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The Risk of a Safety-critical Event Associated with Mobile Device Subtasks in Specific Driving Contexts

Final Report

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EXECUTIVE SUMMARY

Using a cell phone while driving has been associated with an increased crash risk. However, when examining the inherent subtasks, naturalistic driving studies (NDSs) have shown that safety-critical event (SCE) risk is associated with visual-manual subtasks – which take the driver's eyes off the roadway – and not the conversation itself.

This study consisted of an analysis of data from NDSs involving commercial motor vehicle (CMV) drivers and light vehicle (LV) drivers. The first data set used was analyzed in Olson et al.'s 2009 case-control study of CMV driver distraction.[10] This data set comprised 4,451 SCEs (i.e., crashes, near-crashes, crash-relevant conflicts, and unintentional lane deviations) as well as 19,888 baseline epochs that were randomly sampled based on the time driven by each driver. The second data set was the 100-Car Study data set analyzed in Klauer et al.'s 2006 case-control study of LV driver distraction.[9] This data set comprised 828 SCEs (i.e., crashes and near-crashes). The baseline epochs used, however, were the 17,213 epochs prepared in Guo & Hankey[28] because they were randomly sampled based on the time driven by each driver, as opposed to driver representation in the SCE sample.[9] The NDS data sets were partitioned into subsets representative of specific driving contexts. Groupings of (1) level of service, an ordinal measure of traffic density,[29] (2) relation to intersections and merge ramps, and (3) combinations of these two factors were prepared. The data were then "flagged" whenever specific mobile device subtasks were observed. Mobile device usage was investigated by summing all SCEs and baselines for which a subtask was observed in each context and comparing the likelihood of the subtask occurring in each context using chi-squared tests. Odds ratios and their respective 95% confidence intervals were then computed for mobile device subtasks in each context to investigate the association between their presence and the occurrence of an SCE.

It was found that CMV and LV drivers varied as to how much they conversed on a mobile device, but did not vary their engagement in visual-manual subtasks, across the driving contexts examined. Furthermore, CMV drivers conversed less frequently when driving task demands were great, and LV drivers did not. The risk of an SCE associated with mobile device use (collapsed across subtasks) was dependent on the driving context as well as each subtask's associated SCE risk. Only visual-manual subtasks were associated with an increased SCE risk, while conversing was associated with a decreased risk. Overall, the study shows that drivers' engagement in mobile device subtasks, and the associated SCE risk, varies by driving context. The findings can be used to inform the design of in-vehicle interfaces that mitigate distraction by preventing visual-manual subtasks while driving.

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LIST OF ABBREVIATIONS AND SYMBOLS

C.I.	Confidence Interval
CMV	Commercial Motor Vehicle
IVBSS	Integrated Vehicle-Based Safety System
LOS	Level of Service
LV	Light Vehicle
NDS	Naturalistic Driving Study
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
OR	Odds Ratio
PDA	Personal Digital Assistant
SCE	Safety-Critical Event
SHRP 2	Second Strategic Highway Research Program
TTC	Time-To-Collision

CHAPTER 1. INTRODUCTION

In December 2011, the National Transportation Safety Board (NTSB) called for the ban of all portable electronic devices – including Bluetooth® hands-free devices – while driving, reigniting the nation's discussion of driver distraction following the 2009 and 2010 Safety Summits convened by U.S. Transportation Secretary Ray LaHood.[(1)] This watershed recommendation was based on research from the National Highway Traffic Safety Administration (NHTSA) which estimated that 3,092 deaths occurred in 2010 from distraction, as well as investigations performed by the NTSB in which using a cell phone was identified as a probable cause of a fatal or injurious crash.[(2,3)] Proponents of the ban often cite epidemiological research which has shown that using a cell phone – be it handheld or hands-free – is associated with a quadrupling of the risk of injury and property damage crashes when the constituent cell phone subtasks are analyzed together as one activity.[(4,5)]

The approach taken in the above research, however, was to analyze cell phone use as an aggregate of its constituent subtasks (e.g., reaching, dialing, texting, talking, and putting the phone away).[(6)] A series of naturalistic driving studies (NDS) that recorded video of driver behaviors leading up to a safety-critical event (SCE) (e.g., a crash, near-crash, crash-relevant conflict, or unintentional lane deviation) have shown that SCE risk is associated with visual-manual subtasks such as texting and dialing (which take the driver's eyes off the roadway for extended periods of time)[(7)] and not the conversation itself.[(8,9,10,11)] These results were observed in commercial motor vehicle (CMV) and light vehicle (LV) drivers (see Table 1), as well as across broad classifications of low, moderate, and high driving task demands.[(12)] These results clearly demonstrate that the relative risks of different cell-phone-use subtasks are not equivalent.[(13)] The implication is that, even when direct reports from the driver are available, it is difficult for the previously mentioned epidemiological studies to determine where the driver was looking in the seconds leading up to the crash to verify that visual distraction was not a primary factor.

Table 1. Odds ratios (ORs) for mobile device use reported in NDSs of CMV and LV drivers.

		Naturalistic Driving Study		
		Hickman et al.[8]	**Olson et al.[10]**	**Klauer et al.[9]**
Vehicle Type Examined		Tractor-trailers, three-axle trucks, and transit buses	Tractor-trailers	Light vehicles
Data Collection Interval		9/08 – 9/09	5/04 – 5/05 and 11/05 – 5/07	1/03 – 7/04
Number of Drivers		20,417	202	241
Number of Vehicles		13,305	55	109
Number of Crashes		1,085	21	69
Total Number of SCEs		40,121	4,452	830
Number of Baselines		211,171	19,888	20,000
Task	Cell Phone Use (Collapsed)	OR = 1.22*	OR = 1.04	Not computed
	Reaching for Headset/Earpiece	OR = 3.4*	OR = 6.72*	Not computed
	Reaching for Cell Phone	OR = 3.8*	Included in dialing phone	Not computed
	Texting/Emailing/Accessing the Internet	OR = 163.6*	OR = 23.24*	Not computed
	Dialing Cell Phone	OR = 3.1*	OR = 5.93*	OR = 2.8*
	Talking/Listening on Hands-Free Cell Phone	OR = 1.31	OR = 0.44*	No SCEs observed
	Talking/Listening on Handheld Cell Phone	OR = 0.78*	OR = 1.04	OR = 1.3

Note: Asterisk indicates a significant OR. A significant OR greater than 1 indicates an increased risk, and a significant OR of less than 1 indicates a decreased risk.

The decreased risk of an SCE associated with conversing on a mobile device is counterintuitive because it contradicts human information-processing theories, and numerous empirical studies have shown that conversing *alone* on a mobile device degrades driving performance. As synthesized by the National Safety Council[14], conversing on a mobile device increases drivers' ratings of workload[15], leads to missed signals and slower reaction times,[16] leads to poor speed maintenance and headway distance,[17] makes drivers look but fail to remember seeing objects,[18] reduces the area that drivers scan,[19,20] increases reaction time to unexpected events,[21,22] degrades lane keeping performance,[22] decreases travel speed,[23,7] increases following distance,[23] makes drivers less likely to change lanes,[23] decreases the parietal lobe activation (which is associated with spatial processing),[24] leads to missed navigational signage,[25] and increases stop light violations.[26]

It is unclear why these performance decrements have not translated into increased risk in real-world NDSs. One thought is that since NDSs observe drivers over an extended period of time (e.g., multiple weeks to a year), perhaps conversing on a mobile device has not been associated with an increased SCE risk because specific driving contexts have not been isolated. The risk may, therefore, be deflated if the majority of the data in the analysis comprise instances of "satisficed" driving[27]; that is, where the driving task demands are low and drivers have ample residual mental resources to divide attention between driving and the conversation. This issue was addressed in the current study.

The purpose of this study was to investigate the risk of an SCE associated with using a mobile device when driving in specific contexts. It expands on the work of Fitch and Hanowski[12] by isolating specific gradations of traffic density, proximity to intersections and merge ramps, and combinations of these two factors. This isolation provides increased experimental control compared to the gross levels of driving task demands previously analyzed. We hypothesized that drivers' engagement in specific cell phone subtasks, as well as the SCE risk associated with this engagement, would change in different driving contexts.

CHAPTER 2. METHOD

This study consisted of an analysis of two existing naturalistic driving data sets. The data sets were produced by installing video cameras (Figure 1) and vehicle sensors (e.g., accelerometers, range-sensing radars, etc.) in participants' vehicles and continuously recording their driving performance without an experimenter in the vehicle. SCEs that occurred during the 5+ million vehicle-miles collected were detected by algorithms and validated by data analysts who visually inspected a 6-second window of video and sensor data for each potential event. These data sets provided an instant replay of the driver, vehicle, and environment in the seconds leading up to an SCE. The first data set used was analyzed in Olson et al.'s 2009 case-control study of CMV driver distraction.(10) This data set comprised 4,451 SCEs (i.e., crashes, near-crashes, crash-relevant conflicts, and unintentional lane deviations) as well as 19,888 baseline epochs that were randomly sampled based on the time driven by each driver. The second data set was the 100-Car Study data set analyzed in Klauer et al.'s 2006 case-control study of LV driver distraction.(9) This data set comprised 828 SCEs (i.e., crashes and near-crashes). The baseline epochs used, however, were the 17,213 epochs prepared in Guo & Hankey's 2009 study(28) because they were randomly sampled based on the time driven by each driver, as opposed to driver representation in the SCE sample.(9) The following items are noted: (1) the subject vehicle was traveling at least 24 km/h in each sample, (2) the CMV and LV driver data sets were analyzed separately in this study, and (3) all recorded SCEs were analyzed, not just at-fault SCEs. Table 1 presents the number of vehicles and data collection intervals used in these studies.

(a) (b) (c)

Figure 1. Photos. (a) Five camera images multiplexed into a single image recorded in a portion of the vehicles used in Olson et al.(10) (b) Four camera images multiplexed into a single image recorded in the remaining portion of the vehicles studied in Olson et al.(10) (c) Four camera images multiplexed into a single image recorded in the 100-Car Study.(9)
(Consenting research institute personnel are shown in all figures.)

The data sets were queried on existing attributes to identify specific driving contexts. Groupings of (1) level of service (LOS), an ordinal measure of traffic density,(29) (2) relation to intersections and merge ramps, and (3) combinations of these two factors were prepared. Table 2 presents the selection criteria used for the CMV and 100-Car study data sets. The LOS categories were comprehensive, and relation-to-junction categories omitted a small number of samples that took place in parking lots, driveways, bridges, and rail crossings.

Table 2. Selection criteria used to create driving context subsets.

Driving Context		Selection Criteria
Level of Service	LOS A	• All SCEs and baselines that occurred at LOS A (free flow)
	LOS B	• All SCEs and baselines that occurred at LOS B (flow with some restrictions)
	LOS C or Greater	• All SCEs and baselines that occurred at LOS C, D, E, or F (from stable flow where maneuverability and speed are restricted to unstable flow)
Relation to Junction	No Junction	• All SCEs and baselines that occurred on a road with no junction
	Intersection or Entrance/Exit Ramp	• All SCEs and baselines that occurred in or near an intersection, or on an entrance/exit ramp

An SCE or baseline epoch was "flagged" whenever specific mobile device subtasks were observed in the 6-second epochs. In the CMV data set, flags were created for texting on a cell phone, dialing on a cell phone, talking/listening on a handheld cell phone, and talking/listening on a hands-free cell phone. If a flag was true for any of these subtasks, then a flag for "cell phone use (collapsed across subtasks)" was also created. This was done so that "using a cell phone" could be analyzed as a dichotomous variable as has been conducted in some previous distraction studies.[4,5] A separate flag was also created for talking/listening on a CB radio. In the LV data set, flags for dialing on a cell phone, talking/listening on a handheld cell phone, and talking/listening on a hands-free cell phone were created. If a flag was true for any of these subtasks, then a flag for "cell phone use (collapsed across subtasks)" was created. Although texting was not observed in the 100-Car study, a separate flag was created for interacting with a Personal Digital Assistant (PDA).

Mobile device usage was investigated by summing all SCEs and baselines in which a subtask was observed in each context, and comparing the likelihood of the subtask occurring in each context using chi-squared tests. A Bonferroni adjustment was used when multiple comparisons were performed. ORs and the respective 95% confidence intervals (C.I.s) were then computed for mobile device subtasks in each context to investigate the association between their presence and the occurrence of an SCE.

CHAPTER 3. RESULTS

DRIVERS' MOBILE DEVICE USE

Tables 3 and 4 present the percentage of samples in each driving context in which drivers were observed to use a mobile device. CMV and LV drivers' mobile device use significantly differed across the driving contexts examined (denoted by shaded cells in the tables).

CMV Drivers. CMV drivers' cell phone use (collapsed across subtasks) significantly differed across LOS. Cell phone use was greatest in LOS B (10.1%) compared to LOS A (9%) and LOS C or greater (7.4%), $\chi^2(2) = 9.375$, $p = 0.0092$. When considering the inherent subtasks of using a cell phone, these differences were observed because CMV drivers conversed on a hands-free cell phone significantly more in LOS B (4.7%) than in LOS A (3.9%), $\chi^2(2) = 8.539$, $p = 0.014$. Although conversing on a hands-free cell phone was the lowest in LOS C or greater (3.4%), we cannot conclude that use was the lowest here because we failed to observe a significant difference between LOS C and the LOS A and B at the 0.05 level of significance.

CMV drivers' cell phone use (collapsed across subtasks) was also significantly lower when in/near an intersection or merge ramp (6.1%) compared to when traveling on non-junction roads (9.4%), $\chi^2(1) = 18.313$, $p < 0.0001$. This was because CMV drivers varied as to how much they conversed on a mobile device. CMV drivers conversed on a handheld cell phone significantly less when in/near an intersection or merge ramp (2.9%) compared to when on non-junction roads (4.3%), $\chi^2(1) = 6.846$, $p = 0.0089$. They also conversed on a hands-free cell phone significantly less when in/near an intersection or merge ramp (2.7%) compared to when on non-junction roads (4.2%), $\chi^2(1) = 7.58$, $p = 0.0059$.

For mobile device use by level of service and relation to junction, CMV drivers used their mobile device less frequently when in/near an intersection or merge ramp (7%) compared to non-junction roads (9.1%) when the level of service was LOS A, $\chi^2(1) = 5.016$, $p = 0.0251$. The same was observed when the level of service was LOS B (general use was 3.8% when in/near an intersection or merge ramp versus 10.5% when on non-junction roads, $\chi^2(1) = 18.464$, $p < 0.0001$). Mobile device use differed across relation to junction in LOS B because CMV drivers conversed on handheld and hands-free cell phones significantly less when in/near an intersection or merge ramp compared to non-junction roads. Their handheld cell phone use was 1.8% when in/near an intersection or merge ramp, while it was 4.7% when on non-junction roads, $\chi^2(1) = 7.455$, $p = 0.0063$. Their hands-free cell phone use was 1.5% when in/near an intersection or merge ramp, while it was 5.0% when on non-junction roads, $\chi^2(1) = 9.821$, $p = 0.0017$. CMV drivers' likelihood of dialing, texting, or using a CB radio was not found to differ across any of the driving contexts examined.

LV Drivers. LV drivers' cell phone use (collapsed across subtasks) significantly differed across LOS. Cell phone use was greater in LOS B (8.6%) and LOS C or greater (9.6%) compared to LOS A (7.6%), $\chi^2(2) = 11.719$, $p = 0.0029$. These differences were observed because LV drivers conversed on a hands-free cell phone significantly more in LOS C or greater (2%) than they did in LOS A (1.1%) or LOS B (1.3%), $\chi^2(2) = 10.245$, $p = 0.006$. For mobile device use by relation to junction, LV drivers conversed on a hands-free cell phone more frequently when in/near an intersection or merge ramp (7.1%) compared to non-junction roads (6.0%), $\chi^2(1) = 4.439$, $p =$

0.0351. In investigating mobile device use by both level of service and relation to junction, LV drivers conversed on a hands-free cell phone less frequently when in/near an intersection or merge ramp (0.6%) compared to non-junction roads (1.5%) when the level of service was LOS B, $\chi^2(1) = 6.018$, $p = 0.0142$. Similar to CMV drivers, LV drivers' likelihood of dialing, or using a PDA, was not found to significantly differ across any of the driving contexts examined.

Table 3. Percentage of samples in each driving context in which CMV drivers were observed to use a mobile device.

Driving Context		Cell Phone Use (Collapsed Across Subtask)	Texting	Dialing	Talking/ Listening HH	Talking/ Listening HF	CB Radio	Total Samples	Total	
Level of Service	LOS A	9% (1337, 259)	0.1% (5, 20)	1% (75, 98)	4.2% (626, 121)	3.9% (650, 41)	1.8% (300, 25)	17,748	24,338	
	LOS B	10.1% (464, 122)	0.2% (0, 10)	0.9% (25, 28)	4.5% (208, 56)	4.7% (241, 33)	1.9% (97, 14)	5,816		
	≥ LOS C	7.4% (16, 41)	0.3% (1, 1)	1% (2, 6)	2.7% (3, 18)	3.4% (10, 16)	1.7% (2, 11)	774		
	$\chi^2(2)$	9.375, $p = 0.0092$	0.875, $p = 0.6458$	0.229, $p = 0.8918$	5.768, $p = 0.0559$	8.539, $p = 0.014$	0.265, $p = 0.8758$			
Relation to Junction	No Junction	9.4% (1731, 371)	0.2% (6, 30)	1% (93, 126)	4.3% (797, 170)	4.2% (862, 71)	1.9% (383, 39)	22,375	23,882	
	Intersection or Ramp	6.1% (50, 42)	0% (0, 0)	0.5% (5, 3)	2.9% (23, 21)	2.7% (23, 18)	1.4% (10, 11)	1,507		
	$\chi^2(1)$	18.313, $p < .0001$	2.428, $p = 0.1192$	3.009, $p = 0.0828$	6.846, $p = 0.0089$	7.58, $p = 0.0059$	1.881, $p = 0.1702$			
LOS A	No Junction	9.1% (1267, 232)	0.2% (5, 20)	1% (69, 95)	4.3% (594, 107)	3.9% (616, 31)	1.8% (287, 17)	16,453	17,425	23,881
	Intersection or Ramp	7% (48, 20)	0% (0, 0)	0.5% (4, 1)	3.3% (22, 10)	3.3% (23, 9)	1.6% (8, 8)	972		
	$\chi^2(1)$	5.016, $p = 0.0251$	1.479, $p = 0.2239$	2.224, $p = 0.1359$	2.136, $p = 0.1439$	1.005, $p = 0.3162$	0.207, $p = 0.6492$			
LOS B	No Junction	10.5% (450, 107)	0.2% (0, 9)	0.9% (22, 27)	4.7% (201, 49)	5% (237, 27)	2% (94, 12)	5,308	5,705	
	Intersection or Ramp	3.8% (1, 14)	0% (0, 0)	0.5% (1, 1)	1.8% (0, 7)	1.5% (0, 6)	1% (2, 2)	397		
	$\chi^2(1)$	18.464, $p < .0001$	0.674, $p = 0.4116$	0.733, $p = 0.3919$	7.455, $p = 0.0063$	9.821, $p = 0.0017$	1.912, $p = 0.1667$			
≥ LOS C	No Junction	7.3% (14, 31)	0.3% (1, 1)	1% (2, 4)	2.6% (2, 14)	3.4% (9, 12)	2% (2, 10)	613	751	
	Intersection or Ramp	6.5% (1, 8)	0% (0, 0)	0.7% (0, 1)	3.6% (1, 4)	2.2% (0, 3)	0.7% (0, 1)	138		
	$\chi^2(1)$	0.113, $p = 0.7364$	0.451, $p = 0.5016$	0.079, $p = 0.7789$	0.425, $p = 0.5143$	0.571, $p = 0.45$	1.007, $p = 0.3157$			

Table 4. Percentage of samples in each driving context in which LV drivers were observed to use a mobile device.

Driving Context		Cell Phone Use (Collapsed Across Subtask)	PDA Use	Dialing	Talking/Listening HH	Talking/Listening HF	Total Samples	Total
Level of Service	LOS A	7.6% (628, 20)	0% (3, 0)	0.9% (74, 6)	5.8% (482, 14)	1.1% (97, 0)	8,515	18,039
	LOS B	8.6% (586, 20)	0.1% (3, 1)	1% (64, 4)	6.6% (446, 16)	1.3% (95, 0)	7,046	
	≥ LOS C	9.6% (219, 19)	0.2% (4, 0)	1.1% (23, 5)	6.7% (152, 14)	2% (49, 0)	2,478	
	$\chi^2(2)$	11.719, p = 0.0029	5.049, p = 0.0801	0.734, p = 0.6929	4.612, p = 0.0997	10.245, p = 0.006		

Relation to Junction	No Junction	8.2% (1149, 42)	0.1% (10, 1)	1% (134, 12)	6% (850, 30)	1.4% (204, 0)	14,555	17,495
	Intersection or Ramp	8.8% (243, 15)	0% (0, 0)	0.9% (23, 3)	7.1% (196, 12)	1.1% (32, 0)	2,940	
	$\chi^2(1)$	1.131, p = 0.2875	2.223, p = 0.1359	0.354, p = 0.5517	4.439, p = 0.0351	1.802, p = 0.1794		

LOS A	No Junction	7.4% (499, 14)	0% (3, 0)	0.9% (59, 6)	5.6% (378, 8)	1.2% (81, 0)	6,915	8,113	17,494
	Intersection or Ramp	8.3% (96, 4)	0% (0, 0)	1% (12, 0)	6.7% (76, 4)	1% (12, 0)	1,198		
	$\chi^2(1)$	1.261, p = 0.2615	0.52, p = 0.4709	0.041, p = 0.8389	2.264, p = 0.1324	0.26, p = 0.6105			
LOS B	No Junction	8.6% (475, 13)	0.1% (3, 1)	1.1% (57, 3)	6.3% (349, 10)	1.5% (86, 0)	5,673	6,936	
	Intersection or Ramp	8.8% (104, 7)	0% (0, 0)	0.6% (6, 1)	7.8% (92, 6)	0.6% (8, 0)	1,263		
	$\chi^2(1)$	0.046, p = 0.8311	0.891, p = 0.3452	2.737, p = 0.0981	3.437, p = 0.0637	6.018, p = 0.0142			
≥ LOS C	No Junction	9.7% (175, 15)	0.2% (4, 0)	1.1% (18, 3)	6.9% (123, 12)	1.9% (37, 0)	1,966	2,445	
	Intersection or Ramp	9.8% (43, 4)	0% (0, 0)	1.5% (5, 2)	6.3% (28, 2)	2.5% (12, 0)	479		
	$\chi^2(1)$	0.01, p = 0.9219	0.976, p = 0.3231	0.526, p = 0.4683	0.223, p = 0.6367	0.762, p = 0.3828			

RISK ASSOCIATED WITH MOBILE DEVICE USE

Tables 5 and 6 present the ORs and 95% C.I.s for each of the mobile device subtasks performed by CMV and LV drivers in each driving context. Note that only ORs for which C.I.s do not include 1.0 reflect significant effects. Exact tests and the matching C.I.s were adopted when there was a 0 count in the 2 × 2 contingency table.

CMV Drivers. The visual-manual subtasks of texting and dialing were associated with an increased risk of an SCE in numerous driving contexts. The OR for texting was 23.39 in LOS A, 27.78 on non-junction roads, and 27.38 on non-junction roads with LOS A. Because there were no SCEs observed when texting in certain contexts, exact tests were performed. The OR for texting was significantly greatly than 1 in LOS B as well as on non-junction roads with LOS B, indicating an increased SCE risk. The OR for dialing was 7.84 in LOS A, 4.14 in LOS B, 7.71 on non-junction roads, 9.73 on non-junction roads with LOS A, and 6.25 on non-junction roads with LOS B.

Conversing on a cell phone, on the other hand, was associated with a *decreased* risk in some of the driving contexts examined (e.g., protective effect). The OR for conversing on a hands-free cell phone was 0.36 in LOS A, 0.48 in LOS B, 0.44 on non-junction roads, 0.33 on non-junction roads with LOS A, and 0.55 on non-junction roads with LOS B. Similar to the usage findings, the OR for cell phone use (collapsed across subtasks) ultimately depended on the ORs for the inherent subtasks. The OR for cell phone use was 1.27 on non-junction roads, 1.27 on non-junction roads with LOS A, and, interestingly, 0.49 when in/near an intersection or merge ramp in LOS A. The ORs for conversing on a CB radio closely matched those found for conversing on a hands-free cell phone. The OR for conversing on a CB radio was 0.48 in LOS A, 0.52 in LOS B, 0.56 on non-junction roads, and 0.40 on non-junction roads with LOS A.

LV Drivers. Similar to the results found for CMV drivers, visual-manual subtasks were associated with an increased risk of an SCE in numerous driving contexts. The OR for dialing was 3.11 in LOS A, 2.72 on non-junction roads, and 7.23 on non-junction roads with LOS A. The OR for using a PDA was 11.94 on non-junction roads with LOS B. Furthermore, conversing on a cell phone was associated with a decreased risk in numerous contexts. The OR for conversing on a handheld cell phone was 0.49 when in/near an intersection or merge ramp. Exact tests were performed for conversing on a hands-free cell phone when there were no SCEs observed for this subtask. An exact OR of 0 was found for conversing on a hands-free cell phone on roads with LOS B, on roads with LOS C or greater, on non-junction roads, when in/near an intersection or merge ramp, and on non-junction roads with LOS C or greater. Again, the ORs for cell phone use (collapsed across subtasks) depended on the ORs for the inherent subtasks. The OR for cell phone use was 0.58 in LOS C or greater, 0.49 when in/near an intersection or merge ramp, and 2.04 on non-junction roads with LOS A.

Table 5. ORs and 95% C.I.s for each of the mobile device subtasks performed by CMV drivers in each driving context.

Driving Context		Cell Phone Use (Collapsed Across Subtask)	Texting	Dialing	Talking/Listening HH	Talking/Listening HF	CB Radio
Level of Service	LOS A	1.14 (0.99 - 1.31)	23.39 (8.77 - 62.38)	7.84 (5.79 - 10.63)	1.13 (0.92 - 1.38)	0.36 (0.26 - 0.49)	0.48 (0.32 - 0.72)
	LOS B	0.95 (0.77 - 1.17)	Infinity (10.4 - Infinity)	4.14 (2.4 - 7.12)	0.98 (0.72 - 1.32)	0.48 (0.33 - 0.7)	0.52 (0.3 - 0.91)
	≥ LOS C	0.81 (0.44 - 1.48)	0.32 (0.02 - 5.14)	0.96 (0.19 - 4.81)	1.95 (0.57 - 6.71)	0.5 (0.22 - 1.12)	1.78 (0.39 - 8.1)
Relation to Junction	No Junction	1.2 (1.07 - 1.35)	27.78 (11.56 - 66.8)	7.71 (5.88 - 10.11)	1.18 (1 - 1.4)	0.44 (0.35 - 0.57)	0.56 (0.4 - 0.77)
	Intersection or Ramp	0.53 (0.35 - 0.82)	None	0.39 (0.09 - 1.66)	0.59 (0.33 - 1.08)	0.51 (0.27 - 0.95)	0.72 (0.31 - 1.72)
LOS A	No Junction	1.27 (1.1 - 1.47)	27.38 (10.27 - 73.03)	9.73 (7.11 - 13.31)	1.23 (1 - 1.52)	0.33 (0.23 - 0.48)	0.4 (0.24 - 0.65)
	Intersection or Ramp	0.49 (0.28 - 0.83)	None	0.3 (0.03 - 2.73)	0.55 (0.26 - 1.17)	0.47 (0.21 - 1.02)	1.23 (0.46 - 3.3)
LOS B	No Junction	1.21 (0.96 - 1.51)	Infinity (12.7 - Infinity)	6.25 (3.54 - 11.03)	1.22 (0.89 - 1.68)	0.55 (0.37 - 0.83)	0.63 (0.34 - 1.15)
	Intersection or Ramp	2.61 (0.34 - 20.21)	None	0.18 (0.01 - 2.9)	Infinity (0.34 - Infinity)	Infinity (0.28 - Infinity)	0.18 (0.02 - 1.28)
≥ LOS C	No Junction	0.92 (0.48 - 1.78)	0.42 (0.03 - 6.71)	0.84 (0.15 - 4.61)	3 (0.67 - 13.33)	0.55 (0.23 - 1.32)	2.12 (0.46 - 9.78)
	Intersection or Ramp	0.19 (0.02 - 2.04)	None	Infinity (0 - Infinity)	0.09 (0.01 - 1.09)	Infinity (0.01 - Infinity)	Infinity (0 - Infinity)

Note: ORs of infinity are a result of zero observation in specific cells. Exact tests and the matching C.I.s were used.

Table 6. ORs and 95% C.I.s for each of the mobile device subtasks performed by LV drivers in each driving context.

Driving Context		Cell Phone Use (Collapsed Across Subtask)	PDA Use	Dialing	Talking/Listening HH	Talking/Listening HF
Level of Service	LOS A	1.22 (0.77 - 1.95)	0 (0 - 64.82)	3.11 (1.34 - 7.24)	1.1 (0.64 - 1.91)	0 (0 - 1.18)
	LOS B	0.76 (0.48 - 1.2)	7.6 (0.79 - 73.25)	1.43 (0.52 - 3.94)	0.8 (0.48 - 1.34)	0 (0 - 0.72)
	≥ LOS C	0.58 (0.36 - 0.94)	0 (0 - 7.81)	1.53 (0.58 - 4.05)	0.63 (0.36 - 1.1)	0 (0 - 0.43)
Relation to Junction	No Junction	1.1 (0.8 - 1.52)	2.99 (0.38 - 23.44)	2.72 (1.5 - 4.95)	1.06 (0.73 - 1.54)	0 (0 - 0.44)
	Intersection or Ramp	0.49 (0.29 - 0.83)	None	1.08 (0.32 - 3.63)	0.49 (0.27 - 0.89)	0 (0 - 0.79)
LOS A	No Junction	2.04 (1.15 - 3.61)	0 (0 - 116.37)	7.23 (3.05 - 17.16)	1.46 (0.71 - 3.04)	0 (0 - 2.55)
	Intersection or Ramp	0.46 (0.16 - 1.27)	None	0 (0 - 3.27)	0.59 (0.21 - 1.64)	0 (0 - 3.27)
LOS B	No Junction	0.97 (0.55 - 1.73)	11.94 (1.23 - 115.41)	1.89 (0.59 - 6.11)	1.02 (0.53 - 1.96)	0 (0 - 1.25)
	Intersection or Ramp	0.57 (0.26 - 1.25)	None	1.47 (0.18 - 12.3)	0.55 (0.24 - 1.29)	0 (0 - 4.01)
≥ LOS C	No Junction	0.68 (0.39 - 1.17)	0 (0 - 9.1)	1.36 (0.4 - 4.66)	0.78 (0.42 - 1.44)	0 (0 - 0.68)
	Intersection or Ramp	0.37 (0.13 - 1.06)	None	1.72 (0.33 - 9.02)	0.29 (0.07 - 1.24)	0 (0 - 1.19)

Note: ORs of 0 are a result of zero observation in specific cells. Exact tests and the matching C.I.s were used.

CHAPTER 4. DISCUSSION

This study investigated drivers' mobile device use and the associated risk of an SCE in specific driving contexts. The results are discussed relative to these two objectives.

DRIVERS' MOBILE DEVICE USE

Drivers' mobile device use (collapsed across subtasks) was found to vary across the driving contexts examined. However, analyzing the constituent subtasks revealed that drivers varied as to how much they conversed on a cell phone, but not with regard to their engagement in visual-manual subtasks. For instance, CMV drivers were observed to converse on a cell phone less frequently as the level of service decreased. Since decreases in LOS have been rated to substantially increased driving task demands,(30,31,32) this may be indicative of CMV drivers regulating their conversation based on the increased workload. This notion is also supported by the finding that conversing on a mobile device was lower when in/near an intersection or merge ramp – compared to when on non-junction roads – since traveling in/near an intersection has also been rated to increase driving task demands.(30,31) LV drivers, on the other hand, conversed on a mobile phone more frequently when the level of service was LOS C or greater as compared to when it was in LOS A or LOS B. This suggests that LV drivers do not regulate their conversation based on the driving task demands in a manner similar to CMV drivers. However, in a level of service equal to LOS B, LV drivers did converse on a hands-free cell phone less frequently when in/near an intersection or merge ramp compared to when on non-junction roads, suggesting that there may be specific contexts in which these drivers regulate their cell phone conversations.

Recent NDSs have observed similar findings. Using data collected between 2009 and 2010 from the Integrated Vehicle-Based Safety System (IVBSS) Field Operational Test,(33) Funkhouser and Sayer examined every minute of driving collected over an entire week of baseline data for each of the 108 drivers in the study.(34) They found that drivers conversed on a cell phone 6.7 percent of the time the vehicle was in operation. Interestingly, drivers were more likely to be on a cell phone with the wipers off compared to when they were on, as well as at night compared to during the day. Since driving task demands are less demanding in clear conditions, as well as at night when there are fewer vehicles on the road, these differences may be indicative of drivers regulating their cell phone use based on task demands. In fact, Funkhouser and Sayer found that drivers were more likely to initiate cell phone conversations (i.e., dial/answer a cell phone) at lower speeds (below 8 km/h, including stopped).(34) Finally, there was also some indication that endogenous factors regulate drivers' cell phone use. Younger and middle-aged drivers talked more than older drivers, suggesting that age may play a role. Furthermore, the increased use at night may reflect a strategy that drivers use to combat the onset of drowsiness from monotonous driving.(35) The results from that study and the current study affirm that distraction research must consider how drivers regulate their cell phone use as well as the context in which it is used. Note that a reason why the current study did not find differences in how frequently drivers performed visual-manual subtasks may be because the data set did not comprise samples where the vehicle was stopped.

MOBILE DEVICE RISK

The risk of an SCE associated with mobile device use (collapsed across subtasks) was found to be dependent on the driving context. It was associated with an increased risk when CMV and LV drivers drove on non-junction roads with LOS A, and was associated with a decreased risk when both CMV and LV drivers traveled in/near an intersection or merge ramp. However, it must be stressed this risk was dependent on the SCE risk of the inherent subtasks. Mobile device use was associated with an increased risk on non-junction roads with LOS A because the increased risk associated with texting and dialing outweighed the decreased risk of conversing on a hands-free phone or CB radio. In contrast, mobile device use was associated with a decreased risk when traveling in/near an intersection or merge ramp because the decreased risk of conversing on a cell phone outweighed the risk of the visual-manual subtasks. In general, these findings suggest that the risks associated with each subtask, be they positive or negative, have an additive effect on the overall SCE risk of using a mobile device. It is interesting that the visual-manual subtasks were associated with an increased risk when the driving context had low task demands (i.e., non-junction roads with LOS A). Perhaps drivers were less diligent here in dividing their attention between the road and the secondary tasks. How drivers divided their attention between driving and using a mobile device was not controlled in the current study.

A striking finding from this study was that just conversing on any kind of mobile device was never found to be associated with an increased SCE risk for either CMV or LV drivers in the driving contexts examined. Rather, it was associated with a decreased risk in numerous driving contexts representative of both easy and difficult driving task demands. These findings may contradict laboratory and driving simulator studies because they reflect how drivers actually use their cell phones under real-world conditions.

Why would conversing on a mobile device not be associated with an increased SCE risk? First, perhaps the workload imposed by the high driving task demands was insufficient to implicate the risk of conversing on a mobile device. There may be specific contexts not examined in this study where concurrently conversing while driving increases risk. Secondly, perhaps conversing on a mobile device did not increase drivers' arousal above the optimal level required to drive safely. That is, conversing on a mobile device was not a meaningful distraction because the additive workload was manageable by the drivers in this study.

Why would conversing on a mobile device be associated with a decreased SCE risk? Although this result is counterintuitive, it is important to note that drivers observed in NDSs look forward more often when conversing on a cell phone.(36,37,38) Hanowski et al. reported that the same CMV drivers examined in the current study had a shorter mean eyes-off-road time when conversing on a hands-free phone compared to when not conversing on a hands-free phone.(36) Using the IVBSS data, Sayer et al. found that glance durations away from the forward roadway were shortest when LV drivers used a cell phone.(37) Furthermore, Fitch et al. (2013) found that light vehicle drivers in a 204-vehicle naturalistic driving study looked forward 5.1 percent more, on average, when conversing on a handheld cell phone compared to their behavior 30 seconds prior to the start of the call.(11) Since a number of SCEs in the CMV data set comprised lane departures, and a number of SCEs in the LV data set comprised rear-end SCEs, it makes sense that drivers were less likely to be involved in an SCE if they were looking forward more often. This is because they became more likely to detect an unfolding lane departure or rear-end conflict. As such, this study should not be interpreted as stating that cell phone conversation makes drivers safer; rather, looking forward more often makes drivers safer.

In addition to looking forward more often, it has been suggested that drivers compensate for the workload induced by the conversation by changing their vehicle control.[39] Driving simulator research has demonstrated that, when free to do so, drivers decrease their speed, increase their headway, and change lanes less frequently.[23] However, controlled comparisons using naturalistic driving CMV and LV data have not found evidence for longitudinal compensatory behavior.[40] Drivers were not found to increase their headway or decrease their speed when conversing on a cell phone. Lateral vehicle control, however, was found to change; CMV drivers changed lanes less often and LV drivers kept in their lane better when conversing on a cell phone. As such, the increased visual attention to the forward roadway may be a predominant reason for the changes in SCE risk observed in different driving contexts.

PRACTICAL IMPLICATIONS

Although this study was exploratory in nature, it may provide insight into the design of driver-optimized interfaces, workload management, and driver state monitoring systems, as well as collision avoidance systems. First, visual-manual subtasks were found to be risky in various driving contexts, suggesting that these tasks should never be performed while driving. Secondly, conversing on a mobile device was not associated with an increased risk of an SCE in any of the driving task contexts examined. If this is because drivers compensate in the dual task condition, then there is merit for a workload management system to not only measure traffic density and road geometry but also drivers' performance in relation to these conditions (e.g., vehicle speed, headway, and Time-To-Collision [TTC] to lead vehicles). Third, there is an obvious need for collision avoidance systems to help drivers detect threats when they are distracted. These systems should therefore monitor the drivers' visual attention to the roadway as much as they monitor the crash threat of surrounding objects. Overall, the findings suggest that driver-vehicle interfaces that facilitate keeping drivers' visual attention on the road may enable technologies that improve transportation safety, improve mobility, reduce the impact on our environment, and meet the demand to be connected 24/7. Although there is merit in banning the use of mobile devices that require visual-manual interactions to be operated, it may be unjust to ban well-engineered technologies that allow mobile devices to be integrated with a vehicle through sound human factors.

CHAPTER 5. CONCLUSION

This study demonstrates that mobile device use and its inherent risks are dependent on the type of subtasks performed as well as the driving context. It is therefore imperative to decompose mobile device use into its elementary tasks, and to consider the conditions in which the subtasks are performed, to truly understand its effect on driving performance. Such task analysis is commonly performed in human-computer interaction research and merits application in distraction research.[(41)] Overall, this study lends the following insights. First, CMV drivers appear to use mobile devices differently than do LV drivers (i.e., CMV drivers converse less frequently on a mobile device as the driving task demands increase and LV drivers do not). Secondly, visual-manual subtasks are associated with an increased SCE risk in contexts indicative of low and high driving task demands. Furthermore, it is the risk associated with these subtasks that increases the SCE risk from mobile device use. Finally, conversing on a mobile device is not associated with an increased SCE risk in the examined driving contexts for either CMV or LV drivers.

POTENTIAL LIMITATIONS

Potential study limitations were as follows. First, few visual-manual subtask samples (e.g., texting and dialing) existed once the data were divided into the driving context subsets. This may have made their risk estimates imprecise, particularly in higher driving task demand contexts, and caution is urged when using them. Second, arousal/vigilance is dependent on the length of the driver's work shift. This study did not control for drivers' time behind the wheel. Instances when the driver just started his shift were treated the same as instances when the driver had been driving for multiple hours (where a vigilance decrement would be expected). Third, vehicle speed, headway, and TTC were not analyzed. Whether drivers changed their workload strategies was, therefore, not investigated. Fourth, this study did not control for driver demographics; however, the CMV driver population is rather homogeneous. Finally, it should also be noted that the LV data set analyzed in this study was skewed towards younger drivers and non-extended-highway driving. The risk estimates may therefore differ from those that could be obtained using larger naturalistic driving data sets, such as the Second Strategic Highway Research Program (SHRP 2) study.[(42)] Future research must be conducted to investigate these limitations.

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