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DRIVER DISTRACTION FROM CELL PHONE USE AND POTENTIAL FOR SELF-LIMITING BEHAVIOR

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16. Abstract

This project consists of three parts. The first is a review of the literature on driver distraction that primarily focuses on cell phone use. The second two parts involve analysis of an existing field operational test (FOT) database to examine: 1) self-limiting behavior on the part of drivers who use cell phones, and 2) eye glance patterns for drivers involved in cell phone conversations and visual-manual tasks (e.g., texting) as compared to no-task baseline driving. The literature review discusses the apparent contradiction between results of case-crossover and simulator studies that show increases in instantaneous risk due to talking on a cell phone and results of crash-data analyses that show no substantial increase in crashes associated with increases in cell phone use in vehicles. The first data analysis shows some evidence of self-limiting behavior in cell phone conversations. Drivers initiate calls when on slower roads and at slower speeds, often when stopped. However, they call more at night, which is a higher-risk time to drive. The second analysis showed that eye glances when talking on the phone are fixated on the road for longer periods of time than in baseline driving. In contrast, on-road eye glances when engaged in a visual-manual (VM) task are short and numerous. Eye glances on and off the road are about equal in length, and the average total off-road gaze time for a five-second interval is about 2.8 secs, or 57% of the time. Average off-road gaze time out of five seconds in baseline driving is about 0.8 sec, or 16% of the time. Results show the differences in distraction mechanism between cell-phone conversations and texting. Ramifications for potential interventions are discussed.

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Table of Contents

List of Figures

List of Tables

Executive Summary

This project consists of three parts. The first is a review of the literature on driver distraction that primarily focuses on cell phone use. The second two parts involve analysis of an existing field operational test (FOT) database to examine: 1) self-limiting behavior on the part of drivers who use cell phones, and 2) eye glance patterns for drivers involved in cell phone conversations and visual-manual tasks (e.g., texting) as compared to no-task baseline driving.

The basic conundrum around cell phone use while driving is that cell phone use has been shown to decrease driving performance and increase crash risk, yet driver cell phone use rates have increased (though they have been stable since 2005), and crash rates and crash incidence have gone steadily down in the same time-frame. Our updated literature review confirms that this same puzzle, discussed so well by IIHS in 2010 and GHSA in 2011, continues.

Simulator studies clearly show that performance, typically measured by reaction time, degrades when the driver is distracted by a variety of means including cell phone conversations and dialing or texting. Case-crossover studies, in which drivers serve as their own control, show that instantaneous crash risk increases by about 4 times when drivers use the cell phone. Naturalistic driving studies show much weaker effects, but they use incidents and near misses, which tend to produce weaker effects than crashes in general. The value of the naturalistic driving results is still uncertain until sample sizes and the total number of crashes in these databases gets much larger, but the approach is promising.

The crash data, which might be expected to provide the best estimates, are less conclusive because they are known to undercount cell phone use and the presence of other distractions. However, more recent databases do a better job of counting driver distractions, and the most recent analysis shows that about 3% of fatal crashes and 1% of injury crashes were associated with a driver on the phone. The analysis of NMVCCS, a database with much more thorough investigation of crash causation, also showed that about 1% of crashes were associated with a driver talking on the cell phone (in 2005-07). Finally, about 6% of survey respondents reported that they were either texting or calling when they were involved in a crash.

The rates of cell phone use in the crash databases (and survey results) are the same or slightly lower than the use rates reported from observational studies. This suggests that cell phones do not increase crash risk at all—they merely reflect the base rates of use. This does not correspond with the case-crossover or simulator results, so there must be other processes at work.

Two potential factors, self-regulation and masking, may be at work to reverse the impact of the increased risk due to cell phone use in the crash record. Self-regulation suggests that although using the cell phone increases the risk of crashing at that time, drivers may choose safer circumstances in which to make phone calls. This would mean that the overall effect on the crash population is reduced, even though instantaneous risk does increase when the driver picks up the phone.

Masking could occur in either of two ways. First, drivers may be replacing other distractions, such as manipulating the radio, talking with passengers or being lost in thought, by cell phone use. If so, then the overall crash record might not show an effect of cell phone use because distractions have been causing crashes for a long time and cell phone-based distraction is simply replacing other forms of distraction. What little evidence we can find for this does not fully bear this theory out. Secondary task involvement went up across three naturalistic driving studies, but we cannot observe cognitive distraction so some element of masking may still be going on.

Another form of masking might occur in the crash population, where crashes are going down because of improvements in crash avoidance while crashes due to distraction go up. The benefits of Electronic Stability Control (ESC) are clearly seen in crash databases, and ESC is the only recent safety feature that could have a large impact on overall crashes. We point out that ESC could not account for some of the large estimates of the impact of cell phone use, but there may be some level of masking of smaller-scale effects.

To investigate the question of driver self-limiting, naturalistic driving data from the Integrated Vehicle-Based Safety Systems (IVBSS) study were analyzed. Cell-phone clips were compared to baseline clips on a variety of characteristics, including road type, time of day, weather, and speed. Results show that drivers are significantly more likely to initiate calls at when traveling slowly or stopped and on local roads over highways. Drivers are also significantly more likely to initiate calls at night than during the day. The speed and road results are suggestive of self-limiting, but night driving is riskier than daytime driving. Self-limiting does seem to be indicated, but drivers may not fully grasp which situations are safe and which are not.

Another analysis investigated eye glance patterns of drivers who were talking on the phone, engaging in a visual-manual phone task (e.g., texting) and baseline (no-task) driving. When talking on the phone, drivers fixate significantly longer on the forward roadway and spend more total time looking at the forward scene than during baseline. In contrast, drivers who are texting allocate about 57% of their time to off-road gazes. Individual glances, both on- and off-road, are shorter and more numerous than during baseline. The popular press has incorrectly reported previous research showing that gazes while texting make up an average of 4.7 sec out of a 6-sec window. The correct number from previous work (Olson et al., 2009) is 4.0 sec out of a 6-sec window (67%) for texting when no event occurs (typical texting and driving). If our rate is applied to a 6-sec clip length, the comparable estimated off-road gaze time would be 3.4 sec.

In general, the picture of the effect of cell phone use on crashes is still fuzzy. Data on distractions and crashes are improving, but questions of self-regulation and masking are still being investigated. At a broader level, cell phones are just a small part of the larger driver-distraction issue. Many distractions are accepted (e.g., talking to passengers), but any distraction can have an effect on driver performance. Further research into drivers' choices around distractions is clearly warranted to improve highway safety.

Background

Distracted Driving and Cell Phones

The use of cell phones while driving is a complex and sometimes emotionally charged issue. Cell phone use and other driver distractions have been the subject of many studies resulting in a range of findings. However, the most challenging element of the science of driver distraction is that while most simulator studies clearly show performance deficits with secondary tasks, the crash data show steady decreases in total crashes, fatalities, and crash rates. The purpose of this report is to examine the research on distracted driving, especially as it relates to cell phone use, and to try to understand the effects of cell phone related distraction on crash risk.

In 2011, the Governor's Highway Safety Association (GHSA) released a report on distracted driving that was funded by State Farm (GHSA, 2011). This report provides an excellent summary of the distracted driving research published through 2010. The report covers simulator studies, surveys, and field studies related to either rates of engaging in various distracting activities or the relationship between distraction and crash risk. Much of the report centers on cell phone risk, because the authors note that research in distracted driving has primarily focused on cell phone use.

The GHSA report points out the paradox of increasing cell phone subscription and use rates coupled with decreasing crash rates. The Insurance Institute for Highway Safety (IIHS) noted the same trends in a Status Update on cell phones and driving (IIHS 2010). This paradox has led to much discussion regarding the plausibility of estimates suggesting that very large numbers of crashes are caused by cell phone use.

One element of the paradox is that simulator studies clearly and consistently show that any distraction reduces performance (GHSA, 2011). Performance decrements from cell phone use are most often seen in reaction time. However, texting has been shown in simulator studies to increase eyes-off-road time and to increase speed variability and lane-keeping variability. Many of these studies also show that drivers increase headway to compensate for slower reaction time. This, along with the artificial nature of the simulator and the demand characteristics of simulator studies, make it impossible to know how performance decrements in the simulator translate into crash risk.

The first part of this report presents a review of the literature on driver distraction, especially as it relates to cell phone use. We include a summary of the research on the effects of cell phone use, use rates and patterns, and the effect on crash risk. Because of the conundrum described above, there is no clear answer as to how cell phone use affects the overall crash population, nor whether eliminating cell phone use will reduce crashes. However, studies increasingly shed light on the role of cell phones in crashes.

Risk Associated with the Use of a Cell Phone While Driving

For decades, research on attention has shown that dividing attention degrades performance in a wide variety of tasks. Simulator and test-track research on cell phone use and driving performance follow the same pattern. When subjects are given a driving task and then asked to make or respond to a phone call, their reaction times slow. When texting, which requires more visual resources, lane-keeping and speed-keeping can also degrade, showing increased variability (GHSA 2011).

One of the difficulties of interpreting simulator and test-track experimental work is that subjects are instructed how and when to use the phone in experimental situations. Ranney (2008) states, "Experimental studies consistently reveal driving performance degradation (primarily slowed response time) associated with cell phone use; however phone tasks used in these studies are generally unrealistic and often more complex than everyday phone conversations."

In contrast, drivers have choices about when to initiate phone calls when driving, though they may or may not exercise them. For example, incoming calls have some similarity to the experimental situation, and a recent survey suggests that drivers tend to take incoming calls most of the time (NHTSA, 2011). Nonetheless, experimental work has not established how reaction time and other simulator performance measures are associated with crash risk. All that can be determined is that distraction most likely leads to some reduction in capacity being allocated to the driving task. Whether that capacity is needed is unknown.

The best estimates of instantaneous crash risk associated with cell phone use are two that used the case-crossover method (Redelmeier and Tbshirani 1997, McEvoy et al. 2005). Case-crossover is a powerful statistical method where an individual's own behavior at a different time is used as a control for behavior at the time of a crash. In the case of cell phone use, crashes were sampled and then phone records were used to identify whether the driver was on the phone a) at the time of the crash, and/or b) at the same time one week before (different intervals can be used). Both case-crossover studies estimated that crash risk while on the phone is about 4 times higher than while not on the phone.

While the case-crossover method accounts for a number of potential sources of bias by using drivers as their own controls, it is subject to other sources of bias. One source of bias is the fact that phone calls are invariably made after a crash, and crash times are less exact than call times. This potentially leads to overcounting cell phone use on the crash day. The two key studies used different methods to avoid this source of bias, but they both produced the same estimated risk ratio.

Another, more subtle source of bias would arise from interactions in risk in the population that are not accounted for in the analysis. For example, young drivers (17 to 29) account for almost half of the subject population in the case-crossover studies. If the cell phone risk ratio is higher for these less experienced drivers, the results may be biased towards higher risk overall. In general, if drivers with higher *risk ratios* (not necessarily higher overall risk) also tend to call more, then the overall risk ratio estimate that results from the case-crossover method may be high. This is plausibly the case with young drivers, who use the cell phone more while driving than do other age groups (Tison et al. 2011).
One large cohort study using different statistical methods found a risk ratio of 1.1 for all driving by males who use a cell phone compared to all driving by males who never use a cell phone (Laberge-Nadeau et al. 2003). The corresponding rate for females was 1.2. A

cohort study by Wilson et al (2003) found close to the same risk ratio for males and females for at-fault crashes. In both studies, potential confounding factors such as aggressivity, age, and prior crashes were taken into account. However, this risk ratio is not directly comparable to that from the case-crossover studies. The case-crossover risk ratio estimates the risk ratio when a driver is using the phone, relative to when he/she is not. The cohort risk ratio compares all driving for a driver who sometimes uses a cell phone to all driving for a driver who does not use the cell phone.

To attempt a direct comparison, we have to account for the use rate. To do this, we assume that the use rate is 7% and that drivers are equally likely to use the cell phone under all driving conditions (i.e., they do not self-limit by selecting safer driving situations for making phone calls). We also target the average cohort risk ratio of 1.15 (average of males and females). The overall risk ratio would then be the weighted average of driving while on the phone and driving when not on the phone. Equations 1a-1c shows a sample calculation for a combined male/female population. In this example, the estimated risk ratio (comparable to case-crossover estimates) is 3.1.

$$0.07p_c + 0.93p_n = 1.15p_n\ ;\ \ r = {}^{p_c}\!/_{p_n} \tag{1a}$$

$$0.07r = 0.22 \tag{1b}$$

$$r = 3.1 \tag{1c}$$

where p_c is the risk of a crash when on the phone,
p_n is the risk of a crash when not on the phone, and
r is the crash risk ratio when on the phone to when not on the phone

If drivers do self-limit (i.e., use the phone under safer conditions on average), the instantaneous risk ratio must be higher to result in an overall increase in crash risk of 15% across all driving by cell phone users. The purpose of this calculation is to attempt to compare the results of disparate methods from different studies. However, the comparison requires certain oversimplification that may not properly represent cell phone use. Nonetheless, this estimate is consistent with the case-crossover-based estimates.

Another approach to estimating the relative risk associated with cell phone use while driving is based on naturalistic driving data (Klauer et al. 2010). The authors identified crash and near-crash events in the 100-car driving dataset and matched each to approximately 15 control epochs for the same driver and a similar time, day, and location. All case and control videos were coded for a variety of secondary behaviors, and the data were analyzed using conditional logistic regression, controlling for variables such as traffic density, road type, and whether the driver was fault. Hand-held cell phone conversations were included with a number of other tasks deemed to be of moderate complexity, including eating, inserting/retrieving disk or cassette, and grooming, among others. The risk ratio was reported to be 1.3 for these moderately complex tasks compared to no secondary task. The risk ratio associated with more complex tasks, which included dialing a hand held cell phone, was 2.1. Klauer et al. (2010) state that this slight increase in risk might be explained by the reduction in the brief and systematic scanning of the traffic environment.

This risk ratio is directly comparable to those from the case-crossover studies. However, as Ranney (2008) points out, 90% of events were not crashes, and most of the events designated as crashes were not severe enough to be police reported. In fact, when the effect of inattention is separated by event severity, the effect of inattention on crashes is approximately double the effect of inattention on near-crashes in the 100-car study (Flannagan, 2010). In general, effect sizes based on analysis of non-crash incidents and near misses are likely to be underestimates of effect sizes for crashes. Although naturalistic driving studies have great potential to provide answers to questions about driver distraction, the sample size needs to be dramatically larger than that of the 100-car study, and the relationship between critical incidents and crashes needs to be better understood.

While most research has been done on the use of handheld cell phones, questions about the risk of texting and the risk of hands-free cell phone use have also arisen. In some ways, texting and hands-free cell phone use represent the two component subtasks of handheld cell phone use. Texting is similar to the dialing task of using a handheld cell phone. This task requires visual resources and drivers tend to take their eyes off the road for longer periods of time when texting and to some degree, when dialing. In contrast, hands-free cell phone use involves only the cognitive component of handheld cell phone use, the conversation.

Klauer et al. (2010) showed that as the total eyes-off-road time (TEOR) for a task increases, the odds ratio for being involved in a crash or near-crash becomes significantly higher than 1. As TEOR time reaches 10 seconds, the odds ratios begin to increase exponentially, exceeding 4 times the odds at 12 seconds TEOR. As described earlier, odds ratios from this study are probably underestimates of the true risk ratio.

The GHSA (2011) report summarizes the limited available literature on the risk of hands-free cell phone use and the risk of texting. They report that there is no conclusive evidence that hands-free cell phones are safer to use than handheld cell phones. In contrast, the limited data on texting suggests that the risk ratio for texting while driving may be as high as 23. This is consistent with the Klauer et al. (2010) work that focuses on TEOR as a key element of risk increases associated with device use. In general, the GHSA concludes that handheld cell phone use involves a short period of high risk increase (dialing) and longer periods of low risk increase (talking).

Taken together, these studies suggest that the crash risk for using either a handheld or hands-free cell phone when driving is probably between 3 and 4 times the crash risk when not using the cell phone. The risk ratio for texting is probably substantially higher than that, but the research on texting is still very sparse. The cell phone risk ratio applies to the particular driving scenario when using the phone and it is an average across the population. A variety of additional factors, such as self-selection of when to use the phone and differences in risk ratio across the population can have a substantial impact on the overall effect of cell phone use on crashes in the population.

Use Rates

Use rates, defined as the percentage of time that drivers are on the phone (equivalently, the percent of drivers who are on the phone at any given moment), have an important effect on the overall impact of any risk associated with cell phone use. Cell phone subscriptions have been growing exponentially in recent years, but this may or may not mean that use by drivers is growing at the same rate. In fact, based on the findings of the National Occupant Protection Survey (NOPUS), the use of electronic devices by drivers has been relatively constant since 2005 (NHTSA, 2011). The most recent direct observational data, collected in 2010, showed that 5% of drivers were talking on a hand-held device, 0.9% appeared to be talking using a hands-free device, and 0.9% were manipulating a hand-held device. The percentage manipulating a hand-held device was significantly higher than in 2009, when 0.6% were observed doing so.

The NOPUS study employed a nationally stratified sample, but observations were made strictly during daylight hours and drivers were counted only when stopped at intersections. The NOPUS study further estimates cell phone use by adjusting up to account for unobserved hands-free cell phone use. According to the NOPUS report, an adjustment factor of 188% comes from NHTSA's 2007 Motor Vehicle Occupant Safety Survey, which estimates that 55% of drivers are using hand-held phones and 45% are using hands-free phones. By applying this correction factor to observational data, the NOPUS study estimates that 9% of drivers are using either hand-held or hands-free phones while driving in a typical daylight moment. However, estimating hands-free usage through a survey and observing drivers only at stops and during the day, when drivers may use the reduced driving complexity (and risk) to initiate calls, may lead NOPUS rates to be biased high.

In comparison to the NOPUS estimates, findings from a naturalistic driving study conducted by UMTRI in 2009 and 2010 suggest a lower rate of cell phone usage. The UMTRI data are based on a sample of 2160, 5-second video clips when vehicles were in motion, regardless of the time of day. Analysis showed that in 6.1% of the clips drivers were talking on a hand-held device, 1% were talking using a hands-free device, and 0.5% were manipulating a hand-held device (dialing or text messaging). Interestingly, these observed rates have increased only slightly since employing similar analyses to naturalistic data from a study conducted in 2003 and 2004 (Sayer et al. 2005), but is again consistent with the lack of an increasing trend in cell phone use reported by the NOPUS studies.

Involvement Rates

Involvement rates, as opposed to use rates, indicate the proportion of the driver population that engages in different types of secondary tasks at least some of the time. Tilson et al. (2011) recently published results of a national phone survey about the extent to which they engage in various distracting tasks while driving. Although the results do not indicate how often drivers engage in these tasks, they do indicate a fairly broad participation in distracting behavior while driving.

The majority of drivers reported talking to other passengers (80% on at least some trips) and adjusting the radio (65%). Eating and drinking (40%), interacting with children (27%)

and using a portable music player (30%) were also common. All of these behaviors are generally considered acceptable distractions.

Of the sample, 40% reported making or accepting cell phone calls, 10% reported reading incoming email or texts, and 6% reported sending texts or emails. Interestingly, about twice as many drivers reported responding incoming calls compared to initiating calls (similar to texting results). Drivers generally chose to answer calls based on the person or the message, rather than the traffic situation.

Survey respondents also reported very few situations when they would never talk on the phone or send a message while driving. The most cited situations were bad weather (54%) and heavy, fast-moving traffic (25%). Finally, of the respondents who had been in a crash in the past year, 4% reported being on the cell phone at the time and 2% reported texting or reading a text at the time.

The use and involvement surveys, taken together, show that although only about 5-6% of drivers are on the phone at any given time, a large proportion of all drivers (40%) make calls at some time. Thus, cell phone use while driving is widespread in the population.

Both surveys also show that younger drivers text or call at much higher rates than middle-aged and older drivers. Texting and calling is still a relatively new driver distraction, but given the patterns of use and involvement, especially among younger drivers, it seems likely that drivers will continue to text and/or call in the future.

Distraction in Crash Databases

In 2009, NHTSA reported highlights of analyses of crash databases for that year as related to distracted driving (Ascone, 2009). For example, in 2009, 5474 people were killed on U.S. roadways in motor vehicle crashes that were reported to have involved distracted driving. Of these, 18% (995) involved reports of cell phone as a distraction. Thus, cell phones were involved in approximately 3% of all fatalities. Of those injured in crashes in 2009, 20% involved reports of distraction. Of those, 5% involved cell phones. Thus, approximately 1% of injuries were reported as involving cell phones.

One of the difficulties in understanding the effect of distraction, particularly cell phone use, on crashes has been that police reports have historically under-represented distraction or not coded various sources of distraction. As this issue has become more public, coding of distraction has increased in quantity and quality. The National Motor Vehicle Crash Causation Survey (NMVCCS) was conducted between 2005 and 2007 and involved in-depth investigation of the causation of a set of 6,949 crashes. At that time, 22% of drivers were distracted by one or more sources. Of these, 16% were conversing with a passenger and about 3.4% were either talking on or dialing a cell phone. Because in-depth investigations were done on-scene, these estimates are much less likely to be undercounting distraction.

Because this study was done over 5 years ago, texting was not prevalent, but cell phone use rates while driving were about the same as now (NHTSA, 2011). However, the proportion of crashes associated with cell phone use in 2009 crash data is still substantially lower than some reported estimates. For example, the GHSA (2011) reported results of studies that estimate that 22-25% of crashes and as many as 16,000 fatalities are caused by cell phones. All of these studies use simple statistical models that combine risk ratios with use rates, but the estimates are so far out of line with the crash data that the results are not credible.

Without some additional process, the results reported above are incompatible. If cell phone use increases risk by 3-4 times and cell phones are used approximately 9% of the time at random, crashes should increase significantly. However, crash rates are going down. In addition, the rates of cell phone use among crash-involved drivers are about the same as the base rates of use in the population. Typically, this would indicate that there is no change in risk.

For the estimates of cell phone risk ratio and the observed overall effect of cell phones on crashes to coexist, there must be additional processes at work. Two possible explanations are explored in the next sections: 1) cell phone distraction effects are masked, either because cell phone use replaces other distractions for the driver, or because other safety improvements are masking increases in crashes due to cell phone use, and 2) drivers select safer conditions in which to talk on the phone while driving (self-regulation).

Masking

Given that the evidence points to a risk ratio for cell phone use that is greater than one, the fact that crash rates have dropped at the same time that cell phone subscriptions have increased dramatically begs explanation. Since there is no accurate count from the databases of just how many of these crashes were *caused* by cell phone use, it is possible that cell phone use has caused an increase in crashes, but that other safety measures have led to offsetting decreases in crashes, a masking effect.

Of the various causes of crashes, few apply to enough crashes to mask the cell phone effect. The total number of crashes attributed to cell phone use by the National Safety Council (GHSA 2011), for example, is 1.6 million out of the 5.8 million crashes that occurred in 2008. Run-off-road crashes comprise about 20% of all light-vehicle crashes, and Electronic Stability Control (ESC) has the potential to reduce these by more than half. However, ESC has only recently been mandated and is still working its way into the fleet. If a liberal 25% of vehicles are equipped, fewer than 300,000 crashes might have been eliminated by ESC, masking only a portion of the 1.6 million estimated. We are unaware of any other major changes in safety that might account for a large enough number of crashes to mask such a large proportion of the total.

A different kind of masking was suggested by the Insurance Institute for Highway Safety (IIHS 2009), in which distraction from cell phones might be masking distraction from other sources in previous years (when cell phone use rates were lower). In other words, it is possible that distraction from all sources (e.g., talking, eating, changing the radio, etc.) has been causing crashes for many years. As cell phone use rates have gone up, distraction from other sources may be going down, resulting in a relatively constant overall distraction rate.

The only data that speaks to this possibility comes from a series of three field operational tests (FOTs) conducted by UMTRI over the last eight years. From these FOTs the frequency of drivers engaging in secondary, non-driving tasks, has been examined. The FOTs were run in the same geographical location, used identical recruitment procedures, and nearly identical approaches to recording and coding the behavioral data. Table 1 provides a high-level summary of findings regarding the observation of drivers engaging in all secondary tasks and cell phone related tasks.

Table 1. Frequency of All Secondary and Cell Phone Behaviors from Three FOTs.

	ACAS FOT	RDCW FOT	IVBSS FOT
Time Period Conducted	’03 – ‘04	’04 – ‘05	’09 – ‘10
Percent of All Video Clips Containing Secondary Behaviors	19.0	33.5	42.6
Percent of Video Clips Containing Cell Phone Behaviors	4.0	5.3	6.8
Proportion of Secondary Tasks Being Cell Phone Related	16.7%	15.5%	15.9%

The results from FOTs, for reasonably comparable populations and sampling techniques, suggest that the use of cell phones while driving is increasing, but so is the relative frequency of all secondary tasks. However, the proportion of secondary tasks that are cell phone related is fairly constant across that time period, at around 16%. If distraction is an important risk factor for crashes, then cell phones have been a non-increasing, and somewhat limited, part of the larger distraction problem. On the other hand, the increase in all distraction is not consistent with the hypothesis that cell phone use is replacing other distractions.

Self-Regulation

One possible explanation for the simultaneous increase in cell phone use by drivers and decrease in crashes is that drivers may choose when and where to use the phone in such a way that they do so under more benign driving conditions. Self-regulation has not been studied extensively, but there is some evidence that drivers do assess the risks associated with performing a variety of secondary tasks—and this in turn determines their willingness to engage in the task.

Much of the prior research on self-limiting behavior in driving has focused primarily on older drivers. Self-limiting in the driving context involves drivers evaluating their own functional abilities and current driving environment, and then adjusting their driving behavior accordingly. Older drivers have been shown to self-limit, enabling them to remain active as drivers but reduce their exposure to conditions that they find difficult (Baldock et al. 2006, Stalvey and Owsley 2000).

Young et al. (2009) discussed self-regulation and other mitigating factors for distracted driving. They point out that relatively little research has been done on self-regulation, but that many simulator studies show that drivers increase headway and reduce speed when engaging in secondary tasks while driving. In addition, they tend to keep their eyes fixed on the forward roadway and check mirrors and blind zones less when talking on the phone. In addition, Funkhouser and Sayer (2011) found that drivers tend to initiate calls when the vehicle is stopped or moving very slowly.

Young et al. (2009) also report that younger drivers are less impaired by multi-tasking than older drivers. Older drivers tend to self-limit more, however, so the combination of greater involvement in distracting activities, less impairment from distraction, and greater inexperience in driving still balances out to a greater involvement in distraction-related crashes among younger drivers than older drivers.

Lerner et al. (2008) reported that drivers' rated willingness to engage in secondary tasks was strongly negatively correlated with the perceived risk of engaging in the task in a given situation. Perceived risk may or may not be associated with true risk, but these results suggest that drivers do try to self-regulate on the basis of conditions.

Two national telephone surveys included questions about self-regulation in addition to basic use. A recent NHTSA telephone survey of over 6,000 drivers produced mixed results on self-limiting (Tison et al, 2011). Bad weather was cited by 54% of respondents as a reason not to initiate cell phone calls and 25% said that bumper-to-bumper traffic might influence their decision whether to make calls. However, most respondents reported social factors, rather than safety factors as the primary influence on whether and when to call when driving.

Braitman & McCartt (2010) surveyed 1219 drivers and found that 40% of drivers talk on the cell phone while driving at least a few times per week. Drivers ages 25-29 did so the most (66%). In states with all-driver bans on handheld cell phone use, fewer drivers ever talked on the phone while driving (56% vs. 70% for states without bans). In states with bans, drivers who did talk on the phone were more likely to use only hands-free phones (22% vs. 13% for states without bans). Texting, however, was not affected by all-driver bans. Among all drivers, 12% still texted in states with bans, compared to 14% in those without such laws. Among drivers ages 18-24, the rates were 45% (with bans) vs. 48% (without).

Finally, O'Brien et al. (2010) conducted a survey of 1947 high-school teens in North Carolina. Of these, 45% reported using a phone during their most recent trip. This use was about equally distributed between talking and texting. The teens reported more often reading (23%) or responding (11%) to a text than initiating one (4%). Close to half (47%) of teens who talked on the phone while driving reported trying to keep conversations short, and about half of those who texted reported waiting until it feels safe to read and/or reply to texts.

Although these surveys begins to shed light on self-limiting, driving data are required to better determine whether and how drivers self-limit in practice. The specific driving conditions under which talking and texting occur can greatly change the overall effect of the risk increase associated with engaging in these behaviors.

Eye Glances and Cell phone Use

Eye glance data have been used by many studies as an indicator of distraction while driving (Klauer et al 2006, Olsen et al. 2009, Liang et al. in press). Data from the 100-car study suggest that a key factor in crash risk is whether the eyes are on or off the road (Klauer et al. 2010). Off-road glances might reduce driver awareness of roadway context and increase crash risk. The longer an off-road glance, the more the awareness of the driving context may diminish and the greater the opportunity for driving circumstances to change in safety-critical ways.

The initial analysis of 100-Car Study found that when the sum of off-road glance duration exceeded two seconds in the five seconds before and one second after the onset of the precipitating event, the risk of crashes/near-crashes increased by approximately two times (Klauer et al. 2006). Controlled experiments find that long off-road glances (e.g., >2 seconds) lead to larger lane deviation and slower response to lead vehicle braking (Dingus et al. 1989). Glances to an in-vehicle display located further from the road center lead to a slower response to hazardous events (Lamble et al. 1999).

Many sources report that the average glance length when texting is 4.6 sec (e.g., Jacobson & Gostin, 2010; Distraction.gov, 2012). However, this number comes from an analysis of a naturalistic driving study of commercial truck drivers (Olson et al., 2009), and represents the total number of seconds that truck drivers' eyes were off the road during the six seconds prior to a safety-relevant event. The average number of seconds of eyes-off-road time (out of 6 sec.) during texting in that study was 4.0 sec when there was no safety-critical event (baseline). These were not significantly different from each other, though they were both significantly longer than eyes-off-road time (out of 6 sec) when not texting. This same study provided the often-cited odds ratio of 23.2 for involvement in crashes/near-crashes when texting.

The relationship between the results for commercial truck drivers and light-vehicle drivers is unknown. Commercial truck drivers have very different travel patterns and circumstances than light-vehicle drivers. In addition, eyes-off-road time may have different consequences for a large vehicle with very long stopping distances than light vehicles. In any case, there is a clear need for investigation of the effect of texting on driving safety among light vehicles.

Objectives

The impact of cell phone use on driving safety has become a prevalent issue with the rapid growth of cell phone subscriptions. A number of studies document increases in reaction time and increases in crash risk associated with cell phone use while driving (GHSA 2011, Redelmeier and Tibshirani 1997, McEvoy et al. 2005). However, even though cell phone use rates while driving are rising slowly, total crashes as well as crash rates per mile are decreasing in the U.S. This conundrum has led to speculation that self-limiting of cell phone use by drivers might be ameliorating the overall impact of cell phone use on crashes (e.g., IIHS 2010, GHSA 2011).

The first analyses described in this report were aimed at identifying whether drivers show patterns of self-limiting behavior with respect to cell phone use while driving. We are interested in whether cell phone calls were initiated under relatively safe conditions, compared to drivers' general driving conditions. If such a pattern is detected, this would begin to answer the question of how cell phone use can increase risk without seeing significant changes in crash incidence in recent years.

The second set of analyses described in this report aim to compare drivers' eye-glance patterns when engaging in cell phone related tasks with their eye-glance patterns normal driving. Specifically, we compared normal driving, cell phone conversations, and visual/manual tasks such as texting. Glances were assessed for direction and duration, and the glance patterns for the three tasks types were compared within drivers.

Methods

IVBSS Database

The Integrated Vehicle-Based Safety Systems Field Operational Test (IVBSS) involved 108 primary drivers who drove instrumented vehicles for 6 weeks. For the first two weeks of the FOT, the vehicles were equipped like standard sedans. However, in weeks 3 through 6, the participants drove with an integrated suite of collision warnings systems enabled. Data was recorded continuously at 10Hz during all six weeks, with over 600 channels of numerical data and 5 on-board cameras recording video data inside and outside of the car. There were no audio recordings of the conversations. Participants were fully informed of the data recording and the camera locations, in addition to being trained in the operation of the integrated warning systems.

Analysis of Cell phone Use and the Potential Behavior for Self-Limiting

After the FOT was completed, trained reviewers watched all of the video from the first week of driving for all 108 participants. The video data was scored specifically for cell phone usage, including phone calls (referred to here as "conversations") as well as any manipulation, or reading, of the cell phone while driving. A conversation was logged when the participant was holding the phone to the ear, or clearly speaking into/listening to a handheld device on speakerphone. Additionally, some participants frequently were observed in conversation employing a hands-free earpiece. These conversations were more difficult to score, but based on the video reviewers' familiarity with each participant's behavior, it was fairly clear when the participant was engaged in a hands-free call versus simply wearing the earpiece. In these hands-free cases clues about the scenario (whether there were passengers) and clues from the participants' expressions and mannerisms were used to determine if they were actually engaged in a phone conversation as opposed to a conversation with a passenger. After being scored by the reviewers, time series data on cell phone usage was stored in a database for analysis.

To investigate whether drivers self-limit, we compared the rate of cell phone use under different conditions. Each driver's behavior was compared to him/herself to identify whether conditions of cell phone use are similar or different to driving base rates. In this effort, we also considered cell phone use patterns as a function of driver demographics and driving conditions. Understanding the general patterns of cell phone use helps to establish the context for driver distraction. In particular, demographic differences can have an effect on overall crash risk.

Analysis of Eye Glances Associated with Cell phone Use

Prior to the present study, Week 1 (baseline) video was analyzed to identify cell phone use and secondary task involvement. A total of 1,382 cell phone conversations and 2,149 cell phone-related visual/manual task events (e.g., texting and web-surfing) were observed (Funkhouser and Sayer 2012). From these events, a set of five-second video clips were selected. Corresponding 5-second video clips of baseline driving (i.e., normal driving without cell phone events) were also selected using the same selection filters (see below). A total of 1199 video clips were selected for further eye glance coding and analysis as shown in Table 2. Three trained University of Michigan students coded all the events independently and then worked together with UMTRI researchers on all the events to address any inconsistent coding results.

Table 2. Total clips coded for eye glances

	Cell phone conversation	Visual/manual task
Event clips selected	50 drivers; at least 8 clips from each driver (a total of 482 clips)	24 drivers; at least 8 clips from each driver (a total of 230 clips)
Baseline clips selected	50 drivers; at least 8 clips from each driver (a total of 487 clips)	24 drivers; at least 8 clips from each driver (a total of 233 clips)

The selection filters include:

- Only select data with good quality (to exclude events with poor glance determination due to glare or wearing sunglasses)
- Only consider cell phone events that are at least 30 seconds long (to exclude very short phone conversations or visual/manual tasks)
- Only consider events that occurred when driving speed was at least 6m/s (to exclude cell phone events that occurred when the car was not moving)
- Only consider events that occurred on known public roadway (i.e, not on private roads)
- Spacing between each selected clip must be at least 15 seconds apart (to minimize the correlation between each selected video clip)

- All selected cell phone event clips must have corresponding baseline clips that match on driver, roadway type, traffic density, and time of a day
- To improve analysis power, each selected driver should have at least 8 selected cell phone events and 8 matched baseline clips.

Glance coding

In this effort, gaze direction and duration were assessed for each of the clips selected as described above. As shown in Figure 1, glances fell into the following nine zones:

1. Stack
2. Cell phone
3. Others (includes passengers and other rare glance locations)
4. Right (includes passenger seat and the passenger's side mirror and window)
5. Dashboard
6. Left side mirror (driver's side exterior mirror)
7. Interior rearview mirror
8. Forward
9. Left (e.g., head check to the left as well as driver's side window)

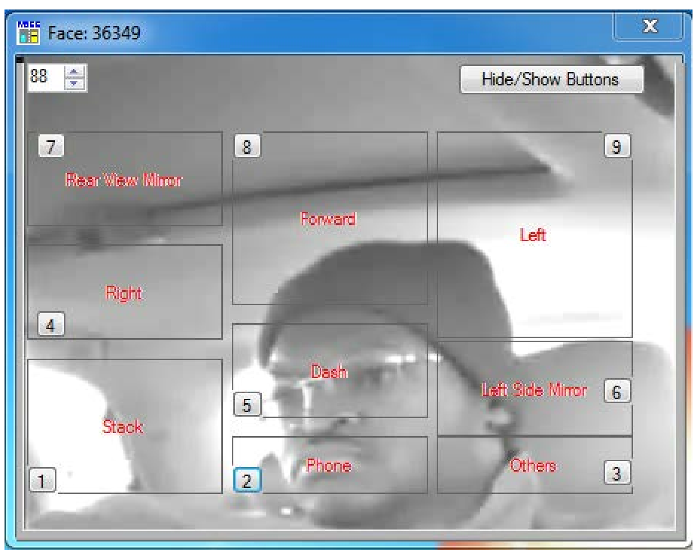

Figure 1. Eye glance coder interface

Data Analysis

The primary focus of data analysis was the comparison of eye glance location and duration for cell phone vs. baseline clips. The analyses of continuous variables (i.e., duration) were performed with linear mixed models using the PROC MIXED procedure in the statistical software package SAS 9.2. Fixed effects predictors included road type, traffic density, speed, day/night, and task. Driver and interactions between driver and any fixed effects were treated as random effects. This accounts for within-subject variance from repeated observations from the same driver and effectively compares a driver to him/herself.

Results

Cell phone Use and the Potential for Self-Limiting Behavior

Overall Cell Phone Use

A total of 1,460 cell phone conversations were identified and examined. The dataset from the first week of the FOT, for all 108 participants, consisted of 868.4 hours of numeric and video data. This is made up of 3,452 discreet trips (ignition on to ignition off). Of the 108 drivers, 94 were engaged in at least one cell phone call in the first week. All the analysis described in this report was based on the driving data of the 94 drivers who used the cell phone at least once.

<u>Age and Gender</u>

Table 3 displays the rate and frequency of cell phone conversations over one week for all 94 cell phone users. Older drivers generally drove much less than other age groups while younger drivers drove the most in terms of driving hours. Male drivers also drove more than female drivers. Similar cell phone use patterns were observed across the three age and two gender groups.

Table 3. Frequency and duration of cell phone conversations by driver age group and gender

Demographic	N	Driving Time (hrs)	Conversations per Hour	Mean % of Time in Conversation	Mean Ave Conversation Duration (min)
Younger	34	355.9	2.1	8.4	2.5
Middle-aged	35	280.2	1.9	9.1	2.9
Older	25	84.5	2.3	8.9	2.3
Male	48	407.3	1.8	8.2	2.7
Female	46	313.4	2.3	9.4	2.5

Where possible, calls were also marked as incoming or outgoing. Across all calls, 30% were incoming. However, within the oldest group of drivers (age 60-70), only 21% of calls were incoming.

Table 4 shows the overall proportion of driving time, as well as cell phone use rates, for the 94 cell phone users during Week 1. Rates are broken down by four environmental variables: road type, day/night, windshield wiper use (proxy for bad weather), and traffic density.

Table 4. Environmental factors and cell phone use

Environment	All Week 1 Time(Hrs)	Proportion of Week 1	Cell Phone Time in Week1 (Hrs)	Proportion of Time in Phone Conversation
Local Roads	147.1	20.40%	19.3	13.10%
Freeways	221.9	30.80%	14.6	6.60%
Surface Streets	351.4	48.80%	29.2	8.30%
Day	559.4	77.70%	45.9	8.20%
Night	161.3	22.30%	16.3	10.10%
Wipers On	56.3	7.80%	4.2	7.50%
Wipers Off	664.5	92.20%	58.5	8.80%
Sparse Traffic	455.8	63.28%	44.6	9.78%
Moderate Traffic	215.2	29.88%	14.5	6.74%
Dense Traffic	49.3	6.85%	3.9	7.88%

Roadway type

Over one week of driving, all the participants who had engaged in at least one phone call spent the most time on surface streets. Participants spent 48.8 percent of their overall driving time on surface streets, and only 30.8 percent on freeways. “Local” roads were generally driveways, parking lots, or very small residential streets. Participants were the most likely to be engaged in a cell phone conversation when on local roads followed by surface streets, then on the freeway.

Day/Night

Participants overall drove 77.7 percent of their driving time during daylight hours. For this study, “daylight” is defined as the period from morning civil twilight through evening civil twilight, (i.e., the period when solar altitude angle is equal to or greater than -6 degrees.), and is not based on a 24-hour clock. Participants were engaged in cell phone conversations for an average of 8.2 percent of their daylight driving time and 10.1 percent of their night driving time.

Windshield Wipers

Windshield-wiper use was treated as a surrogate indicator for inclement weather. Wipers were on for 7.8 percent of all driving time in week 1. Participants were somewhat less likely to be engaged in a cell phone conversation when their windshield wipers were on (i.e., it was raining).

Traffic Density

Most driving time (about 64%) was spent in sparse traffic. Dense traffic occurred less than 7% of the time. Overall, drivers were somewhat more likely to be engaged in a cell phone conversation when there was limited traffic on the road.

Self-limiting behavior

The likelihood of drivers' engaging in cell phone conversation given different environmental factors was further calculated and compared as one measurement of self-limiting behavior. For each driver, the rate of cell phone use was calculated separately under each environmental condition. Mixed models were used to test the effect of each environmental factor, adjusting for age and gender. Driver and interactions with driver were treated as random effects. In this way, each driver's behavior was compared to him/herself across different conditions.

Roadway Type

Table 5 shows average cell phone use rates by road type, age group, and gender. These numbers differ from those in Table 2 because they are the unweighted average rates across all drivers. Rates in Table 2 are weighted by total travel (i.e., they represent the overall per-hour use rates for the group of drivers as a whole, rather than the average use rate across drivers).

The analysis of road type showed a significant effect of roadway type [$F(2,172)=11.4$, $p<0.05$]. Drivers were more likely to make a phone call when they were driving on local roads (i.e., small residential roads, parking lots and driveways) compared to driving on public roads (i.e., freeway and surface roads). The difference between surface roads and freeways was not statistically different. No significant age or gender related differences were observed.

Table 5. Average rate of cell phone use as a function of road type, age and gender

Road type	**Average cell phone use rate**	**Age**	**Average cell phone use rate**	**Sex**	**Average cell phone use rate**
Local	13.9%	Younger	10.1%	Male	10.1%
Freeway	5.8%	Middle-aged	9.3%	Female	8.6%
Surface	8.3%	Older	8.1%		

Day/Night

The average rate of engaging in cell phone conversations given daytime driving was 8.9% while it was 14.7% for night time driving. This difference was statistically significant when controlling for age and gender effects [$F(1, 94)=8.02$, $p<0.01$].

Windshield Wipers

The average rate of cell phone use was 9.4% when wipers were off and 6.9% when wipers were on. This difference was not statistically significant when controlled for age and gender effects.

Traffic density

Traffic density showed a significant impact on cell phone use rates. Drivers were more likely to engage in a cell phone conversation when traffic was sparse ($F(2,182)=8.16$, p<0.001) than under conditions with more on-road traffic. The estimated rate of cell phone use under sparse traffic condition was 11.1% and it was 5.4% under moderate traffic condition and 5.6% under dense traffic condition. No significant differences were observed between moderate and dense traffic conditions.

<u>Driving speed</u>

Driving speed when drivers initiated the cell phone conversation was calculated for the 1460 phone conversations. A total of 339 phone conversations (23.2% of all phone calls) were initiated when the vehicle was not moving (i.e., driving speed=0). Of these, 221 (65%) were outgoing phone calls (i.e., phone calls initiated by subject drivers). The analysis of initial speed showed a significant roadway type effect [F(2, 1445)=586.11, p<0.01] with higher average speed observed on the highway, followed by surface roads, and then on other roadways. No other significant differences were observed. The distribution of the initial speed bins, and of total driving as a comparison are shown in Table 6. Drivers tend to engage in cell phone conversations more often when the vehicle traveling speed is low.

Figure 1 shows the distribution of speed at call start for incoming and outgoing calls, compared to the distribution of all driving speeds. If calls were made and answered completely at random, the two cell phone distributions would be identical to the driving distribution. Instead, outgoing calls are initiated more often when stopped or at low speeds (<25 mph) and less often at high speeds (>55 mph) than they would if there were no consideration for situational factors. The speed distribution for incoming calls that are answered is more similar to all driving, but again, more incoming calls are answered at lower speeds than expected by chance.

Table 6. Distribution of driving speed when initiated the phone conversation and during all driving time

Speed bin (mph)	**Percentage of cell phone**	**Percentage of total driving time**
0	23.20%	17.14%
0-10	15.20%	8.63%
10-25	12.90%	10.78%
25-55	31.80%	31.89%
>55	17.00%	31.56%

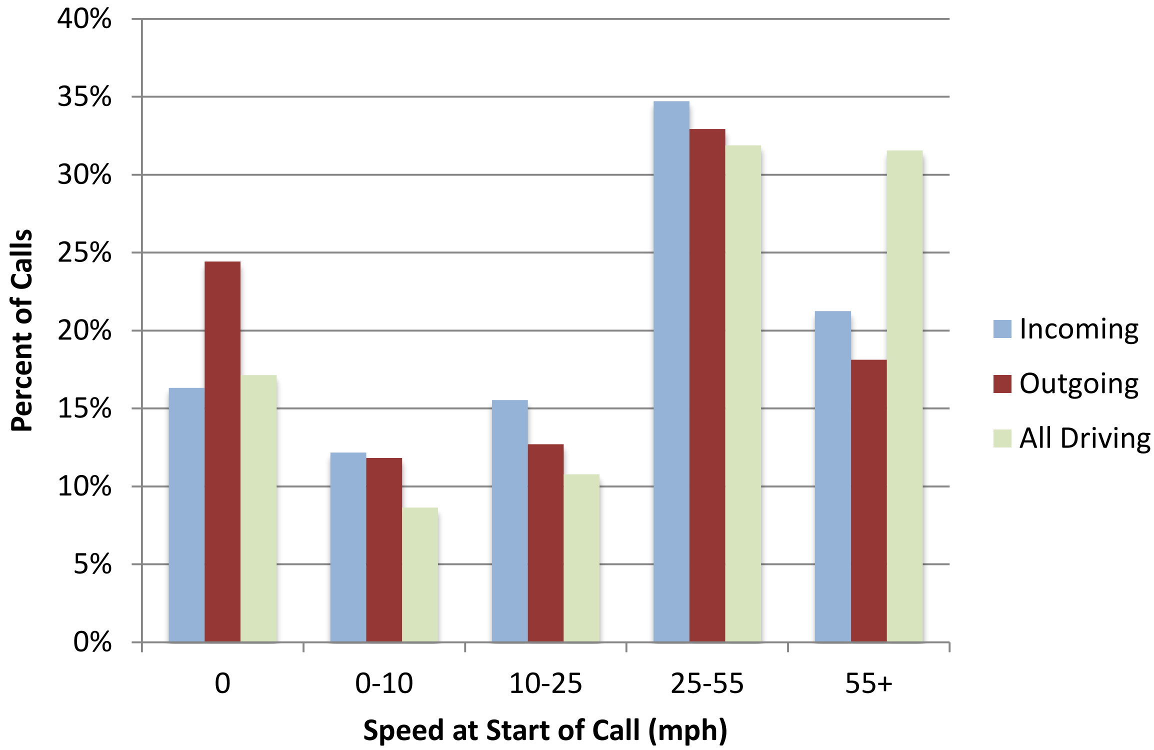

Figure 2. Distribution of speed at call start as a function of call type. Distribution of speed of all driving graphed for comparison.

Eye Glances Associated with Cell phone Use

Cell Phone Conversations

The dataset with cell phone calls and corresponding baseline events was analyzed separately from the dataset with visual-manual tasks and corresponding baseline because the drivers and trips included in each were different. Drivers' eye glances were categorized into two groups: Eyes-on the road (i.e., zone 8), and Eyes-off the road (i.e., all other zones).

First, univariate analyses were conducted to look at the simple effect of each predictor on glance duration. Table 7 gives the mean glance duration by predictor. Glance location (on- vs. off-road), task type (visual-manual vs. no task baseline), and time of day (day vs. night) produced significant effects on mean glance duration. On-road glances, cell phone conversations, and nighttime driving all resulted in longer average glance time.

Table 7. Mean glance duration as a function of predictors in cell phone conversation dataset

Predictor	Level	Glance Duration (sec)	Significance Test
Glance Location	On-Road	3.18	F(1,43.5)=893.28, p<0.0001
	Off-Road	0.66	
Task Type	No Task	2.24	F(1,46.9)=8.97, p=0.0044
	Cell Phone (talking)	2.58	
Age	Young (20-30)	2.29	n.s.
	Middle (40-50)	2.43	
	Older (60-70)	2.52	
Sex	Male	2.36	n.s.
	Female	2.40	
Road Type	Local	2.22	n.s.
	Surface	2.53	
	Highway	2.29	
Time of Day	Day	2.23	F(1,776)=21.35, p<0.0001
	Night	2.76	
Traffic Density	Sparse	2.45	n.s.
	Moderate	2.24	
	Dense	2.53	

Mixed models were used to model average glance duration and total gaze time separately. For both dependent measures, glance location (on/off) was crossed with task type and both were adjusted for roadway type, traffic density, time of a day, and their interactions with task type and gaze location. Since clips were matched on driver, roadway type, traffic density, and time of a day, we expected that most of the covariates would not be significant. Non-significant effects were removed in backwards stepwise fashion.

Significant predictors of average gaze length were task [F(1,1533)=7.40, p=0.0066], gaze location [F(1,61)=754.3,p<0.0001], time of day [F(1,720)=8.82, p=0.0031], and the interactions of task and gaze location [F(1,1534)=8.47, p=0.0037], gaze location and time of day [F(1,578)=4.34, p=0.0376], and task and gender [F(1,1516)=7.17, p=0.0075]. The main effect of gender was retained in the model because of the included interaction, though the main effect itself was not significant.

The interaction pattern for task by gaze location is shown in Figure 3. For glances off the road, average gaze length is approximately the same whether the driver is engaged in a cell phone conversation or not. However, for on-road glances, average gaze length is about 0.5 seconds longer when the driver is engaged in cell phone conversation.

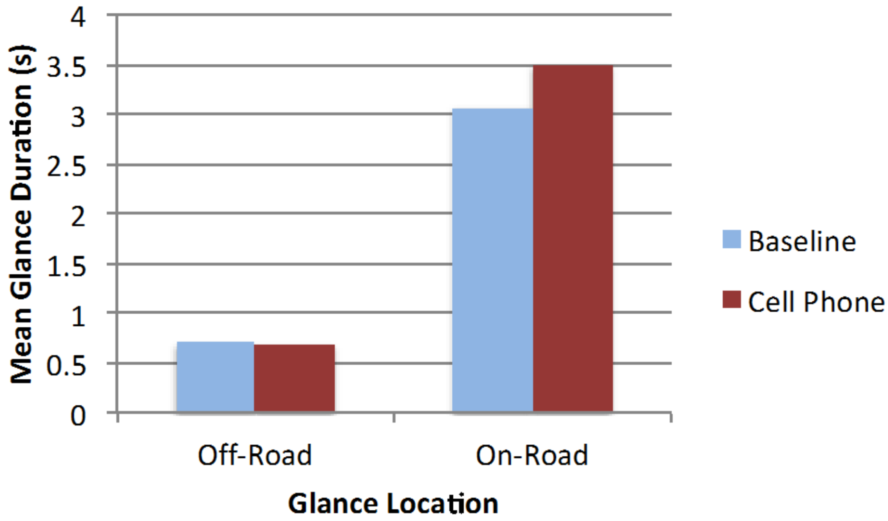

Figure 3. Mean glance duration as a function of task and glance location.

Figure 4 shows the interaction of gender and task type on average glance duration. Male drivers showed nearly equal average overall gaze length regardless of the task they were engaged in. However, female drivers had longer average gaze lengths (by about 0.4 sec) when engaged in cell phone conversation compared to baseline. This effect is independent of the location of the glance.

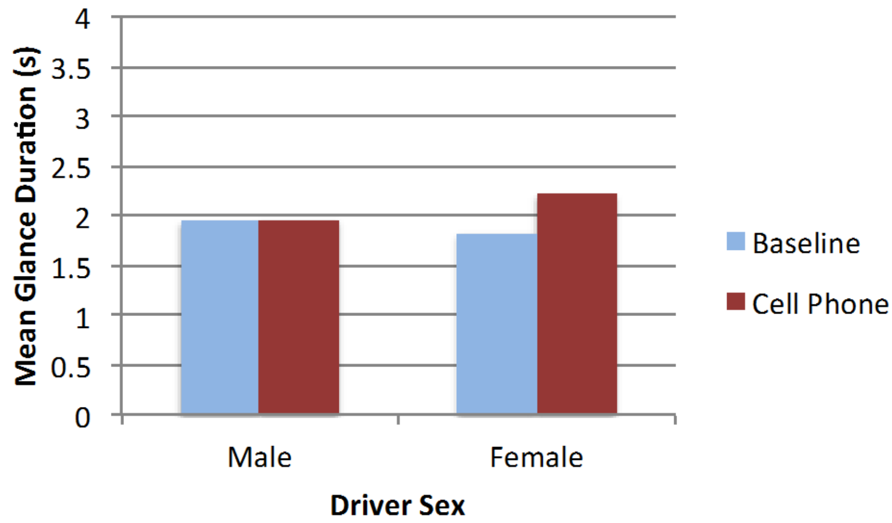

Figure 4. Mean glance duration as a function of task and gender.

Figure 5 shows the interaction of time of day and gaze location. Overall, daytime glances are shorter, but the effect is most pronounced with on-road glances. On-road glances are about 0.5 sec longer at night than during the day.

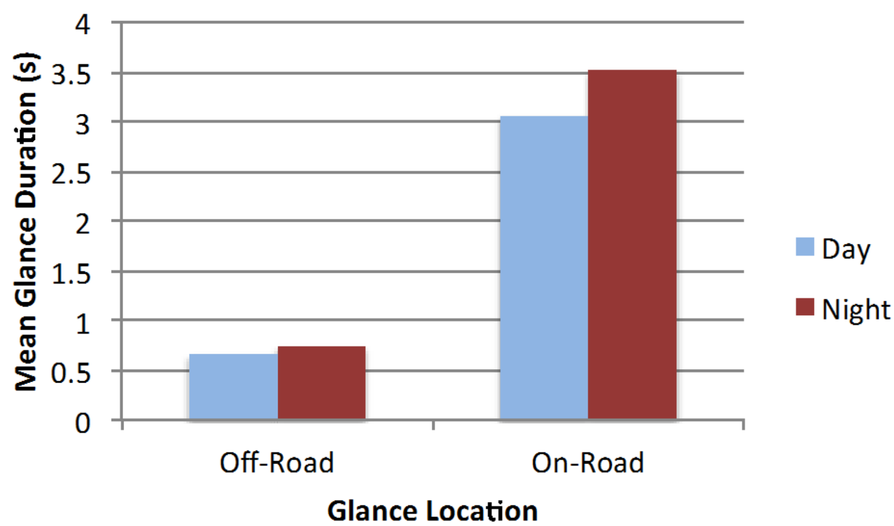

Figure 5. Mean glance duration as a function of time of day and gaze location.

Total glance duration was also analyzed using mixed models. Because the on-road and off-road glance durations must total 5 sec for each clip, they should not include covariates such as sex or road type. However, gaze location and interactions with gaze location are possible. The single significant interaction was between gaze location and task type [$F(1,132)=16.83$, $p<0.0001$], as shown in Figure 5.

Figure 6 shows the interaction of location by task on total glance time within the 5-sec window. Off-road glances take up less total time when the driver is engaged in cell phone conversation than when not engaged in a task. In contrast, on-road glances take up more total time when the driver is engaged in a cell phone conversation. This can be compared to Figure 3 showing average gaze length under these conditions.

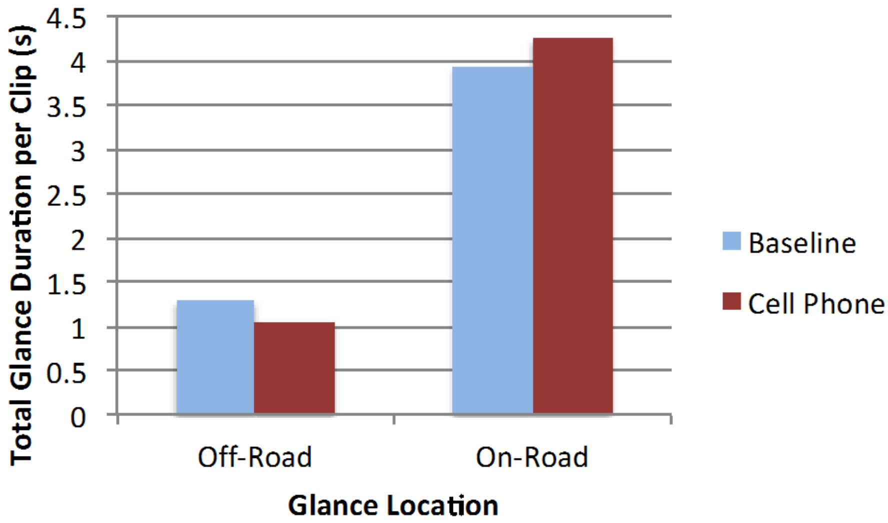

Figure 6. Total glance duration (per 5-sec clip) as a function of task and glance location.

Visual-Manual Tasks

As with the cell phone conversation data, univariate analyses were conducted to look at the simple effect of each predictor on glance duration. Table 8 gives the mean glance duration by predictor. Glance location (on- vs. off-road) and task type (visual-manual vs. no task baseline) produced significant effects on mean glance duration. On-road glances and no task involvement resulted in longer average glance time. The direction of the task effect was opposite the task effect in the conversation dataset.

In addition, the overall average gaze length in this dataset (1.57 sec) was shorter than in the conversation dataset (2.32 sec). Since the visual-manual task results in shorter glances on the road, the VM task appears to have broken up all of the gazes into shorter average segments within the 5-sec. clip. The baseline clips for the two datasets have significant overlap, though they were selected based on a match to each VM or conversation clip.

Table 8. Mean glance duration as a function of predictors in visual-manual task dataset

Predictor	Level	Glance Duration (sec)	Significance Test
Glance Location	On-Road	2.06	$F(1,53.2)=98.69$, $p<0.0001$
	Off-Road	0.94	
Task Type	No Task	2.24	$F(1,38.9)=70.03$, $p<0.0001$
	Cell Phone (talking)	1.08	
Age	Young (20-30)	1.56	n.s.
	Middle (40-50)	1.74	
	Older (60-70)	1.43	
Sex	Male	1.59	n.s.
	Female	1.56	
Road Type	Local	1.60	n.s.
	Surface	1.60	
	Highway	1.70	
Time of Day	Day	1.50	n.s.
	Night	1.75	
Traffic Density	Sparse	1.58	n.s.
	Moderate	1.58	
	Dense	1.70	

The same modeling approach was used for the VM dataset as for the cell conversation dataset. The best-fit model for average glance time included only the interaction of gaze location and task [$F(1,104)=114.85$, $p<0.0001$]. The main effects of task [$F(1,104)=55.41$, $p<0.0001$] and gaze location [$F(1,104)=115.33$, $p<0.0001$] were also highly significant.

Figure 7 shows the pattern of results for the task by location interaction. Average on-road glance duration is substantially shorter when drivers were engaged in a visual-manual task, compared to no task involvement (baseline). Off-road glances were slightly longer on average when drivers were involved in a VM task, compared to baseline. Interestingly, average on-road and off-road glance durations were almost identical (1.07 sec) when drivers were engaged in a VM task. Of single off-road glances, 99% of baseline and 94% of VM-task glances were less than 2.0 sec.

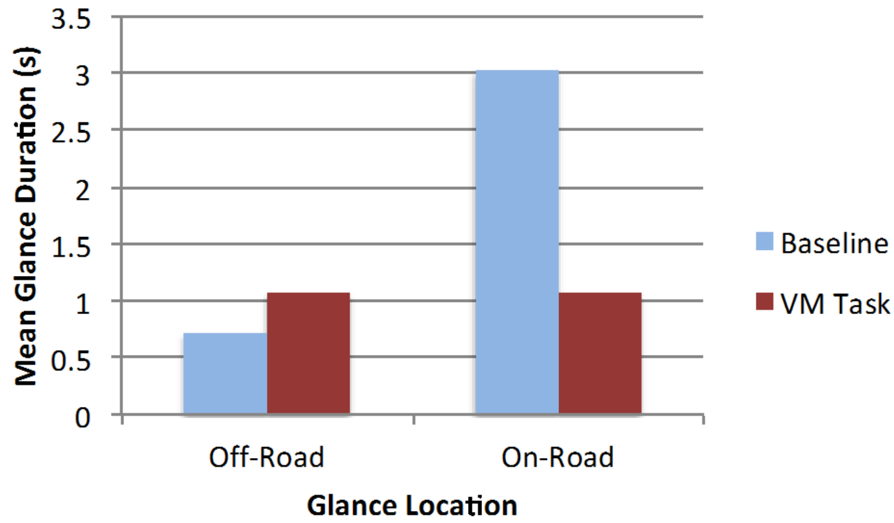

Figure 7. Average glance duration as a function of task and glance location.

A mixed model was also developed for the total glance duration using the VM data. Again, the only significant predictors were the interaction between task and glance location [F(1,49.9)=206.26, p<0.0001] and the main effect of location [F(1,45.2)=52.47, p<0.0001]. The main effect of task was retained in the model to support the interaction term. The pattern of this interaction is shown in Figure 8. In the figure, task duration has been transformed to percentages because a few of the clips were less than 5 sec long. When drivers were engaged in a VM task, the percent of total gaze time allocated to off-road locations was greater than the percent of total allocation on the road. The reverse was true when drivers were not engaged in a task. On average, drivers engaged in a VM task allocated 57% of the total task time to off-road eye locations.

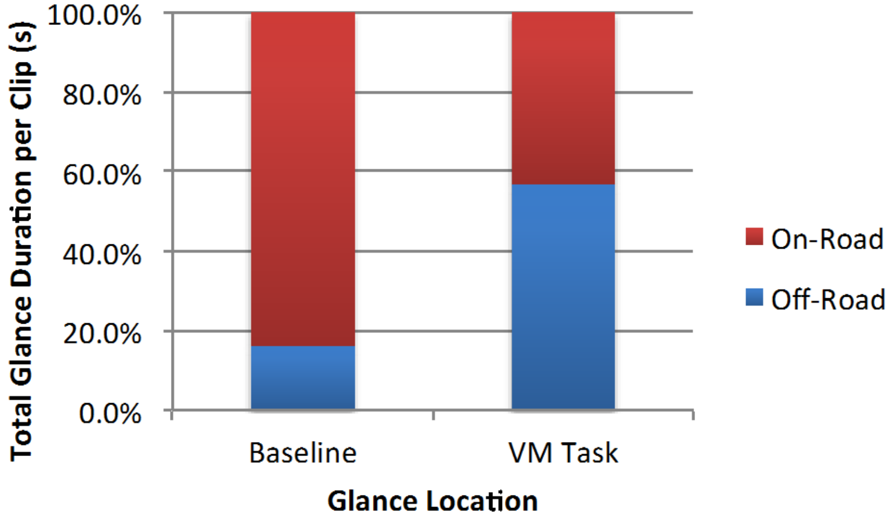

Figure 8. Total glance duration (per 5-sec clip) as a function of task and glance location.

Within the 5-second clips, the number of glances to each location was counted. The average number of glances per clip is shown in Table 4 as a function of task and gaze location. In general, drivers engaged in VM tasks made more glances to all locations.

Table 9. Mean number of glances per clip for each task and gaze location.

Task	Glance Location	Mean Number of Glances	Standard Deviation
Baseline (Conversation Dataset)	Off-road	1.88	1.00
	On-road	1.69	0.84
Cell Conversation	Off-road	1.64	0.84
	On-road	1.55	0.77
Baseline (VM Dataset)	Off-road	1.85	0.97
	On-road	1.64	0.81
Visual-Manual Task	Off-road	2.70	0.94
	On-road	2.34	0.86

Discussion and Conclusions

Cell phone Use and the Potential Behavior for Self-Limiting

Cell phone use patterns from the IVBSS naturalistic driving study were analyzed to identify whether drivers self-limit the use of cell phones while driving. Of the 108 drivers in the study, 94 used a cell phone while driving at least once. These drivers, who made up the analysis dataset, engaged in cell phone conversations 8.6 percent of the total driving time. Overall, conversations had a mean duration of 2.6 minutes, and drivers engaged in conversations at the rate of 2.1 conversations per hour. Younger drivers were more likely to use the cell phone than older drivers. About 70% of phone calls were outgoing calls and therefore fully under the control of the driver, though we did not identify incoming calls that were ignored.

Self-limiting behavior was evaluated by comparing drivers' cell phone use rates under different environmental conditions. For example, drivers used cell phones at a higher rate under sparse traffic conditions, compared to moderate or dense traffic, after adjusting for age and gender effects. This would represent a form of self-regulation because the attention requirements for drivers are lower in sparse traffic. In contrast, there was no difference in use rates as a function of inclement weather (indicated by wiper use).

Drivers were also more likely to be on the phone at night than during the day. In general, night driving would be considered more risky than daytime driving, which would represent a safety disbenefit. We did not analyze the interaction between different environmental factors, so it is possible that drivers' nighttime driving was mostly in sparse traffic or slower speeds, but this basic result is not consistent with a self-limiting explanation for the decrease in crashes while cell phone use increases.

After adjusting for age and gender, roadway type was a significant predictor of cell phone use rate. In general, calling was more likely on local roads (e.g., driveways, parking lots, and small residential roads) than on surface streets or highways. Because speeds are low, local roads would be considered to have lower risk of serious crashes, and a tendency to use the phone on these roads rather than surface streets could be considered a form of self-limiting.

More direct evidence of self-limiting can be seen in the results for speed at call start. Calls were initiated or answered much more often at lower speeds (<25 mph) than would be expected by chance if calls were made at random. Of all driving time, 32% was spent moving at 55 mph or more. However, only 17% of phone calls were initiated at high speeds. In contrast, 38% of phone calls were initiated at speeds under 10 mph, compared to 26% of all driving. It is clear that drivers tend to initiate phone calls (especially outgoing calls) when stopped or moving slowly. This is consistent with the high percentage of calls made on local roads (i.e, parking lots and driveways).

In general, we found evidence that drivers do self-regulate cell phone use in certain ways. Drivers were more likely to initiate calls at low speeds or when stopped, when in sparse traffic, and on low-speed roads. However, drivers did call more at night and did not seem to limit calling during inclement weather.

Calling more at low speeds should ameliorate some of the risk increase associated with cell phone use, at least with respect to injury crashes. However, it may increase opportunities for property-damage crashes that tend to occur in low-speed situations. Although evidence of self-limiting does not mean that cell phone use is safe, it may help shed light on why crashes are not increasing at the expected rate, given increases in cell phone use by drivers.

Eye Glances Associated with Cell phone Use

Since eye-glance location has been associated with risk of involvement in safety-critical events, we compared drivers' eye-glance patterns when engaging in cell phone related tasks with their eye-glance patterns normal driving. In particular, we looked at normal driving, cell phone conversations, and visual/manual tasks such as texting. Glances were assessed for direction and duration, and the glance patterns for the three tasks types were compared within drivers.

Video from the IVBSS naturalistic driving study was analyzed to better understand drivers' gaze patterns when engaged in cell phone-related tasks. Two datasets were constructed. One included gaze coded from clips of cell phone conversations by 50 different drivers under different driving conditions (e.g., traffic, road type, time of day). Those clips were matched to clips from the same driver and trip when the driver was not engaged in a cell phone conversation. A second dataset was constructed in a similar way using clips from 24 drivers who were engaged in visual-manual tasks (e.g., texting, dialing) using a cell phone.

The results of analysis shows that across both datasets, the average duration of on-road glances is significantly longer than the average duration of off-road glances. However, in both cases, there was an interaction between task involvement and gaze location.

When drivers were engaged in a cell phone conversation, their on-road gazes were longer than when they were not engaged in a task. Off-road gaze length was the same, regardless of task involvement. In contrast, drivers engaged in VM tasks had substantially shorter on-road gaze length compared to when those same drivers were not engaged in such a task. In fact, drivers engaged in a VM task had the same average gaze length both on- and off-road. The average gaze length for both locations was just over 1 second, which is about one third of the average gaze length for baseline (no task) driving.

When total gaze time for on- and off-road locations was analyzed, drivers allocated about 3.9 of 5 seconds to the road when they were not engaged in a task. When engaged in a cell phone conversation, they allocated 4.3 of 5 seconds to the road, but when engaged in a visual-manual task, they allocated less than half of the time to the road, at 2.0 sec.

To compare this number to the one reported for truck drivers (Olson et al., 2009), we have to convert to percentages. When engaged in a VM task, the light vehicle drivers in our study allocated 57%, or about 2.8 sec of a 5-sec clip to off-road glances. In Olson et al. (2009), drivers texting in baseline clips (no safety-critical event) spent 4.0 of 6.0 sec, or 67% of the time looking off the road. These numbers are similar (direct comparison is not possible, but both are very high) and substantially greater than when drivers are not texting, leading to higher risk of crashing (Klauer et al. 2010). If the percentage holds, the corresponding value for a 6-sec clip would be 3.4 sec.

The glance frequency results were consistent with a pattern of frequent, short glances to all locations made by drivers engaged in VM tasks. Average on- and off-road gaze length was almost equal, suggesting that drivers were allocating approximately equal attention to the road and their task. Given that baseline driving results in substantially greater allocation of attention to the road compared to other locations, the VM gaze pattern is a risky one. The results of this study demonstrate that for light-vehicle drivers, visual-manual tasks (e.g., texting) change gaze patterns and reduce the length of on-road gazes. This behavior puts drivers at a higher risk of losing awareness of dynamic driving context.

In contrast, those engaged in cell phone conversations made fewer glances and spent more time in long on-road glances. These results were consistent with previous research that shows longer fixation on the road when talking on the cell phone. The evidence on safety consequences of this fixation is mixed.

Potential Interventions

The contrast in gaze patterns between visual-manual tasks and cell phone conversation suggests that the two may affect risk quite differently. Previous studies show increased crash risk associated with cell phone use (McEvoy et al., 2005) and texting (Olson et al., 2009). However, the potential mechanisms of the risk increase may be different for a task that takes the eyes off the road and a task that leaves eyes on the road (perhaps for too long), but takes attention and cognitive capacity off the driving task. Further work is needed to understand the consequences and potential interventions for these two types of secondary tasks.

The interventions most discussed include driver warning systems, driver assistance systems, autonomous crash avoidance (or mitigation) systems, and laws banning certain in-vehicle activities. At this time, 16 states have full or partial bans on handheld cell phone use and all but 5 states have full or partial bans on texting. Braitman & McCartt (2010) report that handheld cell phone bans reduced talking on handheld phones and increased use of hands-free phones. In contrast, texting bans did not affect the percent of drivers who reported texting while driving.

Compared to legal intervention, technological interventions have a greater chance of being tuned to the specific type of distraction that talking and texting create. Talking on the phone results in cognitive distraction, but little driving-control deficit. Thus, driver assistance systems, such as lane-keeping assist, are less useful when the driver is talking on the phone (and looking at the road) than when the driver is texting. Warning systems can both bring the driver’s eyes and cognitive attention back on the road in time to avoid a crash. However, the necessary warning lead-time for a talking driver is probably less than that of a texting driver. Interestingly, autonomous braking systems, where the vehicle takes independent action, might prove to be most effective for texting drivers.

It should be noted that while vehicle-based technological solutions (e.g., autonomous vehicles) might eventually become widespread enough to solve the driver-distraction problem, it is clear that until that time, drivers simply should not be texting or engaging in other complex visual-manual tasks. Talking on the cell phone is a gray area where the evidence is mixed. Though the associated cognitive distraction increases instantaneous risk, drivers seem to self-limit, at least in initiating phone calls, they tend to create larger buffers between themselves and other vehicles, and the overall effect on the crash population has not reached levels predicted by simple models of risk and exposure.

If texting bans are not effective, cell-phone technology that both reads and writes texts with voice commands may be the best technological solution in the short run. Turning texting into talking, while imperfect, may substantially reduce the risk of communicating via cell phone. Meanwhile, stronger enforcement and widespread communication about the risks of texting while driving will hopefully begin to enact the kind of cultural changes among drivers that seat-belt campaigns did years ago.

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