell phone	30	89	0	1	40	48
Text message on cell phone	3	16	0	0	10	6
Talk/listen to handheld cell phone	169	108	0	2	59	47
Talk/listen to hands-free cell phone	157	43	0	0	26	17
Talk/listen to CB radio	40	22	0	1	12	9
Interact with/look at dispatching device	26	108	0	0	39	69

Table 12. Frequency of baselines, SCEs, and SCE classifications for amount of sleep data.

Category/Subtask	Baselines	SCEs	Crashes	Near-crashes	Crash-relevant conflicts	Unintentional lane deviations
No MDU	3,227	1,510	4	36	839	631
MDU	356	329	0	3	162	164
Dial cell phone	26	79	0	1	34	44
Text message on cell phone	2	14	0	0	8	6
Talk/listen to handheld cell phone	135	92	0	2	55	35
Talk/listen to hands-free cell phone	148	43	0	0	26	17
Talk/listen to CB radio	32	21	0	0	12	9
Interact with/look at dispatching device	22	97	0	0	34	63

Risk of MDU Subtasks

As noted, only the most severe SCE classifications were included in analyses in order to increase the ratio of baselines to SCEs. The overall SCE risk of each MDU subtask, visual-manual subtasks, and MDU (including all subtasks) was analyzed, before analyzing the drowsiness/fatigue relationship. Table 13 contains the significant results from the odds ratio analyses with 95% confidence intervals for the subset of SCEs and baselines with driving time, time on duty, and time of day data. It can be seen that the visual-manual subtasks increased SCE risk the most individually and when combined. However, “talk/listen to hands-free cell phone” decreased SCE risk. Although “MDU (including all subtasks)” increased SCE risk, this result fails to recognize the differences between the subtasks. The results were similar in an analysis of the SCE and baseline subset with amount of sleep data; however, “talk/listen to handheld phone” was significant with the most severe SCEs.

Table 13. Significant odds ratio analysis results before the data were divided.

Category/Subtask	Baselines	SCEs	Odds ratio (OR)	Lower limit (LL)	Upper limit (UL)
MDU (including all subtasks)	413	181	1.47*	1.22	1.78
Visual-manual subtasks	59	90	5.20*	3.72	7.28
Text message on cell phone	3	10	10.78*	2.96	39.26
Dial cell phone	30	41	4.50*	2.80	7.25
Interact with/look at dispatching device	26	39	4.49*	2.99	8.15
Talk/listen to hands-free cell phone	157	26	0.52*	0.34	0.79

**Refers to statistically significant results.*

Driving Time and MDU Risk and Frequency

The odds ratio analysis for driving time for visual-manual subtasks and MDU (including all subtasks) for each bin can be seen in Table 14; both combinations of subtasks increased SCE risk for all bins when compared to baselines.

Table 14. Significant odds ratio analysis results for driving time bins.

Bin	Subtask	Baselines	SCEs	OR	LL	UL
Low	Visual-manual subtasks	27	48	6.49*	4.01	10.51
Low	MDU (including all subtasks)	204	88	1.55*	1.18	2.03
Moderate	Visual-manual subtasks	22	27	3.58*	2.01	6.36
Moderate	MDU (including all subtasks)	129	88	1.96*	1.45	2.64
High	Visual-manual subtasks	10	15	5.59*	2.48	12.63
High	MDU (including all subtasks)	80	35	1.64*	1.07	2.51

**Refers to statistically significant results.*

As noted, only baselines were included in MDU frequency analyses because the SCE risk analyses indicated that MDU occurred more with SCEs than baselines. The GLMM results did not indicate significance for all driving time data (p = .10) or the low, moderate, and high bins (p = .71, p = .89, p = .78, respectively), so driving time was not a good predictor of MDU during a baseline. The results of the chi-squared test were not significant, $\chi^2(2, N = 3{,}958) = 0.64$, p = .72. This means the percentage of MDU did not significantly differ across bins; it does not appear that driving time is associated with significant differences in frequency of MDU in this data set. The percentage of MDU was approximately 10% for each bin, as can be seen in Table 15.

Table 15. Frequency table and percentage of device use in baselines for driving time.

Bin	Percentage with MDU	No MDU	MDU	Total
Low	10.4%	1,764	204	1,968
Moderate	10.9%	1,049	129	1,178
High	9.8%	732	80	812

Time on Duty and MDU Risk and Frequency

Odds ratios were used to calculate SCE risk for visual-manual subtasks and MDU (including all subtasks) for all bins of time on duty. The significant results, seen in Table 16, indicate SCE risk increased for all bins, compared to baselines, when drivers were performing visual-manual subtasks; however, MDU (including all subtasks) increased SCE risk for only the low and high bins.

Table 16. Significant odds ratio analysis results for time-on-duty bins.

Bin	Subtask	Baselines	SCEs	OR	LL	UL
Low	Visual-manual subtasks	19	34	6.22*	3.51	11.04
Low	MDU (including all subtasks)	130	68	1.83*	1.34	2.51
Moderate	Visual-manual subtasks	17	21	3.90*	2.03	7.49
High	Visual-manual subtasks	23	35	5.36*	3.14	9.18
High	MDU (including all subtasks)	162	80	1.77*	1.32	2.36

**Refers to statistically significant results.*

Again, only baselines were used in analyses to determine the percentage of baselines with MDU in each bin and whether time on duty is a good predictor of MDU. Results were not significant for the GLMM for all time on duty data (p = .75) or any of the bins (p = .39, p = .84, p = .20, respectively), which means time on duty was not a good predictor that MDU would occur during a baseline. Conversely, the results for the chi-squared test were significant, $\chi^2(2, N = 3{,}958) = 6.35$, p = .04. When tests were conducted to determine which bins were different from each other, results indicated that the moderate bin had a significantly higher percentage of MDU than the low bin (p = .01); see Table 17. The difference in results between the GLMM and chi-squared test is most likely due to the extreme values having more influence on the sample as a whole in the chi-squared test. For the majority of drivers, MDU was observed in approximately 20% of baselines, but there were some drivers with MDU in 100% of baselines. The drivers with 100% use could have affected the results.

Table 17. Frequency table and percentage of device use in baselines for time on duty.

Bin	Percentage with MDU	No MDU	MDU	Total
Low	9.3%	1,271	130	1,401
Moderate	12.5%	850	121	971
High	10.2%	1,424	162	1,586

Time of Day and MDU Risk and Frequency

For time of day, analyses could not be conducted for visual-manual subtasks in the low and high morning bins with crashes, near-crashes, and crash-relevant conflicts because there were zero data points in at least one cell of the contingency table. The significant odds ratio results can be seen in Table 18. Visual-manual subtasks increased SCE risk where analyses were possible. MDU (including all subtasks) increased SCE risk for the low afternoon bin and decreased SCE risk for the low morning bin.

Table 18. Significant odds ratio analysis results for time of day bins.

Bin	Subtask	Baselines	SCEs	OR	LL	UL
Low morning	Visual-manual subtasks	-	-	-	-	-
Low morning	MDU (including all subtasks)	41	2	0.18*	0.04	0.77
Low afternoon	Visual-manual subtasks	5	15	8.50*	3.02	23.88
Low afternoon	MDU (including all subtasks)	27	24	2.55*	1.41	4.60
High evening	Visual-manual subtasks	5	19	9.35*	3.44	25.42
High evening	MDU (including all subtasks)	-	-	-	-	-

**Refers to statistically significant results.*

The analysis of MDU frequency across time of day had more clear results. Again, only baselines were used in the analyses of MDU frequency. The results of the GLMM were significant for all time of day data and all bins ($p < .001$); therefore, time of day was a good predictor of MDU during a baseline. In addition, the results of the chi-squared test were significant, $\chi^2(3, N = 1.267) = 27.84$, $p < .001$. When additional tests were conducted to determine which bins were significantly different, the results indicated that the low morning bin had a higher percentage of MDU than the high morning, low afternoon, and high evening bins ($p < .0001$); see Table 19. In addition, the high evening bin had higher percentage of MDU than the high morning bin ($p = .03$).

Table 19. Frequency table and percentage of device use in baselines for time of day.

Bin	Percentage with MDU	No MDU	MDU	Total
Low morning	17.8%	189	41	230
High morning	4.4%	238	11	249
Low afternoon	4.8%	318	27	345
High evening	8.8%	404	39	443

Amount of Sleep and MDU Risk and Frequency

The odds ratio analyses for amount of sleep for visual-manual subtasks and MDU (including all subtasks) for each bin can be seen in Table 20. Visual-manual subtasks increased SCE risk when compared to baselines for all bins. MDU (including all subtasks) increased SCE risk for all bins except for the low bin.

Table 20. Significant odds ratio analysis results for amount of sleep bins.

Bin	Subtask	Baselines	SCEs	OR	LL	UL
Low	Visual-manual subtasks	10	8	3.39*	1.32	8.75
Low	MDU (including all subtasks)	-	-	-	-	-
Moderate	Visual-manual subtasks	37	61	5.90*	3.89	8.95
Moderate	MDU (including all subtasks)	262	124	1.69*	1.35	2.13
High	Visual-manual subtasks	3	8	8.53*	2.21	32.93
High	MDU (including all subtasks)	27	18	2.21*	1.14	4.25

**Refers to statistically significant results.*

In the analysis of amount of sleep and frequency of MDU, SCEs were included. The results of the GLMM were not significant for all the data (p = .65) or the low, moderate, or high bins (p = .21, p = .28, p = .34, respectively). In addition, the chi-squared test results were not significant, $\chi^2(2, N = 3{,}583) = 0.17$, p = .91. The percentage of MDU did not significantly differ across bins; it was approximately 10% in all bins, as can be seen in Table 21. It does not appear, for this data set, that MDU is significantly associated with amount of sleep.

Table 21. Frequency table and percentage of device use in SCEs and baselines for amount of sleep.

Bin	Percentage with MDU	No MDU	MDU	Total
Low	10.23	55	67	655
Moderate	9.82	2407	262	2,669
High	10.42	232	27	259

The chi-squared test for time on duty also found a difference across bins in MDU frequency in baselines; the moderate bin had a higher percentage of MDU than the low bin. Drivers in this study were observed to have significantly higher MDU frequency in baselines when on duty 5 to 7.99 hours, as compared to when on duty for 1 to 4.99 hours. There were no significant results from the GLMM analyses or the chi-squared tests for both driving time and amount of sleep.

DISCUSSION

The current research examined the relationships between driver distraction and fatigue, and drowsiness. Driver fatigue was estimated by two factors, driving time and time on duty, and driver drowsiness was estimated by the factors time of day and amount of sleep. The purpose of the current research was twofold: (1) to determine SCE risk for six MDU subtasks, visual-manual subtasks, and MDU (including all subtasks) for driving time, time on duty, time of day, and amount of sleep; and (2) to examine the relationship between CMV driver MDU and all factors. The research goals were achieved through a secondary data analysis of the NTDS (Blanco et al., 2008) and CVO (Olson et al., 2009) data. Odds ratios and Fisher's exact tests were used to calculate SCE risk, and a GLMM and chi-squared test were used to examine MDU.

Visual-manual subtasks (i.e., dialing a cell phone, text messaging on a cell phone, and interacting with/looking at a dispatching device) were found to have the highest SCE risk individually when the data were not divided. However, talking/listening on a hands-free cell phone decreased SCE risk. Visual-manual subtasks also increased SCE risk before the data were divided and for all bins of driving time, time on duty, and time of day when analyses were possible. Combining all MDU subtasks into general use fails to acknowledge differences between the subtasks. A comparison of the odds ratio results from the current research to the results from the CVO study (Olson et al., 2009) and Hickman, Hanowski, and Bocanegra (2010) indicates that they were similar: "dialing a cell phone" significantly increases SCE risk, "talk/listen to hands-free cell phone" significantly decreases SCE risk, and "talk/listen to handheld cell phone" was not significant. The similarity between these studies supports the inclusion of only crashes, near-crashes, and crash-relevant conflicts in this particular analysis (as discussed previously, this method was chosen in order to increase the ratio of baselines to SCEs).

Analyses determined that there is a relationship between time of day and MDU. The MDU frequency analyses for time of day had significant results, indicating that MDU in baselines changes across time of day. Tests indicated that the low morning bin had a significantly higher percentage of MDU occurring in baselines than all other bins, and drivers may be using their mobile devices more frequently during the low morning than during other parts of the day. In addition, the high evening bin had a significantly higher percentage of MDU in baselines than the high morning bin. More specifically, MDU was found to occur more frequently in baselines from 2:00 a.m. to 3:59 a.m. (bin category "low morning") than any of the other times examined. When the MDU percentages in baselines are plotted with the alertness circadian rhythm across a 24-hour timeline (Figure 1; MDU percentages as blocks, alertness circadian rhythm as line), it can be seen that the highest MDU percentage observed occurred during a natural low in the alertness circadian rhythm. Perhaps these drivers are using mobile devices while driving as a way to increase alertness during this particular time period.

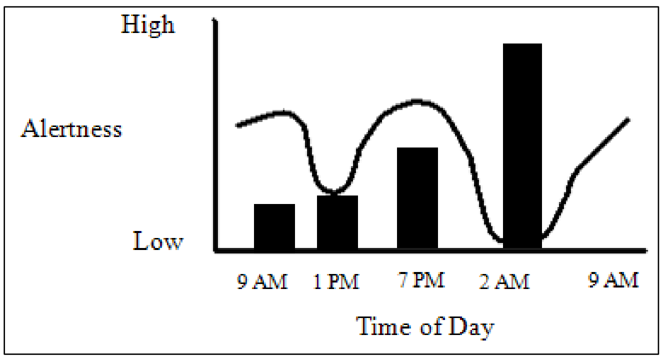

Figure 1. Graph. MDU percentages overlaid on alertness circadian rhythm.

Drivers were found to have more MDU in the middle (5 to 7.99 hours) of their working shifts than the beginning (1 to 4.99 hours). However, when MDU was examined across driving hours during a shift, MDU did not significantly differ between driving hour bins (was approximately 10% in each bin). It is difficult to tell from these findings whether MDU is related to time on duty as a drowsiness or fatigue surrogate. Given the previous finding of increased MDU at an alertness lull, one might expect drivers to use mobile devices more at the end of their workday, when perhaps they are fatigued from the work day. However, as drivers were found to using their mobile devices more at the beginning of their work shift, MDU may be correlated with working tasks. Drivers may be using their mobile devices more at the beginning of their work shift, before driving, to plan their day, communicate with dispatchers and receivers, or map their route.

During the driving portion of their work day, they might not need to use their mobile devices any more at one particular point compared to another.

Limitations

There are two limitations concerning the amount of sleep data. The first is that the current algorithm used to calculate the amount of sleep drivers received the 24 hours before an SCE or baseline was slightly different than the original algorithm. Of the 1,789 SCEs and baselines with original data that remained after filtering, there were 42 mismatches in the calculations for the current research. When expanding this proportion to all of the data, approximately 127 of the 5,422 SCEs and baselines would have been different from the original algorithm.

The second limitation from the sleep data is that when the filters were applied to create a consistent subset, 749 SCEs and baselines were removed. This reduction created an unequal comparison between the results for amount of sleep and the results for time of day, which is the other factor related to drowsiness. The smaller subset could be the reason for the difference in results regarding drowsiness. Future research should investigate if and how the time of day results would change if the 749 SCEs and baselines were removed. The reduced data points also influenced the depth of the analyses.

The next limitation is the amount of data available; after the data were divided into bins, approximately 20% of the subtasks had zero data points in at least one cell of the odds ratio contingency table. This led to the analysis of the MDU subtasks before the data were divided. Future research with a larger data set could provide more detailed information about when drivers perform certain subtasks. This may provide more insight into how drivers self-regulate to prevent or fight drowsiness or fatigue.

Conclusion

The risk of MDU subtasks was consistent with previous research and indicates that visual-manual subtasks are associated with an increased risk in SCEs, while conversational tasks are not associated with the same increased risk. MDU was also found to change with time of day and time on duty, and these findings may reflect the relationship between MDU and driver drowsiness and fatigue. However, further investigation should be performed to determine the reasons for increased MDU during time on duty, as use may also be correlated with job-related tasks. The use of four factors as surrogates of driver drowsiness and fatigue can be enhanced with the inclusion of additional information in future studies. Additional measures of fatigue and drowsiness, such as self-reports or physiological measures (e.g., electroencephalogram [EEG]), may provide more information about when participants were fatigued or drowsy. In addition, questionnaires or interviews regarding drivers' willingness to engage in the mobile device subtasks in different situations or levels of fatigue and drowsiness could be conducted. The responses could support both risk and usage results.

APPENDIX A. FINDINGS TO SUPPORT BINS FOR FACTORS

Driving time	Time on duty	Time of day	Amount of sleep
Sleeper-berth drivers had a decrease in arousal after 4.5 hours and relay drivers had a decrease in arousal after 5 to 8 hours (Mackie & Miller, 1978).	Drivers had an increase in arousal after a break at 3 hours of driving. There was less of an increase after a break at 6 hours, but there was no increase after a break at 9 hours of driving (Harris & Mackie, 1972).	There was no change in blink duration during or after the third call in the morning. However, there was no change in blink duration during or after the second or third call in the afternoon (Jellentrup, Metz, & Rothe, 2011). These likely occurred between 1:45 p.m. and 3:15 p.m.	The night before an SCE, drivers slept for 5 to 6 hours (Hanowski et al., 2000).
After 5 or less hours drivers had a decrease in arousal (Harris & Mackie, 1972).	When the 45 minute break between Block 1 and Block 2 was included, the calls after 5.57 and 6.25 hours did not increase arousal (Jellentrup et al., 2011).	Drowsiness was highest between the late evening and dawn (roughly 8:30 p.m. to 4:30 a.m.; Wylie, Shultz, Miller, Mitler, & Mackie, 1996). During this time, approximately 40% of trips were either starting or ending.	A decrease in performance occurred after sleeping 3 less hours than participant's normal 8 hours (Taub & Berger, 1973).
Blink duration did not decrease during or after a call following 2.5 hours of driving (Jellentrup et al., 2011).	Fatigue of short-haul pilots was determined using a 7-point Sanm-Perelli scale. When the scale was divided, hours 1–6 were in the moderate bin and hours 7–10 were in the high bin (Powell, Spencer, Holland, Broadbent, & Petrie, 2007).	The worst driving performance on curved and straight roadways occurred at 2:00 p.m. (versus 2:00 a.m., 6:00 a.m., 10:00 a.m., 6:00 p.m., and 10:00 p.m.). Performance was better at 10:00 a.m. (versus 6:00 a.m., 2:00 p.m., and 2:00 a.m.). (Lenné, Triggs, & Redman, 1997)	The largest percentage (31%) of drivers need 6 to 7 hours of sleep to perform their best, 26% need 7 to 8 hours, and 23% need less than 6 hours. The majority of drivers (58%) sleep for 6 to 8 hours the 24 hours before a workday, and 17% sleep for less than 6 hours (National Sleep Foundation, 2012).
Participants who drove longer than 3 hours had a greater chance of being in the "high fatigue" category (Barr et al., 2011).		The average adult experiences low arousal from 2:00 a.m. to 4:00 a.m. and 1:00 p.m. to 3:00 p.m. because of the circadian rhythm (National Sleep Foundation, n.d.).	Drivers slept for approximately 5.28 hours (*SD* = 2.03) before an SCE and approximately 6.63 hours (*SD* = 1.47) overall (Hanowski et al., 2005).
		The average adult experiences high arousal from 9:00 a.m. to 11:00 a.m. and 7:00 p.m. to 9:00 p.m. because of the circadian rhythm.(Figure)	Approximately 37% of transportation employees received 6 or less hours of sleep a night (Luckhaupt, Tak, & Calvert, 2010).

REFERENCES

Angell, L. S., Auflick, J., Austria, P. A., Kochhar, D. S., Tijerina, L., Biever, W., ...Kiger, S. (2006). *Driver workload metrics task 2 final report* (No. DOT HS 810 635). Washington, DC: National Highway Traffic Safety Administration.

Aschoff, J. (1965). Circadian rhythms in man. *Science, 148*(3676), 1427-1432.

Atchley, P., & Dressel, J. (2004). Conversation limits the functional field of view. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 46*(4), 664-673.

Barr, L. C., Yang, C. Y., Hanowski, R. J., & Olson, R. (2011). *An assessment of driver drowsiness, distraction, and performance in a naturalistic setting* (FMCSA-RRR-11-010). Washington, DC: Federal Motor Carrier Safety Administration.

Blanco, M., Hanowski, R. J., Olson, R. L., Morgan, J. F., Soccolich, S. A., Wu, S. C., & Guo, F. (2011). *The impact of driving, non-driving work, and rest breaks on driving performance in commercial motor vehicle operations*. (FMCSA-RRR-11-017). Washington, DC: Federal Motor Carrier Safety Administration.

Blanco, M., Hickman, J. S., Olson, R. L., Bocanegra, J. L., Hanowski, R. J., Nakata, A., Greening, M., Madison, P., Holbrook, G. T., & Bowman, D. (2008). *Investigating critical incidents, driver restart period, sleep quantity, and crash countermeasures in commercial vehicle operations using naturalistic data collection*. Washington, DC: Federal Motor Carrier Safety Administration.

Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C. (2008). A meta-analysis of the effects of cell phones on driver performance. *Accident Analysis & Prevention*, *40*(4), 1282-1293.

Cooper, J. M., Vladisavljevic, I., Strayer, D. L., Martin, P. T. (2008). *Drivers' lane changing behavior while conversing on a cell phone in a variable density simulated highway environment*. 87th Annual Meeting of the Transportation Research Board, Washington, DC.

Drews, F. A., Pasupathi, M., & Strayer, D. L. (2004). Passenger and Cell-Phone Conversations in Simulated Driving. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting, 48*, 2210-2212.

Federal Motor Carrier Safety Administration. (2010a). Drivers of CMVs: Restricting the use of cellular phones. *Federal Register*, *75*(244), 80014-80033.

Federal Motor Carrier Safety Administration. (2010b). Limiting the use of wireless communication devices. *Federal Register*, *75*(186), 59118-59136.

Federal Motor Carrier Safety Administration. (2011a). Hours of service of drivers. *76*(248), 81134-81188.

Federal Motor Carrier Safety Administration. (2011b). Summary of hours-of-service (HOS) regulations. Retriebved July 8, 2011, from http://www.fmcsa.dot.gov/rules-regulations/topics/hos.index.htm

Fitch, G. M., & Hanowski, R. J. (2011, September 5-7). *The risk of a safety-critical event associated with mobile device use as a function of driving task demands.* Paper presented at the 2nd International Conference on Driver Distraction and Inattention, Gothenburg, Sweden.

Fitch, G. M., & Hanowski, R. J. (2012). *Exploring drivers' compensatory behavior when conversing on a mobile device.* Paper presented at the 4th International Conference on Applied Human Factors and Ergonomics, San Francisco, California.

Fitch, G. M., Soccolich, S. A., Guo, F., McClafferty, J., Fang, Y., Olson, R. L., . . . Dingus, T. A. (2013). The *impact of hand-held and hands-free cell phone use on driving performance and safety-critical event risk* (Report No. DOT HS 811 757). Washington, DC: National Highway Traffic Safety Administration.

Flannagan, C., & Sayer, J. (2010). *An assessment of research on cell phone risk while driving*. Ann Arbor: University of Michigan Transportation Research Institute.

Hanowski, R. J. (2011). The naturalistic study of distracted driving: Moving from research to practice. *SAE International Journal of Commercial Vehicles, 4*(1), 286-319. doi:10.4271/2011-01-2305

Hanowski, R. J., Wierwille, W. W., Garness, S. A., & Dingus, T. A. (2000). *Impact of local/short haul operations on driver fatigue: Draft of final report with emphasis on field data gathering results*. Washington, DC: Federal Motor Carrier Safety Administration.

Harris, W., & Mackie, R. R. (1972). A study of the relationships among fatigue, hours of service, and safety operations of truck and bus drivers. Goleta, CA: Human Factors Research, Inc.

Hickman, J. S., & Hanowski, R. J. (2012). An assessment of commercial motor vehicle driver distraction using naturalistic driving data. *Traffic Injury Prevention, 13*(6), 566-574. doi:10.1080/15389588.2012.683841

Hickman, J. S., Hanowski, R. J., & Bocanegra, J. (2010). *Distraction in commercial trucks and buses: Assessing prevalence and risk in conjunction with crashes and near-crashes* (Report No. FMCSA-RRR-10-049). Washington, DC: Federal Motor Carrier Safety Administration.

Horrey, W. J., Lesch, M. F., & Garabet, A. (2008). Assessing the awareness of performance decrements in distracted drivers. *Accident Analysis & Prevention, 40*(2), 675-682. doi:10.1016/j.aap.2007.09.004

Horrey, W. J., & Wickens, C. D. (2006). Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 48*(1), 196-205.

Jellentrup, N., Metz, B., & Rothe, S. (2011). Can talking on the phone keep the driver awake? Results of a field-study using telephoning as a countermeasure against fatigue while driving. Paper presented at the 2nd International Conference on Driver Distraction and Inattention, Gothenburg, Sweden.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). *The impact of driver inattention on near-crash/crash risk: An analysis using the 100-Car Naturalistic Driving Study data*. Washington, DC: National Highway Traffic Safety Administration.

Klauer, S. G., Guo, F., Sudweeks, J., & Dingus, T. A. (2010). *An analysis of driver inattention using a case-crossover approach on 100-Car Data: Final report* (No: HS 811 334). Washington, DC: National Highway Traffic Safety Administration.

Knipling, R. R., Mironer, M., Hendricks, D., Tijerina, L., Everson, J., Allen, J., & Wilson, C. (1993). *Assessment of IVHS countermeasures for collision avoidance: Rear-end crashes. Final Report* (No. HS 807 995). Washington, DC: National Highway Traffic Safety Administration.

Knipling, R. R., & Wang, J-S. (1994, November). *Crashes and fatalities related to driver drowsiness/fatigue*. Washington, DC: National Highway Traffic Safety Administration.

Larue, G. S., Rakotonirainy, A., & Pettitt, A. N. (2011). Driving performance impairments due to hypovigilance on monotonous roads. *Accident Analysis and Prevention, 43,* 2037-2046. doi:10.1016/j.aap.2011.05.023

Lenné, M. G., Triggs, T. J., & Redman, J. R. (1997). Time of day variations in driving performance. *Accident Analysis and Prevention, 29*, 431-438. doi:10.1016/S0001-4575(97)00022-5

Lerner, N., Singer, J., & Huey, R. (2008). *Driver strategies for engaging in distracting tasks using in-vehicle technologies* (Report No. DOT HS 810 919). Washington, DC: U.S. Department of Transportation.

Luckhaupt, S. E., Tak, S., & Calvert, G. M. (2010). The prevalence of short sleep duration by industry and occupation in the National Health Interview Survey. *SLEEP, 33*(2), 149-159.

Mackie, R. R., & Miller, J. C. (1978). *Effects of hours of service regularity on schedules, and cargo loading on truck and bus driver fatigue*. Washington, DC: National Highway Traffic Safety Administration & Bureau of Motor Carrier Safety.

Maclure, M., & Mittleman, M. A. (2000). Should we use a case-crossover design? *Annual Review of Public Health, 21*, 193-221.

Maples, W. C., DeRosier, W., Hoenes, R., Bendure, R., & Moore, S. (2008). The effects of cell phone use on peripheral vision. *Optometry-Journal of the American Optometric Association, 79*(1), 36-42.

McEvoy, S. P., Stevenson, M. R., McCartt, A. T., Woodward, M., Haworth, C., Palamara, P., & Cercarelli, R. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: A case-crossover study. *BMJ, 331*(7514), 428–430.

National Highway Traffic Safety Administration. (2012, February 24). Visual-manual NHTSA driver distraction guidelines for in-vehicle electronic devices, Notice of Proposed Federal Guidelines. *Federal Register, 77*(37), 11200.

National Highway Traffic Safety Administration. (2015a). *2014 Crash data key findings* (No. DOT HS 812 219). Retrieved from http://www-nrd.nhtsa.dot.gov/Pubs/812219.pdf

National Highway Traffic Safety Administration. (2015b). *Traffic safety facts research note* (No. DOT HS 812 132). Retrieved from http://www.distraction.gov/downloads/pdfs/Distracted_Driving_2013_Research_note.pdf

National Highway Traffic Safety Administration. (2015c). *Traffic safety facts 2013* (No. DOT HS 812 139). Retrieved from NHTSA website: http://www-nrd.nhtsa.dot.gov/Pubs/812139.pdf

National Highway Traffic Safety Administration. (2015d). *Traffic safety facts 2013 data: Large trucks* (No. DOT HS 812 150). Retrieved form NHTSA website: http://www-nrd.nhtsa.dot.gov/Pubs/812150.pdf

National Sleep Foundation. (n.d.). *Sleep drive and your body clock*. Retrieved February 9, 2012, from http://www.sleepfoundation.org/article/sleep-topics/sleep-drive-and-your-body-clock

National Sleep Foundation. (2012). 2012 Sleep in America poll: Planes, trains, automobiles and sleep. Retrieved from http://www.sleepfoundation.org/sites/default/files/2012%20Sleep%20in%20America%20Poll-%20Summary%20of%20Findings.pdf

National Transportation Safety Board. (2011). No call, no text, no update behind the wheel: NTSB calls for nationwide ban on PEDs while driving [Press Release]. Retrieved February 6, 2012, from National Traffic Safety Board Web site http://www.ntsb.gov/news/2011/111213.html

Neurauter, M., Hankey, J., Schalk, T., & Wallace, G. (2012). Outbound texting: comparison of speech-based approach and handheld touch-screen equivalent. *Transportation Research Record: Journal of the Transportation Research Board, 2321*, 23-30.

Olson, R. L., Hanowski, R. J., Hickman, J. S., & Bocanegra, J. (2009). *Driver distraction in commercial vehicle operations: Final report* (No. FMCSA-RRR-09-042). Washington, D.C.: Federal Motor Carrier Safety Administration.

Owens, J. M., McLaughlin, S. B., & Sudweeks, J. (2010). On-road comparison of driving performance measures when using handheld and voice-control interfaces for mobile phones and portable music players. *SAE International Journal of Passenger Cars – Mechanical Systems*, *3*(1), 734-743.

Powell, D., Spencer, M. B., Holland, D., Broadbent, E., & Petrie, K. J. (2007). Pilot fatigue in short-haul operations: Effects of number of sectors, duty length, and time of day. *Aviation, Space, & Environmental Medicine, 78*, 698-701.

Ranney, T. A., Baldwin, G. H., Parmer, E., Martin, J., & Mazzae, E. N. (2011). *Distraction effects of manual number and text entry while driving* (No. DOT HS 811 510). Washington, DC: National Highway Traffic Safety Administration.

Redelmeier, D. A., & Tibshirani, R. J. (1997). Association between cellular-telephone calls and motor vehicle collisions. *New England Journal of Medicine, 336*(7), 453–458.

Sayer, J. R., Devonshire, J. M., & Flannagan, C. A. (2007). *Naturalistic driving performance during secondary tasks.* Paper presented at the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.

Strayer, D. L., Cooper, J. M., Turrill, J., Coleman, J., Medeiros-Ward, N., & Biondi, F. (2013). *Measuring cognitive distraction in the automobile*. Washington, DC: AAA Foundation for Traffic Safety. Retrieved from https://www.aaafoundation.org/sites/default/files/MeasuringCognitiveDistractions.pdf

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied*, *9*(1), 23-32.

Taub, J. M. & Berger, R. J. (1973). Performance and mood following variations in the length and timing of sleep. *Psychophysiology*, *10*, 559-570. doi:10.1111/j.1469-8986.1973.tb00805.x

Tijerina, L. (2009). *The science and politics of cell phones and driver distraction.* Retrieved from http://ergonomics.osu.edu/sites/ergonomics.osu.edu/files/uploads/Tijerina_Cell%20Phones_Driver_Distraction.pdf

Williamson, A. (2009). The relationship between driver fatigue and driver distraction. In M. Regan, J. D. Lee, & K. L. Young (Eds.), *Driver distraction: Theory, effects, and mitigation* (pp. 383-392). Boca Raton, FL: CRC Press.

Wylie, C. D., Shultz, T., Miller, J. C., Mitler, M. M., & Mackie, R. R. (1996). C*ommercial motor vehicle driver fatigue and alertness study: Technical summary* (FHWA-MC-97-001). Washington, DC: Federal Highway Administration.

Young, K., Regan, M., & Hammer, M. (2003). *Driver distraction: A review of the literature* (Report No. 206). Victoria, Australia: Monash University Accident Research Centre.