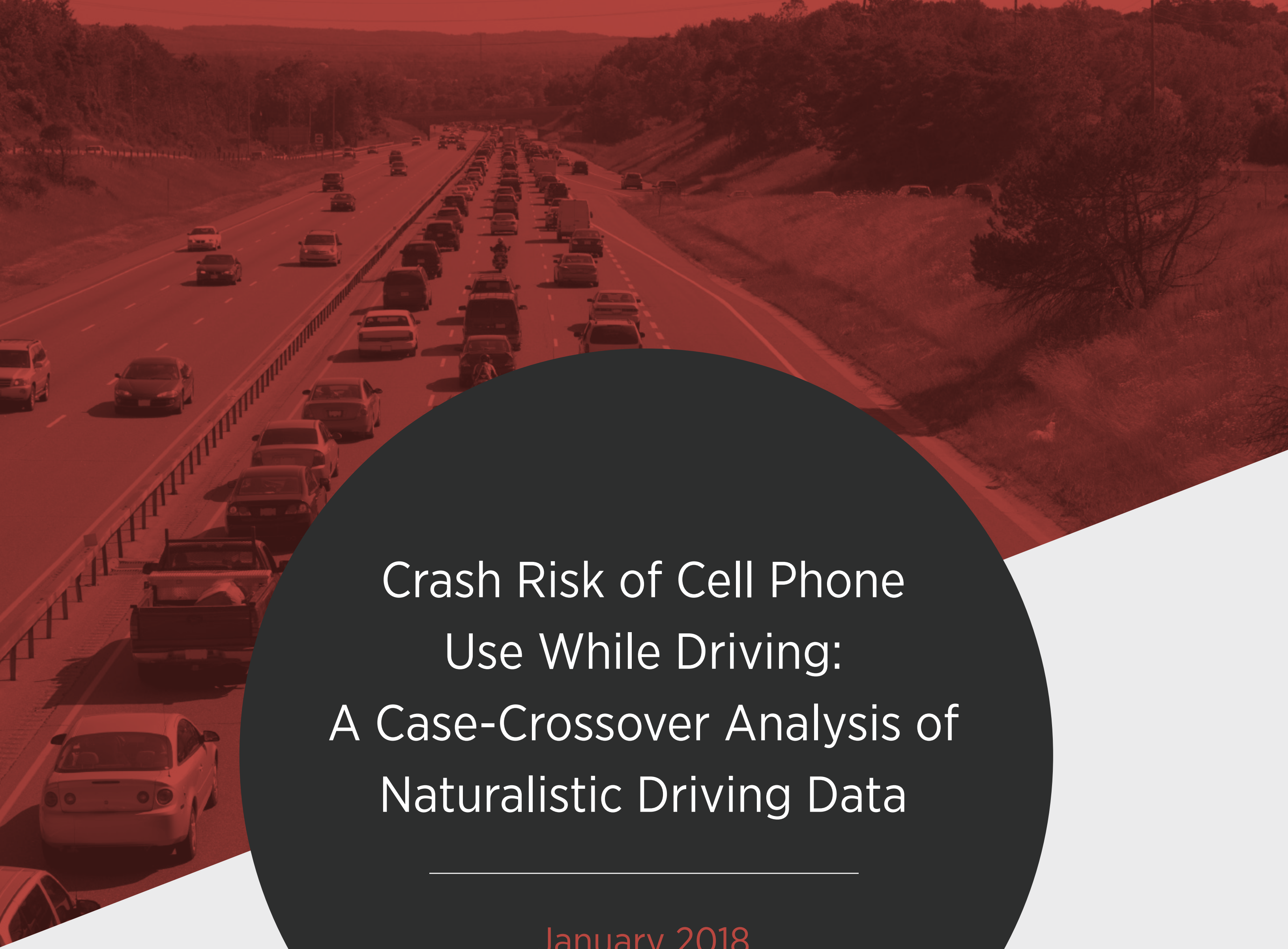

Crash Risk of Cell Phone Use While Driving: A Case-Crossover Analysis of Naturalistic Driving Data

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Title

Crash Risk of Cell Phone Use While Driving: A Case-Crossover Analysis of Naturalistic Driving Data

(January 2018)

Authors

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Foreword

The mission of the AAA Foundation for Traffic Safety is to save lives through research and education. *Driver Behavior and Performance*, one of our focus areas, contributes to our mission by guiding drivers toward safe decisions. This study is intended to help drivers making safe decisions by examining what happens when drivers choose to divert their attention from the driving task and engage in cell phone use while driving.

This report should be a useful reference for researchers, the automotive and electronics industries, and traffic safety advocates.

C. Y. David Yang, Ph.D.

Executive Director
AAA Foundation for Traffic Safety

About the Sponsor

AAA Foundation for Traffic Safety
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Founded in 1947, the AAA Foundation for Traffic Safety is a not-for-profit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies and other organizations or sources.

Abstract

Cellular telephone use while driving is a risk factor, but how much of one is a hotly debated issue – particularly as more people use smartphones that are essentially hand-held internet-accessible computers. Numerous studies conducted with driving simulators and on-road driving suggest that using a cell phone while driving, particularly visual-manual interaction, can significantly impair driving performance.

This study investigated the relationship between cell phone use and crash risk using data from the Second Strategic Highway Research Program Naturalistic Driving Study, which included data from a sample of 3,593 drivers whose driving was monitored using in-vehicle video and other data collection equipment for a period of several months between October 2010 and December 2013. The relationship between driver cell phone use and crash involvement was quantified using a case-crossover study design in which a driver's cell phone use in the six seconds immediately prior to the crash was compared with the same driver's cell phone use in up to four six-second segments of ordinary driving under similar conditions (time of day, weather, locality, lighting, and speed) within the three months prior to the crash. Cell phone use, crash involvement, and traffic and environmental conditions were assessed using in-vehicle video. The final study sample included 566 severe, moderate, and minor crashes matched to 1,749 segments of ordinary driving.

Odds ratios for the association of cell phone use with crash involvement were estimated using conditional logistic regression. Odds ratios were calculated for overall cell phone use, conversation, overall visual-manual cell phone use, and several specific visual-manual tasks including texting, dialing, browsing, and reaching for or answering the phone; the reference condition was driving without performing any observable secondary task. Results were also stratified by traffic density, crash severity, and crash type.

Visual-manual tasks overall and texting in particular were associated with significantly elevated incidence of crash involvement relative to driving without performing any observable secondary tasks (visual-manual interaction overall: Odds Ratio [OR] 1.83, 95% Confidence Interval [CI] 1.03 – 3.25; texting: OR 2.22, CI 1.07 – 4.63). The increase in the incidence of crash involvement associated with visual-manual tasks was greater for crashes in free-flow traffic conditions (OR 2.46, CI 1.10 – 5.51) and in types of crashes in which the subject driver generally played a clear role (run-off-road crashes: OR 3.15, CI 1.30 – 7.67; rear-end crashes: OR 7.77, CI 1.65 – 36.56) than for all crash types taken together. The incidence of crash involvement was elevated slightly during hand-held cell phone conversation; however, the estimate was very imprecise and was not statistically significant (OR 1.16, CI 0.50 – 2.70). The relationship between hands-free cell phone conversation and crash involvement could not be assessed meaningfully because there were very few crashes or baseline epochs in which hands-free cell phone conversation was observed.

In general, results reflected similar patterns to previous studies, with visual-manual tasks (particularly texting) associated with significantly increased crash risk. Estimated risks were somewhat lower than in previous studies, likely due to the careful matching of crashes to baseline epochs in which the same drivers were driving under similar traffic and environmental conditions, thereby inherently controlling for many individual driver-specific and situational factors that may be related to both cell phone use and crash risk.

Introduction

The impact of cell phone usage on driving safety has been the subject of considerable debate in the research community, with research on the impact of cell phones (or "radiophones") dating to at least the 1960s (Brown, Tickner & Simmonds, 1969; Kames, 1978). A significant amount of research was conducted in the years following the turn of the century as cell phones became ubiquitous and more frequently used during driving. The bulk of these studies examined driver performance using driving simulators and in controlled on-road driving, and results generally showed a significant relationship between cell phone use and decreased driving performance, increased (simulated) collision rates, lower driving speeds, increased (slower) hazard response times, and higher mental workload (Drews, Pasupathi & Strayer, 2008; Horrey & Wickens, 2006; Strayer, Drews & Crouch, 2006; Horberry, Anderson, Regan, Triggs & Brown, 2006; Rakauskas, Gugerty & Ward, 2004; Strayer, Drews & Johnson, 2003; Strayer & Johnston, 2001).

Recent research has examined the evolving potential for driver distraction posed by the advent and ensuing dominance of smartphones, which increased from 2% market penetration in 2005 to 81% in 2016 (Lella, 2017). For example, Crandall & Chaparro (2012) compared simulated driving performance when texting using either a touch screen or keyboard interface and found higher lane position variability and workload for the touch interface. He et al. (2014) analyzed the relative risks of speech-based and hand-held text messaging using an Android-based smartphone in a driving simulator and found increases in lane position and speed variability relative to baseline driving for both input modalities. Munger et al. (2014) compared manual and voice-controlled entry of navigation destinations on a smartphone in a driving simulator and found advantages in a variety of driving performance metrics and subjective workload for the voice-controlled system; however, both manual and voice-controlled modalities reduced detection response task (DRT) performance relative to baseline driving.

Numerous studies have identified links between cell phone use and actual on-road driving performance. For example, Harbluk, Noy, Trbovich & Eizenman (2007) found that hands-free conversation about math problems on a cell phone was associated with an increased concentration of glances at the forward roadway, fewer scanning glances during driving, and an increased frequency of hard-braking events in the most difficult experimental condition examined. Similarly, Mazzae, Goodman, Garrott, & Ranney (2004) found that conversation on a cell phone—either hand-held or hands-free—resulted in fewer driving-related glances and a higher percentage of time looking at the forward roadway, while dialing using either modality resulted in reduced glance time to the forward roadway. Owens, McLaughlin & Sudweeks (2011) found that hand-held dialing and music track selection (using a music player, though this function is generally available in modern smartphones) while driving on public roads significantly increased interior glances, steering variance, and mental demand, while voice control of these functions did not.

In a small-scale naturalistic driving study, Sayer, Devonshire & Flannagan (2005) found that cell phone use was associated with increased steering variance and increased glance concentration on the forward roadway, although the study did not report any safety-critical events (SCEs). In one of the first large-scale studies of naturalistic driving data, the 100-car Naturalistic Driving Study, Klauer et al. (2006) found that dialing a hand-held cell phone significantly increased the likelihood of being in a crash or near-crash, but having a conversation on a hand-held cell phone did not significantly increase risk. Outcomes in that study were predominantly near-crashes and minor crashes. Fitch et al. (2013) found that overall hand-held cell phone use and visual-manual hand-held cell phone tasks were associated with increased risk of safety critical events; however, simply talking on a hand-held phone or using a hands-free cell phone absent of any visual-manual tasks were not. In a separate naturalistic study focused on novice teenage drivers, Klauer et al. (2014) found significant increases in the risk of crashes or near-crashes associated with a variety of secondary task behaviors, including visual-manual cell-phone related tasks.

In a recent study using the Second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study (NDS) data set, Dingus et al. (2016) employed a case-cohort study design in which the frequency of driving behaviors including but not limited to cell phone use were compared in the seconds immediately prior to crashes versus in a stratified random sample of ordinary driving by the study subject to estimate the effects of those behaviors on crash risk. That study found statistically significant odds ratios (ORs) for crash involvement associated with overall hand-held cell phone use (OR = 3.6), phone browsing (OR = 2.7), dialing (OR = 12.2), reaching for a hand-held cellular phone (OR = 4.8), hand-held texting (OR = 6.1), and hand-held talking (OR = 2.2) when compared with "model driving," which was defined in the study as driving without any observable impairment, drowsiness, or distraction. However, analyses did not control for other factors that might have influenced crash risk.

Redelmeier and Tibshirani (1997) conducted a case-crossover analysis of the relationship between talking on a cell phone and crash risk by directly comparing cellular phone activity within a 10-minute window preceding a crash with the cellular activity during the same period on the day before the crash. Cell phone use was verified by examining drivers' cellular phone records; driving during the comparison periods was verified through interviews with the drivers. Using this method, the researchers estimated that talking on a cell phone was associated with roughly fourfold increase in risk during cell phone usage compared with driving without talking on a phone. The researchers found no evidence that the risk differed between hand-held versus hands-free cell phones. Crashes in that study were crashes that resulted in significant property damage (as assessed by police) but no reported injuries; however, a similar study conducted several years later by McEvoy et al. (2005) used a similar case-crossover approach to examine cell phone use among drivers treated in an emergency department due to injuries sustained in a crash, and found that cell phone use was associated with approximately a fourfold increase in risk of involvement in crashes that resulted in injury to the driver. However, in the absence of naturalistic driving data, both of these studies had limited ability to account for other factors (e.g., traffic, weather) that might have influenced crash risk.

In one of the most carefully controlled studies of the impact of secondary tasks such as cell phone use on driving safety, Klauer, et al. (2010) applied the case-crossover study design to naturalistic data from the 100-car Naturalistic Driving Study. In this study, secondary tasks were categorized into simple, moderate, and complex; risk was calculated using data from 830 crashes and near-crashes (predominantly near-crashes and minor crashes, as in Klauer et al., 2006). In contrast to previous studies of naturalistic driving data, which used a case-control or case-cohort study design, crashes and near-crashes were compared with baseline epochs selected specifically to control for other factors present in the crash or near-crash that might also have been correlated with crash risk. Specifically, baseline epochs were selected from the same driver, at a point in time previous to the crash or near-crash, on the same general day of the week (weekday versus weekend), during the same time of day (± 2 hours), and at the same location or type of location. With this study design and analytical approach, the resultant odds ratio estimates were lower than in a case-control study of same data. For example, the ORs associated with complex and moderately complex secondary tasks were 3.1 and 2.1, respectively, when estimated with case-control methods, but were reduced to 2.1 and 1.3, respectively when estimated using the case-crossover approach. The authors hypothesized that this pattern of results could have been attributable to the increased statistical control of driver characteristics afforded by the case-crossover study design.

More recently, Victor et al. (2015) conducted a case-crossover study using preliminary SHRP 2 NDS data to study the risk of striking rear-end conflicts (i.e., cases in which the subject vehicle conflicts with the rear of a lead vehicle) during periods of driver inattention. In this study, a single case-crossover baseline was used for each epoch of interest, which included both crashes and near-crashes. The reference condition included all driving excluding the task under consideration. Here, visual-manual engagement with portable electronic devices resulted in a significantly increased OR of 2.8, and texting resulted in a significantly increased OR of 5.6. Interestingly, talking on a cell phone was associated with a significantly *decreased* OR of 0.1. This represents the first known study to conduct a case-crossover analysis using SHRP 2 NDS data, and the first known case-crossover study of the crash risk associated with specific visual-manual cell phone tasks, although the complete data set was not yet available at the time of its publication.

In summary, laboratory-based studies and studies of controlled on-road driving have consistently demonstrated that talking on or manipulating a cell phone while driving adversely affects certain aspects of driving performance; however, such studies do not directly investigate crash risk. Past analyses of smaller naturalistic driving studies have consistently shown that visual-manual interactions with cell phones increases the risk of involvement of safety critical events, with mixed results with respect to simply talking on a cell phone. While such studies have included some crashes, their outcomes have been predominantly near-crashes and minor crashes. Epidemiological studies have linked cell phone use to involvement in real-world crashes, but these studies were conducted before the era of the modern smartphone and had limited ability to control for situational factors that might have influenced crash risk. Recent analyses of data from larger naturalistic driving studies have also linked cell phone use to involvement in real-world crashes, but they have also had limited control for environmental and situational factors that might have influenced crash risk.

The purpose of the current study was to leverage data from the largest naturalistic driving study to date—the SHRP 2 NDS—to quantify the relationship between cell phone use and crash risk. This study builds upon and extends previous work in several ways. Analyses are based only on actual real-world crashes, rather than near-crashes or other safety-critical events. Specific modes of cell phone use (e.g., talking, texting, dialing, browsing) are examined individually rather than only in aggregate. Cell phone use immediately prior to crashes is compared with driving by the same driver while driving under similar traffic and environmental conditions at multiple points in time before the crash, thereby controlling for driver-related and situational factors that might also influence crash risk.

Method

This study used a case-crossover design (Maclure, 1991; Mittleman et al., 1995) to examine the relationship between engagement in various modes of cell phone use and the risk of being involved in a crash. Drivers' engagement in specific cell phone-related tasks immediately prior to crashes was compared with engagement in the same cell phone-related tasks in a sample of brief segments of ordinary noncrash driving by the same drivers driving within three months prior to the crash under traffic and environmental conditions similar to those present at the time of the crash. The underlying data, sample selection for this study, and statistical analysis are described in detail in the following sections.

Study Sample

Data for the current study were collected for the SHRP 2 NDS, which recruited a sample of drivers, equipped their vehicles with cameras and other sophisticated data collection equipment, and collected detailed data continuously while the study subjects' vehicles were being driven. Data were collected across six study sites in the U.S. to ensure geographical diversity: Bloomington, Indiana; Buffalo, New York; Durham, North Carolina; Seattle, Washington; State College, Pennsylvania; and Tampa, Florida. Data collection and the coding of driver, vehicle, and environmental factors were centrally organized and performed by the Virginia Tech Transportation Institute (VTTI). Data were collected for a total of 38 months, from October 2010 to December 2013, with the total involvement time varying by driver. Data recorded from any drivers who had not consented to participate in the study, e.g., other people driving the study participant's vehicle, were identified and were excluded from any further reduction or analysis. Institutional Review Board (IRB) approval and a data use license were obtained from Virginia Tech to gain authorization to use SHRP 2 NDS data analyzed in this study.

The SHRP 2 NDS recruited an approximately equal mix of male and female drivers from varying age groups, different socioeconomic strata, and different geographical areas across the United States. Participants drove a variety of light-vehicle types, including cars, sport-utility vehicles, and vans. The driver sample was designed to be generally representative of the driving population, with the exception that younger and older drivers were over-recruited due to their status as high-risk populations in the context of motor vehicle crashes. More information regarding the representativeness of the data set is discussed in Antin et al. (2015) and Dingus et al. (2015).

A total of 3,593 drivers participated in the SHRP 2 NDS data collection. Table 1 summarizes the demographic characteristics of all participants in the SHRP 2 NDS.

Table 1. Age and sex of participants in the SHRP 2 Naturalistic Driving Study.

Age Group	Female	Male	Unknown	Total
16-19	304	246	0	550
20-24	425	323	0	748
25-34	233	223	0	456
35-49	215	202	0	417
50-64	261	217	2	480
65-74	191	201	0	392
75+	220	276	0	496
Unknown	29	24	1	54
Total	1,878	1,712	3	3,593

Identification of Crashes

Potential crashes were identified in the SHRP 2 NDS using participant reports, automatic crash notifications, and algorithms developed in previous naturalistic driving studies (Dingus, Klauer, et al., 2006; Fitch et al., 2012; Hanowski et al., 2008; Simons-Morton et al., 2011). The algorithms identified rapid longitudinal decelerations, rapid lateral accelerations, short time-to-collisions, and substantial swerving. Approximately 700,000 potential events were found. Trained data reductionists visually inspected each triggered event to validate whether it was actually a crash and to rate the severity levels of events determined to be crashes. A total of 1,533 crashes and minor collisions were identified (Table 2).

The current study examined only severe, moderate, and minor crashes (Levels 1-3); low-risk tire strikes (Level 4) were not included in the current study. Crashes that occurred in parking lots, in driveways, in active work zones that affected the flow of traffic, during parallel parking, in particularly unusual localities (e.g., a campground), or in fog were excluded (n=152).

Table 2. Summary of crash severity levels recorded in the SHRP 2 Naturalistic Driving Study.

Crash Type	Description	Number of Crashes
Level 1 (“Severe”)	Airbag/injury/rollover/high delta-V (change in speed of subject vehicle by >20 mph) crashes	120 (7.1%)
Level 2 (“Moderate”)	Police-reportable crashes (i.e., where there was at least $1,500 of damage as estimated by viewing the forward video data or a 1.3 g acceleration in any direction; included police-reported crashes and others of similar severity that were not reported)	159 (10.2%)
Level 3 (“Minor”)	Crashes involving physical contact with another object, or roadway departure with minimal or no damage	621 (40.7%)
Level 4 (Not included in current study)	Low-risk tire strike (e.g., clipping a curb during a tight turn)	638 (42.0%)

Identification and Selection of Baseline Epochs

The research team sought to identify four baseline epochs matched to each crash with respect to the driver, traffic, and environmental factors present at the time of each crash, so that cell phone use immediately prior to crashes could be compared with cell phone use while the same driver was driving under similar conditions.

Matching criteria included the following factors:

1. Driver
2. Date within three months prior to the crash
3. Weekday vs. weekend
4. Time of day within ± 1 hour of precipitating event (PE) for crash
5. Average speed over 30-second baseline epoch within ± 10 mph of speed at PE
6. Weather: Any precipitation versus none
7. Locality: Interstate/bypass versus open country/residential versus urban/moderate residential/business
8. Lighting: Daylight versus dark
9. Traffic density: Level of Service (LOS) A1/A2 versus LOS B/C versus LOS D/E/F
10. Vehicle speed at PE (point value): <2 mph versus 2-5 mph versus >5 mph

The baseline selection process was two-phased to maximize both efficiency and precision. In the initial selection phase, computer algorithms examined numeric trip summary data to identify candidate 30-second segments of driving that matched the same driver as the crash, occurred within three months prior to the crash (to minimize experiential effects), occurred within one hour before or after the time of the precipitating event (PE) of the crash, matched the same general period of the week in which the crash occurred (weekday versus weekend), and had an average speed within ± 10 mph of the speed at the time of the PE.

After segments of driving that met all these criteria were identified, one 30-second epoch out of each two minutes of qualifying driving was selected at random for the second phase of review. In this second phase, trained data reductionists manually reviewed video of each candidate epoch to determine whether it met those matching criteria (precipitation, lighting conditions, locality, traffic density, and travel speed at the time of the PE) only ascertainable by means of manual review of video. Candidate epochs were reviewed in ascending order of the time difference from the crash (i.e., potential baselines closest to the time of the crash were considered first).

Two rounds of visual inspection were performed, first with stricter matching criteria, and then with less strict criteria when initial inspection did not enable the identification of a sufficient number of matched baseline epochs. The visual criteria used in the two rounds are listed in Table 3. Note that the second-round filters are a subset of the first round, such that baselines that meet the criteria of the first round by definition meet those of the second round.

Table 3. First- and second-round visual filtering criteria for matched baseline epochs.

	First-round Filters	**Second-round Filters**
Weather	Snow vs. Fog vs. Rain vs. Dry	Precipitation (Snow/Rain) vs. None
Locality	Moderate Residential vs. Business/Industrial vs. Interstate/Bypass vs. Urban vs. Open Country/Residential	Interstate/Bypass vs. Open Country/Residential vs. Urban/Moderate Residential/Business
Lighting	Day vs. Dark/Lit/Unlit vs. Dawn/Dusk	Day vs. Dark
Traffic Density (Level of Service)	A1 /A2 (free-flow traffic) vs. B/C (stable flow with restrictions) vs. D/E/F (unstable flow, speed significantly restricted, some stoppages)	Same as first round
Speed at Onset of Precipitating Event (point value)	≤ 2 mph 2-5 mph >5 mph	Same as first round

A total of 1,749 baseline epochs were matched to 566 crashes. The first phase of selection failed to identify any potential matches for 91 crashes; these crashes generally occurred early in the subject's participation in the SHRP 2 NDS (i.e., few driving epochs were available prior to the crash) or under conditions (e.g., time of day or type of road) that were atypical for that given driver. An additional 91 events returned at least some potential matches during the first phase, but none were confirmed as matches in the second phase. This second group of crashes failed to produce matches for a variety of reasons, and often for multiple reasons. For example, crashes with atypical timing and/or driving speed conditions for a given driver may have yielded few potential matches in the first phase, of which none were found to be valid matches in the second phase due to differences in traffic or weather. A flowchart summarizing the baseline selection process is provided in Figure 1.

The total number of crashes included in the final sample, by severity, and the number of matched baselines per crash is presented in Table 4.

Table 4. Number of matched baseline epochs per crash in relation to crash severity for final case-crossover study sample.

	Number of baseline epochs				
Crash Severity	**1**	**2**	**3**	**4**	**Total**
Severe	13	11	13	47	84
Moderate	18	19	16	50	103
Minor	61	48	54	216	379
Total	92	78	83	313	566

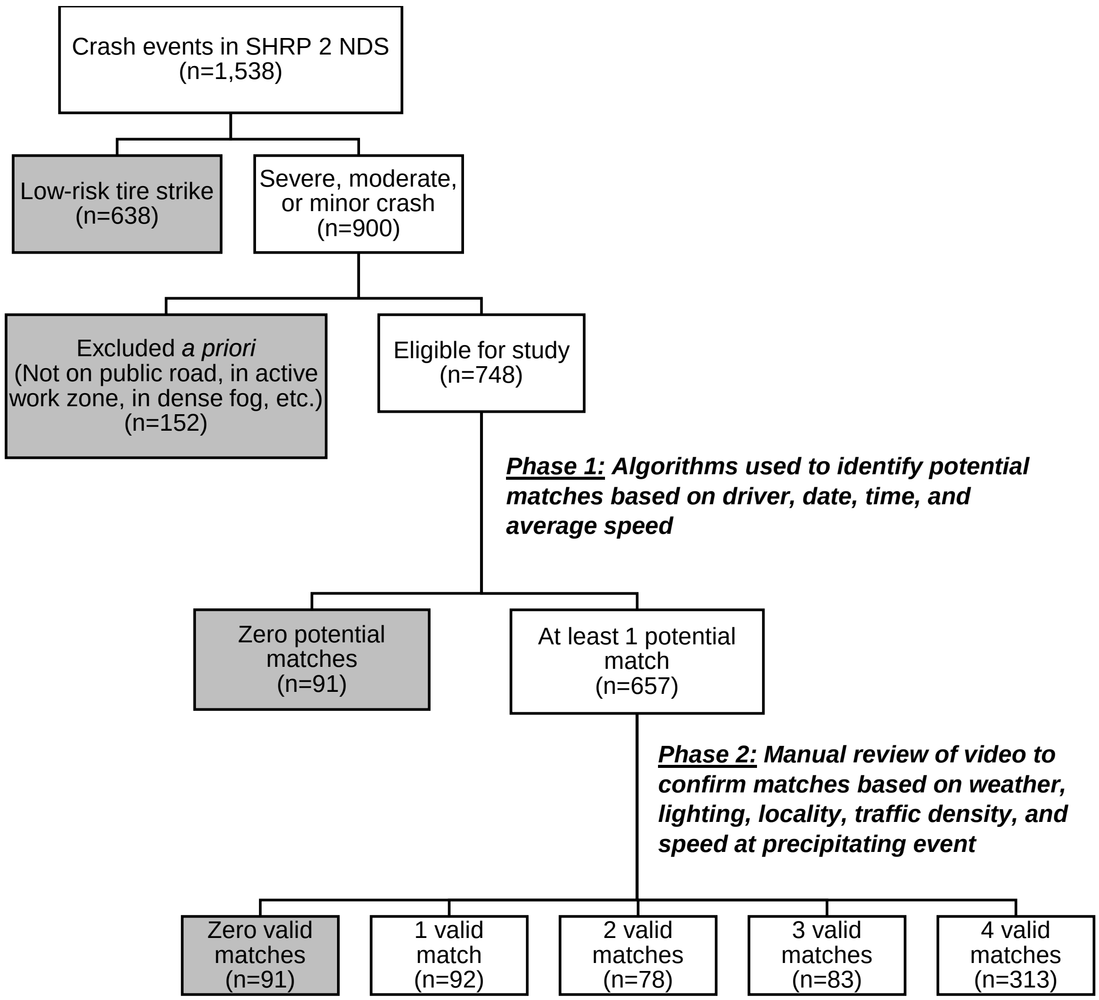

Figure 1. Selection of crashes and matched baseline epochs for inclusion in study.

Table 5 shows the demographic distribution of the drivers in the final case-crossover study sample.

Table 5. Age and sex of crash-involved drivers in final case-crossover study sample.

Age Group	Female	Male	Total
16-19	92	62	154
20-24	89	69	158
25-34	29	28	57
35-49	22	23	45
50-64	28	22	50
65-74	23	9	32
75+	29	41	70
Total	312	254	566

SHRP 2 NDS Quality Control

Data reductionists assigned to the SHRP 2 NDS crash and baseline reduction were chosen based on their superior performance during previous projects. Once assigned to the SHRP 2 NDS project, these reductionists spent several hours familiarizing themselves with the data dictionary. They then attended a two-hour training session during which each variable was discussed while instruction was provided on how to code example events and videos. Each reductionist was given a set of 20 expertly reduced events to review on their own, followed by a set of 10 test events to reduce. Their responses to those 10 events were compared with an expert rater response, and feedback was provided to the trainees. Reductionists were retrained on variables that were coded incorrectly, and a second set of 10 events was administered with a final round of training feedback. Once reductionists were performing at an acceptable accuracy rate (approximately 90%), they began to reduce new events on their own. All crashes and near-crashes in the SHRP 2 NDS were first reduced by a reductionist and were then reviewed by a senior reductionist or reduction coordinator for a 100% rate of quality-control checks.

Reductionists assigned to baseline coding were quality checked by senior personnel at the same 100% rate until their accuracy was established and consistent for at least one week, after which time their rate of quality checks was reduced to 75%, to 50%, or to 25% in some cases. For crash, near-crash, and baseline reduction, the original reductionists returned to their reduced events to make any corrections. Any remaining disagreements were resolved by a third person at the coordinator or group leader level. Finally, before these data were published, they were examined in detail for internal consistency, logic, and completeness; any questionable responses were examined along with the corresponding video. The coded data were updated as needed.

Video Coding

To allow evaluation of a variety of cell phone usage behaviors, secondary task coding was conducted for a 30-second period preceding the PE for all crashes and for all baseline epochs. Data reductionists viewed video of the driver's face and hands frame-by-frame and recorded types and start and end times for all secondary tasks in which the driver engaged. The coding of various cell phone usage tasks, other secondary tasks, traffic, environmental, and other situational factors is described in detail in the *SHRP 2 Researcher Dictionary for Video Reduction Data*, *Version 3.4* (2015), available on the SHRP 2 NDS InSight website (https://insight.shrp2nds.us). Most previous studies generally only coded the five seconds preceding the PE through the end of the crash, along with six-second baseline epochs. However, this extended coding period enables examination of the sensitivity of results to differences in the length of time over which task engagement is considered.

Statistical Analysis

The current study estimated the relationship between a variety of cell phone-related behaviors and the risk of being involved in a crash by comparing the frequency of exposure to each task of interest at the time of a crash with the frequency of exposure to engagement in the same task in the matched baseline epochs. The latter are used to provide an estimate of drivers' exposure to cell-phone tasks while driving under conditions similar to those in which the crash occurred. The statistic used to express the relationship between secondary task engagement and crash risk was the odds ratio (OR).

Odds ratios were estimated using conditional logistic regression models for matched-set data (Connolly et al., 1988; Mittleman et al., 1995). Logistic regression is a state-of-practice approach to calculate ORs with respect to certain driving risk factors in traffic safety research (Guo et al., 2016). Conditional logistic regression eliminates the effects of all factors common to all of the events in each matched set (or stratum) by conditioning on the matching mechanism. In the current study, the events in each matched set are one crash and one to four baseline epochs; factors common to all of the events in the same matched set include the effects of the environmental factors used in the matching (time of day, day of week, weather, lighting, locality, traffic, and speed) and all factors related to the individual driver (age, sex, driving skills, propensity to take risks, etc.). Because each matched set i is known to include exactly one crash (i.e., $\sum_{j=1}^{n_i} Y_{ij} = 1$), the likelihood that the k^{th} observation in set i contains a crash and that the other n_i-1 observations do not contain crashes, conditional upon set i including exactly one crash, is given by:

$$\mathbb{P}\left(Y_{ik} = 1, Y_{ij,j\neq k} = 0 \middle| X, \textstyle\sum_{j=1}^{n_i} Y_{ij} = 1\right) = \frac{\exp(\beta X_{ik})}{\sum_{j=1}^{n_i} \exp(\beta X_{ij})},$$

where Y_{ij} is the response variable (1 = crash, 0 = baseline epoch) for j^{th} event in set i; n_i is the total number of events in set i; X_{ij} is the exposure of interest (e.g., cell phone use: 1=using cell phone, 0=not using cell phone); and β is the effect of the exposure X, which is shared by all of the matched sets included in the model and is the coefficient that maximizes the conditional likelihood across all strata. (Stratum-specific effects, in ordinary logistic regression denoted α_i, do not appear in the equation because they cancel out.) Exponentiating β yields the OR for the association of the exposure (cell phone use) with crash involvement.

In this study design, the OR approximate an Incidence Rate Ratio (Miettinen, 1976; Wacholder et al., 1992), which in this study represents the ratio of the incidence of crash involvement in a six-second segment of driving in which the driver engages in a given cell phone task relative to the incidence of crash involvement in a six-second segment of driving under similar conditions in which the same driver does not engage in any observable secondary task. Thus, for example, a hypothetical OR of 2.0 for texting would indicate that the incidence of crash involvement in six-second segments of driving in which the driver is texting is double the incidence of crash involvement in six-second segments of driving in which the same driver is driving under similar conditions and does not engage in any observable secondary task.

Separate logistic regression models were fitted for each specific cell phone task of interest, including:

- Talking (hand-held)
- Talking (hands-free)
- Texting
- Dialing
- Browsing

- Locating/reaching for/answering the phone
- Overall visual-manual cell phone use (texting, dialing, browsing, or locating/reaching for/answering)
- Any cell phone use (any of the above)

The above models were fitted for all crashes together and for crashes stratified by crash severity, traffic density, crash type, and subject driver role (striking versus struck).

The models were fitted using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC).

Sensitivity Analyses

The following analyses were performed to examine the robustness of the above-described analyses to modifications to key aspects of the study design.

Comparison with All Driving

This analysis investigated the relationship between engagement in various cell phone-related tasks and crash involvement with a reference condition of simply not performing that specific cell phone task, rather than restricting the reference condition to driving without performing any observable secondary tasks (e.g., eating, interacting with a passenger, manipulating the vehicle HVAC controls) as in the main analysis.

Extended Driving Segments

The main analyses in this study examined the association of engagement in various cell phone-related tasks and crash involvement over a six-second segment of driving time, analogous to most past studies of naturalistic driving data. In this sensitivity analysis, ORs were estimated based on whether the driver engaged in each cell phone task at any point in the 30 seconds preceding the crash as compared with task engagement in corresponding 30-second baseline epochs, to assess the sensitivity of the results to changes in the length of time over which task engagement is considered.

Comparison to Driving on Previous Day Only

Unlike the current study, previous case-crossover studies of the relationship between cell phone use and crash risk (Redelmeier & Tibshirani, 1997; McEvoy et al., 2005) did not have access to continuously recorded in-vehicle video data with which to carefully control for traffic and environmental conditions present at the time of crashes, and thus selected comparison periods based only on the driver and time of day. To investigate the sensitivity of the results to matching criteria used in the current study versus selecting matched baseline epochs based only on time of day, this analysis matched each crash to a single baseline epoch matched to the same driver at the same time of day as the crash (within ± 10 minutes) on the day before the crash occurred, irrespective of traffic conditions, environmental conditions, or other secondary tasks in which the driver engaged.

Results

The main study results presented in this section compare drivers' odds of crash involvement when using a cell phone relative to driving without performing any observable secondary tasks, both overall and stratified by selected environmental and crash-related factors. Sensitivity analyses, presented subsequently, compare the main study results with results of analyses performed with (a) an alternative reference condition (all matched baseline epochs rather than only those in which drivers were not performing any observable secondary tasks), (b) longer segments of driving (30 seconds rather than six seconds), and (c) different selection criteria for baseline epochs (matched to crashes with respect to time of day only, without considering environmental conditions).

The odds of a driver being involved in a crash in a six-second period during which he or she used a cell phone, relative to the odds of crash involvement while driving under similar traffic and environmental conditions without performing any observable secondary task, are shown in Table 6. Asterisks in tables denote instances in which there were too few crashes and/or baseline epochs involving a specific cell phone task to compute an odds ratio. Statistically significant increases in risk were found for overall visual-manual tasks (OR = 1.83) and for texting (OR = 2.22). Notably, 42 of 65 crashes that involved any form of visual-manual interaction with cell phones involved texting. Hand-held cell phone conversation, locating/reaching for/answering the phone, and overall cell phone use (all manner of cell phone use combined) were associated with elevated risk of crash involvement (OR > 1); however, odds ratios for these tasks were not statistically different from 1.0 at the 95% confidence level.

Table 6. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving.

	Crashes		Baseline Epochs			
	Cell Phone Task	No Observable Secondary Task	Cell Phone Task	No Observable Secondary Task	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	83	170	236	613	1.48 (0.89–2.45)	0.129
Talking (hand-held)	21	170	72	613	1.16 (0.50–2.70)	0.739
Overall Visual-Manual	65	170	143	613	**1.83 (1.03–3.25)**	**0.040**
Texting	42	170	70	613	**2.22 (1.07–4.63)**	**0.033**
Browsing	12	170	55	613	0.68 (0.23–2.02)	0.489
Dialing (hand-held)	5	170	5	613	*	*
Locating/Reaching/Answering	13	170	18	613	1.86 (0.44–7.81)	0.395
Hands-free Call	2	170	25	613	*	*
Headset/Earpiece	1	170	7	613	*	*
Integrated device	0	170	6	613	*	*
Speakerphone	1	170	12	613	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios; ORs statistically significant at 95% confidence level are shown in bold.

Stratified Analyses

To further investigate results found in the overall analyses presented above, analyses were stratified by several factors including crash severity, traffic density, crash type, and the subject driver's role in the crash.

Crash Severity

Odds ratios for the association of cell phone-related tasks with involvement in moderate or greater severity crashes (i.e., Levels 1 and 2) are presented in Table 7; odds ratios for involvement in minor crashes (Level 3) are presented in Table 8. No odds ratios reached statistical significance in either analysis, likely due to limited sample size. However, the magnitudes of the odds ratios for overall visual-manual engagement, text messaging, and phone locating/reaching/answering were similar in these stratified analyses to those found in overall analyses not stratified by crash severity. There do not appear to be meaningful differences in the crash risk of phone-related tasks when stratified by severity level.

Table 7. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: Moderate & severe crashes only.

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	30	57	78	189	1.22 (0.47–3.15)	0.685
Talking (hand-held)	5	57	24	189	1.05 (0.16–6.75)	0.962
Overall Visual-Manual	24	57	46	189	1.75 (0.57–5.32)	0.325
Texting	16	57	25	189	2.32 (0.54–9.99)	0.261
Browsing	5	57	16	189	0.34 (0.04–3.10)	0.336
Dialing (hand-held)	1	57	2	189	*	*
Locating/Reaching/Answering	4	57	5	189	1.73 (0.10–30.76)	0.708
Hands-free Call	1	57	8	189	*	*
Headset/Earpiece	0	57	1	189	*	*
Integrated device	0	57	0	189	*	*
Speakerphone	1	57	7	189	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table 8. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: Minor crashes only.

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	53	113	158	424	1.59 (0.88–2.89)	0.125
Talking (hand-held)	16	113	48	424	1.19 (0.46–3.07)	0.726
Overall Visual-Manual	41	113	97	424	1.86 (0.95–3.63)	0.071
Texting	26	113	45	424	2.19 (0.94–5.13)	0.070
Browsing	7	113	39	424	0.91 (0.25–3.24)	0.881
Dialing (hand-held)	4	113	3	424	*	*
Locating/Reaching/Answering	9	113	13	424	1.91 (0.37–9.95)	0.444
Hands-free Call	1	113	17	424	*	*
Headset/Earpiece	1	113	6	424	*	*
Integrated device	0	113	6	424	*	*
Speakerphone	0	113	5	424	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Traffic Density

Analyses were stratified by traffic density, grouped as free-flow traffic (LOS A) versus traffic with at least some restrictions (LOS B-F). This grouping was used because more than half of all crashes included in the study occurred in free-flow traffic, and there were too few crashes at other specific level of service to examine other levels individually. Table 9 presents odds ratios for association of cell phone use with crash involvement in free-flow traffic only, and Table 10 presents odds ratios for association of cell phone use with crash involvement in more restricted traffic. Visual-manual interaction with a cell phone was found to be associated with a statistically significant increase in crash risk in free-flow traffic (OR = 2.46). Notably, the odds ratios for texting (OR=2.26) and for locating/reaching for/answering the phone (OR=6.50) were suggestive of substantially elevated risks under free-flow conditions, but were not statistically significant, likely due to the limited sample size. In general, odds ratios for the association between cell phone use and crash involvement were similar (texting, talking) or larger (all others) when driving in free-flow traffic than when driving in traffic with restrictions.

Crash Type and Role in Crash

Data were stratified by crash type. Only crashes in which the subject driver struck the lead vehicle (*rear-end crashes*) and crashes in which the subject driver drove off the roadway (*road-departure crashes*) were present in sufficient numbers for statistical analysis, as other crash types were many and varied. Table 11 shows odds ratios for the association of cell phone use with involvement in rear-end crashes. Table 12 shows odds ratios for the association of cell phone use with involvement in road-departure crashes.

Tables 11 & 12 show that cell phone use overall and visual-manual interaction with a cell phone in particular significantly increase the risk of involvement in rear-end crashes and road-departure crashes. The large odds ratios for texting and browsing suggest that these behaviors are associated with increased risk of rear-end crashes and road-departure crashes as well; however, these were not statistically significant, likely due to inadequate sample size. For example, the odds ratios for involvement in rear-end crashes while browsing vs. while not performing any observable secondary task was 5.46, but this estimate was based on only three rear-end crashes that involved browsing. All odds ratios estimated specifically for involvement in rear-end crashes and road-departure crashes were substantially larger than for all crashes combined (Table 6), likely because rear-end crashes and road-departure crashes represent crash types in which the subject driver has a clear active role. Moreover, these crash types are likely less influenced by the chance behavior of other road users than are some of the other types of crashes included in Table 6 (e.g., crashes in which the subject driver is struck by another driver).

Odds ratios for the association of cell phone use with involvement in any type of crash excluding crashes in which the subject driver was struck from behind were also estimated (Table 13). This analysis simply excludes the crashes in which the subject driver arguably played the least active role. With crashes in which the subject driver was struck from behind excluded, odds ratios for all cell phone tasks increased somewhat relative to those calculated using all crashes, and the odds for overall cell phone use became statistically significant. Odds ratios for texting and for overall visual-manual cell phone use both increased in magnitude relative to analysis based on all crashes and remained statistically significant.

Analyses of crashes in which the subject driver was struck from behind were performed, but there were too few cases to calculate odds ratios for any of the cell phone tasks examined. (Only six crashes in which the subject driver was struck from behind involved any cell phone use on the part of the subject driver.)

Table 9. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: Free-flow traffic only (Level of Service A).

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	41	98	113	337	1.84 (0.90–3.76)	0.095
Talking (hand-held)	11	98	33	337	1.14 (0.38–3.44)	0.813
Overall Visual-Manual	32	98	67	337	**2.46 (1.10–5.51)**	**0.029**
Texting	20	98	38	337	2.26 (0.82–6.26)	0.116
Browsing	5	98	20	337	1.53 (0.25–9.72)	0.644
Dialing (hand-held)	3	98	3	337	*	*
Locating/Reaching/Answering	7	98	8	337	6.50 (0.65–64.71)	0.110
Hands-free Call	2	98	16	337	*	*
Headset/Earpiece	1	98	5	337	*	*
Integrated device	0	98	4	337	*	*
Speakerphone	1	98	7	337	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table 10. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: Traffic with some restrictions (Levels of Service B, C, D, E, or F).

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	42	72	123	276	1.19 (0.58–2.41)	0.635
Talking (hand-held)	10	72	39	276	1.17 (0.31–4.44)	0.813
Overall Visual-Manual	33	72	76	276	1.34 (0.59–3.02)	0.482
Texting	22	72	32	276	2.18 (0.76–6.29)	0.149
Browsing	7	72	35	276	0.47 (0.12–1.82)	0.276
Dialing (hand-held)	2	72	2	276	*	*
Locating/Reaching/Answering	6	72	10	276	0.52 (0.05–5.25)	0.576
Hands-free Call	0	72	9	276	*	*
Headset/Earpiece	0	72	2	276	*	*
Integrated device	0	72	2	276	*	*
Speakerphone	0	72	5	276	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table 11. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: Rear-end crashes only.

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	22	19	48	102	**4.73 (1.22–18.31)**	**0.025**
Talking (hand-held)	2	19	15	102	*	*
Overall Visual-Manual	20	19	31	102	**7.77 (1.65–36.58)**	**0.010**
Texting	15	19	14	102	6.30 (0.74–53.26)	0.091
Browsing	3	19	12	102	5.46 (0.53–56.71)	0.155
Dialing (hand-held)	1	19	2	102	*	*
Locating/Reaching/Answering	4	19	3	102	*	*
Hands-free Call	0	19	3	102	*	*
Headset/Earpiece	0	19	0	102	*	*
Integrated device	0	19	0	102	*	*
Speakerphone	0	19	3	102	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table 12. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: Road-departure crashes only.

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	46	62	105	263	**2.78 (1.25–6.15)**	**0.012**
Talking (hand-held)	15	62	33	263	1.83 (0.60–5.61)	0.289
Overall Visual-Manual	35	62	61	263	**3.15 (1.30–7.67)**	**0.011**
Texting	22	62	31	263	2.62 (0.92–7.51)	0.073
Browsing	6	62	21	263	2.91 (0.40–21.00)	0.288
Dialing (hand-held)	4	62	3	263	*	*
Locating/Reaching/Answering	7	62	8	263	3.77 (0.32–43.72)	0.289
Hands-free Call	1	62	14	263	*	*
Headset/Earpiece	1	62	4	263	*	*
Integrated device	0	62	5	263	*	*
Speakerphone	0	62	5	263	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table 13. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during six-second segments of driving: All crashes excluding subject driver struck from behind.

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	77	149	211	552	**1.80 (1.06–3.07)**	**0.031**
Talking (hand-held)	20	149	64	552	1.32 (0.56–3.13)	0.525
Overall Visual-Manual	60	149	128	552	**2.19 (1.19–4.02)**	**0.011**
Texting	40	149	63	552	**2.54 (1.18–5.50)**	**0.018**
Browsing	10	149	50	552	0.78 (0.26–2.35)	0.655
Dialing (hand-held)	5	149	5	552	*	*
Locating/Reaching/Answering	12	149	15	552	2.51 (0.53–11.88)	0.245
Hands-free Call	2	149	23	552	*	*
Headset/Earpiece	1	149	6	552	*	*
Integrated device	0	149	5	552	*	*
Speakerphone	1	149	12	552	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Sensitivity Analyses

Comparison to All Driving

Table 14 presents odds ratios that compare the odds of crash involvement while performing each cell phone task to the odds of crash involvement while driving under similar conditions without performing that specific cell phone task, irrespective of other nondriving tasks in which the driver might have been engaging, such as eating, manipulating the vehicle HVAC controls, or interacting with a passenger.

Table 14. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific cell phone task during six-second segment of driving.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	**No**	**Yes**	**No**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	83	483	236	1,513	1.16 (0.84–1.59)	0.372
Talking (hand-held)	21	545	72	1,677	0.87 (0.51–1.47)	0.601
Overall Visual-Manual	65	501	143	1,606	**1.66 (1.16–2.38)**	**0.005**
Texting	42	524	70	1,679	**2.18 (1.41–3.36)**	**<0.001**
Browsing	12	554	55	1,694	0.67 (0.35–1.29)	0.229
Dialing (hand-held)	5	561	5	1,744	2.91 (0.81–10.47)	0.102
Locating/Reaching/Answering	13	553	18	1,731	**2.59 (1.20–5.57)**	**0.015**
Hands-free Call	2	564	25	1,724	**0.09 (0.01–0.75)**	**0.026**
Headset/Earpiece	1	565	7	1,742	*	*
Integrated device	0	566	6	1,743	*	*
Speakerphone	1	565	12	1,737	0.19 (0.02–1.72)	0.141

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

In contrast to odds ratios comparing the odds of crash involvement while performing each respective cell phone task versus while driving without performing any observable secondary tasks (Table 6), odds ratios in this analysis were generally similar in magnitude but were estimated with greater precision due to the increased number of crashes and matched baseline epochs available for analysis. For example, the odds ratios comparing the crash involvement when texting versus when driving without engaging in any nondriving tasks was 2.22 (Table 6), whereas the corresponding odds ratio comparing crash involvement when texting versus driving without texting was a nearly identical 2.18, but with a narrower confidence interval (Table 14). Notably, the odds ratios for crash involvement when locating, reaching for, or answering the phone was a statistically significant 2.59, larger than the estimate of 1.86 in the main analysis. In addition, with the additional data available in this analysis, the odds ratio for dialing, which could not be estimated in the main analysis due to limited sample size, was a substantial (but not statistically significant) 2.91.

Odds ratios for crash involvement associated with conversing on a cell phone were smaller than in the main analysis. For hand-held conversation, the odds ratio was 1.16 when compared to driving without engagement in any nondriving task (Table 6) and 0.87 when compared to driving without engaging in hand-held cell phone conversation (Table 14), though neither was statistically significant. The odds ratio for hands-free conversation versus not engaging in any nondriving task could not be estimated due to insufficient sample size; however, the odds ratio for hands-free conversation vs. not engaging in hands-free conversation was 0.09. This result should be treated with a great deal of caution, however, as while statistically significant, hands-free conversation was only observed in a total of two crashes and 25 baseline epochs.

Stratified analyses analogous to those presented in Tables 7-13 but following the approach used in this sensitivity analysis (comparing cell phone use in crashes versus in all matched baseline epochs irrespective of engagement in other secondary tasks) are presented in the appendix.

Extended Driving Segments

Table 15, below, shows odds ratios based on extended 30-second segments of driving, in contrast to the six-second segments used in Table 6. These odds ratios compare the odds of crash involvement associated with engaging in specific cell phone tasks at any point during the 30-second segment of driving, compared with engaging in no observable nondriving tasks during the 30-second segment. Notably, there were nearly as many crashes that involved some form of cell phone use as that involved no engagement in any nondriving task in the 30 seconds leading up to the crash. This same pattern was observed in the matched baseline epochs as well. The odds ratio associated with texting was slightly larger in this analysis (OR = 2.58) than in the analysis based on six-second segments (OR = 2.22, Table 6), and was statistically significant in both analyses. The odds ratio for dialing was similar in magnitude (OR = 2.56) but was not statistically significant. All other odds ratios were smaller than in the corresponding analysis based on six-second segments of driving. Hands-free cell phone use was not examined here because as in the main analysis presented in Table 6, there were too few cases to calculate odds ratios.

Table 15. Odds ratios for crash involvement associated with cell phone use tasks vs. driving without performing any observable secondary tasks during 30-second segments of driving.

	Crashes		Baseline Epochs			
	Cell Phone Task	**No Observable Secondary Task**	**Cell Phone Task**	**No Observable Secondary Task**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	105	111	303	306	1.06 (0.61–1.83)	0.834
Talking (hand-held)	20	111	79	306	0.77 (0.24–2.48)	0.662
Overall Visual-Manual	94	111	217	306	1.31 (0.72–2.39)	0.385
Texting	46	111	99	306	**2.58 (1.02–6.52)**	**0.046**
Browsing	30	111	88	306	0.49 (0.19–1.22)	0.123
Dialing (hand-held)	8	111	15	306	2.56 (0.23–29.12)	0.448
Locating/Reaching/Answering	50	111	89	306	1.14 (0.49–2.69)	0.760

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Comparison to Driving on Previous Day

Table 16 presents odds ratios comparing cell phone use at the time of crashes to cell phone use by the same driver in a six-second segment of driving at the same time as the crash (within ± 10 minutes) on the day before the crash occurred.

Table 16. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segment of driving; baseline epochs sampled from same driver 24 hours before crash.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	**No**	**Yes**	**No**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	14	70	12	72	1.33 (0.46–3.84)	0.594
Talking (hand-held)	4	80	4	80	1.00 (0.25–4.00)	1.000
Overall Visual-Manual	12	72	7	77	2.67 (0.71–10.05)	0.147
Texting	9	75	5	79	5.00 (0.58–42.80)	0.142
Browsing	2	82	2	82	1.00 (0.14–7.10)	1.000
Dialing (hand-held)	1	83	0	84	*	*
Locating/Reaching/Answering	1	83	0	84	*	*
Hands-free Call	0	84	1	83	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Most notably, the same driver was driving within ± 10 minutes of the same time of day on the day before the crash in only 84 of all 900 minor, moderate, and severe crashes in the SHRP 2 NDS database. In this analysis, while no results were statistically significant in part due to limited sample size, odds ratios were generally similar in magnitude to those found in the main analysis and reported in Table 6, in which baseline epochs were matched carefully to crashes with respect to traffic and environmental conditions present at the time of the crash.

Discussion

Using continuously recorded video from a sample of drivers involved in crashes, this study quantified the relationship between cell phone use and crash risk by comparing drivers' cell phone use immediately prior to crashes to cell phone use by the same drivers when they were driving under similar traffic and environmental conditions on up to four occasions in the three months preceding the crash. Results showed that visual-manual interaction with a cell phone was associated with nearly double the odds of crash involvement when compared with driving without performing any observable secondary tasks; texting in particular was associated with more than double the odds of crash involvement. By contrast, simply talking on a hand-held cell phone while driving was associated with only a small and statistically nonsignificant increase in the odds of crash involvement.

The main analyses presented here were based on a comparison of each task to driving without performing any observable secondary task, thus providing a consistent reference for all comparisons and for ease of interpretation of results. For example, when studying the effects of hand-held cell phone conversations on crash risk, a reference condition of simply not engaging in hand-held cell phone conversations would have also included other risk-increasing secondary tasks (e.g., texting), whereas when examining the crash risk associated with texting, the reference condition would exclude texting but could include tasks such as hand-held cell phone conversation.

Interpretive advantages notwithstanding, comparisons of each cell phone-related task to driving without performing any secondary tasks does present some drawbacks. First, from a statistical standpoint, this reduced the number of available crashes and baseline epochs not involving cell phone use by more than half, which decreased statistical power. Second, from a practical standpoint, when a driver is not performing one secondary task, he or she is likely to be performing some other secondary task, which this comparison does not take into account.

Because of these considerations, an additional sensitivity analysis was conducted to examine the association of each cell phone use task with the odds of crash involvement relative to the reference condition of simply not performing the specific cell phone task in question, with no other assumptions about or restrictions on other tasks in which the driver may have engaged. In most cases, odds ratios for crash involvement associated with cell phone tasks tended to be slightly lower when compared to all driving without performing that specific task than when compared to driving without performing any secondary tasks, however, the odds ratios were estimated with greater precision in this sensitivity analysis due to the greater number of crashes and baseline epochs included in the analysis.

In a number of cases, particularly with respect to hands-free cell phone use relative to driving without performing any secondary tasks, odds ratios could not be calculated due to the very low number of crashes and baseline epochs in which these tasks were observed. This suggests lower attributable risk overall, either due to low risk on an individual task basis, a lower prevalence rate overall, or a combination. Based upon previous findings of Dingus et al. (2016), which estimated both risk and prevalence, this result appears to be attributable mainly to the low prevalence of tasks such as talking on a hands-free phone or device. Relatedly, observational surveys by NHTSA have found decreases in recent years in the proportion of people observed talking on cell phones (NHTSA, 2016).

To further investigate factors contributing to omnibus estimates of crash risk, analyses were stratified by several variables, including crash severity, traffic density, and crash type. The association of cell phone use with crash involvement did not vary significantly by crash severity within the range of crash severities observed in the study. The risk associated with any visual-manual cell phone interaction was higher in free-flow traffic than in heavier traffic, which is somewhat counterintuitive and may suggest that drivers allow themselves to divert their attention further from the driving task when driving in light traffic or no traffic than in heavier traffic. Future studies could examine this question in greater depth by examining the distribution of drivers' eye glances away from the forward roadway in relation to traffic conditions. The magnitude of the association between cell phone use and crash risk was generally larger for specific crash types in which the driver had a clear active role, such as rear-end crashes (in which the subject driver struck the vehicle in front of him or her, not crashes in which the subject driver was struck from behind) and road-departure crashes, especially in the case of visual-manual interaction with cell phones. Notably, while the odds ratio for involvement in any crash associated with visual-manual cell phone interaction was 1.83, odds ratios for road departure crashes and rear-end crashes were much greater at 3.15 and 7.77, respectively. These results are sensible, indicating that engagement in visual-manual tasks with a cell phone while driving increases a driver's risk of actively contributing to a crash to a greater degree than it increases mere involvement in a crash, which may be influenced to a nontrivial degree by the actions of other road users.

To investigate the sensitivity of the study results to variations in the length of time over which cell phone use was considered, analyses were replicated using a 30-second window preceding each crash in comparison to 30-second matched baseline epochs, to contrast with the six-second periods used in the main analysis. Results were broadly similar, with texting exhibiting approximately a similar increase in crash risk in both analyses (OR = 2.58 based on 30-second segments of driving vs. 2.22 based on six-second segments of driving). However, overall visual-manual tasks in the 30 seconds prior to a crash were no longer associated significantly with crash risk, and no other factors became significant. Notably, substantial numbers of crashes as well as baseline epochs involved locating/reaching for/answering a cell phone within the 30-second segments examined but not within the six-second segments, likely because of the short duration of the task. In many cases, locating/reaching for/answering a phone is followed by engagement in another task such as talking, dialing, or texting, and likely appeared as such in the main analysis of the shorter six-second segments. Future research could examine the 30-second segments surrounding crashes and baseline epochs reduced for the current study by segmenting time windows leading to a crash into sliding bins, as well as by incorporating the general duration and frequency of tasks into analyses, which was beyond the scope of the present study.

While the general results in this study parallel those found in prior research, finding visual-manual cell phone engagement (particularly text messaging) associated with significantly elevated crash risk, specific odds ratio values were lower than those reported in most previous studies. This is likely due to the greater level of control for other potential risk factors inherent in the design of this case-crossover study relative to previous research. Specifically, crash-involved drivers served as their own controls, which controlled for individual differences in individual risk. Baseline epochs were also matched to crashes with respect to traffic and environmental conditions, thus controlling for situational factors that might influence both cell phone use (i.e., influence drivers' decisions regarding whether to interact with their phone at any given moment) and also independently influence crash risk. In contrast, most previous studies of naturalistic data used case-control approaches that attempted to control for individual and situational differences in risk to varying degrees by means of modeling rather than by matching, and none has controlled for all of these potential confounding factors to the degree that the current study did.

Also of note, the reference condition to which cell phone use was compared in the current study, i.e., driving without performing any observable secondary tasks, was somewhat less restrictive than that used in Dingus et al. (2016) and Guo et al. (2016), which excluded not only crashes and baseline epochs involving other observable secondary tasks (e.g., eating or interacting with a passenger) but also crashes and baseline epochs in which the driver exhibited signs of fatigue or other impairments. As those were not excluded in the present study, the odds ratios estimated in the current study may be expected to be somewhat lower since some baseline epochs included in the current study may have included highly risky states (extreme fatigue, substance impairment) that were excluded from those studies.

Also in contrast to most previous studies of naturalistic driving data, results were based on analysis of actual crashes only, whereas others (with the exceptions of Dingus et al. [2016] and Guo et al. [2017]) have been based on analyses of near-crashes pooled with crashes, where the vast majority of the outcomes examined have been near-crashes. In the study perhaps most similar to the current study, Klauer et al. (2010) used a case-crossover study design to examine the risk of engagement in "complex," "moderate," and "simple" secondary tasks, using data from an earlier naturalistic study and examining risk of involvement in crashes or near-crashes. In that study, the estimated risk of crash or near-crash involvement associated with complex secondary tasks was an odds ratio of 2.1, similar in magnitude to the odds ratios for texting (2.22) and overall visual-manual cell phone use (1.83) in the current study. The odds ratio estimated by Klauer et al. (2010) for "moderately complex" secondary tasks was 1.3, similar to the odds ratio for hand-held cell phone conversation (1.16) in the current study. While Klauer et al (2010) did not report results for specific cell phone tasks, and data analyzed by Klauer et al. were collected before most cell phones supported text messaging, the criteria used by the authors to classify task complexity would have classified texting as a complex secondary task; hand-held cell phone conversation was listed among tasks that the authors included among moderate complexity tasks. Thus, on balance, the results of the current study align quite closely with those of Klauer et al. (2010).

Case-crossover studies performed without the benefit of naturalistic data (Redelmeier & Tibshirani, 1997; McEvoy et al., 2005) used the crash-involved drivers as their own controls—like the current study—but accounted for no situational factors other than time of day. Those studies both estimated that using a cell phone while driving approximately quadrupled a driver's risk of crash involvement. The current study attempted to replicate the approach of those studies by means of a sensitivity analysis in which a single baseline epoch was sampled for each crash using selection criteria roughly analogous to that used in those previous studies—a single baseline epoch was sampled from each crash-involved driver 24 hours (± 10 minutes) before the crash occurred, without regard to any of the other matching variables (speed, traffic, weather) used as matching criteria in the main analysis reported here. Notably, of all 900 minor, moderate, and severe crashes in the SHRP 2 NDS, the same driver was also driving during this comparison window in 84 (9.3%) of the crashes, compared with 50% reported by Redelmeier & Tibshirani (1997) and 33% reported by McEvoy et al. (2005). Odds ratios obtained in this sensitivity analysis nonetheless were generally similar to the main results of the current study and were markedly different from those reported in those earlier studies. The reasons for these discrepancies are unclear. Given the large difference between the current study and previous studies with respect to the proportion of subjects who were driving during the time-based control period, it appears possible that previous studies may have included some subjects who were not actually driving during the selected control periods, an observation also noted by Young (2011).

Limitations

The results of this study should be interpreted with an understanding of several limitations.

First, although the SHRP 2 data set is of unprecedented scale, the strict matching criteria imposed for baselines resulted in low statistical power for several comparisons, which was further compounded by the specific type of analysis performed. In a case-crossover study, only matched sets (i.e., a crash and the baseline epochs matched to it) in which the exposure of interest (i.e., the specific cell phone task) differs between the crashes and the baseline epochs contribute information to the analysis, as matched sets in which the driver is always or never performing the task of interest cancel out. It is possible that with sample comprising a larger number of crashes and/or a greater matching ratio (more matched baseline epochs per crash), some results not statistically significant in the present study might have reached statistical significance (e.g., the odds ratio of 1.86 for locating/reaching for/answering a cell phone implies a substantial increase in risk but was not statistically significant due to the very limited sample size). Similarly, odds ratios for some specific tasks (e.g., dialing) could not be estimated at all. Given the similarity of the results of the current study to those obtained previously by Klauer et al. (2010) in a study that included near-crashes in addition to crashes, it is possible that the statistical power of the current study could be improved by expansion of the study sample to include outcomes such as tire-strikes and/or near-crashes in addition to crashes.

Second, the SHRP 2 NDS oversampled younger and older drivers. As such, the crash risks reported may over-represent younger and older (especially younger) drivers' behavior and performance. For example, while drivers under age 25 are overrepresented in all crashes nationwide, they accounted for approximately 23% of all driver crash involvements nationwide (NHTSA, 2017) but 55% of driver crash involvements in this study. Analyzing the same data using a case-cohort approach and comparing cell phone use to driving without any observable distraction, fatigue, or impairment, Guo et al. (2016) found that the relationships between many potential driving distractions and risk of crash involvement varied by age.

Third, it is important to note that while the current study stratified results by crash severity and found little difference in the relationship of cell phone use to the incidence of more severe versus less severe crashes within the range of severities examined, the SHRP 2 NDS (and thus the current study) included few crashes that resulted in injuries and none that resulted in fatalities. It is possible that cell phone use may have a smaller (or larger) impact on crashes that result in severe injury or death than on crashes of the severities examined here. While the relationship between cell phone use and risk of involvement in a fatal crash or a crash resulting in severe injury remains unknown at present, some other risk factors are known to have greater impacts on fatal crashes and crashes resulting in severe injuries than on property-damage-only crashes or all crashes taken together; a salient example is drowsiness (Tefft, 2012). Short of an extremely large naturalistic driving study that includes large numbers of crashes resulting in severe injuries or fatalities, future work could attempt to address this limitation by stratifying crashes (and perhaps also near-crashes) more finely by crash types that map onto the types of crashes that tend to result in more severe outcomes, for example based on factors such as road type, crash geometry, and speed prior to the precipitating event.

Finally, one inherent limitation of the case-crossover design is that many crashes in which the subject was driving under conditions unusual for that driver (e.g., at a time of day or on a specific type of road) were excluded from the analysis due inability to locate baseline epochs that satisfied the matching criteria, which required the driver to be driving under similar conditions on other trips; 24% of all otherwise-eligible crashes were excluded for this reason. Examination of these cases indicated that the prevalence of cell phone use was similar both statistically and practically among crashes included in analyses versus in those excluded due to inability to find matched baseline epochs; however, it is possible that the relationship between cell phone use and crash risk may differ when driving in atypical conditions than in more routine environments.

Conclusion

This study found that visual-manual interaction with cell phones while driving, particularly but not exclusively relative to text messaging, was associated with approximately double the incidence of crash involvement relative to driving without performing any observable secondary tasks. Associations between visual-manual cell phone interaction and crash risk tended to be stronger in free-flow traffic and in types of crashes in which the subject driver played a clear role, such as rear-end and road-departure crashes. Estimated risks were lower than in most past studies that examined risk of involvement in real-world on-road crashes, likely due to the greater control for individual and situational risk factors in the current study. Additional research is needed to further the understanding of the relationship between specific modes of cell phone use while driving and the risk of crash involvement, specifically addressing the robustness of results to variations in the source population, analytic approach, confounder control, reference condition, and crash severity.

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Appendix

The following tables present results from the sensitivity analysis in which the relationship between engagement in various cell phone-related tasks and crash involvement with a reference condition of simply not performing that specific cell phone task, rather than restricting the reference condition to driving without performing any observable secondary tasks, overall and stratified by crash severity, traffic density, and crash type.

Overall

Table A1. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving.

	Crashes		**Baseline Epochs**			
	Cell Phone Task		**Cell Phone Task**			
	Yes	**No**	**Yes**	**No**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	83	483	236	1,513	1.16 (0.84–1.59)	0.372
Talking (hand-held)	21	545	72	1,677	0.87 (0.51–1.47)	0.601
Overall Visual-Manual	65	501	143	1,606	**1.66 (1.16–2.38)**	**0.005**
Texting	42	524	70	1,679	**2.18 (1.41–3.36)**	**<0.001**
Browsing	12	554	55	1,694	0.67 (0.35–1.29)	0.229
Dialing (hand-held)	5	561	5	1,744	2.91 (0.81–10.47)	0.102
Locating/Reaching/Answering	13	553	18	1,731	**2.59 (1.20–5.57)**	**0.015**
Hands-free Call	2	564	25	1,724	**0.09 (0.01–0.75)**	**0.026**
Headset/Earpiece	1	565	7	1,742	*	*
Integrated device	0	566	6	1,743	*	*
Speakerphone	1	565	12	1,737	0.19 (0.02–1.72)	0.141

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Crash Severity

Table A2. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Moderate & severe crashes only.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	No	Yes	No	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	30	157	78	470	1.31 (0.76–2.26)	0.336
Talking (hand-held)	5	182	24	524	0.54 (0.19–1.52)	0.242
Overall Visual-Manual	24	163	46	502	**2.18 (1.16–4.11)**	**0.016**
Texting	16	171	25	523	**2.40 (1.16–4.96)**	**0.019**
Browsing	5	182	16	532	1.00 (0.34–2.95)	1.000
Dialing (hand-held)	1	186	2	546	2.00 (0.18–22.06)	0.571
Locating/Reaching/Answering	4	183	5	543	3.12 (0.74–13.20)	0.122
Hands-free Call	1	186	8	540	0.27 (0.03–2.71)	0.265
Headset/Earpiece	0	187	1	547	*	*
Integrated device	0	187	0	548	*	*
Speakerphone	1	186	7	541	0.30 (0.03–3.12)	0.311

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table A3. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Minor crashes only.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	No	Yes	No	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	53	326	158	1,043	1.09 (0.73–1.61)	0.682
Talking (hand-held)	16	363	48	1,153	1.06 (0.57–1.96)	0.862
Overall Visual-Manual	41	338	97	1,104	1.47 (0.95–2.27)	0.083
Texting	26	353	45	1,156	**2.06** (1.20–3.55)	**0.009**
Browsing	7	372	39	1,162	0.54 (0.23–1.25)	0.150
Dialing (hand-held)	4	375	3	1,198	3.43 (0.73–16.20)	0.120
Locating/Reaching/Answering	9	370	13	1,188	2.41 (0.98–5.95)	0.057
Hands-free Call	1	378	17	1,184	*	*
Headset/Earpiece	1	378	6	1,195	*	*
Integrated device	0	379	6	1,195	*	*
Speakerphone	0	379	5	1,196	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Traffic Density

Table A4. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Free-flow traffic (Level of Service A).

	Crashes		Baseline Epochs			
	Cell Phone Task		**Cell Phone Task**			
	Yes	**No**	**Yes**	**No**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	41	267	113	828	1.11 (0.71–1.75)	0.651
Talking (hand-held)	11	297	33	908	0.91 (0.45–1.87)	0.801
Overall Visual-Manual	32	276	67	874	**1.69 (1.02–2.81)**	**0.042**
Texting	20	288	38	903	**1.85 (1.00–3.43)**	**0.049**
Browsing	5	303	20	921	0.72 (0.26–1.98)	0.519
Dialing (hand-held)	3	305	3	938	2.93 (0.57–15.14)	0.201
Locating/Reaching/Answering	7	301	8	933	**3.43 (1.12–10.53)**	**0.032**
Hands-free Call	2	306	16	925	0.14 (0.02–1.21)	0.073
Headset/Earpiece	1	307	5	936	*	*
Integrated device	0	308	4	937	*	*
Speakerphone	1	307	7	934	0.37 (0.03–4.12)	0.417

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table A5. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Traffic with some restrictions (Level of Service B/C/D/E/F).

	Crashes		Baseline Epochs			
	Cell Phone Task		**Cell Phone Task**			
	Yes	**No**	**Yes**	**No**	**Odds Ratio (95% CI)**	**p-value**
Any Cell Phone Use	42	216	123	684	1.20 (0.77–1.88)	0.420
Talking (hand-held)	10	248	39	768	0.82 (0.38–1.78)	0.620
Overall Visual-Manual	33	225	76	731	1.64 (0.99–2.71)	0.055
Texting	22	236	32	775	**2.56 (1.39–4.74)**	**0.003**
Browsing	7	251	35	772	0.63 (0.27–1.51)	0.304
Dialing (hand-held)	2	256	2	805	2.89 (0.38–22.23)	0.309
Locating/Reaching/Answering	6	252	10	797	2.02 (0.69–5.88)	0.197
Hands-free Call	0	258	9	798	*	*
Headset/Earpiece	0	258	2	805	*	*
Integrated device	0	258	2	805	*	*
Speakerphone	0	258	5	802	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Crash Type

Table A6. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Rear-end crashes.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	No	Yes	No	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	22	68	48	233	1.74 (0.91–3.33)	0.097
Talking (hand-held)	2	88	15	266	0.36 (0.08–1.69)	0.193
Overall Visual-Manual	20	70	31	250	**2.68 (1.31–5.49)**	**0.008**
Texting	15	75	14	267	**4.20 (1.78–9.95)**	**0.001**
Browsing	3	87	12	269	0.79 (0.20–3.17)	0.744
Dialing (hand-held)	1	89	2	279	1.19 (0.10–14.86)	0.895
Locating/Reaching/Answering	4	86	3	278	**6.05 (1.05–34.91)**	**0.044**
Hands-free Call	0	90	3	278	*	*
Headset/Earpiece	0	90	0	281	*	*
Integrated device	0	90	0	281	*	*
Speakerphone	0	90	3	278	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table A7. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Road-departure crashes.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	No	Yes	No	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	46	210	105	684	1.55 (0.98–2.45)	0.060
Talking (hand-held)	15	241	33	756	1.32 (0.68–2.57)	0.419
Overall Visual-Manual	35	221	61	728	**2.29 (1.37–3.83)**	**0.002**
Texting	22	234	31	758	**2.65 (1.41–4.99)**	**0.003**
Browsing	6	250	21	768	0.92 (0.35–2.42)	0.872
Dialing (hand-held)	4	252	3	786	4.14 (0.90–19.10)	0.069
Locating/Reaching/Answering	7	249	8	781	**3.32 (1.08–10.21)**	**0.037**
Hands-free Call	1	255	14	775	*	*
Headset/Earpiece	1	255	4	785	*	*
Integrated device	0	256	5	784	*	*
Speakerphone	0	256	5	784	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Driver Role in Crash

Table A8. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: All crashes excluding subject driver struck from behind.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	No	Yes	No	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	77	423	211	1,329	1.19 (0.86–1.66)	0.298
Talking (hand-held)	20	480	64	1,476	0.93 (0.54–1.59)	0.781
Overall Visual-Manual	60	440	128	1,412	**1.69 (1.17–2.45)**	**0.006**
Texting	40	460	63	1,477	**2.27 (1.45–3.57)**	**<0.001**
Browsing	10	490	50	1,490	0.60 (0.29–1.22)	0.158
Dialing (hand-held)	5	495	5	1,535	2.91 (0.81–10.47)	0.102
Locating/Reaching/Answering	12	488	15	1,525	**2.96 (1.29–6.76)**	**0.010**
Hands-free Call	2	498	23	1,517	**0.10 (0.01–0.80)**	**0.030**
Headset/Earpiece	1	499	6	1,534	*	*
Integrated device	0	500	5	1,535	*	*
Speakerphone	1	499	12	1,528	0.19 (0.02–1.72)	0.141

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.

Table A9. Odds ratios for crash involvement associated with performing specific cell phone tasks relative to driving while not performing that specific task during six-second segments of driving: Subject driver struck from behind.

	Crashes		Baseline Epochs			
	Cell Phone Task		Cell Phone Task			
	Yes	No	Yes	No	Odds Ratio (95% CI)	p-value
Any Cell Phone Use	6	60	25	184	0.79 (0.24–2.61)	0.701
Talking (hand-held)	1	65	8	201	0.38 (0.04–3.46)	0.387
Overall Visual-Manual	5	61	15	194	1.38 (0.38–5.01)	0.622
Texting	2	64	7	202	1.18 (0.21–6.71)	0.855
Browsing	2	64	5	204	1.53 (0.25–9.57)	0.647
Dialing (hand-held)	0	66	0	209	*	*
Locating/Reaching/Answering	1	65	3	206	1.10 (0.11–10.78)	0.937
Hands-free Call	0	66	2	207	*	*
Headset/Earpiece	0	66	1	208	*	*
Integrated device	0	66	1	208	*	*
Speakerphone	0	66	0	209	*	*

ORs computed using conditional logistic regression for matched-set data; * denotes insufficient sample size to estimate odds ratios.